FAKULTÄT
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Faculty of Informatics

Spielbasierte Anwendung zur Rehabilitation und Schmerzlinderung bei Menschen mit amputierten Gliedmaßen mittels Augmented Reality

MASTERARBEIT

zur Erlangung des akademischen Grades

Master of Science

im Rahmen des Studiums

Biomedizinische Technik

eingereicht von

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Wien, 1. April 2019

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FAKULTÄT FÜR !NFORMATIK
Faculty of Informatics

Game-based application for rehabilitation and phantom limb pain relief of amputee patients based on augmented reality

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Biomedical Engineering

by

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to the Faculty of Informatics

at the TU Wien

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Vienna, 1st April, 2019

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Wien, 1. April 2019

Paula Abad Liso

Acknowledgements

I would like to thank my advisors Peter Purgathofer and Fares Kayali for making this possible and let me work in the HCI group, and for always being willing to help.
I also like to thank Cosima Prahm, who provided the hardware for the project, gave me a lot of information about amputee patients and let me take part in her lectures and patient follow-up sessions; and Matthias Steinböck, for helping me with technical aspects and helping with any problems encountered.
Finally, I owe a lot of thanks to my family; my flatmates Sarah, Max and Philipp, for supporting me and always giving me good advice; and my new friends I've met in Vienna, specially Juan and Simon.

Abstract

Up to 85% of the amputee patients present Phantom Limb Pain (PLP) after the operation. Although the frequency and intensity of this pain decrease with time, about 5-10% of patients still have severe pain. The outcome of current treatments is insufficient and many times patients abandon rehabilitation due to demotivation. Thus, the overall scope of this work is to design a more effective to carry out the muscular rehabilitation at the same time, keeping the patients engaged during its rehabilitation.

For creating engagement through fun, a game-based application is developed. Unity is the program used to program the Augmented Reality application. Augmented reality glasses (Microsoft Hololens) are used to visualise virtual objects as well as a virtual arm. Finally, to capture the muscular EMG signals and movement of the arm a Myo armband is used. This will be placed under the patient's elbow during rehabilitation. Finally, Blender is the program used to create the 3D model of the required objects.

During the game-based application, the user will be able to manipulate objects with a virtual arm through its EMG signals. There are two main modes to manipulate objects: *Non-Magic* mode and *Magic* mode. Each of these modes contains two modes. *Non-Magic* mode is composed by *Grab and Release* mode and *Twist Wrist* mode. *Magic* mode consist of *Grab and Release* mode and *Zoom in and out* mode. There are three different types of muscle activation to control the game that are very similar to the activations patients use with their prosthesis.

This project consists of different phases. The first thing done was to gather information about related work and make research on Phantom Limb Pain and Augmented Reality. Besides that, lectures from the Medical University, rehabilitation sessions and follow-up sessions of patients were attended, in order to better understand the problem. Workshop sessions to discuss how the prototype was going to be were then held. Afterwards, it was necessary to study and get familiar with the tools that were going to be used: Unity, Myo Armband, Hololens, and Blender. The first result was to have the basic functionality of the prototype working, in which the user was able to move a virtual reality arm through Myo and see it through the Hololens. After another workshop, in which was discussed how the game-based application will be, a prototype of it was developed.

The evaluation of the prototype shows that an Augmented Reality game-based application is a good idea to increase engagement during rehabilitation but it would be necessary to improve some parts of the prototype. Furthermore, it is shown that Augmented Reality technology is in its early stages and its benefits cannot be fully enjoyed.

Kurzfassung

Bis zu 85% der amputierten Patienten zeigen nach der Operation Phantom Limb Pain (PLP). Obwohl die Häufigkeit und Intensität dieser Schmerzen mit der Zeit abnimmt, haben etwa 5-10% der Patienten immer noch starke Schmerzen. Das Ergebnis der derzeitigen Behandlungen ist unzureichend und viele Patienten verzichten aufgrund von Demotivation auf die Rehabilitation. So ist der Gesamtumfang dieser Arbeit ist es, eine effektivere Gestaltung der Durchführung der Muskelrehabilitation zur gleichen Zeit, die die Patienten während der Rehabilitation beschäftigt. Um Engagement durch Spaß zu schaffen, wird eine spielerische Anwendung entwickelt. Unity ist das Programm, mit dem die Augmented Reality-Anwendung programmiert wird. Augmented-Reality-Brillen (Microsoft Hololens) werden sowohl zur Visualisierung virtueller Objekte als auch eines virtuellen Arms eingesetzt. Schließlich wird zur Erfassung der muskulären EMG-Signale und der Bewegung des Armes ein Myo-Armband verwendet. Diese wird während der Rehabilitation unter den Ellenbogen des Patienten gelegt. Schließlich ist Blender das Programm, mit dem das 3D-Modell der benötigten Objekte erstellt wird. Während der spielerischen Anwendung kann der Benutzer durch seine EMG-Signale Objekte mit einem virtuellen Arm manipulieren. Es gibt zwei Hauptmodi, um Objekte zu manipulieren: Nicht-Magischer Modus und Magie-Modus. Jeder dieser Modi enthält zwei Modi. Der nicht-magische Modus besteht aus dem Greif- und Freigabemodus und dem Drehgelenk-Modus. Der Magic-Modus besteht aus dem Grab- und Release-Modus und dem Zoom-In- und -Out-Modus. Es gibt drei verschiedene Arten der Muskelaktivierung, um das Spiel zu steuern, die den Aktivierungen, die Patienten mit ihrer Prothese verwenden, sehr ähnlich sind. Dieses Projekt besteht aus verschiedenen Phasen. Das erste, was getan wurde, war, Informationen über verwandte Arbeiten zu sammeln und Forschungen über Phantom Limb Pain und Augmented Reality durchzuführen. Außerdem wurden Vorlesungen der Medizinischen Universität, Rehabilitationssitzungen und Nachbeobachtungen von Patienten besucht, um das Problem besser zu verstehen. Anschließend fanden Workshops statt, in denen diskutiert wurde, wie der Prototyp aussehen würde. Danach war es notwendig, zu studieren und sich mit den Werkzeugen vertraut zu machen, die verwendet werden sollten: Einheit, Myo-Armband, Hololens und Mixer. Das erste Ergebnis war, die Grundfunktionalität des Prototyps zu haben, bei dem der Benutzer in der Lage war, einen Virtual-Reality-Arm durch Myo zu bewegen und ihn durch die Hololens zu sehen. Nach einem weiteren Workshop, in dem diskutiert wurde, wie die spielbasierte Anwendung aussehen wird, wurde ein Prototyp davon entwickelt. Die Auswertung des

Prototyps zeigt, dass eine Augmented Reality-Spieleanwendung eine gute Idee ist, um das Engagement während der Rehabilitation zu erhöhen, aber es wäre notwendig, einige Teile des Prototyps zu verbessern. Darüber hinaus zeigt sich, dass sich die Augmented Reality-Technologie in einem frühen Stadium befindet und ihre Vorteile nicht voll genutzt werden können.

Contents

CHAPTER 1

Introduction

1.1 Problem definition

Up to 85% of the amputee patients present Phantom Limb Pain (PLP) after the amputation of their limb. PLP is painful sensation patients feel on their absent limb. Although the frequency and intensity of this pain decreases with time, about 5-10% of patients still experience severe pain [1]. Phantom Limb Pain occurs due to a cortical reorganization that are plastic changes in the primary somatosensory cortex [2].

Both pharmacological and non-pharmacological treatments have been used to treat PLP. Nonetheless, the outcome of current treatments is insufficient and rarely results in a complete reduction of the pain sensation. Besides that, excessive medication is not proper due to possible side effects. Therefore, designing a non-pharmacological treatment that effectively reduces PLP would represent a major change in the quality of life of the patients.

Nowadays, the most commonly used non-pharmacological treatment is Mirror Therapy (MT). In MT the patient moves their non-amputated limb in front of a mirror located in the middle of both limbs. By doing so, the brain perceives that the amputated limb is being moved and create the illusion of non-painful movement in the missing limb. This method is only successful in some cases and only unilateral amputee patients can benefit from it. Therefore, although MT has to be considered as a useful complementary treatment, it cannot be established as the main treatment for PLP [3].

On the other hand, there is a high abandonment rate in upper-limb amputee rehabilitation and use of prosthetic devices. The prosthesis rejection reasons include difficulties to use it, poor training, costs, and negative reaction of other people. Nevertheless, the use of prosthetic devices can make life easier in many aspects and its regular use would improve aspects like trauma disorders and back and neck pain due to body decompensation. The hopeful side of this is that 68% of amputee patients who rejected the use of a prosthetic device would try to use it again if technology improvements at a low cost take place [4]. So it is likely that the patients who abandon rehabilitation due to demotivation, excess of effort demand and boredom, would reconsider to go back to rehabilitation if the method is motivating and more interesting. Furthermore, rehabilitation rejection would be reduced, with an increase of the patient's affinity for wearing a long-term prosthesis on a day-to-day basis (96% of the patients who did rehabilitation immediately after the amputation, against 56% of the patients who delayed rehabilitation). Finally, it is better to avoid rehabilitation rejection, especially the first days, than delay it, since an early rehabilitation appears to be more successful and less amputation pain is reported.

1.2 Aim of the work

The overall scope of this work is to develop an effective rehabilitative method for PLP. To do so, two factors have been addressed: Firstly, the application has to be useful for rehabilitation. In other words, it has to demand the activity of all the muscles involved so the patient will be able to control a prosthesis. Secondly, keeping the patients engaged and motivated during the task is key for methods that require several sessions of treatment, so they do not abandon it. For that purpose, part of a video game has been developed. By playing the video game, the patient is able to see the movements of his/her amputee limb via Augmented Reality (AR). Thus, the patient performs motor tasks while wearing AR glasses that allow them to see the movement of a virtual limb. The patients will have to overcome a set of challenging activities with the complete game. Thus, patients will be able to see their improvement, helping them to be effectively engaged during the intervention. By doing so, we expect relief of the PLP. Additionally, to control the virtual limb, all the muscles involved in the use of a prosthesis should be trained, potentially resulting in a recovery of the muscular tone. This should allow them to make finer movements while using a prosthesis.

It is important to point out that the objective of this work is not to prove that a video game is better for rehabilitation than the currently used methods but to research how the rehabilitation of patients can be improved through a video game. Therefore, it is studied in what ways the prototype developed is useful for the rehabilitation of patients. A part of a video game has been created. With it, it is already possible to investigate how useful can be the rehabilitation based on this video game. Furthermore, it will be possible to complete the video game in the future, in order to further improve the engagement of patients with their rehabilitation. This work is just a preliminary evaluation of the game since it is still in its early stages.

1.3 Structure

This work is divided into six chapters. The first of them is the present introductory chapter, which talks about the current problems in amputee patients rehabilitation and the reasons that led to this work. It also talks about the aim of this work. Chapter 2 begins with a description of what body ownership perception is, introduce the famous example of the hand rubber illusion and describes the importance of body continuity. This is followed by the state-of-the-art of phantom limb pain rehabilitation, virtual and augmented reality and games for health. Then, the design phase and all the activities carried out to learn about amputee patients and decide how the prototype was going to be are described. This activities include the initial meeting, a workshop to decide the design of the game, rehabilitation and follow-up sessions with real patients, Medical University lectures and a talk about a developed game. Chapter 3 describes the methods used in this work for the design part and for the evaluation part. Chapter 4 talks about the implementation of the prototype, explaining each of its parts separately. In Chapter 5 the qualitative results of the prototype are studied and the results of the work are discussed. Chapter 6 is for the conclusion as well as for the limitations encountered. Finally, Chapter 7 details what can be done after this work, and explains the idea for the whole video game.

CHAPTER 2

Background

This chapter explains the background and design phases of the prototype. It begins with a description of what body ownership perception is, introduce the famous example of the hand rubber illusion and describes the importance of body continuity. This is followed by the state-of-the-art of phantom limb pain rehabilitation, virtual and augmented reality and games for health. Then, the design phase and all the activities carried out to learn about amputee patients and decide how the prototype was going to be are described. This activities include the initial meeting, a workshop to decide the design of the game, rehabilitation and follow-up sessions with real patients, Medical University lectures and a talk about a developed game.

2.1 Body ownership perception

> *When I decide to write, I do not need to look for my hand in the same way that I have to look for a pen or a piece of paper, for the simple reason that my hand is "always there" (James 1890), present with me.* [5]

A very important topic in the present project is the body ownership perception since one of the main objectives of this work is to design a method that helps in the best possible way against Phantom Limb Pain. Therefore, this section studies how the brain can perceive virtual body parts as its own. Thus, body ownership is the feeling that something is part of us.

As humans, we can perceive our body in two representation ways. One of the ways is the body schema [6]. The *body schema* allows us to perceive how much space our body inhabits, where are the parts of our body and how big they are. But this can be easily

changed, in fact, we are constantly changing it. For example, if we are carrying a big object, we know that the space that we are occupied with the object is bigger and we are more careful and avoid obstacles. The space we occupy when we have extra objects in our body is known as *extended peripheral space* and the space our body occupy is called *peripheral space*. This schema representation of our body is useful to move through the environment without hitting any obstacle.
On the other hand, there is another representation of our body, called *body image*. The body image is our mental representation of ourselves, of how we imagine our face and our body, and it can affect our emotions. For example, if we feel pretty we can have more self-confidence [7].

We perceive the world around us through our senses. When an unexpected event reaches our senses we not only pay attention to it with the sense we have perceived it, but we also try to detect the event with some of our other senses, in order to understand what is happening or to confirm what we thought the input is. We can feel or hear better if we look in the direction of the stimuli. For example, we can understand better what another person is saying if we look to the mouth of the spokesperson, or we can be confused about the exact point location on our body that is being touched if we don't look at it [8]. This is called multisensory integration.
When there is a multisensory spatial interaction in a part of our body, our perception of touch and where is our body located can be affected. But not only that, it can also affect our sense of self-ownership and sense of agency of our body parts [6].

2.1.1 The famous example of the Rubber Hand Illusion

The rubber hand illusion is an example of body ownership illusion, that is the feeling that an artificial body part is part of our real body. The body hand illusion [6] is an experiment where a rubber hand is located next to the real hand in a plausible and natural position, laying on a table in front of the participant. The real hand is hidden by a panel. Both hands, the real and the rubber hand, are stroked with a brush. What happens is that the participant perceives the rubber hand as its own hand, since he/she is feeling the brush at the same time as seeing the rubber hand.

2.1.2 Another Hand Rubber Illusion example

The Rubber Hand Illusion is due to activity in multisensory areas (with the higher activity in the ventral premotor cortex) [9]. There is an experiment that proves that body-ownership is not only or mainly related with visual stimuli, but also that proprioceptive and tactile signals are correlated for some period of time. In the experiment, the subject's eyes are covered and a rubber hand is placed near his/her right hand. Then, the experimenter moves the left hand of the patient and touch the rubber hand while is touching the right hand of the patient with the other hand and in the same point. They showed that the subjects feel that they are touching their own hand for approximately

9.7 s.
They also proved that the activated brain areas during the illusion are the ventral premotor cortex and the cerebellum. The activation of this areas indicates a correlation between visual, tactile and proprioceptive signals of the hand instead of visualize the representation of an object in peripersonal space, because the subjects are blindfolded. The illusion not only depends on the simultaneity of touching the rubber hand while the real hand is being touched, but also on the texture of the hand, so the subject's hand was covered with a rubber glove.

2.1.3 The importance of body continuity

For achieving body ownership regarding an object it is more important the sense of connection to the body than its appearance [10]. It is possible to feel body ownership for objects without a hand shape and anatomy if the movement of the object follows the same movement the subject is performing in space time. This study contradicts the Hand Rubber Illusion studies, since in those studies they state that the ownership illusion is caused by multisensory matching between feeling and watching an object with the same anatomy as their hand. They showed that the object doesn't have to look like what we identify as a hand and it doesn't need to have the same anatomical and postural appearance as a real hand, since they demonstrated that it is possible to feel body ownership by controlling a balloon or a square. Therefore, it is shown that we have a high plasticity of our body representation.

2.2 State-of-the art

2.2.1 Phantom Limb Pain

Phantom Limb Pain is the pain people feel in their deafferented or amputated limb after the operation. It is due to plastic changes especially in the cortex but also in other levels in the neuraxis [11] [12]. Therefore, amputated people still feel that they have their limb after being amputated (phantom limb awareness). This occurs to all amputees but not all of them feel PLP since this is a neuropathic pain syndrome. But although not everyone suffers from it, it is a very common syndrome. PLP can appear at different intensity levels. It can appear as a little discomfort sporadically or it can be continuous and very painful pain. It can also appear immediately after the operation or many years after it. There are several reasons for the appearance of PLP. It can be due to pre and postoperative pain, or due to physical or psychological factors.

Brain changes after the amputation

Central changes that led to PLP occur in the brainstem, the thalamus, and the cerebral cortex.
Regarding cortical reorganization, it has been demonstrated that functional structural architecture changes of the primary somatosensory cortex led to phantom limb pain. In

these changes, the representative zone of the brain corresponding to the amputated limb is invaded by adjacent areas. This phenomenon is called *topographical remapping.* Frontal and parietal areas may also have a role in PLP and this is related to the mismatch of motor intention and sensory feedback, where these areas of the brain are activated. Finally, PLP can be related to the pain patients had before the amputation since the felt pain is similar in some cases. This is called the *pain memory hypothesis.*

Phantom Limb Pain rehabilitation

> *Phantom limb pain (PLP), which is present in about 50% to 80% of amputees, and in most patients with brachial plexus avulsion, is recognised as very difficult to treat and is often resistant to classical pharmacological and surgical treatment approaches including.* [13]

In 2013 M. Alejandra et al. [14] made a summary of the methods used to deal with Phantom Limb Pain. The main conclusion of this study was that less than 10% of the patients obtain long-term pain relief, highlighting the importance of designing new methods to treat PLP. Therefore, current solutions are still at an early stage of development. Current treatments can be divided into pharmacological and non-pharmacological. Pharmacological treatments include opioids, NMDA receptor antagonists, anticonvulsants, antidepressants, calcitonin, and anesthetics. Non-Pharmacological treatments include Transcutaneous Electrical Nerve Stimulation (TENS), electroconvulsive therapy (ECT), mirror therapy, acupuncture, deep brain stimulation, and spinal cord stimulation, among others. However, as stated by Alejandra and colleagues, the effect of such treatments is limited.

Mirror therapy option was proposed in 1996 by Ramachandran et al. [15]. This results presented a pain reduction for all the PLP patients, presenting the Mirror Therapy as a promising method. Nevertheless, although this technique leads to a certain degree of pain reduction, it does not lead to complete pain relief, hindering the applicability of this method for PLP [3]. However, the results of this study are promising, indicating that designing more advanced methods based on these findings could lead to better results.

Virtual therapies can be also used as well as mirror therapy, which offers visual feedback to the movement the patient is performing with the phantom limb. The treatment that Catherine Mercier and Angela Sirigu tested [13] with upper amputee patients, consisted of first recording movements of the existing limb, and then projecting them into a mirror located in front of the patient. Then, the patients were asked to follow the same movement with their absent limb as precisely as possible, so they felt that they could move their limb. This led to a reduction of the phantom pain in some patients and only in one of them the pain was completely gone.

2.2.2 Augmented Reality and Virtual Reality

Augmented Reality and Virtual Reality are increasingly being used in video games. Video games generate a lot of engagement in people who play them, so it may be a good idea to learn from them. A clear example of this engagement with video games is Pokemon GO. This game used to appear in all communications media and people of all ages play it. The most beneficial part of this game was that aimed people to be more active and accordingly, they were healthier [16].

2.2.3 Games for health

Games are becoming an important tool in medicine since they allow people to have a healthier life. They also allow patients to manage their illness in a more motivational mood [17].

Augmented Reality is being used in many medical fields. One of them is medical training, that allows doctors to train on an interactive virtual layer over a real scene, which is safer. This includes laparoscopic tasks training, neurosurgical procedures training, and echocardiography training [18].

Augmented Reality is also used in rehabilitation of people who had suffered a stroke and whose upper extremities have been affected by it [19]. It is also used for rehabilitation and PLP relief of amputee patients. Therefore, Augmented Reality and Virtual Reality are the next levels of Mirror Therapy. One of the advantages of AR is that it can be also used for bilaterally amputee patients since there is no existing hand any movement or reflection could be mirrored from. R Brnemark carried out a study with a patient who suffered PLP. This patient showed resistance to a variety of treatments including Mirror Therapy for 48 years [20]. The signals were collected and processed by pattern recognition and they were used as input for Augmented Reality and Virtual Reality environments and a Racing game. Finally, the patient had periods without pain when was continuous pain what he had before.

Example 1

C. Prahm et al. developed a virtual rehabilitation for upper limb myoelectric prosthesis control. Through this game-based application, patients can have good rehabilitation, with more motivation, effort, and performance than if they do classical rehabilitation. Classical rehabilitation is based on making repetitive movements by following signal curves with muscles. In this study, they evaluated three different video games with different control methods. They could activate one muscle or another or co-contraction, that is a simultaneous contraction of both muscles (used for switching in the prosthetic devices between joints) [21] [22]. They show that the 2-electrode interface that is used in prosthetic devices can be trained through video games since they obtained positive results in their study.

The three different games were a racing game, a dexterity game, and a rhythm-based game. The control of the game was through 2 electrodes instead of a keyboard or mouse, with one exception. The first of the games, the racing game (*Super Tux Kart*), was controlled by EMG and keyboard. With the EMG signals, participants could control the movement of the car to the left and to the right and with the keyboard the controlled accelerating and braking. In the rhythm game (*Step Mania 5*), EMG from the two electrodes controlled the activation of successive arrows moving in one direction when they reached the match position, and with co-contraction, they could activate two arrows simultaneously when this was required. Finally, the dexterity game (*Pospos*) consisted of collecting items in a labyrinth. With one muscle or the other participants controlled whether to go left, right, up or down and with co-contraction they change from right/left mode to up/down mode and vice versa. Figure 2.1 show an image of each of these games.

Figure 2.1: Games played by the participants. From left to right: Racing Game, Rhythm Game and Dexterity Game. [22]

Example 2

M. Melero et al. developed an augmented reality dancing game for prosthetic rehabilitation of upper limb amputees [23]. In this game they use a screen to show the patients which dance steps they have to follow, a Myo Armband to make them perform some gestures and a Microsoft Kinect sensor to track patient movements. They measured different time frames to evaluate the game and the patient's performance.

The game starts with a menu that gives the option to choose between starting the game, read the tutorial or make a demo, create a player profile or change settings. If the users don't have a profile they have to make one where they have to calibrate the Myo Armband. Then they have to choose the game mode (easy, medium or hard) and a song and finally, the game starts. During the gameplay, the patients have to follow the dance moves of an instructor and these are detected by the Kinect. At the same time, they have to perform hand movements that are detected with Myo and are indicated on one side of the screen. They have a countdown and when they finish the game another screen appears with the therapy feedback. An image of the gameplay can be seen in Figure 2.2.

Figure 2.2: Gameplay of the dancing game. [23]

Example 3

E. Köktürk et al. made a game-based application to perform activities at home that alleviate phantom limb pain [24]. The game is called LIMBrehabVR and it is designed to its use through Oculus Rift VR, but they have another version for mobile phone, in the case that the patients prefer that option. In the game, the patients can personalize their avatar by choosing gender, clothing, skin colour and the surrounding environment. Furthermore, it contains speech commands, so the users can control the game through their voice if they don't want to use key commands. The sensor used is IMU because of its size and cheap price. They picked the signals from accelerometer, gyroscope, and magnetometer.

The game consists of making the patients freely move their hands, so when they see the movement they immediately feel a relief of their PLP. They can also use models with pre-established movements and what they have to do is to copy these movements. Figure 2.3 show the software user interface of the game.

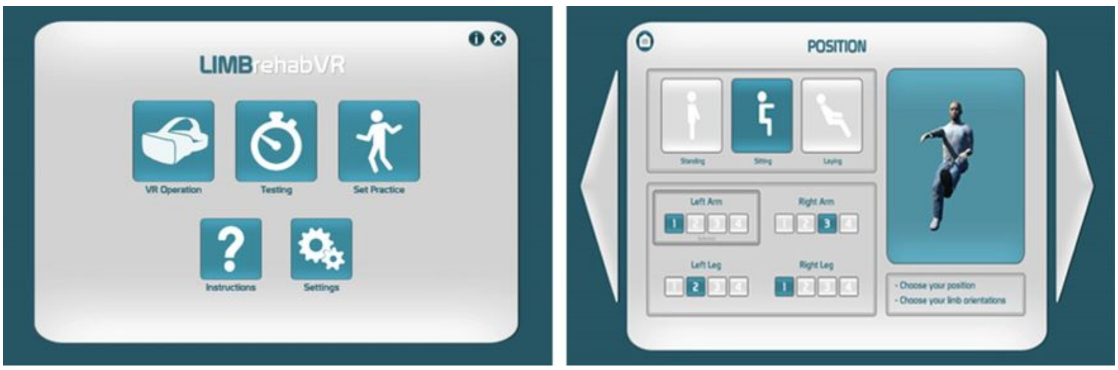


Figure 2.3: User interface of the game LIMBrehabVR. [24]

2.3 Design phase and activities performed

In order to understand better the problem of PLP in amputee patients and understand how they feel and what they need, a series of activities were attended. This activities were: Meetings to decide what the goal was, how the prototype was going to be and which tools (hardware and software) were going to be used; a workshop with people working in the field and a patient in which we made a brainstorming and we decided the design of the video game; rehabilitation and follow-up sessions with patients; lectures from the medical University where many technical aspects were explained; and a talk of a postdoc student who talked about her PhD project, which is closely related to the present project.

2.3.1 Initial meeting

This meeting was held between Prof. Fares Kayali, Cosima Prahm, Matthias Steinböck and Paula Abad Liso. The objective in this first sessions was to talk about what were the needs of amputee patients and from those needs decide what type of application was going to be developed, whether it was going to be a phone app or a Hololens app and what was the main goal of the project, among others. It was decided in this sessions that Unity was going to be the program used along Myo Armband and Microsoft Hololens. The application was going to be intended for upper limb amputee patients with transradial level amputation (below the elbow) and the main objective was to relief PLP at the same time as the muscular rehabilitation is carried out. It was also decided that through the application patients would be able to see and control by the use of the Myo Armband a virtual arm.

2.3.2 Workshop

This meeting was held at the Christian Doppler Lab for Bionic Reconstruction [1] at the Medical University of Vienna (at Allgemeines Krankenhaus (AKH)). Apart from the participants of the initial meetings, some other participants were invited in order to enrich the outcomes of this workshop: Prof. Peter Purgathofer, a therapist from AKH, a developer of the prosthesis used by AKH patients [25] and a left arm transradial amputee patient. The objective of the session was to brainstorm with people of different fields and experts about how rehabilitation and PLP relief techniques can be improved, and gather ideas for the future game. The session was developed as follows. At the beginning of the meeting, a few minutes were allotted to Cosima's explanation about the PLP, so that all participants would know the context. After that, the presentation of the Unity demo and the explanation of what it was intended to do with it took place. This was followed by a group discussion on patient needs and state-of-the-art of the practices in therapy, in order to start from a basis.

[1] https://www.meduniwien.ac.at/hp/bionicreconstruction/

For the brainstorming, the group was split into two different groups with the aim of gather gameplay ideas. It is a good option to make smaller groups for two main reasons: the larger the group is, the lower the performance is [26], due to production blocking and evaluation apprehension, and along with this, a group with a larger number of participants gives less time to talk to each participant. The second reason is that, once the brainstorming is done, the ideas of each group are shared and new ideas may show up since each group follows a different line of thought and each person is influenced by the ideas of other participants. Some of the gathered ideas are explained in Chapter 7, some of them were also discarded. So the next step was to create a large group again, consisting of all the participants and share the ideas resulting for each brainstorming. To share the ideas, it was a spokesperson appointed for each group, who talked about the ideas of their group. Then, ideas of both groups were combined to create better ideas and also new ideas came up. Finally, the discussion was closed and we set on an idea for the prototype of the present project, as well as for the final video game. The idea of the present project is explained in the implementation chapter (Chapter 4) and the idea for the video game is explained in the Chapter 7, which exposes the future work.

The workshop was a big step for this project since the participation of people from different fields forming an interdisciplinary group allows to clarify doubts and limitations and allows to cover the needs of the people of each field.

2.3.3 Rehabilitation and follow-up sessions

A couple of follow-up sessions were held during the time in which this project was being developed. It was held at the Christian Doppler Lab for Bionic Reconstruction at the Medical University of Vienna. The follow-up sessions were led by Univ. Prof. Dr. Oskar C. Aszmann, a professor in the Medical University of Vienna from the Department of Surgery, Division of Plastic & Reconstructive Surgery. Some of the patients were new, some of them were already operated, with or without amputation surgery, and a group of these had already gone through rehabilitation. Other people (experts and no experts) were also participating and attending the session, such as therapist, engineers, PhD students and medical students, among others.

There are several reasons that lead to the loss of a limb. Many of the patients have a traumatic amputation, i.e. due to an accident or injury. Most of them due to a car or motorcycle accident, but there are also patients who lost the limb due to a work accident or for a different reason like bone cancer. Many of the new patients who lost their limb in an accident are young people since they are more likely to be involved in accidents [27]. For example, one of the patients who was a child had elbow cancer. He had already undergone surgery in which his elbow had been removed and his muscles and nerves were relocated so that after the rehabilitation process he could use and move his hand normally, with the only difference that he no longer had the elbow joint. It is a successful outcome since the most common option, in this case, is to amputate the limb. Therefore,

both the patient and his family as well, as the doctors, were very satisfied with the result. Another successful example is a patient who lost his limb and who was using a myoelectric hand, which consist of three fingers (one thumb and two other fingers) controlled by the myoelectric signal of the muscles under the elbow (in the way explained in 2.2). This patient changed his prosthesis to a bebionic hand, which works by means of pattern recognition. So the patient, who was learning how to use it, stated that he felt it like his own hand and that with the older prosthesis it was like his real hand wanted to get into it, that gives an idea of the importance of the ownership feeling. To the patients who had not been operated yet, the doctor informed them what his plan of action was for the operation and the results expected from it.
Finally, in the sessions in which the patients had been recently operated, whether it was amputation or not, the doctor checked what they could feel in their arm or another part of their body, to see if it had successfully changed since the last time. Some of the amputee patients felt some parts of their absent limb in another part of their body, due to the somatosensory cortex reorganization (cortical homunculus is redistributed) after the loss of a limb. To the patients who didn't lose the limb, the doctor checked what could they feel and where.

After these follow-up sessions, some of the patients went on their rehabilitation. This takes place in the same laboratory after all the appointments were over. The aim of the rehabilitation is to train muscles and induce new brain connections in order to make it possible for patients to control their prosthesis.

2.3.4 Medical University lectures

Two lectures from the Medical University were attended. In those sessions, technical aspects of the prosthesis, as well as biological changes regarding amputation, were explained in two different sessions. The lectures were given by Cosima Prahm at the Christian Doppler Lab for Bionic Reconstruction in the Medical University of Vienna. in this hospital they attend patients in the whole process of their amputation. The AKH is also the last resource for some patients who tried other options without success.
At the end of the first session, we tried a bionic hand used to learn how to control muscles and rehabilitation (Figure 2.4). With two antagonist muscles, it was possible to control the hand movements (twist of the wrist and opening of the hand) and it was possible to change between modes with co-contraction. With the other two electrodes it was possible to control the elbow. So in sets of two students, we controlled the arm, each of us one joint. The goal was to coordinate the activation of our muscles in order to throw or catch a ball (Figure 2.5).

Transplants

Transplant are a good option to improve quality of life and functionality [28]. However, it has to be done in hospitals and by doctors who usually work with that, since it is a complicated type of surgery and it can fail in some aspects. The common outcome is

Figure 2.4: Bionic hand at the Christian Doppler Lab for Bionic Reconstruction.

Figure 2.5: Students trying the bionic hand. In the image on the left each of the students is controlling one movement of the bionic hand, one of them the arm lifting and the other one the hand opening. In the image on the right one student is trying to throw the ball.

that the patient is able to open and close the hand, what is enough. To reconstruct all the nerves from elbow to wrist it takes approximately a year.
Sometimes an extra muscle is needed in the arm, so surgeons make a transfer of muscle

from the leg of the patients to their arm. For transplants, immunosuppressants must be taken the whole life. That is why the transplant is not performed if only a hand has been lost. It is also necessary to stop smoking if a transplant has been done, since smoking constricts the blood vessels, so if a patient smokes it may lead to necrosis.

Prosthesis types

There are different types of prosthesis but the choice of one or another mainly depends on the patient's needs. Cosmetic prostheses are static, they can't be controlled, so they are only for aesthetic purpose. They are lightweight so they can be filled with something to stabilize the weight on both sides of the body, in order to avoid decompensation. Mechanical prostheses or body-powered prostheses work with the movement of the body, the shoulder movement can be an option. For example, if the patient lifts the shoulders, the elbow bends; if the patient moves its shoulders backward, the hand opens. Myoelectric prostheses are the prostheses chosen in the AKH hospital and they are controlled by electrodes. One of the problems is that they are very expensive. Michelangelo hand is an example of myoelectric prosthesis [2]. It has a very advanced technology and a hand anatomy and movements. If the sensor detects a pressure drop, it tightens harder so the held object doesn't fall off. One of the problems is the weight, as it weights 1.5 Kg and a real hand is 300 gr.
The choice of prosthesis depends on different factors. The cheapest and easier prosthesis to use is the passive hand, but activity-specific hands, that are a type of passive prosthesis, are bought by athletes since they have a utility for them. This prosthesis and the body-powered prostheses are cheaper than the myoelectric prostheses. The advantages of body-powered prosthesis are training time, feedback, maintenance, durability and frequency of adjustment and if harness and cabling system is improved they would be better. On the other hand, the main advantage of myoelectric prosthesis is that if they are daily used they can reduce phantom limb pain. Furthermore, they are more aesthetic and they are the best choice for light activities. However, the way of improving this prosthesis is by improving their control methods and there's not a big change in the methods used [29].

Amputation levels

There are different amputation levels and for each level of amputation different rehabilitation methods and prosthesis. The amputation levels are transcarpal (fingers or part of the hand), wrist disarticulation (at the wrist), transradial (below the elbow), elbow disarticulation (at the elbow), transhumeral (above the elbow), shoulder disarticulation (at the shoulder) and forequarter (above the shoulder). The most common amputations are transradial and transhumeral, since if it is necessary to amputate at the elbow, they make the amputation around 7 cm higher in order to place the prosthesis, so the height

[2] https://www.ottobockus.com/prosthetics/upper-limb-prosthetics/solution-overview/michelangelo-prosthetic-hand/

of the hands above the ground is the same.
The problem is that there are more joints than electrodes, so what is done in this case is a switch between modes as explained in Chapter 1.

Homunculus

> *The neurological homunculus is a functional picture of the body in which the space occupied by a particular network is directly associated with the neurological importance of the organ encoded by the network, and not by its relative mass in the body.* [30]

Or in other words, a homunculus is a representation of our body parts on the brain, in which the most sensitive parts of our body are the biggest parts (Figure 2.6). The biggest parts are the face and the hands since we can feel more precisely with them. For example, if someone touches out fingertip we know that they are touching our fingertip with a very little error. But if someone touches our back we are more confused about the point they are touching, so the error is bigger. If a person loses a hand, that as we have already said, has a big homunculus representation, the area corresponding to other parts of the body become bigger. The face is likely to become bigger, so sometimes when the face of a hand amputee person is touched, they can feel the hand there.

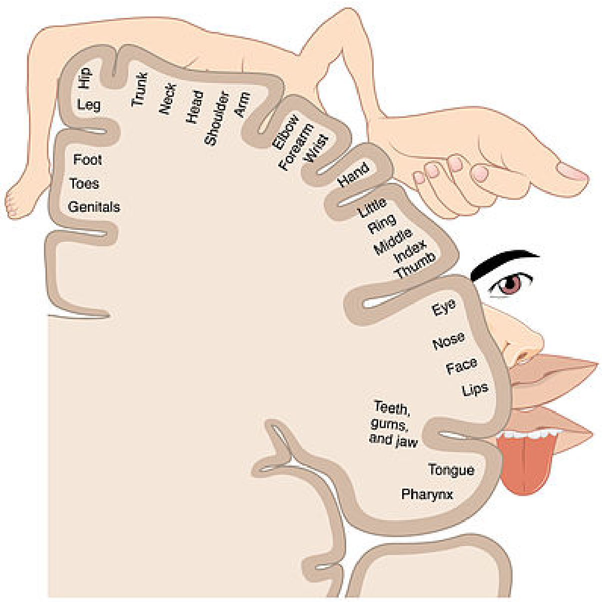


Figure 2.6: Neurological homunculus [31].

Electrodes

The muscle is defined by the neuron it is enervated by. So, why are muscle signals used instead of nerve signals to control the prosthesis? There are some reasons to use muscle signals instead of nerve signals. First of all, muscles are natural amplifiers of the nerves and nerves have a very small signal and there is noise between parts. Furthermore, sweat improves the signal but if there is a lot of sweat it can be worse because crosstalk could happen, since if there is no contact the signal is very spoiled. Hair and scars are also not very good for the signals, and environmental electrical signals also interfere.
Regarding the type of use, there are two different types of electrodes: NAD electrodes, that are only used for diagnosis reasons and service electrodes, that are surface electrodes for the prosthetic use.
There are also passive and active electrodes. The difference between them is that active electrodes have a pre-amplifier located inside of the electrode which avoids much of the noise and what makes them more expensive.

Types of pain after the operation

We have talked a lot about phantom limb pain since that is the main topic of this project, but there is another type of pain occurring after the operation: the stump pain or Residual Limb Pain (RLP) [32]. The stump pain is a real pain that happens when neuroma is formed in the limb. It can appear in up to 74% of amputee patients and, as happened with PLP, it can lasts year. The difference with PLP is that RLP is worse at the beginning just after the amputation and decreases with time. With PLP it is possible to experience a very painful feeling like if your leg is bent or as if a knife is stabbed in your leg or burning. This is less common in children since their brain is more sensitive. What it is used to solve this problem now is to use the Mirror Therapy, explained in Section 2.1.

Control of the prosthesis

To control the myoelectric prosthesis 8 electrodes are used, placed around the arm. The raw signal is used since zero crossing are useful in this case. So the signal is not filtered, rectified, and not mean square is done. For the control of this prosthesis, embedded microprocesses are used. This makes possible to make more precise movements and allows to think directly in the movement you want to perform, as if it was a real hand, instead of having to think what muscle to contract to change to another joint. This is achieved by the use of pattern recognition: according to the signals coming from the 8 electrodes, the required movement is known. It is done with supervised learning.
The feedback needed by the patient are the following variables: position, velocity, contact, and strength. It is desirable that the patient know this data, and it is done through electrostimulation. The problem is that it may interfere with electrodes.
There is a paradox regarding amputation levels: the more arm amputation level, the more number of joints are needed to replace. Therefore, more signals are needed, but there are no more muscles so it is necessary to "create" them. For transhumeral amputation,

pectoral muscles are used, joining arm nerves with pectoral nerves. An electrode is positioned in each part of the chest (muscle innervation). The power can be located outside the body or implanted inside of the body. If the battery is placed outside the body it works by induction but the battery is big and heavy.
Prosthetic and bionic reconstruction is made when the connection of the nerves is lost (for example in motorcycle accidents when there is a whiplash between the head and the arm).

2.3.5 Hand ownership talk

A PhD talk from Tiare Feuchtner from the Ahrhus University in Denmark was attended. The topic of her PhD is *Designing for Hand Ownership in Interaction with Virtual and Augmented Reality*. She states that creating a body ownership illusion by means of virtual and augmented reality, is it possible to make the user believe that it is his/her own body and create more engagement. The *body ownership illusion* can be either a false part of the body (like a rubber hand) or a virtual part of the body. She demonstrates that our mental body representation is more malleable than expected through two different examples, one by virtual reality technology and the other by augmented reality [33].

Regarding the augmented reality application, what Tiare showed was that we can still feel that a limb belongs to us even if it is deformed, since what the human being detects as his own body can be very malleable [34]. In this example, the user's arm is lengthened up to more than two times the real length of the arm, exceeding body limits, and the user still feels that it is his/her arm. This is done by camera tracking of the real arm and the environment. The challenge here was to make the brain detect the lengthening of the arm as natural. The function to length the arm is based on the Go-Go Interaction technique [35]. What this technique does is maintain the original arm length when the hand is close to the body, but once a threshold is exceeded, the arm is lengthened exponentially with the distance from the hand to the body.
She also pointed out that it is necessary to represent the whole virtual arm instead of just the hand since representing only a hand is unnatural and the objective of perceiving the hand as one's own is not achieved. Moreover, a virtual hand is more easily perceived as an own hand if the virtual arm is lengthened than if the hand is on its position but the arm is omitted. Users stated that they perceived the disconnected hand just as a mouse cursor. So it is concluded that body ownership is highly affected by the connectivity of the parts of the body and by appearance, since the more a limb look like a real limb, the more it is perceived as own. Another good practice to do in augmented reality is to implement occlusion if the hand is under an object and shadows if the hand is over it. Figure 2.7 shows an example of the lengthened of the arm, creating a shadow when it is over the table (A) and with occlusion when it is under the table (B).

The virtual application Tiare did was about what she calls Ownershift [36]. Ownershift is a technique in which the virtual hand is gradually separating from the real hand over

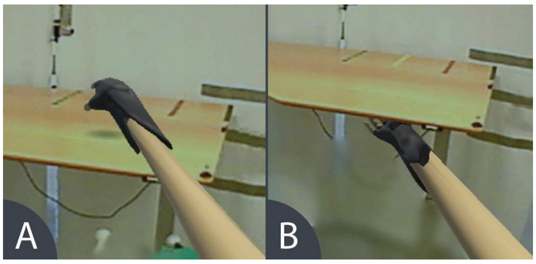


Figure 2.7: Lengthened virtual arm with the user's arm extended. Example of shadow with the hand over the table (A) and occlusion with the hand under the table (B) [34].

time in overhead manipulation tasks. This is done to reduce the effort the user has to do but with the illusion that his/her hand is still in the initial position. In the end, the users have their arm in a lower and less effort position while they think they have it over the head. The maximum difference between the initial and the final position was 65 cm, which is 60º around the shoulder. At the beginning of the activity, the users had a small ball bouncing on their fingertip and every time the ball touched it they could fell a short vibration. This was followed by an activity that consisted of tapping alternatively two targets on a panel. The objective was to reach the targets as fast an accurate as possible and the users felt a vibration every time they touched the panel. The vibration allows to feel ownership of the hand and make the interaction more real. Figure 2.8 shows how the real hand shifted from the initial position to the final and easier position.

Figure 2.8: Shift that gradually experimented the hand from the overhead position to a easier position to perform task [36].

The last study that Tiare presented consisted of exploring different types of multisensory stimuli and visual realism and how they affect the hand illusion [37]. The experiment was made with 3 different representations of the hand: a very realistic hand, an abstract hand and a less realistic hand with only a stick that represented the arm and triangles as fingertips. There were also 3 different types of feedback: a complete track of the movement of the hand, an inanimate hand that changed to red colour with the user's pulse and an inanimate hand without any feedback. They found out that the more realistic the hand was, the better the body ownership illusion was. However, half of the participants also felt body ownership illusion even with the very unrealistic hands if they could move them. Figure 2.9 shows all the different representations of the hand in the 3 feedback cases.

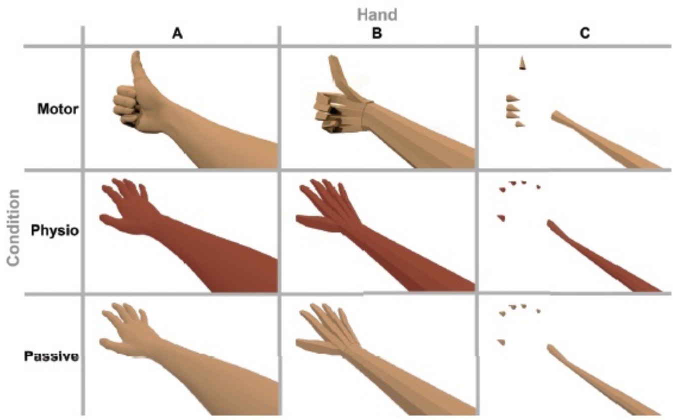


Figure 2.9: Different representations of the hand under different feedback conditions [37].

Finally, Tiare explained that with augmented reality and virtual reality is it possible to exaggerate small movements or reduce large movements while maintaining the hand ownership illusion, so your new hand is the hand that you see through the AR or VR device. This can be very useful for this project since it is possible to reduce the frustration of patients by making larger virtual movements with less effort at the beginning and increase the effort over time for better rehabilitation.

CHAPTER 3

Methodology

3.1 Methodology and results

The practical steps for creating and evaluating this prototype will be structured in three phases: the design phase, the development phase, and the evaluation phase. If after the evaluation phase would be necessary to make any change, the three phases will be repeated.

These 3 phases are now described with more detail.

3.1.1 Design phase

The first phase is the design phase. This is a very important phase to develop the rest of the phases successfully. This requires to gather information about the related work and about the available technology, as well as patients needs. This is carried out as follows:

- In the first stage of this project, it is necessary to gather information about previous related work. Further research was thus needed to examine the different possibilities to deal with Phantom Limb Pain. Furthermore, it is necessary to understand what PLP exactly is and why it is generated, in order to find useful solutions. Finally, research about Augmented Reality has also been carried out, since AR is used in this project. Moreover, scientific papers and lectures from the Medical University of Vienna helped to get familiarised with the state of the art.

- Subsequently, rehabilitation sessions, and follow-up sessions were attended. This allows seeing the problem first-hand, by seeing the patient's mood and needs. It also allows seeing what are the currently used techniques. With this information, we decided how the application had to be developed. We also decided which group of patients were going to be targeted: patients whose arms were amputated below the elbow, as the remaining muscle signals are easier to manage than those of patients amputated below the shoulder.

- We then had a workshop to discuss how the prototype of the game was going to be.

3.1.2 Development phase

This is followed by the development phase, in which the prototype and the means for the evaluation of the prototype were developed.

- The objective was to develop and Augmented Reality application and use it from the Microsoft HoloLens, in which the patient must be able to see and move a virtual arm. The arm movement has to be carried out through its muscular electric signals thanks to a set of electrodes (Myo Armband) placed on its muscles. The goal was to program part of a video game that patients will use to carry out their rehabilitation.
- To accomplish this task it is necessary first to learn how to use the tools, especially Unity, C# and Blender. This was carried out following some tutorials and exploring the tools.
- Parallel to the development of the prototype a questionnaire was created to test it. The questions are:
  - Do you think the patient will perceive the use of the prototype as positive or negative for its motivation?
  - Do you think the patient will perceive the use of the prototype as positive or negative for its rehabilitation?
  - Which aspects of the prototype are perceived as positive or negative?
  - What is your opinion regarding the Myo Armband?
  - What is your opinion regarding the Hololens?

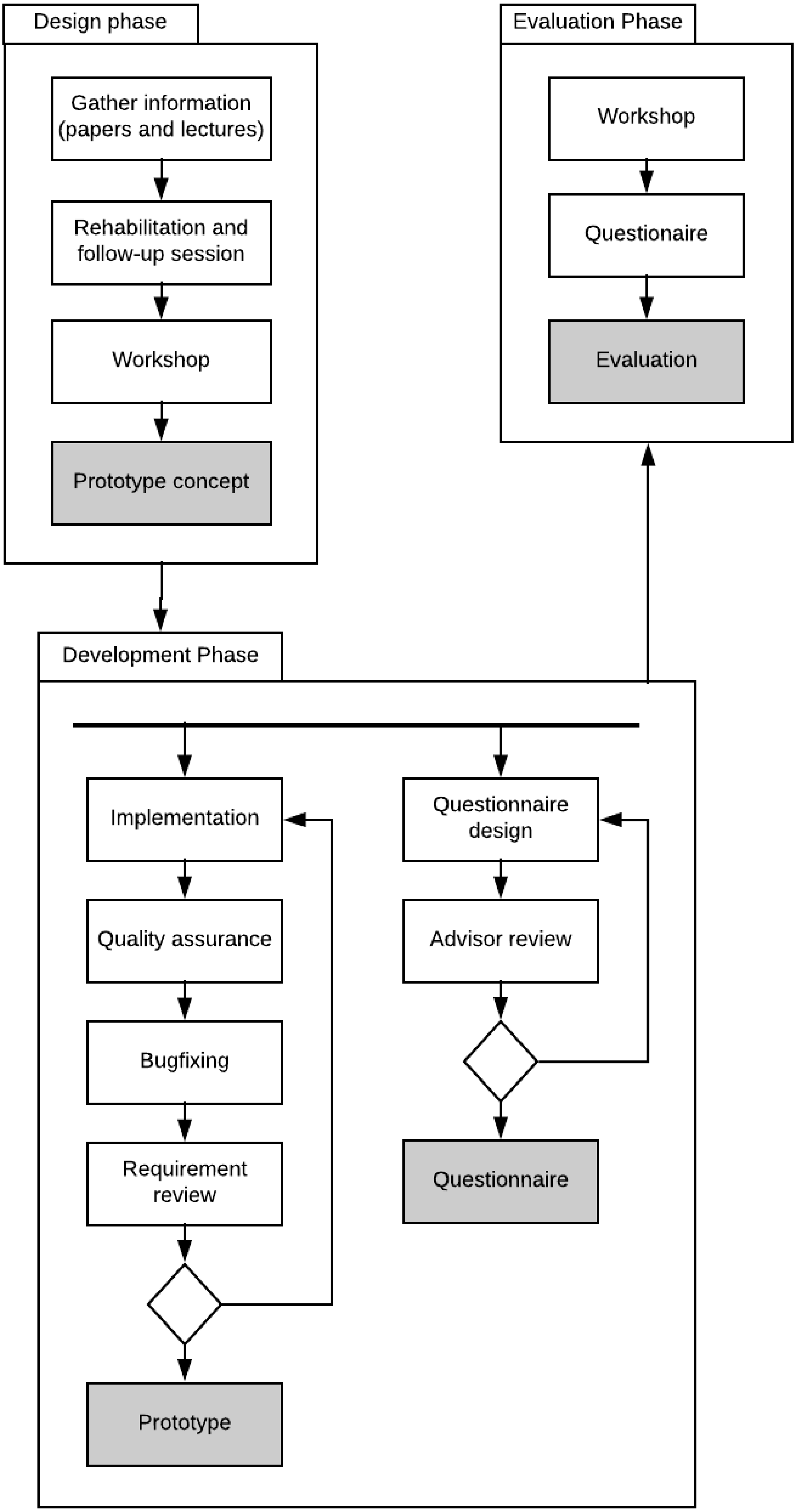
3.1.3 Evaluation phase

In the final stage, the evaluation of the prototype takes place. The prototype is evaluated qualitatively since a quantitative evaluation can't provide much information. This will be carried out as follows:

- We tested the prototype. The test was done with a group of 8 able-bodied people. This will bring information to possible improvements.
- The Thematic Analysis [38] is the method used for the evaluation. Thematic analysis is a tool used for analysis in quantitative research whose aim is to look for patterns within data. It is divided into six phases. The phases are explained with more detail in Chapter 5.

- All the participants were asked to fill out the questionnaire and give their opinion about the prototype. Their comments during the trial were also noted. It is analysed in accordance with the described aim of this work.

Figure 3.1 shows an overview of the three phases that were followed.



Design phase
Gather information (papers and lectures)
Rehabilitation and follow-up session
Workshop
Prototype concept
Evaluation Phase
Workshop
Questionaire
Evaluation
Development Phase
Implementation
Quality assurance
Bugfixing
Requirement review
Prototype
Questionnaire design
Advisor review
Questionnaire

3.2 Technical aspects of the prototype

The overall goal is to make the prototype useful for patients. This is achieved by creating engagement through fun. This is one of the biggest problems during rehabilitation, patients are bored and give up the rehabilitation, mostly if they do not see fast results.

The program is implemented using Unity® 2017.4.17f1 Personal [39]. Unity® is a cross-platform real-time engine that enables the creation of 2D and 3D video games. The platform provides a C# [40] interface, so the game was implemented using C#. It also accesses to the .Net framework for implementing the game logic. The game engine manages the physics and graphics calculations of the game. Unity® along with Vuforia Engine platform [41] allows to create an Augmented Reality application.

Microsoft Hololens glasses [42] are used to visualise a virtual environment and a virtual arm. Microsoft Hololens is a pair of mixed reality smart glasses that allows to make holographic applications. See Figure 3.2

To capture the muscular signals a Myo Armband [43] will be used (see Figure 3.2). This armband let use the electrical activity in muscles to control digital technologies. It consists of eight electrodes that pick up EMG muscle signals by muscular areas, a three-axis gyroscope, a three axis accelerometer, and a three-axis magnetometer. The Myo Armband can be connected to a computer wirelessly using a USB Bluetooth device.

Finally, the 3D models used within Unity® were created using Blender [44], an open source 3D creation software.

Figure 3.2: Microsoft Hololens and Myo Armband.

CHAPTER 4

Implementation

4.1 Gameplay

The game screen shows a virtual hand quite similar to a real hand and several objects scattered around the room.
The game starts with a Menu where you can either play the game or read the game instructions: The patient has the possibility to switch between normal mode and magic mode. This is done by muscle activation and it is explained in Section 4.2.3. In normal mode, the look of the hand is the same as the look of a normal hand. However, in magic mode, the hand glows and emits a blue light halo. It is possible to manipulate objects in both modes, but in each mode, it is done differently. In order to grab an object in non-magic mode, you have to bring your hand closer to the object in the same way as you would do with a normal hand. The hand grabs each object according to the type of object it is. For example, when holding a bottle, the hand is placed in a circular way around it. However, only the fingers are used to hold a key. In this mode, it is also possible to turn the hand left and right.
To manipulate an object in magic mode, the only requirement is that the hand must be pointing towards the object. The first thing to do is to grab the object (even if it is in the distance) and once grabbed it can be moved around the room, as well as move it closer and further away.
When an object is released, it does not fall under the force of gravity. As it is an AR and not a VR application, there isn't any object like a table to stop the fall of the object, so they would fall indefinitely and they would be lost. In this case, the objects only react to external physical forces, so when an object is released it will move in the same direction as the hand was moving when it released the object and the speed of the object will also depend on this force.

4.2 Prototype design and architecture

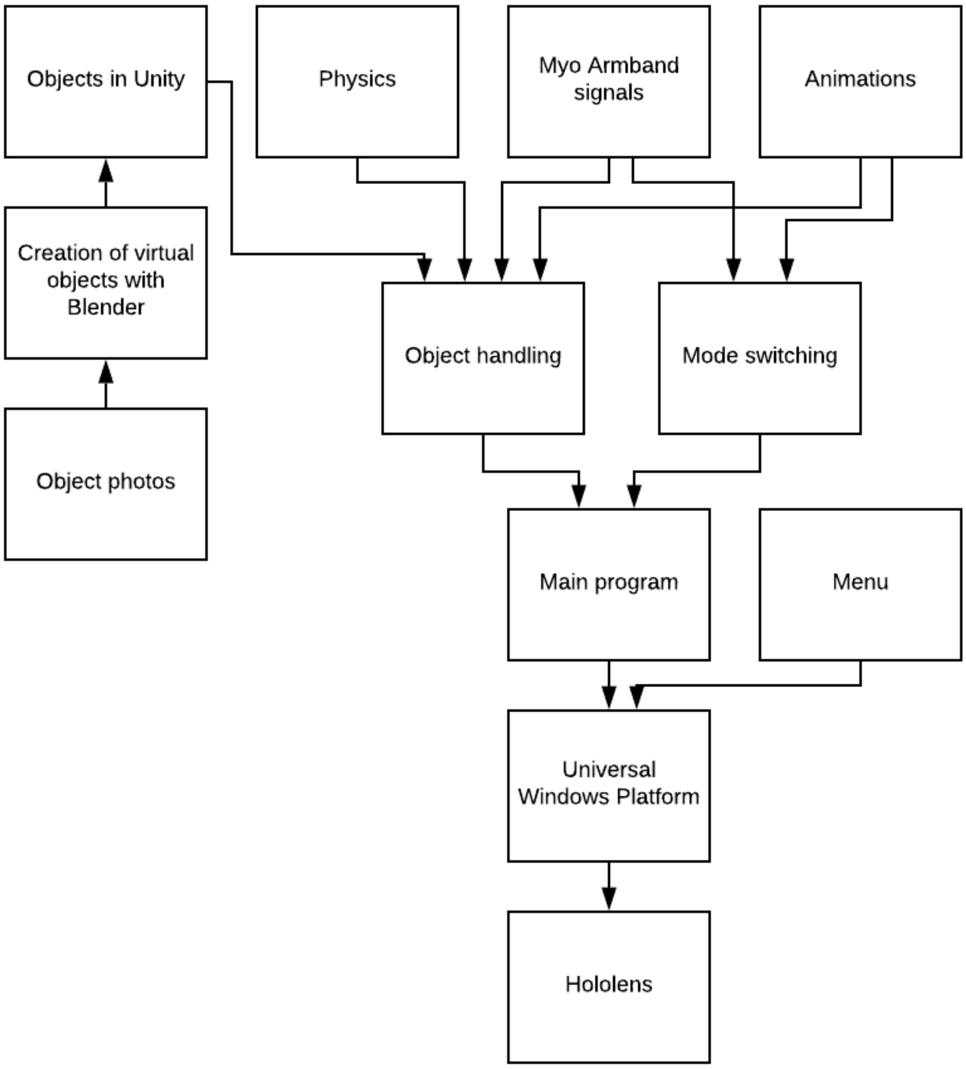


Figure 4.1: Architecture of the prototype.

This section describes the main modules of the prototype. Figure 4.1 shows an outline of the prototype architecture with its main modules. Firstly, various pictures of different objects were taken in order to make their 3D model in Blender. Once the 3D model of the objects was made, they were imported into Unity and a rigid body and colliders were added to them, to allow them to interact with other objects. This, along with Unity's physics engine, EMG signals from the Myo Armband and animations in Unity, make

the manipulation of objects possible. On the other hand, EMG Myo signals and Unity animations allows to change modes during the game.
Object handling and mode switching are managed within a Unity scene and controlled by the main program. Another scene contains the main menu with the game instructions on it.
Finally, thanks to Universal Windows Platform it is possible to visualise the game scene through the Microsoft Hololens.

4.2.1 Scenes

The Unity program contains two successive scenes. The first scene is the Menu, shown in Figure 4.2. In the Menu there are three buttons: Play button, Instructions button and Quit button. The game starts when the Play button is selected. Pressing this button will switch to the next scene, which is the game. In the Game scene, it is possible to move the virtual arm and manipulate the objects.

Figure 4.2: Main Menu.

4.2.2 3D Models

All objects used in the game, except the arm, were created using Blender. The model of the arm was downloaded from the internet. The objects are a copy of real objects that are available in the rehabilitation room at the Allgemeines Krankenhaus (AKH) in Vienna. This was done in order to give patients the possibility to clone these real objects through the game and then manipulate them with the virtual hand that they control with the Myo Armband through the EMG signals. This was not done in this prototype but can be developed for the final video game. Figures 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 show a comparison of the real objects with the objects created in Blender. Figure 4.9 shows another view of the models of all the objects created using Blender, without any material attached to them.

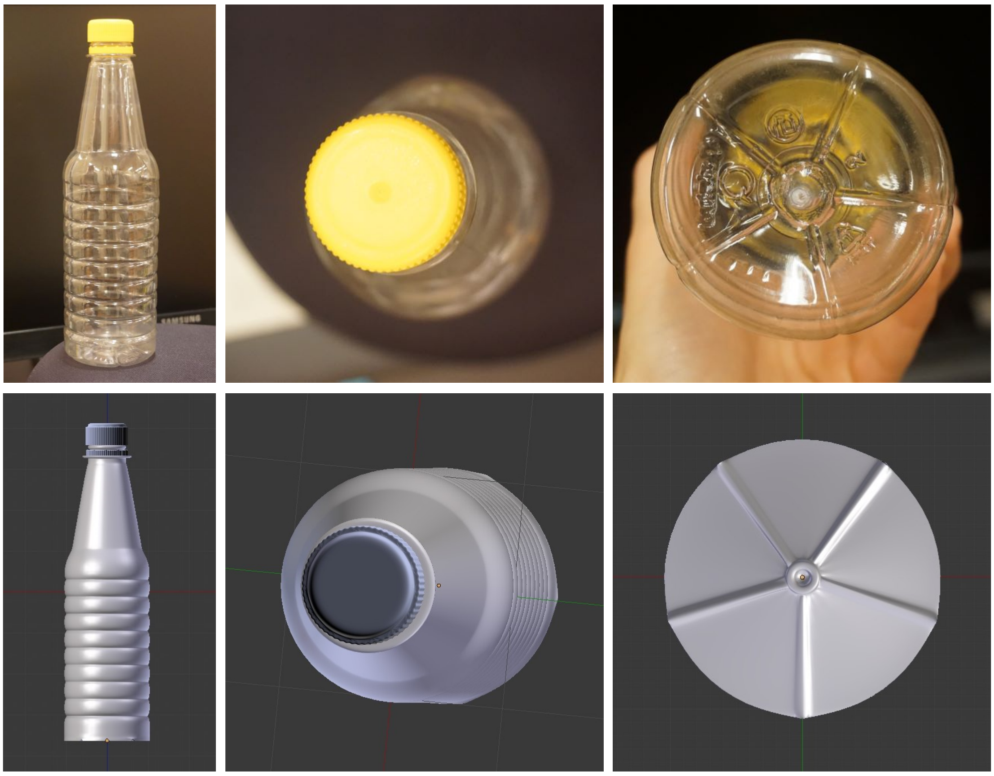


Figure 4.3: Comparison of the real bottle with the bottle created in Blender.

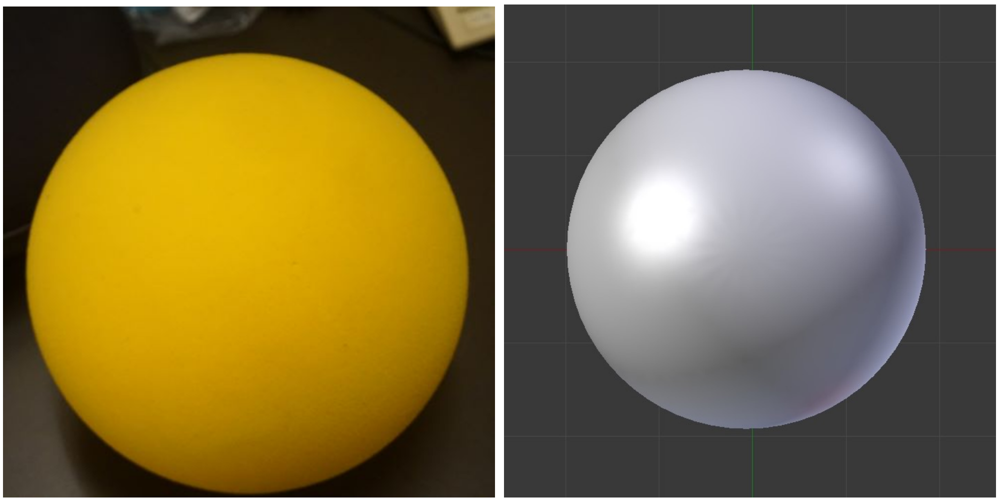


Figure 4.4: Comparison of the real foam ball with the foam ball created in Blender.

Regarding the material of objects, it is possible to assign a material and/or texture to the object in Blender and then export it to Unity along with the object. However, this

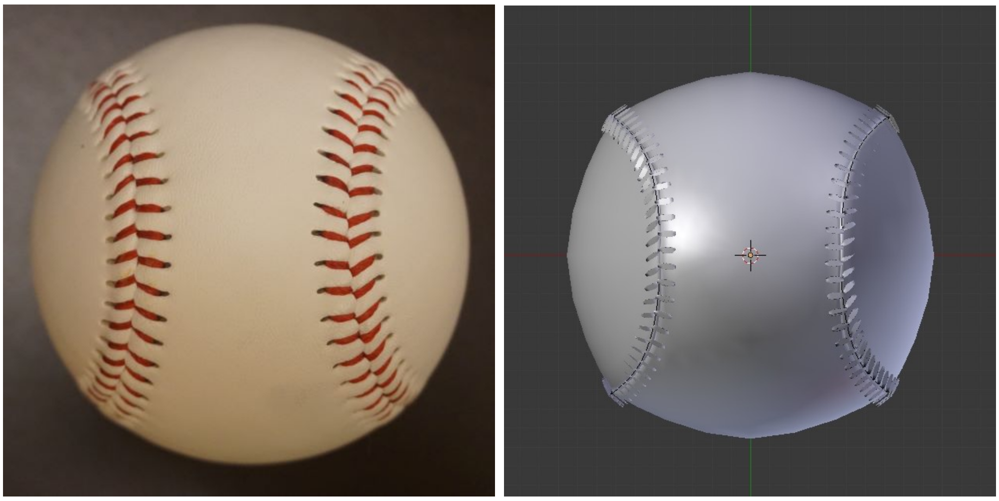


Figure 4.5: comparison of the real baseball with the baseball created in Blender.

Figure 4.6: comparison of the real mug with the mug created in Blender.

process is a bit longer than creating the material directly in Unity. For this reason, this second option was chosen, since the result is very similar. The materials to be assigned to each object were created in Unity. Figure 4.10 shows the objects with the materials already assigned in Unity. In objects with two different colours, it was necessary to separate it in two different objects in Blender, in order to make possible to assign two different material to the objects.

Figure 4.7: comparison of the real knife with the knife created in Blender.

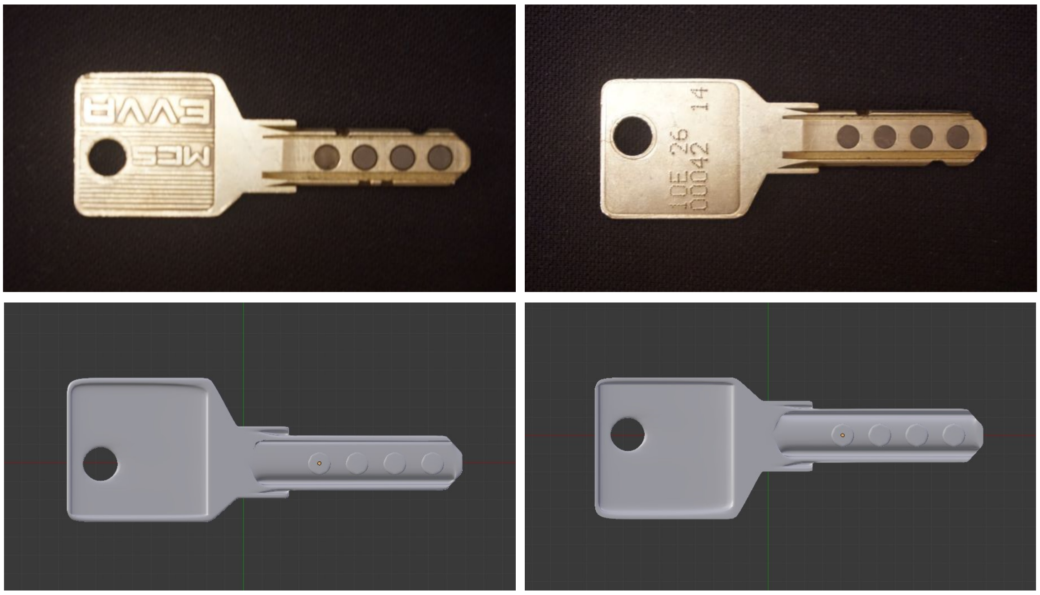


Figure 4.8: comparison of the real key with the key created in Blender.

In order to make objects behave like real objects and act under the laws of physics, a Rigidbody component has been added to each object. By attaching a Rigidbody to an object it will move under the control of Unity's physics engine. This causes the object to fall under the force of gravity, if it is enabled, and makes it possible to apply forces to the object. It will also make the object to react to collisions with other objects. However, in order to do this, it is also necessary to attach a collider to the object.

A collider defines the shape of the object so that it acts according to the shape when it collides. The shape of the collider must be approximately the same shape as the object, but it is not necessary for the shape to be exactly the same. Therefore, some of the primitive collider types have been used: Capsule Collider, Sphere Collider, and Box

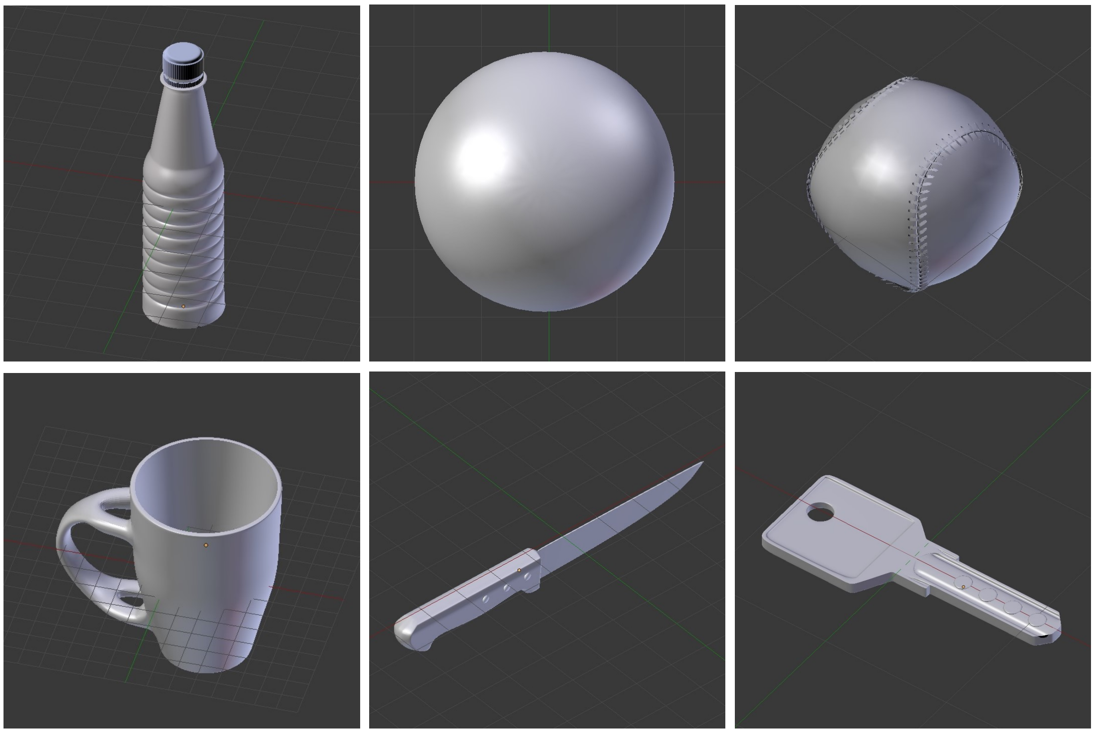


Figure 4.9: 3D models of the objects in Blender, without materials or textures.

Collider. By using these simpler colliders it is possible to keep a low processor overhead.

4.2.3 Activations

This section explains the muscular activation that must be performed to control the virtual arm in the game. Myo SDK comes with default detectors which are: **WaveIn**, **WaveOut**, **FingerSpread** and **Fist**. These Boolean values are activated when the action they describe is performed, so they are used in the C# program.

"Fist" has only been used to position the arm pointing forward in the game so that it can be aligned with the direction of the Myo bracelet when it is placed in that position. However, the "r" key can also be pressed for this purpose. So, in the case of an amputee patient used the prototype, he/she must press the "r" button since they cannot do more than three muscle activation. **WaveIn**, **WaveOut** and **FingerSpread** are used to control the game. **FingerSpread** is used to switch between modes. Thus, to switch between *Magic* and *Non-Magic* mode, double *FingerSpread* must be performed (the second must be performed before 1.3 seconds have elapsed since the first). In *Non-Magic* mode, in order to switch between *Grab and Release* mode and *Twist Wrist* mode, *FingerSpread* must be performed once. And in *Magic* mode, in order to switch between *Grab*

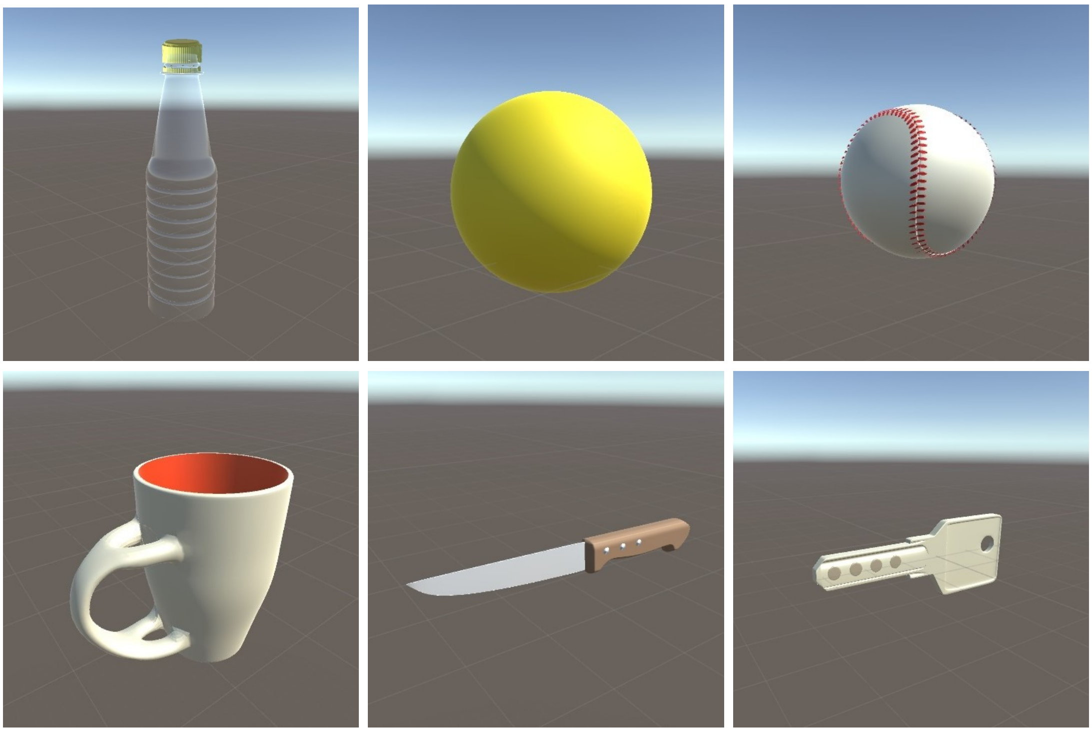


Figure 4.10: 3D models of the objects in Unity, with their materials assigned.

and Release mode and *Zoom In and Out* mode, *FingerSpread* must also be performed once.

In *Non-Magic* mode and *Grab and Release* sub-mode, **WaveIn** is used to grab and object and **WaveOut** to release it. In *Non-Magic* mode and *Twist Wrist* sub-mode, **WaveIn** is used to rotate the hand to the left and **WaveOut** to rotate the hand to the right. In *Magic* mode and *Grab and Release* sub-mode, **WaveIn** is used to grab an object in the distance and **WaveOut** to release it. Finally, in *Magic* mode and *Zoom In and Out* sub-mode, **WaveIn** is for zoom out the object we are grabbing and **WaveOut** to zoom it in. These actions were chosen to be as similar as possible to the control modules of the prostheses used in the actual evaluation [45]. This will make it easier in the future to use this method in the program.

Some restrictions

- Is it not possible to change from Normal mode to Magic mode and vice versa if an object is been grabbed, so it will be necessary to release it first.
- Is it only possible to change to Zoom in and Zoom out mode if there is an object in the hand.

- The minimum distance at which we can zoom the object in is 25 cm and the maximum distance at which we can zoom the object out is 5 m.
- In order to grab an object in Non-Magic mode, it is necessary to approach the object at a distance reachable by hand.

The game instructions are explained in a simple way by clicking on the *Instructions* button in the main menu. This is shown in Figure 4.11.

Figure 4.11: Game instructions in the main menu before starting the game.

4.2.4 Modes

Non-magic mode

In this mode, in order to pick up an object, the user has to approach the object. An image of the arm in rest position is shown in Figure 4.12 (left). The position of the hand when holding the object depends on the object and its shape. Therefore, a different animation of the hand was created for each object. This is shown in Figure 4.13.

The main script of the game is called *HandGrabbing*. This script manages most of the game logic. To detect if there is an object near the hand, the function *Physics.OverlapSphere* has been used in this script. This function attaches a sphere to the object we want with a specific radius. In this case, the sphere has been attached to the first phalanx of the middle finger, with a small offset and a radius of 7cm. In this way, a collider will be detected if part of an object is inside this sphere. In addition, as mentioned above,

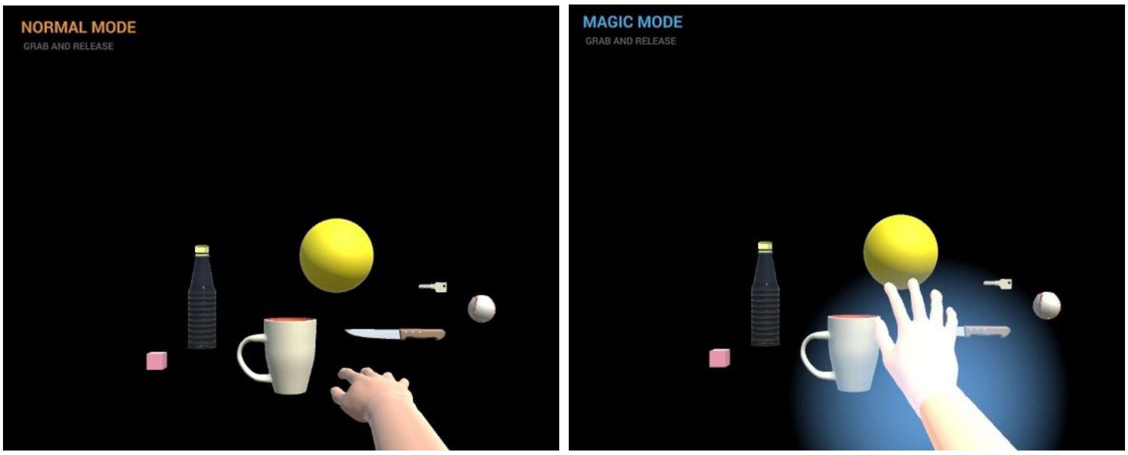


Figure 4.12: Comparison between *Non-Magic* mode and *Magic* mode.

depending on the type of object, the hand will be closed in different ways when the object is picked up. The object the hand is grabbing is detected through a label set to the object. If there are two objects within the sphere, the one closest to the centre of the sphere is picked up. The dimensions of the sphere can be seen in the Figure 4.14 (white sphere), although during gameplay this sphere does not appear.

In Non-Magic mode, besides picking up objects it is possible to rotate the wrist to the left and right in *Wrist Twist* mode. Figure 4.15 shows this.

Magic mode

In this mode, it is possible to pick an object from the distance as long as the object is not closer to the hand than the minimum distance and not further than the maximum distance. These distances are 0.25 meters and 5 meters, respectively. In *Magic* mode, the animation is the same for all the objects and the same when it does not have any object picked, but different from *Non-Magic* mode. Furthermore, the arm is glowing with a blue light. This is shown in Figure 4.12.

To detect if it is possible to grab an object, the function *Physics.SphereCast* has been used in the *HandGrabbing* script. This function cast a sphere along a ray and return a boolean that is true when the ray hits an object. It also gives information about the object. So the origin of the ray is in the Myo Armband and pointing in the forward direction of the arm, with a length of 4 m and a radius of 4 cm. A representation of the ray is shown in Figure 4.16 (a), where the red sphere is the end of the ray and has the chosen radius. When the **WaveIn** gesture is performed to grab the object, the closest object to the hand is grabbed if two or more objects are detected at the same time. This is shown in Figure 4.16 (b), where the magic hand has taken the knife instead of the

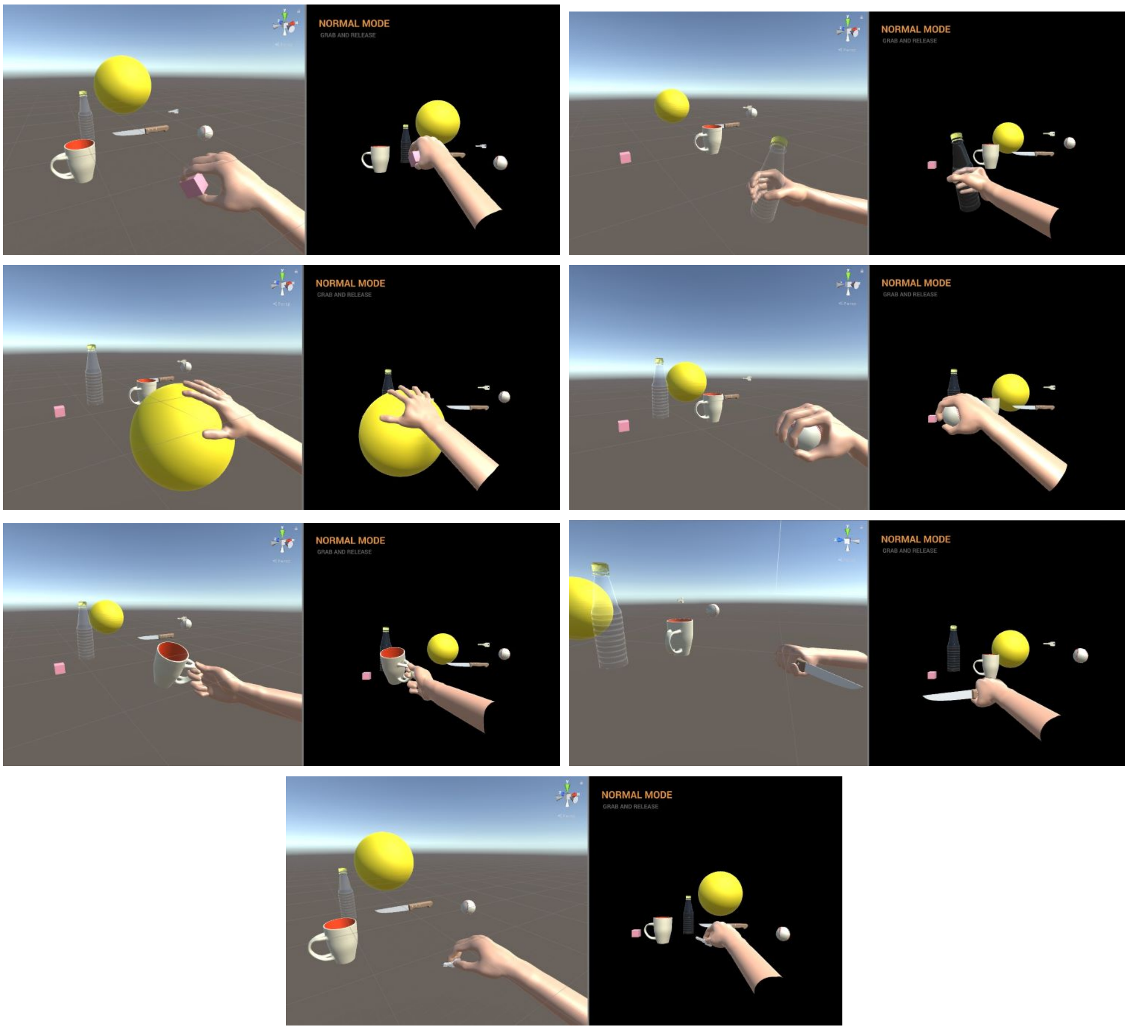


Figure 4.13: Virtual hand holding different objects.

Foam ball, due to its closer distance. In order to make the object follow the movement of the arm in a natural way, the following steps are done:

- An invisible pointer is attached to the arm GameObject at a distance equal to the distance at which the object was detected. This pointer is what follows exactly the move of the arm. The pointer representation is shown in Figure 4.16 (b) (blue sphere).
- The object follows the movement of the pointer with a delay depending on the speed at which the object has to follow the pointer.

Furthermore, if *Zoom In and Out* mode is chosen, it will be possible to zoom in and out

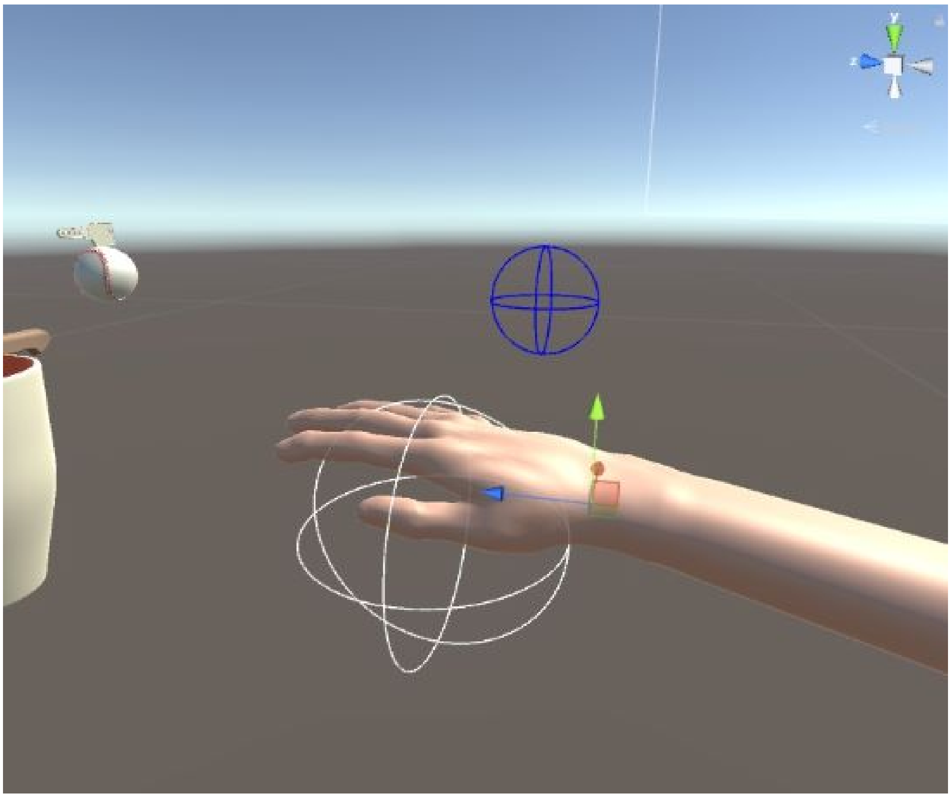


Figure 4.14: Object detection sphere (white).

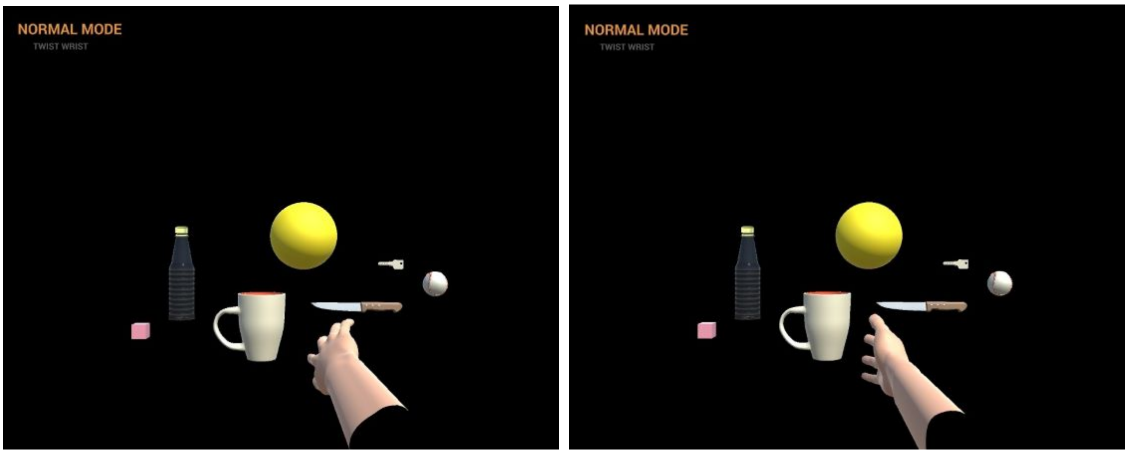
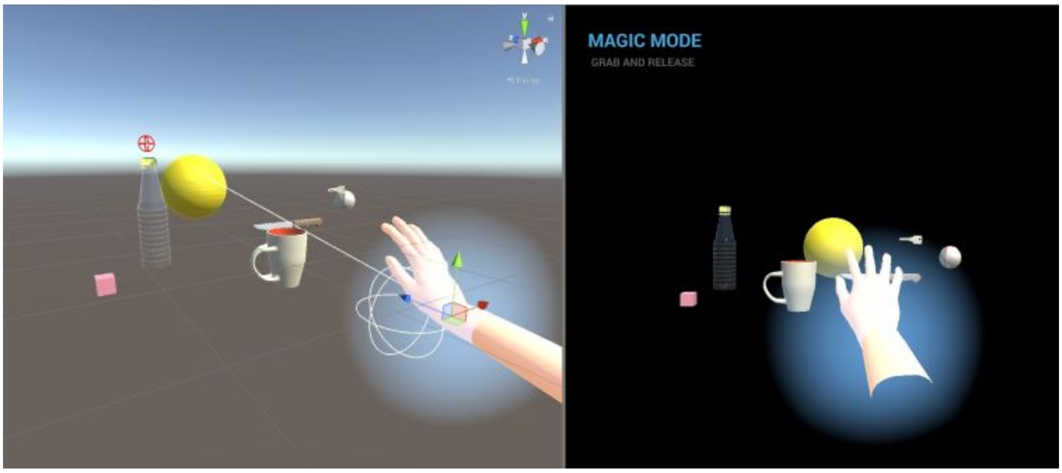
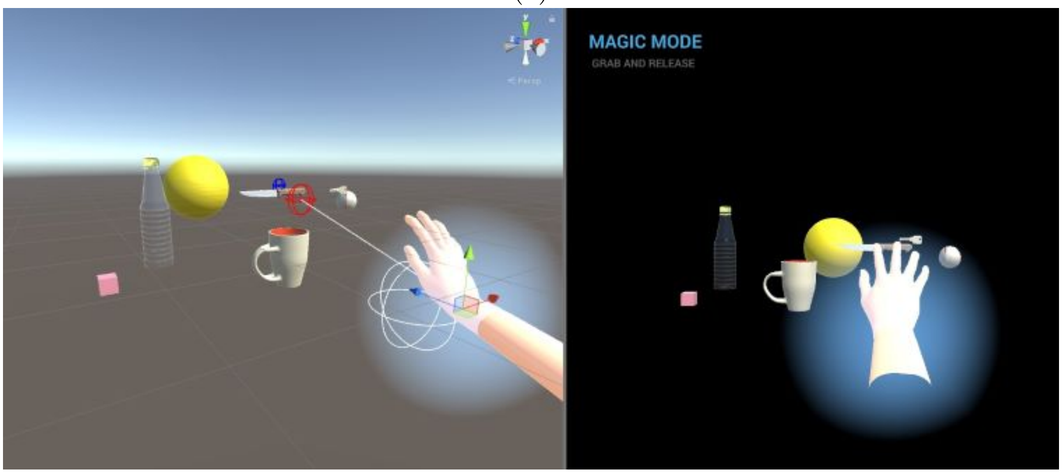


Figure 4.15: Wrist rotated left and wrist rotated right.

the object, apart from moving it around. Figure 4.17 shows two images of the magic hand controlling two of the objects, bringing the bottle closer and moving the knife away. A wide open hand was created for the zoom in animation and a hand with the fingers



(a)



(b)

Figure 4.16: Representarion of the sphere cast (red) and the pointer (blue).

facing forward was created for the zoom out animation.

4.2.5 Animations

The only object that performs animations in this prototype is the arm. After creating all the needed animations for each of the actions by setting the angle of rotation of each finger joint, it is necessary to set the logic that switches between them. Figure 4.18 shows the existing animations and how they are linked. The transition between animations are controlled by variables, and these variables are controlled within the script *HandAnimation*, which changes the value of the variables according to the game state. For example, when the bottle object is going to be grabbed, the animator variable *IsGrabbing* turns true and the animator variable *GrabbedObject* gets the value 1, which is the value corresponding to

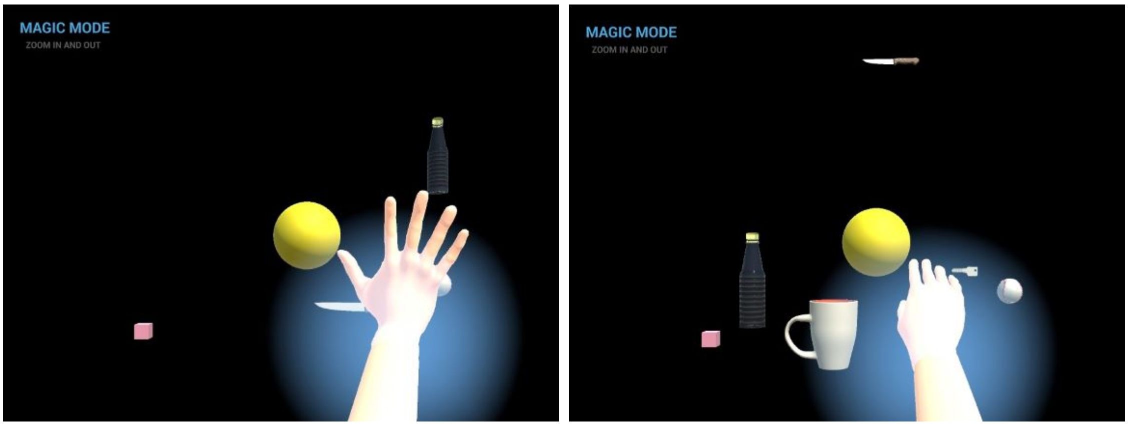


Figure 4.17: Zoom in and zoom out.

the bottle. So when the variables acquire the necessary values, the animation transition happens. Variables that control transitions are also shown in Figure 4.18, in the left side of the Animator window.

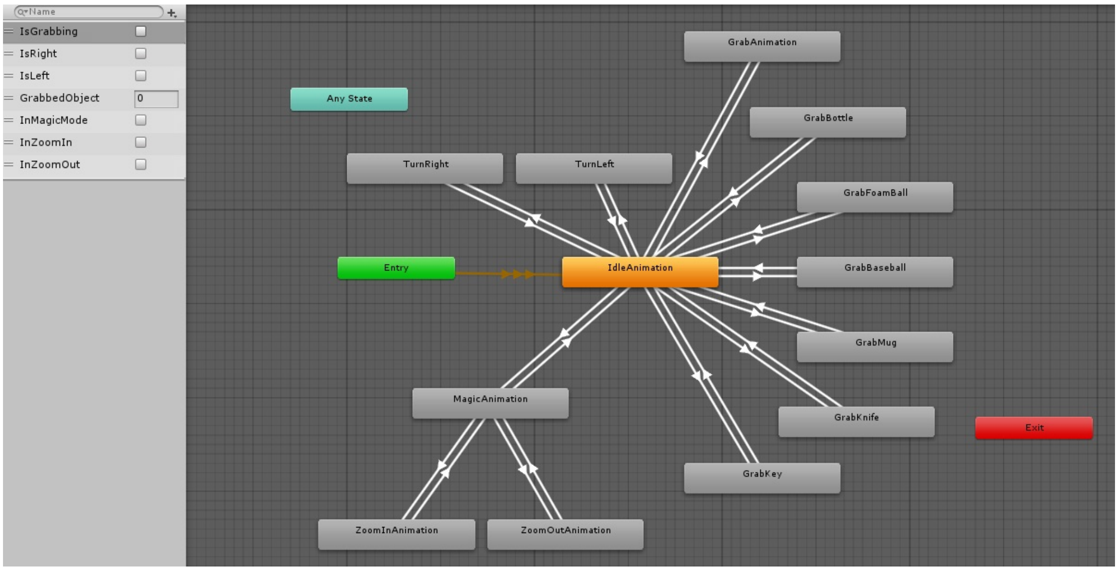


Figure 4.18: Animator. Interface that controls the animation system.

4.2.6 Motion Control

This subsection explains how the movement of the objects works in both *Non-Magic* mode and *Magic* mode.
When an object is grabbed in Non-Magic mode, this object becomes a kinematic object, so physic forces do not affect the object and the virtual hand can grab it. When an object

is already grabbed, its new position is calculated every frame. Therefore, the position and rotation of the object will be the same position as the first phalanx of the middle finger with an offset. To do so, the Unity function *Transform.TransformPoint* was used to transform the position from local space to world space. When the object is released, its kinematic value turns again to false and the velocity depending on the force of the hand applied to them is calculated. This velocity is calculated as a function of the time elapsing between its position in one frame and the next.

When an object is grabbed in *Magic* mode, its kinematic value is also turned to true. In this case, the pointer that has to follow the object becomes a child of the arm object, so its movement is referenced to the movement of the arm. The new local position of the pointer is set at the distance in which the sphere cast detector hits with the object.
However, it is possible to change this distance from the *Zoom In and Out* mode. In this mode, a vector is calculated in every frame. This vector contains the distance from the hand to the pointer, along with the direction that the pointer has to take, depending on whether it is in zoom in mode or in zoom out mode. So when zoom in or zoom out gesture is performed, the Unity function *Transform.Translate* is used to move the object in the desired direction with a certain constant speed.
Finally, to make the object follow the pointer, the same solution as with *Zoom In and Out* mode is used. Therefore, a vector from the object to the pointer is calculated. The vector points the pointer so the object moves on its direction with a constant speed but never reaching it completely to prevent the object from swinging around the pointer. When the object is released its kinematic value turns again to false.

4.3 Integration of modules

An important step in this project is to integrate the different modules: Unity, Hololens and Myo Armband.

In order to use the Myo Armband along with Unity, a Myo package was downloaded and imported into Unity. The name of this package is Windows SDK 0.9.0 [1] and it allows to use, among other options, the predefined Myo movements used in this project: **WaveIn**, **WaveOut** and **FingerSpread**. After importing the Myo SDK, some bugs appear in the console. To solve this problem what it has to be done is to open the script with the name *ColorBoxByPose* and replace *renderer* with *GetComponent<Renderer>()* or directly delete that script.

To use the Hololens along with Unity it is necessary to follow a series of steps [2] to set up the camera and change some settings. Afterward, it is necessary to connect

[1] https://support.getmyo.com/hc/en-us/articles/360018409792-Myo-Connect-SDK-and-firmware-downloads
[2] https://docs.microsoft.com/en-us/windows/mixed-reality/holograms-100

both PC and Hololens to the same WiFi network in order to connect both devices and send data from the PC to the Hololens. To do so, go to Window > Holographic Emulation, select the option *Remote to device* and insert the IP of the Hololens. Finally press *Connect*. What has to be done from the Hololens is to open an application called *Holographic Remote* and from there it is possible to see the Hololens IP. From this moment and if all the steps are correctly followed, the game will be seen through the Hololens.

4.3.1 Problems encountered

Some problems appeared during the development of the prototype. This subsection is a short summary of those problems.

The desired solution was to deploy the app to the Hololens, so it would not be necessary to use a PC to send the data to the Hololens and it would be possible to use the Hololens camera instead of the PC camera to use target detection. The normal way to do that would be: 1.Build the project using the *Universal Windows Platform* (UWP) and save it in the desired folder, 2. Open the created project in Visual Studio and change the settings to *Release*, *x86* and *Remote Machine* and enter the IP address of your Hololens, 3. Click Play in the Unity editor.

However, to deploy the app to the Hololens is not possible as the Myo SDK was not intended for *Universal Windows Platform*. To receive the Myo sensor data there is a file in the Myo SDK that uses *System.Threading* and which uses threads. However, in *Universal Windows Platform*, asynchronous Tasks are used instead of Threads, and nothing is implemented for the use of Myo along with the *Universal Windows Platform*. Therefore, to solve this problem it would be necessary to rewrite the Myo SDK.

On the other hand, as mentioned above, it is not possible to use the Hololens camera to detect targets if the app is not deployed to the Hololens. This limitation closes a lot of possibilities that would be carried out, such as give the possibility of making the virtual objects appear when the real object is detected by the Hololens camera, or map the environment so it would be possible to make virtual objects interact with real objects.

CHAPTER 5

Evaluation Study

In the evaluation of the prototype the qualitative answers of the participants to five questions, as well as their comments during the prototype trial, will be studied according to the Thematic Analysis. Thematic Analysis [38] [46] [47] is used to study qualitative data and its aim is to record pattern (also known as themes) within it. Thematic Analysis is a six-phase process: 1. Familiarising yourself with your data, 2. Generating initial codes, 3. Searching for themes, 4. Reviewing themes, 5. Defining and naming themes, 6. Producing the report. Thematic Analysis is the qualitative method chosen for the study of the data because of its flexibility and because it is an easy method to learn and use by researchers with little experience in qualitative research.

Eight able-bodied subjects take part in the experiment (6 men and 2 women, from 22 to 27 years old, all of the students and with different knowledge about the technology used). First of all, the participants were explained how the prototype works and the movements they have to make to control the game. The Hololens and the bracelet were also put on. Then, they were given the time they needed to test the prototype. The participants tested the prototype for 10 to 15 minutes (Figure **??**). Finally, they were given time to comment on their impressions and the questionnaire was made to them right after they finished testing the prototype. All the steps of the evaluation were done to each participant separately so that the opinions of one participant did not influence the opinions of the other. The questions made to the participants were the following:

1. Do you think the patient will perceive the use of the prototype as positive or negative for its motivation?

2. Do you think the patient will perceive the use of the prototype as positive or negative for its rehabilitation?

Figure 5.1: Participants of the qualitative study trying the prototype.

3. Which aspects of the prototype are perceived as positive or negative?

4. What is your opinion regarding the armband?

5. What is your opinion regarding the Hololens?

All participant comments about their impressions were noted, as well as their answers to the questions. Then, all their comments were read as many times as needed to get familiar with them, as indicated in step 1 of the Thematic Analysis. This step is the most important since it allows to collect good information from the data set.
After studying the data and follow the Thematic analysis steps, the following themes are identified: fun, easy to understand and frustrating. Most of the participants referred to these topics in a positive or a negative way, or at least they showed an emotion that was linked to the topics.

5.1 Topics

5.1.1 Fun

The main goal of this project was to make a more fun rehabilitation than the currently used. This topic shows the reaction of the participants regarding fun. 5 out of 8 participants made some comment that showed they thought it was fun, such as 'This is cool!', 'This is awesome', 'Oh, oh, come in! Star Wars!' or 'Can I try it again?' (this last question was asked by 3 participants). It is necessary to say that 2 of the 3 people who did not show any excitement about the prototype had already tested some of its parts previously. They also did not say any negative comment about fun or related to fun.
These results show that, at least in a short term period of time, the game would generate fun and, consequently, engagement. It is logical to think that it could generate engagement especially in patients to whom the game will be useful.

5.1.2 Easy to understand

It is desirable that the game is as easier to understand as possible, since the different type of people would use it, such as old people who are not used to new technologies. There is some information from all participants about how quickly they figured out how to use the prototype. However, in this topic, it is not possible to say if it is easy to understand quickly the functionality or not, because it took a different amount of time to each person, but at the end everyone got it. For example, the question 'Can I try it again?' indicates that the people who ask it finally understood the modes at the end at the first time and they were interested enough to want to try it again. There are also some direct comments about this topic, such as 'You need some time before you know how to use the electrodes armband, but after that, the game is easier'. There is another case in which one girl said 'Don't worry, I got it' when it was going to be explained again to her.
Regarding this topic, it is possible that patients would understand faster the game than random able-bodied people since the way of controlling the game is pretty similar to the way of controlling the prosthesis and they are used to use the prosthesis or at least they have been taught about how to control it.

5.1.3 Frustrating

Upper extremity amputees experience high levels of frustration due to a sudden restriction in function, sensation, and appearance on account of the loss of the limb [48]. If the rehabilitative method has a poor outcome and it is difficult to use or to understand, will lead to higher levels of frustration and, consequently, will cause them to abandon rehabilitation.
Only 1 out of 8 participants showed frustration with comments like 'I see it a little bad', referring to what he saw through the lenses, or 'Why does what you want to do fail so much?', referring to the control of the game. The rest of the participants, in contrast, showed motivation asking questions and asking to repeat the prototype again. However,

some comments, even if they did not show frustration, could show frustration if the mood of these people was another, more pessimistic one. For example, one girl declared that 'You have to hold the Hololens in order to see the whole screen'. For her, this is not a problem since she only has to use them for a few minutes and she does not need it. Nevertheless, this could be a big problem and can lead a patient to high levels of frustration and stress.
The good side is that it can also give motivation, as some people report with comments like 'I think this is gonna be very positive for motivation, maybe not for older people right now, but mainly for young and technological people. Because this is always seen as more attractive and less a routine and more as a kind of game' or 'The armband look very comfortable and easy to wear, it's cool. And the same with the Hololens, novelty can help many people to make rehabilitation more attractive, more light.'.
It is possible that some patients will show, on the one hand, more motivation, since the game will be useful for them and, on the other hand, more frustration due to their larger limitations in control and movements. But this could depend more on each patient.

5.2 Qualitative study by modules

It is also interesting to study the participant's opinion regarding each module separately: the Game, the Myo Armband, and the Hololens. This way, it will be easier to identify the problems separately and see what will be necessary to change.
To get information from each of them we pay special attention to the three last questions of the questionnaire: 'Which aspects of the prototype are perceived as positive or negative?', 'What is your opinion regarding the armband?' and 'What is your opinion regarding the Hololens?'. The last two questions are direct questions about the devices and their use, and the first of them will give information about the three modules. Some of the information is also taken for the two first questions of the questionnaire and from the voluntary comments during the trial of the prototype.

5.2.1 The game

After the participants tested the prototype, they were explained what the problem is and how the game would be in the future, so they could make an opinion about the game and this type of rehabilitation. Subsequently, they are able to give good feedback. There was some critical feedback, however, most of the comments were positive. Probably, if the participants would have been people who work in the medical area, more specifically in the area of amputee patients, or the patients themselves, the feedback would have been richer. Nevertheless, due to time constraints, this was not possible.

Positive comments about the game are about the usefulness of the game for patients or about their own fun while testing it. Comments related to the game are the following: 'The game can be interesting for people who need it', 'Cool how he gets close and how he gets away, that's been cool to me. Very precise', 'Nice tool to practise the controls for the prosthesis', 'Oh, oh, come in! Star Wars!', 'The objects seem very realistic, they keep their place, having a magic arm is awesome', 'I'm not really an expert, but for people that lost some limbs it's maybe some hope. Good sign and motivating.'. There are also some comments that show doubt, like 'It depends on the patient or the person. For me personally, it is motivating but I don't know if it would help in my rehabilitation'. An finally, there is also some feedback like 'Would be good to have calibration of the hand', where the person who said this meant that with a great movement of the real hand, the virtual hand only twists a little because the armband is directly under the elbow so it does not get the whole twist of the hand. The utility of this can be studied since it is maybe less effort to turn the hand during the game. However, the way of turning the hand with a prosthesis is by changing mode (from open-close to right-left) and it is desirable to make the game controls as similar to the prosthesis as possible [21]. Another feedback comment was 'Objects are in the air. Would be nice that objects would be integrated into the environment', that gives another idea about how further to develop the prototype.

The idea of the game is interesting for all participants. Several of them think it can be hopeful and fun rehabilitation. However, since the prototype is still in its early stages, it will be necessary to invest a lot of time in its research and development in order to use it as successfully as possible.

5.2.2 The Myo Armband

There is diversity in opinions about the armband, although these are directly related to the response the armband gave to each user. It turns out that the armband responds better to women (included me) than men. It may be that the sample of female participants is not significant to affirm this with certainty since 2 is the number of female participants and 6 the number of male participants. However, it would be interesting to consider this. Not only regarding the armband, but also and specially regarding the development of the game, since usually developers imagine themselves as if they were the users, therefore the products they develop are mostly based on their needs [49] [50] and these are probably not the needs of everyone, especially in the topic covered. There is especially a gap between gender and people of different ages, nowadays that it is difficult to be informed of the latest innovations due to rapid technological progress. Therefore, designing and developing in a technological context should be a continuous process in which developers and users are continuously involved, sharing their ideas and impressions, and saying what is and what is not achievable [51].

The comments given about the Myo Armband are both positive and negative. Firstly, the comments of female participants were 'It wasn't hard to handle it at all, it was cool. I like that it vibrates so you know you've made the movement successfully' and 'You need some time before you know how to use the electrodes armband. But after that, the game is easier'. The second one needed time to let the armband warm up, but afterwards, she could control it without much effort. Regarding the rest of the participants, there are some of them that state that is more difficult to perform some movements over the others, such as 'It's harder to do the "WaveIn" than the other movements', 'Left right really good and the FingerSpread not good', but then they improved the technique and figured out how to control it better: 'A trick, To FingerSpread you have to focus in your fingers and not in muscles' or 'You have to get the technique, is an exercise thing'. On the one hand, there are some very good comments about the armband, especially regarding the ease use of it, like 'I find it very comfortable and it seems easy. It's very cool and easy to put on', 'It is very comfortable to use the armband because you don't have to attach any wire'. On the negative side, they said 'The Myo is very tight', which can be the most problematic as it is something that is part of the design, 'The directional position works well but some times it doesn't recognise my movements', 'Manageability can be a little difficult, can't it?', 'The only problem was what happened when it warmed up.' (the armband stopped working) or 'The armband didn't listen to me' and 'Why does what you want to do fail so much?'. These last 2 comments are from the same person who showed frustration. The good thing is that most of the people learn how to use it better with time so they didn't feel anymore that they didn't have control of it. Finally, there was also one participant who made a suggestion about how could it be better and recognise muscle activation better stating that 'This is actually quite smooth, it works very well. It would be interesting to use only two electrodes'. This can lead to a better EMG recognition and may work better especially for some people.

The armband is a good idea for rehabilitation since it is practical and easy to use and transport. However, it is no longer manufactured since October 2018. the solution would be to look for something similar or just to use to wire electrodes, although the idea of carrying cables all the time is not very attractive. So it would be wise to explore the options.

5.2.3 The Hololens

All participants had the same or almost the same opinion regarding the Hololens: they like how they look, they like Augmented Reality and how virtual objects match the environment but they also complained about the size of the window of the lenses, the place where you can see the virtual objects, and about the fact that many of them had to hold the glasses in order to see this screen. All the comments of the participants regarding the lenses were something that they like about the lenses followed or preceded by the handicap they see on them. For example 'I think that novelty can help many people to make rehabilitation more attractive, more light. The only handicap is that the field of vision was very limited', 'Glasses are heavy, a bit uncomfortable for me but maybe not for people that need the game', 'The design of the glasses is very futurist but you have to hold them in order to see the whole screen', 'I liked how you can see the 3D objects, I liked trying on the glasses. But you cannot see the image, they are nice but...', 'The objects seem very realistic but the Hololens technology is not really yet.'. Thus, it can be seen that people think that glasses are good since you can see good

quality through them, well merged with the environment objects, but they also think that the technology and the design can be improved. More examples of this are 'I have to hold the glasses all the time because I have to wear my own glasses and it doesn't lay on my nose', 'The frame is too small', 'It can be a problem to patients with glasses, like in 3D movies' and 'I don't like that I had to hold the glasses'.This is completely normal as Hololens and augmented reality technology is relatively new. There are also some cases in which participants had to struggle to put on the lenses and it took time to them to figure out how to put on the lenses. One attendee thought that the virtual window was really small until he figured out that was because he had the lenses in a bad position. 'The screen is very little' until he notices he had the lenses hanging a bit, then he added 'Oh this is awesome' when he managed to see the whole scene.
Finally, one of the participants who had some little experience with virtual reality said 'I prefer Hololens over Oculus because you can see the real environment'. Oculus is a virtual reality glasses, which instead of overlapping virtual objects over the real environment (AR), they create a completely virtual environment. So this may be a sign that we took the right way using the appropriate technology.

From the results of this evaluation, it follows that AR can be a good tool to use in the rehabilitation of amputee patients, but perhaps we still have to wait for this technology to develop a little further.

5.3 Discussion

What participants saw as positive and, therefore, we can continue working in that way, is the idea of the game, in order to make the rehabilitation more fun, combined with augmented reality and letting patients fully control the game through EMG electrodes. However, existent technology is not developed enough, although it is being developed rapidly, so maybe in the nearly future, we can take better advantage of it, since the feedback we got is mainly related to technology, especially how the Hololens can be improved. The development of the game also has to be further developed in order to create a whole useful video-game for prosthetic rehabilitation. This has to be done with the assistance of patients who can give good feedback.

The difference between this project and other VR or PC projects used for rehabilitation or PLP relief is that it is more realistic to see your hands in the real environment where you are, instead of a virtual environment. The handicap in this case with our project is, in the one hand, that the Hololens screen is very small to make the experience completely realistic and, in the other hand, that it would be desirable that the objects could interact with the environment. Regarding the AR reality example introduced in the state-of-the-art in Section 2.2, our project has the advantage that patients can see their hands through the Hololens instead of a screen. However, we could do a set of instruction for the patients to make them perform a series of activities like dancing in their case, or handle objects in our case.

These type of PLP relief methods are better than taking medicines or undergo surgery since it is harmless for the body and it is less stressful than undergoing surgery. Furthermore, those methods are not effective in all the cases and should always be taken as a second option.

Although there is still much to develop, it seems that this is the best option to achieve our goal of making a PLP relief and rehabilitative method as fun and engaging as possible and as harmless as possible.

CHAPTER 6

Conclusion

The main object of this project was to perform the first steps to make a video game to make a better rehabilitative and PLP relief method for upper limb amputee patients. As stated by the participants, we are in a good way to achieve it, since they see the game as potentially fun. On the one hand, these participants are not amputee patients, so they cannot give the feedback we would like to have a person who really needs a new method for its rehabilitation. But, on the other hand, most of the participants were random people not related to this project, so it is also good to have a completely new and fresh opinion.

But even though we are in the correct direction, a lot more has to be developed if we want to make this a full and successful rehabilitative method. Firstly, the game has to be further developed, not only this mini-game in particular but also the whole game (Future work is explained in Chapter 7). Secondly, we have to find the best way to use the available tools, as well as being continuously informed of the latest news and updates in order to make the best use of them. With these tools I mean, in this context, the Hololens, the Myo Armband, but also the software. Finally, explore new tools can be also a good option since technology is improving very fast and it can be some new useful tool on the market.

Apart from that, the development of the game should be carried out in close cooperation with patients, since they are the people who are going to need the developed project. They must be patients of different ages since not everyone has the same technology perception. Young patients can give a more open vision about what they think they need on its rehabilitation and they may give also some good ideas since most of the young people have some knowledge over technology and they may even play or have played some video game, or see other people do it. For their part, older people will give us more idea of the limitations that the video game must have since they are not used to advanced technology, and they'll also give us an idea of how easy it has to be to make it accessible to people of all ages.

Regarding the hardware, decisions must be taken. In respect of the Myo Armband, decisions about whether to use the whole set of electrodes of the armband, just two electrodes of it or another different two electrodes with wires attached must be taken. It is also necessary to think that it is difficult to integrate Myo with the Hololens, so maybe another electrodes option can be desirable. To make this decision, good performance, as well as comfort, are aspects to think about. Hololens gives us a more difficult problem to solve since the main problem with them is the size of the virtual screen. However, it is possible to work with them even though if they have that little screen size. Maybe the experience will not be completely immersive but they make it possible to see very good quality holograms and this can be enough. It is not possible to see more with a computer since, besides the PC screen, you see everything else that is in the room you are. Hololens can be seen as an integrated screen that allows you to move in a room and interact with virtual objects and make them interact with the real environment.
To sum up, although there is still much to develop, both on the hardware developers' side and in our side, the idea of a rehabilitative method taking advantage of new technology such as augmented reality, can bring many advantages, especially patients motivation and a real good rehabilitation and PLP relief, which are our main goals.

CHAPTER 7

Future Work

As mentioned in Chapter 1, this work is just a preliminary evaluation of the game, since it is still in its early stages. During the workshop sessions, we discussed how the complete game will be. The idea is to have a complete game that lasts several minutes with different phases and different types of challenging activities to do. This way the game will be more fun for the patients.

There was a variety of ideas and there is not only one possibility for the video game. However, the most interesting idea was to create a escape room with different mini-games. The idea of an escape room is interesting because apart from all the small objectives there is an overall objective, which is to escape from a room. However, the overall objective could also be a different one, such as reaching a desired virtual place for example. In addition to the overall goal, there are smaller goals, which are to overcome every mini-game or activity. This provides a good result, as overcoming each challenge independently also produces satisfaction.

The order in which the games will be overcome is chosen by the patient. A small book containing a label on each page will be printed. Each of the labels can be a representative illustration of each of the mini-games, a word or an abstract illustration. So, when the patient decides which next mini-game he/she wants to play, all he/she has to do is to look at the label of the desired game, so the camera can see it, and make some movement with their arm, activating one, two or both muscles, in order to choose that game.

The patient will be able to perform up to a maximum of 6 different movements in each of the mini-games. These variations are: activate one muscle or another, activate them quickly or slowly and do co-contraction or double co-contraction. At the beginning of each of the mini-games, a box will show the instructions to overcome it, telling which moves are involved in it and explaining the function of each of these movements.

The magic hand game model must be maintained throughout the entire game. Maybe not in all video games, but in a large part of them. Magic is a positive thing for the later mood of patients. This is because if the patient can perform normal movements with the virtual hand, it can generate addiction or depression since the patient will not be able to perform these same movements with the prosthesis. Within a magical environment, this is more unlikely to happen, as no one person can do magic. Therefore, in this way they do not perceive it as a possible and unattainable reality but only as a game.

The games to overcome can be of different types. For example, to the prototype created in this work other functionalities can be added, such as making the colour of the objects change or make them shine or explode, among others. This game can be entertainment only, in which the patient manipulates the objects the way he/she wants. Another option is to guide the patient by telling him/her what to do with each object. A third option would be similar to the last one, but having to carry out the activities in the shortest amount of time possible.

The other games can be calm games in which the patient just explores, games in which time runs out, games to overcome record time, games in which the difficulty increases, precision games, etc. In addition, games can be real and everyday tasks or unreal things.

Some examples are described below.

- Several coloured balls are floating around. The patient will be able to pick up the different coloured balls and move them around the room while squeezing them. The coloured balls colour the 3D space they pass through if they are squeezed at the same time.
- The patient will have to take care of a plant to make it grow. Some of these treatments are watering it, pruning it or opening the window to make the sun's rays to enter.
- Some examples of everyday life tasks are: placing tools in their position on a wall, cooking, manicuring, cleaning or tidying up a room, having a wide variety of decorative objects and decorating a wall or a room, among others.
- Real virtualized games, like Jenga® or LEGO® constructions.
- Change cubes from one place to another as fast as possible, like in the Box and Blocks Test [52].

- Reaction games, where the patients don't know what he/she has to do next. He/She only know what he/she has to do just before the game starts. Another reaction game could be a ball moving along a table towards the patient's hand. The patients have to catch the ball just in the moment that it arrives at his/her hand. Or more challenging: with a movement, they catch the ball and with another movement, they control the speed of the ball. Finally, a game where the patients have to move a bottle to collect good objects falling from the sky and avoid bad objects.

- Colour drawings by areas.

The game must have an initial screen explaining the instructions. On the start screen, patients will have to select the game. In this start screen, a marker will appear with the points scored (total or average) and the remaining challenges they have to overcome to complete the game. Within each of the mini-games will also appear a marker with the points earned in that game or the remaining time, if it is a game with countdown. At the end of the game, animation will appear celebrating that the game has been successfully overcome. It will also appear a table with the scores achieved so far from the patient and of the rest of the players.

APPENDIX A

Gameplay

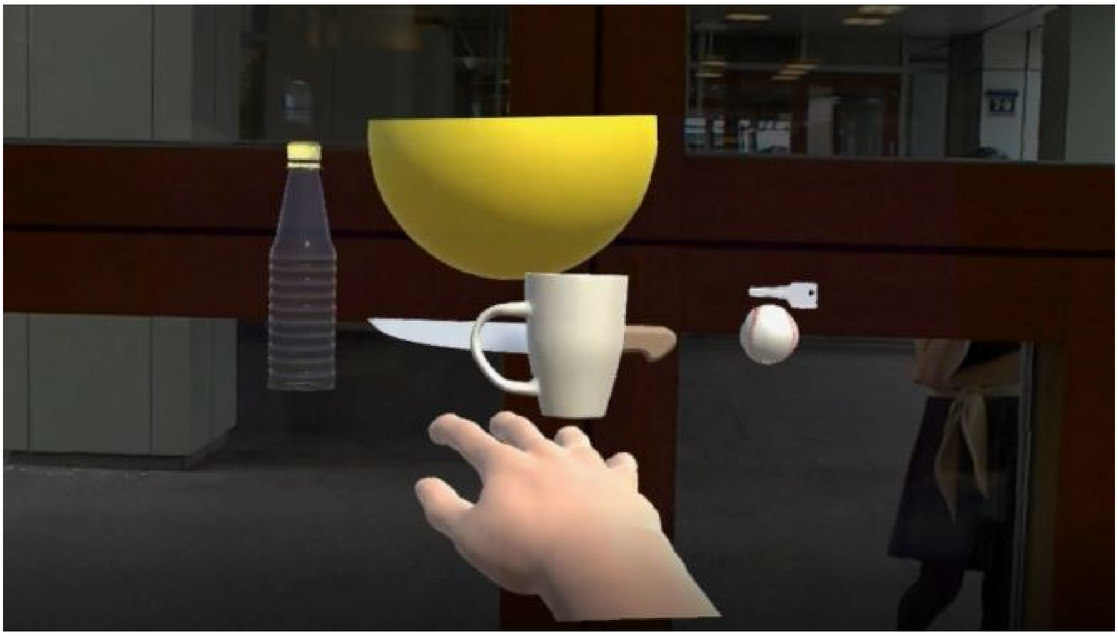


Figure A.1: Relaxed virtual hand in non-magic mode.

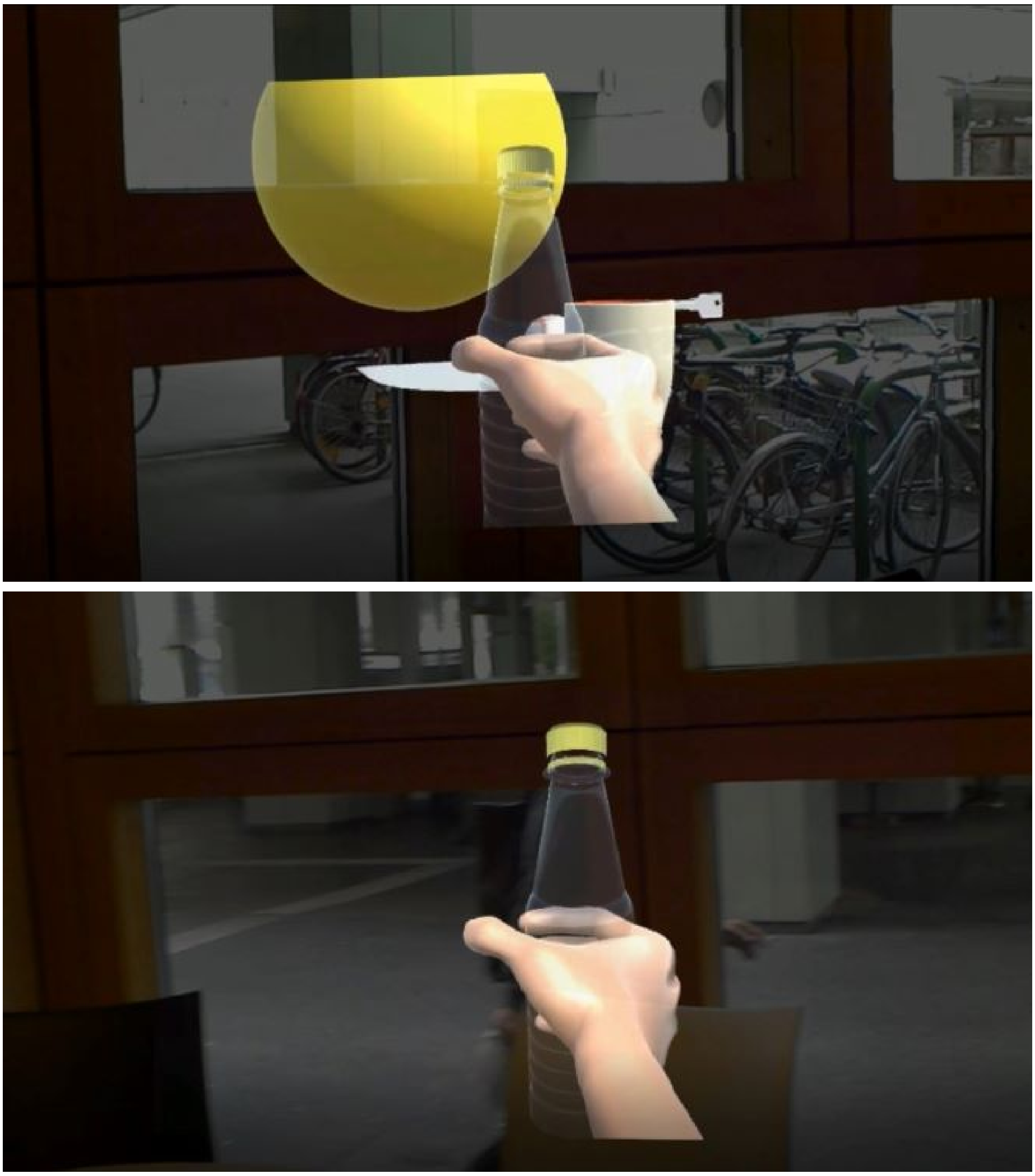


Figure A.2: Virtual hand handling a bottle in non-magic mode.

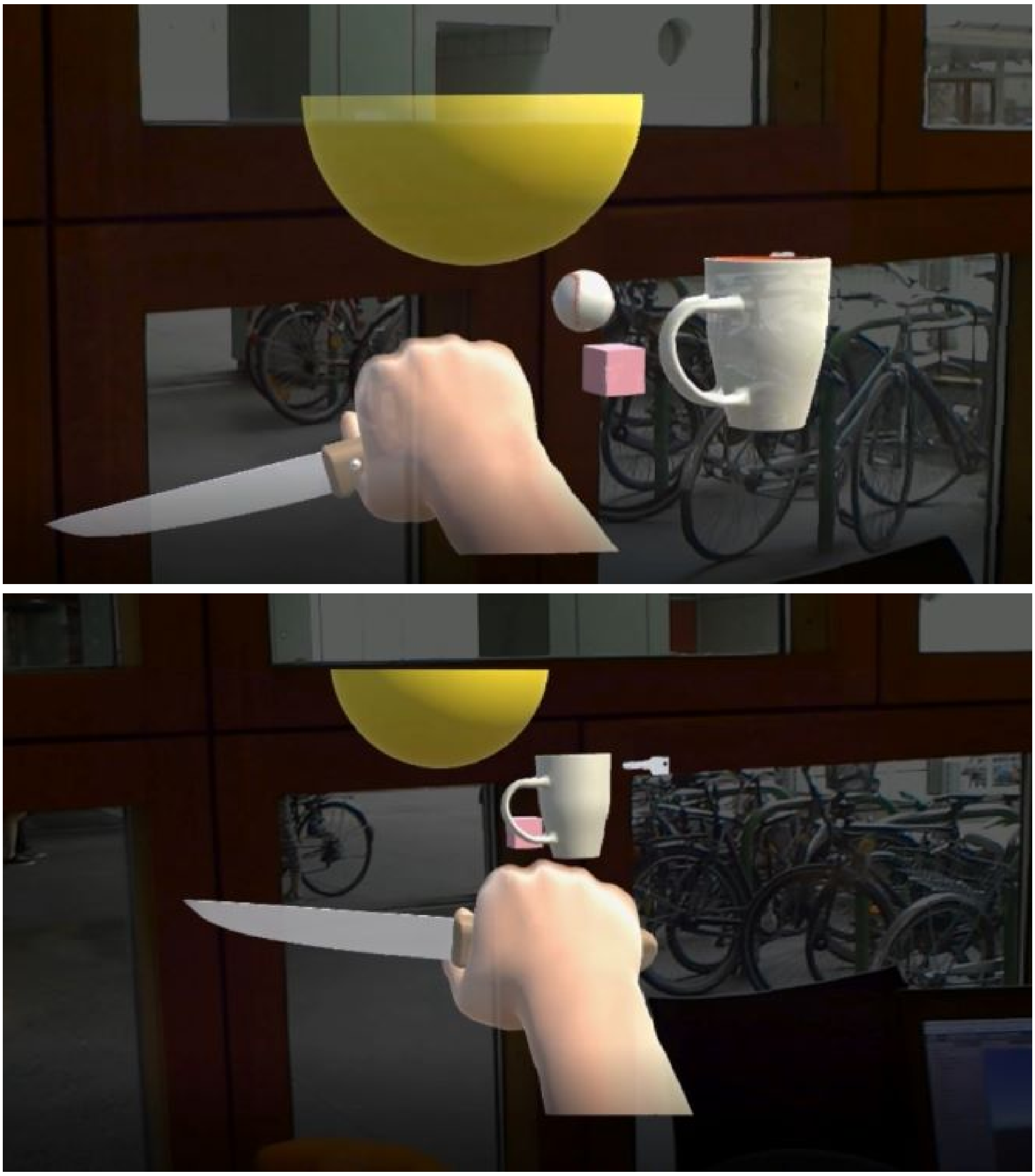


Figure A.3: Virtual hand handling a knife in non-magic mode.

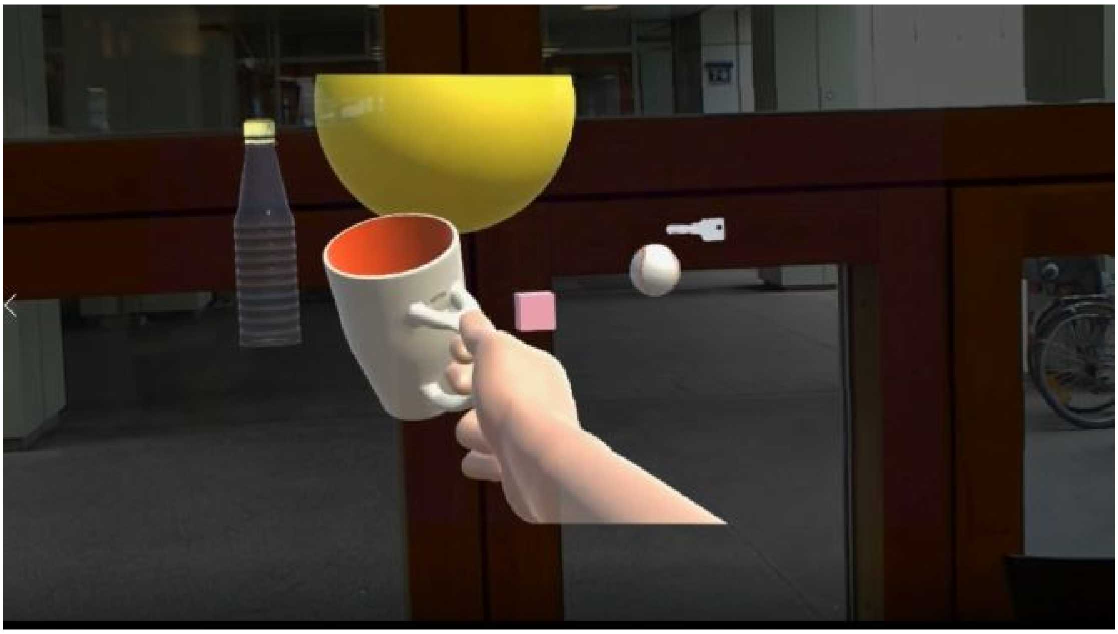


Figure A.4: Virtual hand handling a mug in non-magic mode.

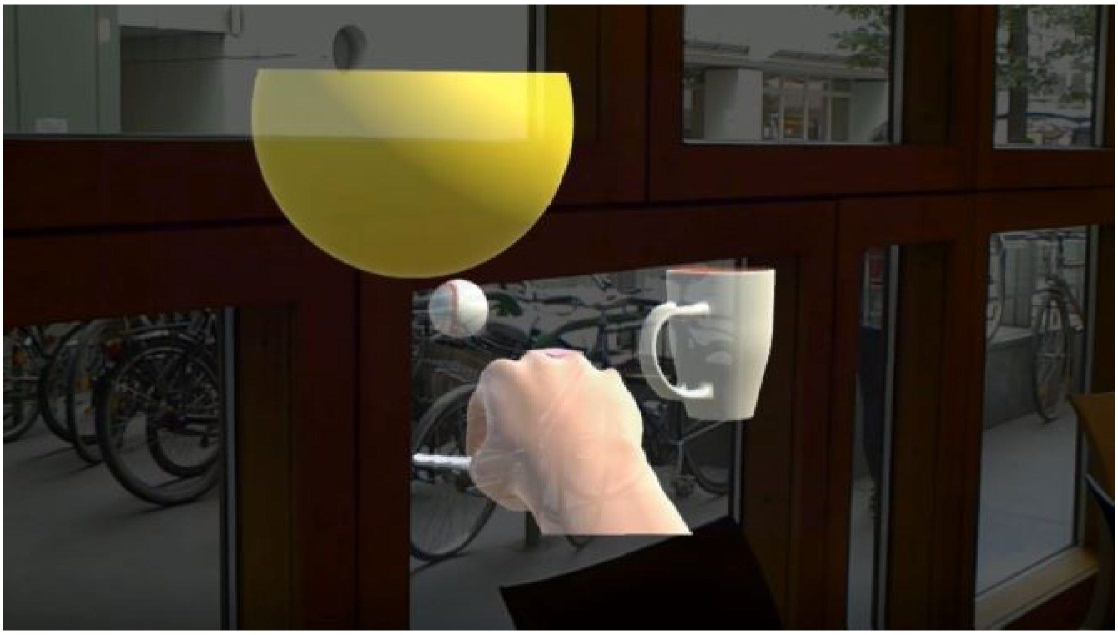


Figure A.5: Virtual hand handling a knife in non-magic mode.

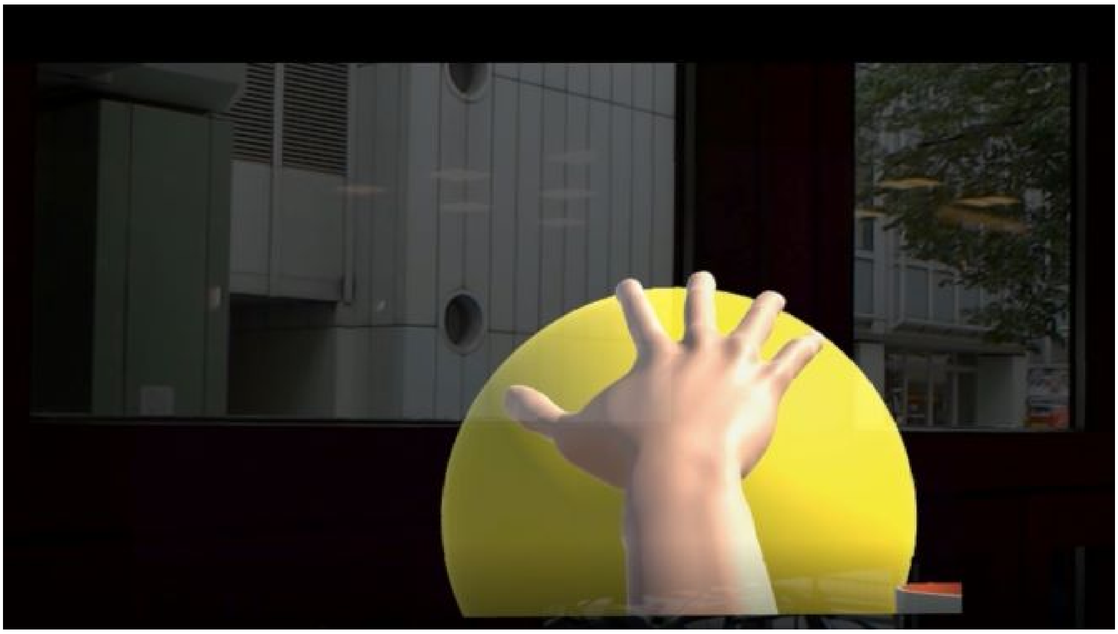


Figure A.6: Virtual hand handling a foam ball in non-magic mode.

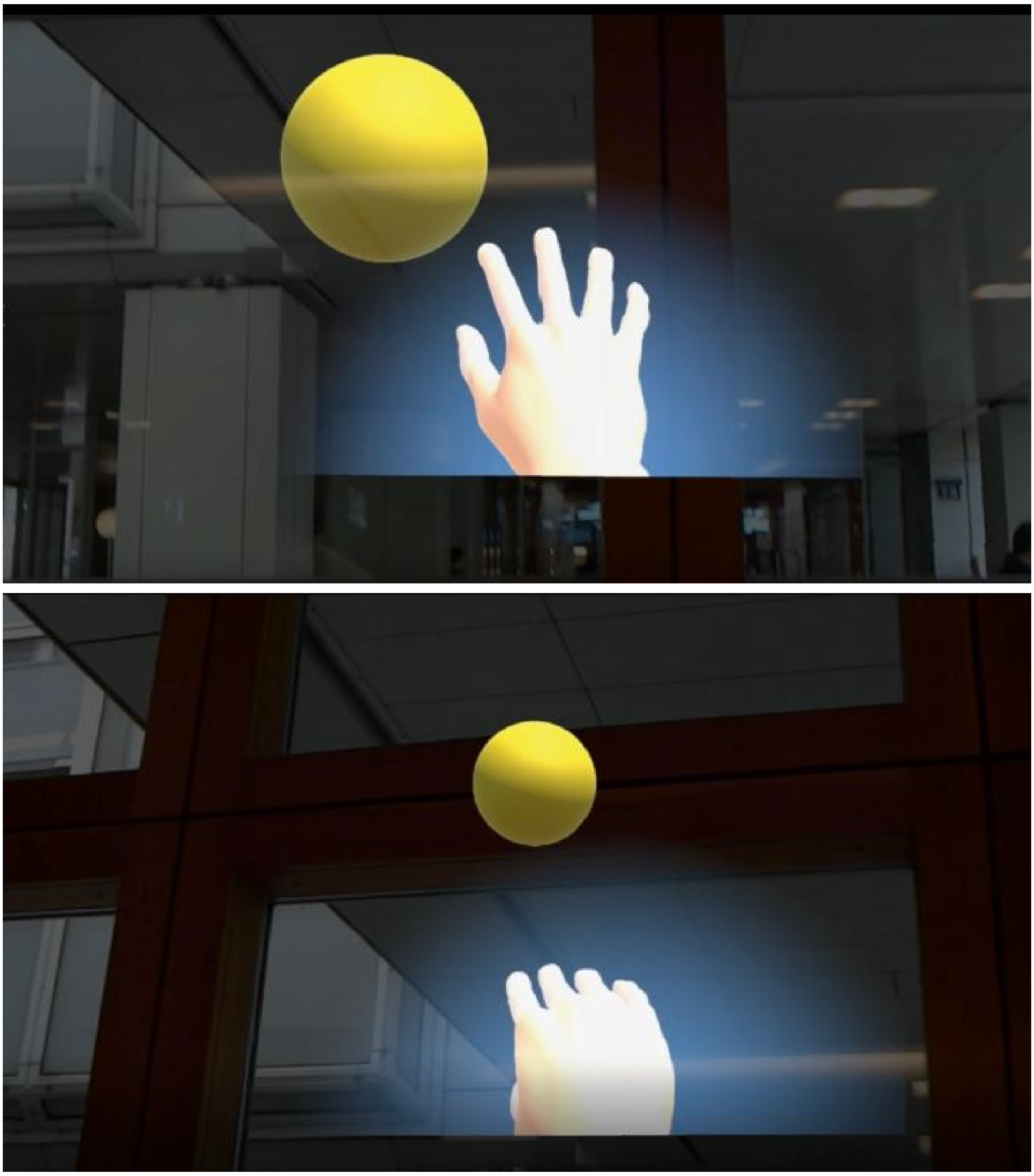


Figure A.7: Virtual hand zooming in and out a foam ball in magic mode.

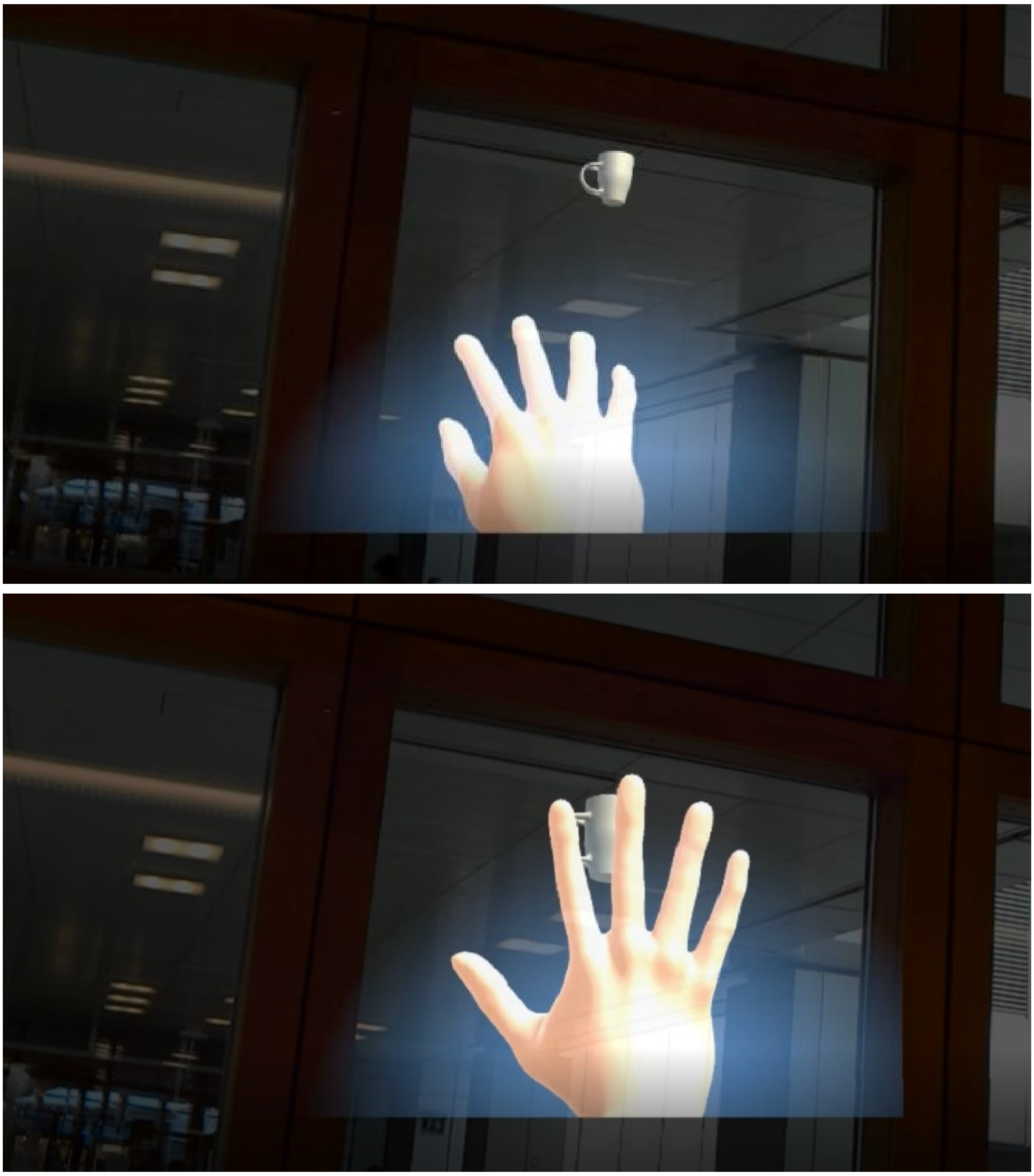


Figure A.8: Virtual hand zooming out and in a mug in magic mode.

List of Figures

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