VReckAR

A Comparative Study of Virtual Reality and Augmented Reality in The Context of Training Games for Myoelectric Prothetics

Master Thesis

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Abstract

This thesis documents a comparative study of virtual reality and augmented reality in the context of training games for myoelectric prosthetics. The motivation is that a meaningful number of amputees abandon their myoelectric prosthetic in part because they lack the motivation to train, which makes them unable to control it efficiently. Recent studies show a potential in utilizing augmented reality techniques in this context, but so far it remains uncertain that it provides a benefit when compared to more traditional virtual reality techniques. A prototype game based on the classic arcade game What-A-Mole supporting both techniques was implemented and tested on 10 able-bodied subjects and evaluated using the intrinsic motivation inventory questionnaire. The results from the test show no significant difference between the two techniques in any of the measured parameters.

Preface

This master's thesis is composed as a result of a 10th semester medialogy project by Morten Bak Kristoffersen at Aalborg University during spring 2013.

References

The sources in this report are referenced to using brackets containing the surname of the first 2 authors and the publications year. If there are more than 2 authors, the brackets will contain the surname of the first author followed by "et al.". If the reference bracket is placed before a full stop, only the phrase itself is based on the source from the reference. If the bracket is placed after a full stop, the whole section above is based on the source. All referenced sources will be placed in alphabetical order by the author's surname in the section "Bibliography" at the last pages of the report.

DVD

The appendix DVD will contain

- Unity3D project files
- Documentation (report and product movie)
- Spreadsheet containing the test data
- Cited references that are not widely available

Danish summary

The Danish summary that must be included as stated on page 53 in the Curriculum for the master's programme in medialogy is included in the appendix.

Thanks

I wish to thank the following:

- Lars Knudsen and Ann Morrison for excellent supervision during the project.
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Contents

Introduction

To be self-dependent and perform daily activities such as dressing, eating and care for ones hygiene without help is important to most people. In healthcare, these activities are called Activities of Daily Living (ADLs) and when assessing if a person needs help from a home carer at home, it is often determined by the person's ability to perform ADLs. An alternative to use home carers is to give people equipment and rehabilitate them to do things differently than they were used to. There are some general cases for how to do this, elderly people get zimmer frames and railings in their homes, hearing impaired get hearing aids and upper-extremity amputees' get prosthetics. For the amputee, the prostheses are more a part of their body, than just a piece of equipment. This is mainly due to that the prosthetic, although detachable, becomes a part of their body and their body-image. There are 3 general types of upper-extremity prosthetics, see **Fejl! Henvisningskilde ikke fundet.**.

Figure 1: The three basic types of upper-extremity prosthetics (adapted from p. 13 of [Fejl! Henvisningskilde

Cosmetic prosthetics are designed to improve the amputees' body-image and helps them to blend in by being comfortable and by resembling real arms as much as possible. The cable-controlled prosthetics are designed for more practical use, which is why they have a hook or a pincher instead of a hand. The grabbing mechanism is controlled by a cable that goes to the opposite shoulder of the amputated limb. The myoelectrically controlled prosthesis combines the cosmetics from cosmetic prosthetics and a functionality equivalent or higher than the cable controlled prosthetics. They are driven by electricity and controlled by decoding muscle activity from the remnant muscles with the use of electromyography (EMG). EMG is used to record muscle activity, or more precisely, the electric potential generated by the muscles from which the myoelectrical prosthetics derives its name. It is normally recorded by using surface electrodes which is problematic as the potential is very weak and heat, sweat and changing electrode placements, due to movement, makes it hard to acquire good signals. Recently, a patient was fitted with an *osseointegrated* (bone-anchored) socket for prosthetic use in which EMG electrodes was implanted in the nerves and muscles [Sahlgrenska University

Hospital and Chalmers University of Technology, 2013]. Myoelectrically controlled prosthetics offer more degrees of freedom (DOF) than cable controlled prosthetics thus they offer a greater possibility to restore the amputees' ability to perform ADLs.

There are some downsides to myoelectrically controlled prosthetics. They are more expensive, less durable and to achieve a higher rehabilitation rate than cable controlled prosthetics requires a lot of training. Especially the training has proven to be a major challenge for some, even to the extent that they have abandoned their myoelectric prosthesis in favour of a simpler kind [Lamounier et al., 2012]. When a patient abandons a myoelectric prosthetic, they do not only abandon an opportunity to greatly rehabilitate, but also waste their training and the work of the occupational therapist and the prosthetist. Work to improve the acceptance rate of myoelectric prosthetics is primarily focusing on 2 areas; to improve the functionality of the myoelectric prosthetics and to improve the training process. Works in improving the functionality can be divided into several subfields; ranging from signal processing and acquisition to comfort to increased DOF and better control algorithms. The improvement of the training process involves developing new training methods including simulators, video games and robotic arms.

In 1990 the first training system incorporating a computer game was developed by Lovely et al. [Lovely et al., 1990], before that time, training was performed by looking at the EMG signal together with a therapist and learning how the signal reacted to different muscle contractions. The motivation for the first training system was that patients, especially children, had trouble maintaining motivation. From then on the training systems have become more and more advanced; from the first 2D point and click shooting game to systems showing a virtual prosthetic to systems where the virtual prosthetic is used to play games.

Even though the systems have become more advanced, patient motivation is still a problem, so further development is needed. Systems like this will always need some on-going development as games in general becomes more and more advanced in terms of graphics and features, this means that people become harder and harder to impress. A way to keep up with the on-going development is to use myoelectrical control to control conventional computer games. This has been done with Guitar Hero [Armiger and Vogelstein, 2008], Wii Tennis [Oppenheim et al., 2010] and Trackmania [NCALOI, The natural control of artificial limbs, 2012] although none of the systems have been tested with amputees, the results are promising. However, I believe that this kind of game control should be used as a supplement, rather than a replacement, for more conventional simulators. I believe too much focus is put in controlling the game and that a more direct mapping between training and the outcome of the training (e.g. controlling a prosthetic) is required as the way a conventional game is controlled is not necessarily similar to how a prosthetic is controlled, even though the myoelectric signal is used for both.

In a review of myoelectrical training systems, Dawson et al. [Dawson et al., 2011] points out, among other things, the following as a focus point for further development

First, they must be inexpensive, portable and reliable so that they can be accessible and affordable to rehabilitation centers. Ideally, the rehabilitation centers would be able to afford multiple training systems and be able to send them home with the patients to train remotely.

In this perspective the following initial problem formulation is formulated:

How can a training system for myoelectric prosthetics be made more motivating to use, while maintaining accessibility and affordability?

Accessibility and affordability in this context refers to that the system should be functional in any home and that it should not require special equipment. As a myoelectrical prosthesis can cost in the area of 100,000$ [Lam, 2010], equipment such as an laptop which cost less than a hundredth of the prosthesis is deemed affordable in this context.

In the next chapter an analysis will be performed to explore different theories and concepts related to digital training systems and rehabilitation of amputees.

Analysis

Targetgroup

Amputees can be divided into 3 groups based on the cause for their limb loss; these are congenital (missing limbs at birth) caused by disease (e.g. diabetes, which is the most common) or caused by trauma (injury) [Clements, 2008]. In general, there is not much demographic data on amputees besides that most are males due to more males working in heavy industry which increases the chance for trauma. However, there are some demands that must be satisfied before a patient is offered a myoelectric prosthetic [Premera Blue Cross, 2012] which limits the target group to patients who is mentally ready to master a myoelectric prosthetic. I personally believe that these requirements will leave out most patients that are +60 years old as well as those who are frightened by new technology. The great diversity of amputees requires a training simulator that suits anyone especially children; as children will be more motivated to use it and they are the group who lacks motivation the most and it does not exclude adult subjects. Also, the training simulator should be easily approachable, but allow for skill progression, as the system should be useable for the novice as well as for the expert while facilitating and maintaining FLOW [Csikszentmihalyi, 1991], which makes the subject forget the outside world and control the simulator without active thought. If FLOW is achieved it would be a sign that the control of the simulator have become so natural that no active thought is necessary which means that control of the prosthesis can be done without active thought as well. To achieve FLOW requires an activity that is of appropriate difficulty for the patient, but other factors such as immersions helps to maintain FLOW.

Rehabilitation

Rehabilitation of upper-extremity amputees have recently gained increased attention since USA invaded Afghanistan and Iraq. As a result, Smurr et al. [Smurr et al., 2008] have developed a protocol and investigated the causes for successful rehabilitation. The main factor in successful rehabilitation of upper-extremity amputees has shown to be the time between the amputation and the fitting of the prosthesis. Research have demonstrated that patients fitted with a prosthesis within 30 days of amputation have a 93% rehabilitation rate with a 100% return to work rate within 4 months, whereas those fit after 30 days of amputation have a 42% rehabilitation rate with a 15% return to work rate. This 30 day period is termed the “golden window. [Smurr et al., 2008]

To fit the prosthesis within the golden window is not always possible. Smurr et al. [Smurr et al., 2008] discusses this problem, which is especially prevalent in their field of treatment of amputee soldiers. They suggest that within a 2 to 3 week period after amputation that the patient is fitted with electrodes to begin myoelectric training with the Myoboy system [Otto Bock, 2004]. Although they mention that care has to be taken in using the Myoboy system, as “*The excitement of success and the involvement of competition in the training process are contagious, but must be monitored to prevent fatigue and subsequent increased discomfort.*” They conclude their experiences of preprosthetic training saying:

The skills and knowledge that the client gains with preprosthetic training are critical to motivation and success with his or her prosthesis. Clients that receive preprosthetic training demonstrate some amount of immediate success at first fitting. This promotes motivation, gain of function in the residual limb, and a preliminary sense that the client will once again have control over his or her life. The earlier the client learns these valuable principles, the easier it is to transition to actual prosthetic use and refrain from poor ergonomic postures leading to cumulative trauma disorders.

Although Smurr et al. have positive experiences using preprosthetic training there is no research that back up their claims. With the exception of children [Egemann et al., 2009], researchers have been unable to find a correlation between training and successful fitting [Roeschlein and Domholdt, 1989], [Silcox et al., 1993]. However, since those studies were performed, a lot of development has happened to myoelectric training systems and development is still on-going. This could indicate that it is not possible to improve successful fitting through training, although significant progress has been made in preprosthetic training

A problem that many amputees face is phantom limb pain. Phantom limb pain is painful sensations in the missing (e.g. phantom) limb. Phantom limb pains are a complex phenomenon that is not fully understood, however one of the causes is believed to be cortical reorganisation. Cortical reorganisation is a phenomena related to neuroplasticity (commonly referred to as brain plasticity) which is the on-going process in which our brains evolves through life as opposed to being static. Cortical reorganization is the reorganization of the cortical maps of the brain. An example of a cortical map is the mapping of the somatosensory cortex which is the main receptive area for touch. In the mapping of the somatosensory cortex, a sensation in a limb (e.g. the hand) can be mapped directly to a point in the cortex, for an illustration of the concept see Figure 2)

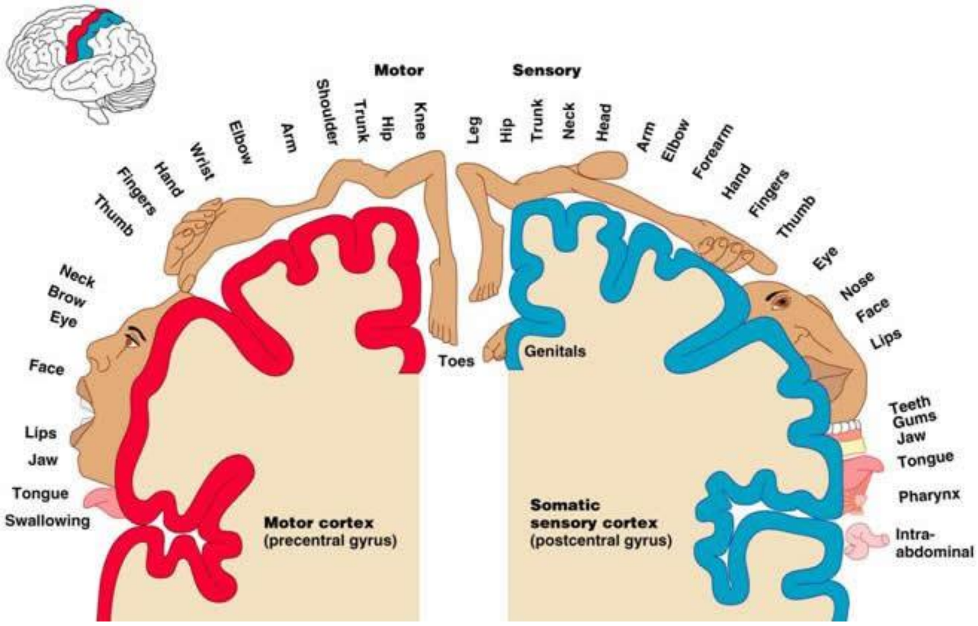


Figure 2: The mapping of the Motor cortex (left), which handles planning and execution of movements, and the Somatic sensory cortex (right) which handles the sense of touch (adapted from [Carter, 2006])

It is believed that the remapping of the somatosensory cortex is one of the causes for phantom limb pain, however the use of myoelectric prosthetics has shown to prevent cortical reorganization and thereby phantom limb pain [Lotze et al., 1999]. Besides phantom limb pain, cortical reorganization of the motor cortex is also one of the reasons that patients should start training with a myoelectric device within the golden window, as cortical reorganisation maps the sites from the amputated muscles onto nearby muscles which reduce motor function [Karl et al., 2001]. I believe that myoelectric training with a system like the MyoBoy [Otto Bock, 2004] has the same effect for cortical remapping that the use of a myoelectric prosthetic has.

The traditional treatment of phantom limb pain is by using mirror box therapy which was proposed by [Ramachandran and Rogers-Ramachandran, 1996]. This method works by having patients place their hands inside a box with mirrors and then they are asked to make movements with their hand. Because of the mirrors, it gives the illusion that the opposing limb (the phantom limb) also moves which alleviates the pain. However, there are some drawbacks, mainly being that using the mirror box is rather dull, only support a very limited number of movements and is only useable by hand amputees. Immersive computer based systems using either *virtual reality* [Bach et al., 2012], [Murray et al., 2007] or *augmented reality* [Knudsen et al., 2010], [Eynard et al., 2005] have showed to alleviate phantom pain by inducing the same illusion as the mirror box but without the same constrains.

Virtuality Continuum

For the most part, day to day rehabilitation of amputees is handled by health professionals such as occupational therapist and a prosthetist, but professions such as biomedical engineers and computer scientist are also involved by developing better prosthetics, algorithms and systems to facilitate rehabilitation. Some of the developed digital systems are interactive and allows the patient to control a virtual prosthetic by using the same myoelectric signal as the one used for the prosthetic. Some of those systems utilises *mixed reality* modalities to facilitate different needs.

Mixed reality is a concept presented in 1994 by Milgram and Kishino [Milgram and Kishino, 1994] where they introduced the *virtuality continuum*, which defines mixed reality as *anywhere between the extrema of the virtuality continuum* where real environments is in one extrema and virtual environments is in the other, see Figure 3.

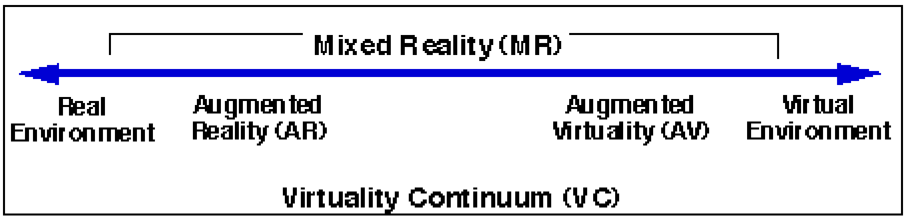


Figure 3: Virtuality Continuum (adapted from [Milgram and Kishino, 1994])

Augmented reality is defined as "*augmenting natural feedback to the operator with simulated cues"* and augmented virtuality is defined as "*Is the surrounding environment principally virtual, but augmented through the use of real (i.e. un-modelled) imaging data?"* (working question used as definition) [Milgram et al., 1994]. More general, augmented reality is defined as systems where virtual objects are superimposed, or augmented, on a video feed or a see-through display and augmented virtuality is defined as virtual scenes where real objects are superimposed, or augmented. Some researchers differ between exocentric and egocentric perspective in augmented reality, but in this report, *augmented reality* is used to cover both definitions. Milgram et al. [Milgram et al., 1994] sum up some of the defining factors in mixed reality systems, see Table 1.

Class of Mixed Reality System	Real (R) or CG world?	Direct (D) or Scanned (S) view of substrate?	Exocentric (EX) or Egocentric (EG) Reference	Conformal Mapping (1:1) or not (1:k)?
1. Monitor-based video, with CG overlays	R	S	EX	1:k
2. HMD-based video, with CG overlays	R	S	EG	1:k
3. HMD-based optical ST, with CG overlays	R	D	EG	1:1
4. HMD-based video ST, with CG overlays	R	S	EG	1:1
5. Monitor/CG-world, with video overlays	CG	S	EX	1:k
6. HMD/CG-world, with video overlays	CG	S	EG	1:k
7. CG-based world, with real object intervention	CG	D, S	EG	1:1

Table 1: Some major differences between classes of Mixed Reality (MR) displays. Substrate refers to the hardware used to display the scene where "scanned" refers to any kind of monitor. HMD is an abbreviation for head-mounted display. Conformal mapping refers to if a remapping of the perspective is necessary do avoid distortions to the user (recreated from [Milgram et al., 1994])

In the next chapter the state of the art will be examined with a focus on simulators which incorporate games for training. Weaknesses and strengths of the different systems will be analysed and used in a design for a new training system for myoelectric training.

State of the art

Dawson et al. [Dawson et al., 2012] have developed a Myoelectric Training Tool (MTT) that was developed to allow the subject to control a physical robotic arm and a virtual 3D robotic arm, see Figure 4.

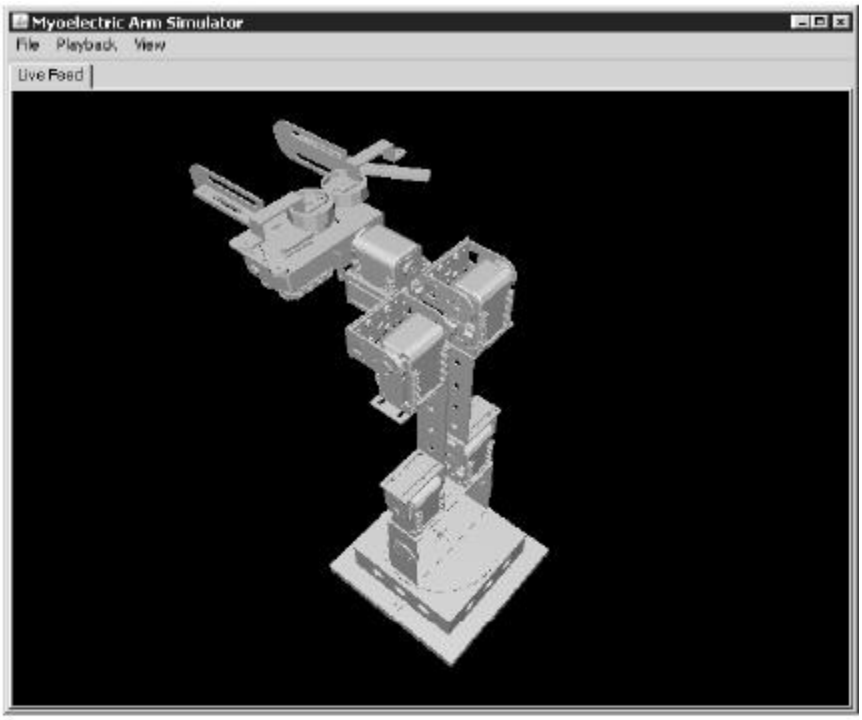


Figure 4: The virtual robotic arm used in the MTT (adapted from [Dawson et al., 2012])

The MTT allows for control of 2 DOF simultaneously and includes a training activity, that is a modified version of the Box and Blocks test used in occupational therapy [Mathiowetz et al., 1985]. The box and blocks test requires the patient to move as many blocks as possible from one box to another in 60 seconds, whereas the modified versions have the patient move 5 balls from one box to another as quickly as possible. The given reason for the modification is that preliminary trials showed that patients were only able to move 1-3 blocks in 60 seconds. Also, the size and shape of the box was modified to the limited workspace of the robotic arm. The system was tested on 5 able-bodied subjects, which first used the virtual environment for 5 minutes to train, before moving on to the physical robotic arm. The results show a significant difference in the time taken to move the first ball compared to the last ball. The authors conclude that the *result suggests that on average the subjects improved their skill in myoelectric control over the course of the trials*. In a qualitative survey with a 5-point Likert scale evaluating comfort, intuitiveness, delay and effectiveness of the robotic arm compared to the virtual arm shows lower, but not significant, results for the virtual arm. This indicates that the virtual arm might be as good as the physical arm.

Lamounier et al. [Lamounier et al., 2012] have developed a system that *is designed to reproduce the operation of a real prosthesis in an immersive Augmented Reality environment*. The system uses an head mounted display to give the patient a first person perspective of the environment, see Figure 5.

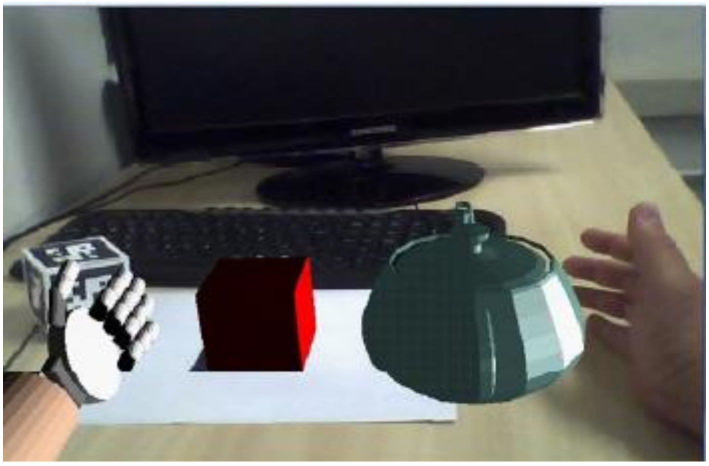


Figure 5: The subject's perspective in the augmented reality environment by Lamounier et al. (adapted from [Lamounier et al., 2012])

Several fiduciary markers are used for placement of the objects in the environment including the 3D virtual prosthetic. The system has not been tested in a clinical setting, but has been tested internally with amputees, although there is no mention of the results or the activity used in the internal testing. The system also supports virtual reality by discarding the video feed, although the system still uses the markers to place the objects in relation to each other.

Anderson and Bischof [Anderson and Bischof, 2012] have developed an augmented reality interface, the Augmented Reality Myoelectric (ARM) Trainer, with the purpose of training myoelectric prosthetics. The ARM trainer is designed so the patient can use it at home, as it runs on a laptop and only requires a webcam, which is built-in all modern laptops and an EMG amplifier, which is required for all myoelectric prosthetic trainers. The patient is presented with a mirrored view of them self (exocentric) with the virtual 2D arm augmented on their stump. The ARM trainer does not use fiduciary markers for the placement of the virtual 2D arm or prosthetic and the paper does not describe how placement of the virtual objects work other that it is automatic. There is a built-in game in the ARM trainer called Space ARMada, in which the patient must shoot spaceships by using the virtual limb as cannon, which fires when the subject goes from fully open hand to fully closed hand and vice versa, see Figure 6.

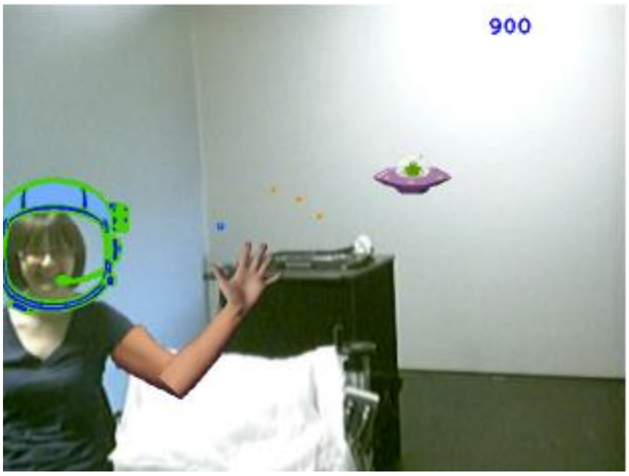


Figure 6: Space ARMada. The patient is shooting an enemy spaceship with the virtual limb (adapted from [Anderson and Bischof, 2012])

The game is tested against a clone of the commercial Myoboy game [Otto Bock, 2004] on 12 amputees. They evaluate the games by assessing the patients' subjective opinion towards each game (e.g. "I enjoyed this game very much) on a 5 point Likert-scale and by measuring muscle isolation and muscle control accuracy. They report that Space ARMada scores significantly higher in the qualitative ratings than the clone of the Myoboy game, but does not score significantly higher in muscle isolation and muscle control accuracy.

Mossel et al. [Mossel et al., 2012] have developed the *Augmented Reality Framework for Distributed Collaboration (ARTIFICE),* for which Mossel along with others [Mossel, 2012] in collaboration with prosthetic manufacturer Otto Bock have developed a *Virtual Arm Prosthesis Trainer.* The system uses the iotracker system with a head mounted display to let patients play a game where floating balls must be collected with a virtual arm seen from an egocentric perspective, see Figure 7. The system is yet to be tested on patients and they are developing a more entertaining game.

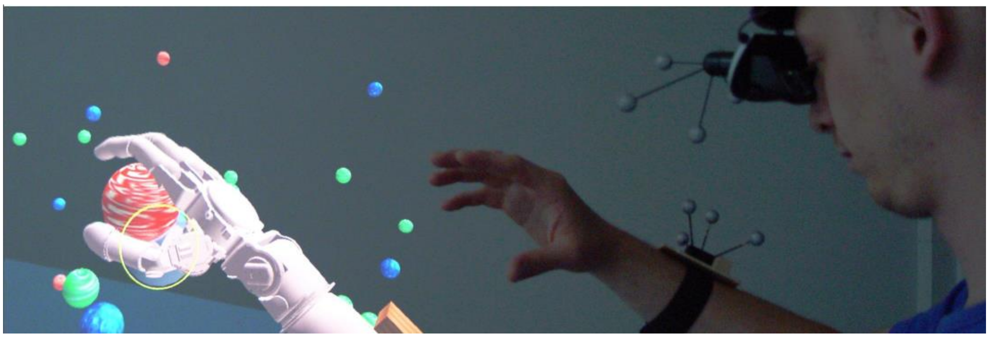


Figure 7: The Virtual Arm Prosthesis Trainer, where the subjects view input is projected in the background

In my previous work [Kristoffersen, 2012] I developed a training system in which the subjects could perform the Target Achievement Control test [Simon et al., 2011], in which the subject should match the pose of a semi-transparent arm. The system supported augmented reality and virtual reality as well as egocentric and exocentric perspective by using the Optitrack system along with a monitor and a head mounted display, see Figure 8.

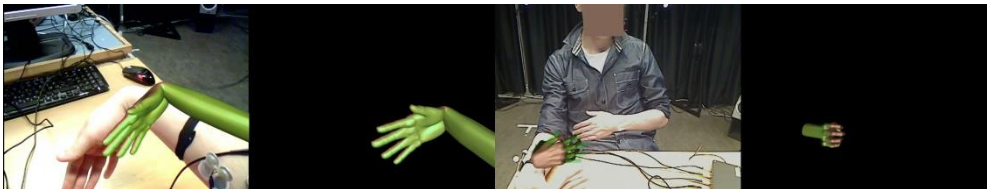


Figure 8: The training system by Kristoffersen From left to right; augmented reality with egocentric perspective, virtual reality with egocentric perspective, augmented reality with exocentric perspective and virtual reality with exocentric perspective (adapted from [Kristoffersen, 2012])

The system was developed to explore which combination would be the most suitable and 8 able-bodied test subjects were tested and quantitative data was collected through a semi-structured interview. The subjects rated the different combinations on a 0-100 scale in different categories (graphics presentation, training suitability, perspective, real-arm illusion and overall) where the first combination they tried automatically scored 50 in all. No significant data was revealed through this study, but there were a slight tendency towards augmented reality combined with a head mounted display.

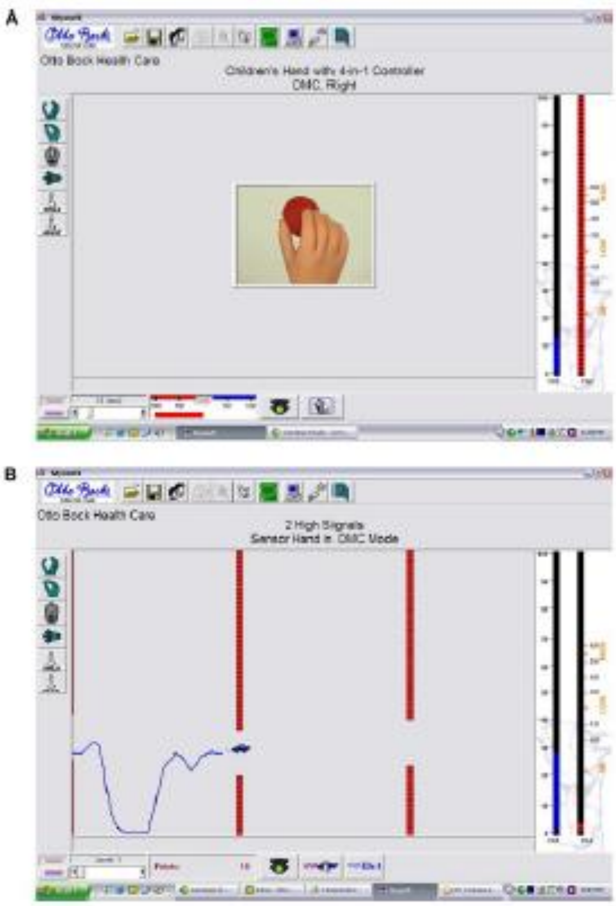
All of the above systems are academic systems, but there are also commercial systems. Although they do not represent the state of the art as such, 2 of them will be described briefly. Touch Bionics' Virtu-limb [Touch Bionics, 2012] is a system that can either control a base-mounted i-limb from Touch Bionics or a virtual 3D i-limb shown on screen, see Figure 9. It does not provide any training activity.

Figure 9: Virtu-Limb system From Touch Bionics (adapted from [Touch Bionics, 2012])

Otto Bock's 757M10 MyoBoy system [Otto Bock, 2004] is a system that can measure muscle potentials and simulates a wide range of prothetics from Otto Bock by showing a virtual 2D hand. The system also includes 2 games; in the first the patient must grab a ball with the right contraption force – too little force drops the ball and too much punctures it. In the second game the patient must manoeuver a car through holes in approaching walls by modulating their muscle potentials, see **Fejl! Henvisningskilde ikke fundet.**.

[Dawson et al., 2011] is recommended for a thorough review of myoelectric training systems.

See



Study / training system	Training game	Augmented reality (AR)/ virtual reality (VR)	Monitor / head mounted display (HMD)	Class of mixed reality system, see Table 1	Experiment
[Dawson et al., 2012]	Box and blocks test	VR	Monitor	Non mixed reality system	Comparative test against a physical robotic arm using able-bodied subjects
[Lamounier et al., 2012]	None	Both	HMD	2	Internal test with amputees
[Anderson and Bischof, 2012]	2D Video game	AR	Monitor	1	Comparative test against clone of [Otto Bock, 2004] using amputees
[Mossel, 2012]	3D video game	VR	HMD	7	None
[Kristoffersen, 2012]	3D video game	Both	Both	1 and 2	Comparative test against the 4 combinations of AR/VR and monitor/HMD using able-bodied subjects
[Otto Bock, 2004]	2D Video game	VR	Monitor	Non mixed reality system	Not applicable
[Touch Bionics, 2012]	None	VR	Monitor	Non mixed reality system	Not applicable

Table 2 for a summary of the reviewed myoelectrical training systems.

Figure 10: Myoboy system from Otto Bock. A shows the first game in which the user must use the right contraption force to hold, but not crush, a ball. B shows the car game where the user must modulate their muscle signals to control the car through the wall gaps (adapted from [Smurr et al., 2008])

	test			reality system	robotic arm using able-bodied subjects
[Lamounier et al., 2012]	None	Both	HMD	2	Internal test with amputees
[Anderson and Bischof, 2012]	2D Video game	AR	Monitor	1	Comparative test against clone of [Otto Bock, 2004] using amputees
[Mossel, 2012]	3D video game	VR	HMD	7	None
[Kristoffersen, 2012]	3D video game	Both	Both	1 and 2	Comparative test against the 4 combinations of AR/VR and monitor/HMD using able-bodied subjects
[Otto Bock, 2004]	2D Video game	VR	Monitor	Non mixed reality system	Not applicable
[Touch Bionics, 2012]	None	VR	Monitor	Non mixed reality system	Not applicable

Table 2: Summary of the state of the art in myoelectric training systems.

Both virtual reality and augmented reality can both be used successfully in the context of a myoelectric prosthesis trainer. Even though Anderson and Bischof [Anderson and Bischof, 2012] without doubt claims that augmented reality is superior to virtual reality, but I beg to differ. I believe that augmented reality potentially is better, but further studies are required to determine if it is the case, as I see the comparison made in by Anderson and Bischof [Anderson and Bischof, 2012] as invalid. My argument is that they compare a new augmented reality game with a clone of a 9 year old 2D virtual reality game, which also does not have many features in common with the new game. Head mounted displays and egocentric perspectives is also being employed, but data remains insufficient to determine whether they improve the experience for the subject when compared to monitors and exocentric perspectives, although it indicates that it is. Different kind of training schemes are being employed; ranging from simulation of occupational therapeutically tests to fully custom games, they all provide correct physiological training, but data remains insufficient to determine if one kind is better than the other. All the systems let the subject control a virtual arm and all except one uses 3D graphics for this purpose.

Problem formulation

Several training systems exist for the training of myoelectric prosthetics, but so far it is unknown which kind is the best. To determine this, I have compiled a list with the variables I see as the most significant:

- System reality; virtual reality vs. augmented reality
    - For virtual reality; graphical setting
    - For augmented reality; field of view
- Display modality; head mounted display vs. monitor
- Perspective; egocentric vs. exocentric
- Arm modality; 3D vs. 2D; resemblance with real arm
- Training activity; occupational test vs. custom test vs. none

Many different values for these variables can probably, with a good design, result in a good training system, but some values are more investigated than others and further research might reveal a superior combination.

Additional studies in the lines of [Kristoffersen, 2012] to further investigate the possibilities of different display modalities along with different system realities would be very interesting. However a study like that which investigates 4 different systems with 3 independent variables (system reality, display modality and perspective) will inevitably be problematic to get significant results from. The main cause for this is the amount of independent variables; if 1 system is rated better, it can be hard to pinpoint which of the independent variable(s) that causes it without testing for all independent variables, which in this case would require the implementation and test of 8 systems. Furthermore, when designing 8 systems with 3 independent variables, issues such as having a training activity which makes "equal" sense in all 8 systems can prove difficult and can possibly skew the result. For example; the TAC test used always displays 2 arms (the one the subject controls and the one to pose-match), this probably affected the results concerning body-image in augmented reality negatively. Other issues with more systems to test are that they require more test subjects to get significant results, which is a problem when using a time-booked lab along with the time restraints in a student project. To create a training system that makes sense with 3 independent variables is not only a design challenge, but also a technical challenge – especially if the system should be affordable as suggested by Dawson et al. [Dawson et al., 2011].

In this study, only one independent variable will be investigated. This is to ensure a more focused study that will have a higher chance of achieving significant results. A study focusing on either display modality or system reality will have to be chosen. If focusing on display modality, it will make most sense to compare a monitor or another screen against a head mounted display, as these represent the 2 main perspectives (exocentric vs. egocentric). If focusing on reality modality, it will make most sense to compare virtual reality and augmented reality, as augmented virtuality is rather complex to implement and purely real environments are investigated in depth by other researches. Which system reality to choose is not apparent, as they both are important for the experience of any given system. However, the initial problem formulation of this study puts an emphasis on accessibility and affordability as this is pointed as a major research interest by Dawson et al. [Dawson et al., 2011]. Even though head mounted displays have become more widespread and systems like the Oculus Rift head mounted display has a great potential, the integration of a webcam in almost all laptops as well as the low price for a standalone webcam, makes augmented reality a more affordable and accessible option than a head mounted display. Therefore, this study will investigate the possibilities of augmented reality in the context of training systems for myoelectric prosthetics. This leads me to the following problem formulation

> *In the context of training simulators for myoelectric prosthetics, in which the patient controls a virtual prosthetic, is augmented reality superior to virtual reality?*

From my initial problem formulation

> *How can a training simulator for myoelectric prosthetics be made more motivating to use, while maintaining accessibility and affordability?*

I formulate the following sub-question to the problem formulation

> *Can a training simulator for myoelectric prosthetics that utilises augmented reality, in which the patient controls a virtual prosthetic, maintain accessibility and affordability?*

From the thoughts presented above the following hypothesis is formulated:

> *Augmented reality will be the preferred system reality, as opposed to virtual reality, for a training simulator for myoelectric prosthetics*

Notice that the hypothesis only covers preference and not motivation. As a study testing motivation would be very extensive and should have 3 groups of patients (an augmented reality group, a virtual reality group and a control group using conventional methods) to employ the method of difference [Mill, 1843] and the patients will have to be tested after an extended period of time before long term motivation can be assessed. Here it is assumed that a system that is preferred short term would also be preferred long term and a more preferred system is more motivating to use. This assumption is based on my presupposition that people who have a great interest in a subject, also spends more time on it and uses equipment, that are associated with it of a quality (music enthusiasts have expensive hi-fi, hobby cyclist use expensive light weight bikes and so on)

Methods and Materials

This chapter will investigate how to create and design the training simulator. After the analysis, it is prevalent that related research puts an emphasis on providing a training activity in the training simulator. In this respect and to have my results cover training simulators with training activities in them the training simulator designed will provide one as well. Also, I have an ambition of improving the state of the art which I see as very narrow and, especially for the commercial systems, as very simplistic. Last but not least, there are no systems in the state of the art besides my own [Kristoffersen, 2012] that allowed for a proper comparison between augmented reality and virtual reality and that system is not accessible or affordable as it is dependent on an advanced 3D tracking system.

Concept

To create a training activity which also facilitates correct physiological training requires a good concept. An expert interview with Max Ortiz-Catalan, research engineer at Integrum AB[1] and corresponding author of [Ortiz-Catalan et al., 2013] and Nichlas Sander, also research engineer at Integrum AB and author of [Sander, 2012] was conducted to pinpoint a design reference that would be suitable. The ideas that I brought into the interview for discussion was virtual versions of tests known from occupational therapy such as the Box and Blocks test or similar to those presented by Kuttuva et al. [Kuttuva et al., 2005] with tactile feedback. However, we discussed the possibilities of using tactile sensors and it became apparent that tactile displays would not only be hard to use, but they do not believe in a future for those display for sensory feedback, as the possibility to use *target muscle reinnervation* for sensory feedback seems to have a better potential. Focus then shifted from these somewhat realistic training activities to game-like activities. They had emphasis on that it should support elbow flexion as that was an important motion for trans-humeral (above elbow) amputees and that it should be playable by children as they have the greatest motivational problems. Elbow flexion is the same motion used as when hammering a hammer, so the talk naturally focused on different kinds of hammering games. After a while the idea of basing the game on Whac-A-Mole [Wikipedia, 2013] arose and was chosen. Whac-A-Mole is a classic arcade game designed in 1976 and consists of a waist-height cabinet with 5 holes. The goal of the game is to hit, or whack, “moles”, that at random pops op of one of the holes, with a rubber mallet, see Figure 11.

[1] Integrum AB is an orthopedic company with focus on bone anchored implant systems for prosthetic fixation located in Gothenburg, Sweden.

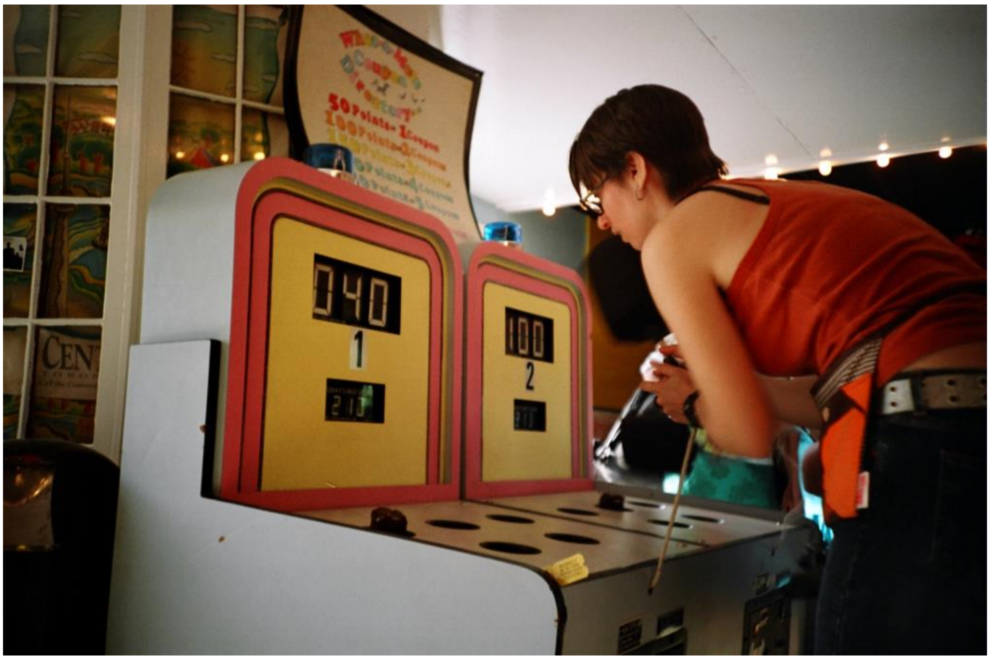


Figure 11: A Whac-A-Mole player swinging the mallet towards a mole. Notice that there are 2 game cabinets in the picture and not 1 (adapted from [Wikipedia, 2013])

The game runs for a limited time and points are given for each mole that has been whacked. The moles only pop up for a limited time, before rescinding down again, which requires that the player reacts fast. Moles that have been whacked may reappear thus making it impossible to have whacked all the moles. Whac-A-Mole seemed as a good choice as it is popular, simple, easy to difficulty-adjust and can be operated with one arm. It was discussed how this game could be modified to facilitate more than just elbow flexion. I got the idea that maybe the player could grab the mole, instead of whacking them, which would support the hand open/close movements. This idea was accepted and other possible movements were briefly discussed, but it was chosen to focus on elbow flexion and hand open/close.

Graphic design

Due to the wide range of people suffering from amputations, the graphics of the game must be fitting for a wide range of people, especially children as they have the greatest motivational problems. A cartoony look is chosen as it turns the violent gameplay into cartoon violence, caters to children and avoids comparison with games with a very high graphical fidelity. I have on a previous semester been co-developing an augmented reality game with a cartoony look called Box Bunny [Kristoffersen et al., 2011] in which a bunny with a quadratic head is the main antagonist, see Figure 12.

Figure 12: The bunny model with texture used in the game

The graphical style for Box Bunny was chosen by 41 people from the target group (*modern smartphone users, in the age group 18-30 years*) among 6 different styles based on their preference [Kristoffersen et al., 2011]. I believe the style will be fitting for the training game, as modern smartphone users between 18 and 30 is quite a large group and most people have a relationship to a cartoony style. New animations and sounds will have to be made to fit the gameplay, but besides that, the 3D bunny model from that project will be used. In the same style, the bunnies will rise up from an idyllic grassy field.

The virtual arm needs to be somewhat anatomical correct, as control of it will not make sense if it does not contain the same joints as a real arm. It should also appear somewhat like a real arm, but as this might be unobtainable, it could appear like a prosthetic instead. For children, it could also look more like a cartoon arm e.g. it could look like Iron Man's arm which spark the child's imagination and make them feel special. The placement of the arm should in the augmented reality version fit on the stump, as this will give the patient a feel of how they will look with a prosthetic and it might improve their body-image.

The graphics shown instead of the video feed in the virtual reality version will have to fit the style of the rest of the game. In the original Box Bunny game, the protagonist was a farmer on a flying tractor with a retractable vacuum cleaner that sucked the bunnies from the ground. However, this does not make much sense in this setting. In other virtual reality training simulators the background have been anything from black space [Sander, 2012] to a room that fits the rest of the environment [Kuttuva et al., 2005]. Black space seems very bleak and I see no other reason than time restraints to use a background like that as it add nothing to the experience. A background suiting the idyllic grassy field is chosen and for this purpose a clear blue sky seems appropirate. A clear blue sky is not very exciting either and should be complemented with extra details such as birds that are flying by and the Sun traveling across the sky along with other details. Camera effects such as the Sun's light causing glare on the virtual camera could also be used, but I believe that effects like that will be inappropriate in a game with an exocentric perspective.

Game design

The game will incorporate several elements known from computer games to make the game more enjoyable, which will facilitate FLOW. In computer game theory, a lot of emphasis is put on rewarding the player when they achieve something [Salen and Zimmerman, 2004]. Nowadays rewards are considered more than just points on a high-score, but ranges from nice audio-visual effects to achievements (which can be compared to medals that the player can show off to other players) and even story progression is considered a reward [Salen and Zimmerman, 2004].

The game will use graphical effects and funny sounds to motivate the player along with a score system. Achievements and story is not used primarily due to the limited timeframe of this project. The game will have 5 difficulty levels, 5 is chosen to make it more compatible with the test (see test chapter). The difference between the difficulty levels are round time, the number of bunnies present at one time and the min/max time between a bunny rises. A setting that would also alter the difficulty is the amount of holes, but this will require a larger board which will alter the behaviour of the augmented reality, so this setting is constant. Also, the bunnies don't go down before they are whacked, as I am afraid that too much focus will be put on the placement of the virtual arm. See Table 3 for the different setting used in the different difficulty levels.

Difficulty	Round time	Max number of standing bunnies	Min time between bunny rise	Max time between bunny rise
Easiest	90	4	0	3
Easy	60	4	1	5
Medium	60	3	3	10
Hard	45	3	5	10
Hardest	30	2	5	10

Table 3: The values used for the different difficulty settings

Implementation

Before choosing the platforms to use for the implementation an analysis is conducted. The most fundamental choice is the localisation technique for the augmented reality, as this determines the required equipment and the way to interact with the system. The requirements for precision is that it can match the stump of the patient, which requires that it is placed within 5 centimetres from the centre of the stump and is able to somewhat match the refresh rate of the camera, so the position can be updated if the patient moves. There are 3 main localisation techniques for augmented reality, optic based, satellite (GPS) based and static solutions. The optic based requires one or more cameras and works by using image processing to recognize 1 or more objects that are used as an origin for the augmented graphics. Often these objects are simply special images printed on paper, but recent systems have begun to use object recognition as well. This technique is fast, cheap (depending on the camera used) and precise. However it requires more processing power than the other techniques to detect the object. Satellite based solutions require a GPS or similar input and uses this localisation data often together with compass data to augment the graphics at a specific location. This technique is also cheap, but is not nearly as fast or precise as other techniques. Static systems augment the graphics at a static point at the screen, which can be changed manually by the user. This technique is cheap, fast and requires no extra equipment, but it cannot update the position to match the stump if the patient moves.

An optic based solution is chosen as it is most capable of augmenting the graphics on the stump of the patient and will allow the position to update if the patient moves the stump, which might improve the patient's body-image as described in graphic design chapter. A webcam is chosen as a camera device as it is widespread and is able to give a good enough tracking for the purpose of this project

Initially the system was attempted to be implemented in C++ using the Ogre3D graphics library [Torus Knot Software Ltd., 2013], the ARUCO augmented reality library [Aplicaciones de la Vision Artificial, 2013] and the Bullet physics library [Game Physics Simulation, 2013]. This was chosen as all of the mentioned libraries are open source, which gives the opportunity to be in full control and later on distribute the implementation in any way wanted. However, this was abandoned as I had trouble making the different libraries work together.

As I have extended experience with the Unity3D game engine [Unity Technologies, 2013], a platform for augmented reality that was compatible with Unity3D was prioritized. After some search 2 candidates were found, IN2AR [Beyond Reality, 2013] and Vuforia [QUALCOMM Incorporated, 2013]. They offer similar features and the time to set them up with Unity3D are roughly the same. The main difference between the 2 is that IN2AR has a rather disruptive icon overlay which requires a license to avoid. Vuforia on the other hand does not support PC deployment which means that the game will have to be tested inside the Unity3D editor. Vuforia is chosen as the game is not to be distributed and if it is, it would be relatively easy to change to IN2AR. If funds were no issue, IN2AR would be chosen, but a solution based on open source software would still be the optimal solution as the system itself could then be open source and a lot of outside developers could contribute and modify it to suit their own needs.

Vuforia uses marker-based augmented reality, which requires a physical marker that can be printed on a consumer-grade printer. Vuforia shows a mirrored video feed which cannot be changed when using it in the Unity3D editor, however this is not deemed a large problem as some monitor based augmented reality setups use mirrored video [Barakonyi et al., 2004] and [Anderson and Bischof, 2012] which gives the illusion that the monitor is a mirror. It is possible to define the markers, but markers with a lot of details, e.g. many local high contrast areas give the best tracking. This is because Vuforia's tracking algorithm is optimized for this kind of images as it allows for partial tracking of the marker. I assume that the tracking algorithm is some variant of *Scale Invariant Feature Transform (SIFT) [Lowe, 1999]* or *Speded Up Robust Features (SURF)[Bay et al., 2008],* but the specifics have not been revealed.

2 markers are used for the games; 1 for the game board and 1 for the virtual arm. The marker for the game board fills an entire A4 page and the virtual board is made to fit this size. This marker is put on the table like it was a real game board. The marker for the arm is a quadrat with a side length of 10 cm. and the virtual arm is made to fit inside this square see Figure 13 and Figure 14.

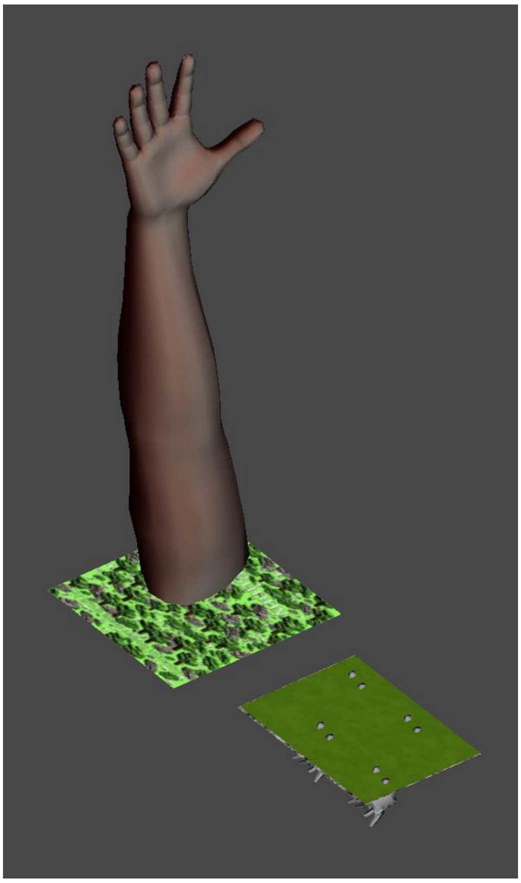


Figure 13: The markers and their associated objects as seen inside the Unity3D editor. Notice the size ration between the markers and the virtual objects

Figure 14: The game using augmented reality. Notice the markers that can be seen behind the augmentations

The marker is attached to the able-bodied subjects by using a cut-off belt with extra holes, so that it represents a large adjustable armband. The belt is supposed to be worn just above the elbow to simulate a just above elbow amputee, see Figure 15.

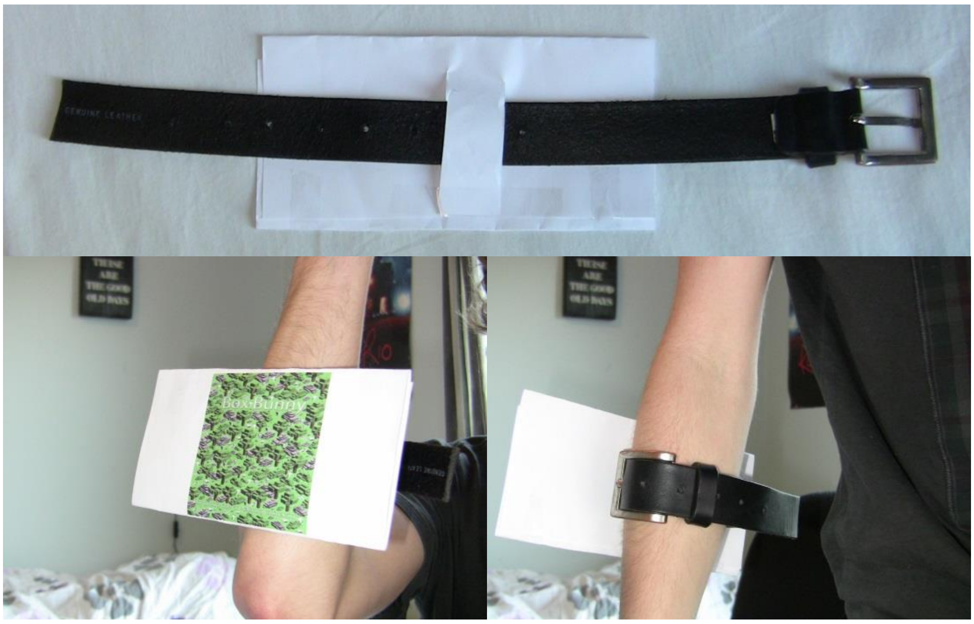


Figure 15: The donning of the marker used for the virtual arm on an able-bodied subject. The top image shows the backside of the marker in which a slit is made in which the belt goes thru. Bottom left shows the donned marker from the side and the bottom right shows the backside of the donned marker

The marker is donned on the opposite arm of the electrodes as the electrodes and the cables connected to them are in the way. This was unfortunately deemed necessary as the cables to the myoelectric amplifier was very short (~43 centimetres) and as 4 bi-polar electrodes and 1 single electrode has to be attached to the arm there are not much space for movement and a lot of cables that could become tangled. This will require some coordination for the subject as they will have to control the placement of the virtual arm with one arm and control the joints of it with the opposite arm. This will not be a problem with amputee subjects as the marker will be fitted directly at the tip of the stump whereas the electrodes are fitted along the muscles on the arm. However, longer cables should be used in the future.

The game is designed to be displayed on a standard monitor in almost full screen. Optimally would be full screen, but Unity3D does not allow the editor scene window to fill the whole screen. The camera used is an external webcam (Creative Live Cam Chat HD) which is chosen as the one in the used laptop is not very good and cannot be adjusted. Technically, nothing prevents the use of any webcam. The camera is in this case placed atop the middle of the screen.

The game logic is implemented using C# and handles bunny movement (using lerp and a co-routine), when the bunny should pop-up (based on the difficulty level and the number of bunnies already up) when they should go down (based on the placement of the arm, which should be above the bunnies), localhost TCP/IP connection with BioPatRec, arm animation, bunny animation, points, difficulty, time and the shifting between augmented reality and virtual reality. In the virtual reality version, a skybox of a clear blue sky is shown, besides that, it is identical to the augmented reality version, see Figure 16.

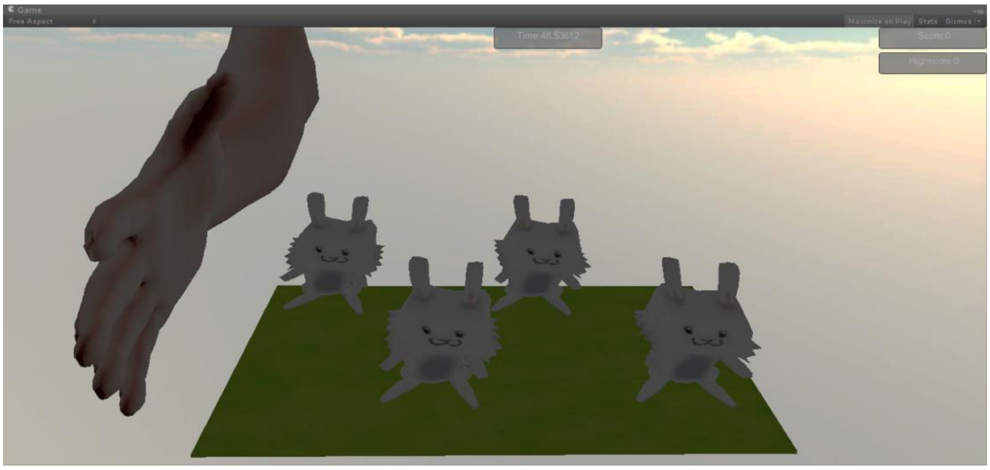


Figure 16: The game using virtual reality, but still controlled by the same markers as the augmented reality version

In the concept chapter it was described that the subject should be able to pick up bunnies to facilitate the hand open and close movement. However, it proved very difficult to simulate this in Unity3D in a way that was possible to perform for the subject. Instead I decided to implement a new way to facilitate the hand open and close movement by having subjects either chop or smash the bunnies. A chop is when a subject hits a bunny with open hand, which is a bit difficult, as the collider used to detect collision with a bunny is very narrow, but it gives the double amount of points that smashing does. Smashing on the other hand is when a subject hits a bunny with closed hand, which is easier than chopping as the collider is larger.

To extract the myoelectric signals, BioPatRec [Ortiz-Catalan et al., 2013] is used. BioPatRec is an open-source *research platform for testing and development of algorithms for prosthetic control* which is implemented in Matlab. BioPatRec handles signal acquisition, classifier training and pattern recognition and is able to send the predicted movement through a TCP/IP connection. The hardware side of the signal acquisition is handled by a National Instruments USB-6009 [National Instruments Corporation, 2013] data acquisition card along with an amplifier for myoelectric input. The amplifier is a proprietary design by Integrum AB, whom have lend it out in support of this project.

Test

To validate my hypothesis,

> *Augmented reality will be the preferred system reality, as opposed to virtual reality, for a training simulator for myoelectric prosthetics*

A test will be conducted. In the test, both versions of the game will be tested to evaluate which version is preferred.

The test procedure will be as follows; I will greet the test subject and introduce them to the test. The subject will be told that this is a training game for the control of robotic arm prosthetics and that it works by reading muscle signals from the arm with the use of electrodes. They are told that to test, they will have to be fitted with electrodes as well. If they continue, they are asked for permission to let them be video recorded during the test, they are promised that the recording will only be used internally and if they are going to be part of the documentation for the project, they will either be asked in advanced or be made anonymous by blurring their face. If they don't want to be recorded, the test will simply move on without them being recorded. The reason for this is that all the video material is not going to be analysed, only interesting situations will be analysed and also it is good to have documentation for what happened during the test.
Secondly, the subject will be donned the electrodes on the flexor digitorum profundus (hand close), the extensor digitorum (hand open), the biceps brachii (elbow flexion) and the triceps brachii (elbow extension) muscles on their left arm. This is followed by a training session in BioPatRec, which is required as BioPatRec is based on machine learning algorithms to parse the muscle potentials from the subject, see Figure 17.

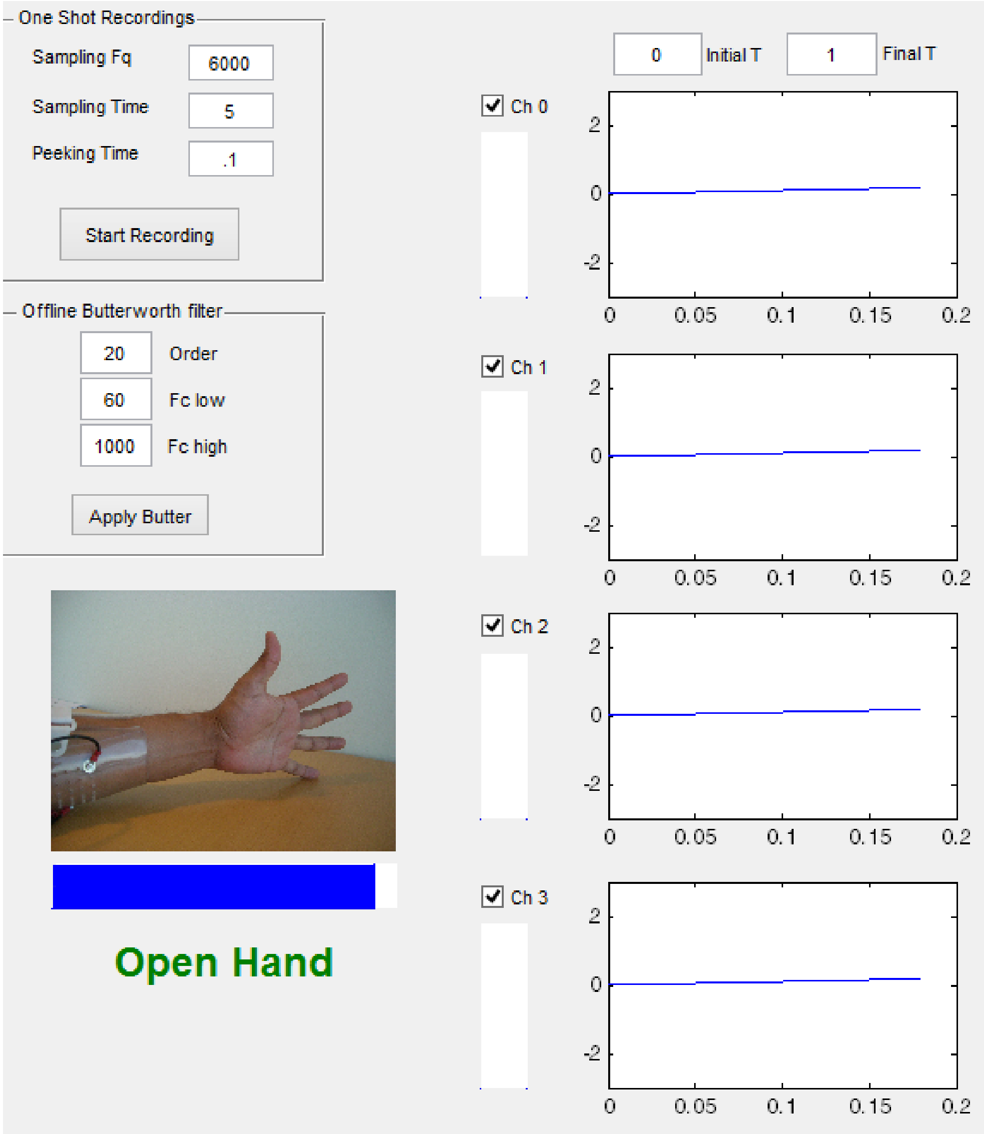


Figure 17: Snippet of the training interface of BioPatRec. At the left hand right side are from the top recording settings, filter settings, picture of the movement to perform, progress bar showing the remaining time of the current movement and text telling which movement to perform. At the right hand side are displays showing the signals (1 for each channel). Note that no signal is present which is why the signals are identical.

The movements trained in the training session is hand open, hand close, elbow flexion and elbow extension, as these are the movements used in the games (rest is added using signal treatment). The settings for number of repetitions, contraction time and relaxing time are left at their defaults (3 for all settings) which have worked well for testing the system. The recording is done using a National Instruments USB-6009 using 4 channels and a sample frequency of 6,000 Hz.

The training data is then used to train a classifier that can translate the muscle potentials into movements during testing. The main settings used are contraction time for training is 0.5, overlapping time windows (overlapped cons), the regulatory feedback network (RFN) pattern recognition algorithm is used with standard settings, as it is fast and provide nearly as good results as Linear Discriminant Analysis (LDA) and Multi-Layer Perceptron (MLP). Consequently all the pre-requisites for testing the games have been met. The order of which game they start with will be randomised by using balanced randomisation between subjects, to avoid that the second game will be perceived differently because it is presented last and because the subject have improved their ability to play the game. The play session for each game will start with a "training" round, in which the subject gets a feel of the gameplay and the way to interact with the game. The training round will be a very easy version of the game. The training round will be observed and when the I believe that the subject have understood and gained a feel of the game, the training round ends. The subject then starts the first of 3 rounds in the game on the medium difficulty setting, see Table 3. After each round, the subject is asked about the difficulty of the level and the difficulty is then adjusted accordingly among the 5 difficulty settings. After the 3 rounds, the game is evaluated by either interviewing the subject or handing the subject a questionnaire, for patient or able-bodied subjects accordingly (see appendix 1 and 2). The interview is a semi-structured interview. This technique is used to ask the subject about specific events in the game and focus on the parts that prove more interesting. Also, the sample size for patient subjects is probably low, so the comparability gained from using structured interviews is not really relevant. The questionnaire will be a 23 (25 for the augmented reality version of the game) item version of the Intrinsic Motivation Inventory [Ryan, 1982]. The intrinsic motivation inventory consists of up to 45-items categorized in 7 subscales. In this study, a verified 22-item version [von Held, 2012] with 4 subscales is used as this study focuses on intrinsic motivation. The 4 subscales are interest/enjoyment, perceived competence, perceived choice and pressure/tension. The questionnaire is adapted to the study by changing the words working/doing with playing and task/activity with game. The average of the statements in each subscale is calculated and results in the final score for that subscale. Additionally, an extra question is added, *I felt in control of the virtual prosthesis,* which is asked to assess if the training session in BioPatRec was successful and if the subject felt in control. For the augmented reality version, 2 additional items are added which is, *I like seeing myself on the monitor,* and is asked to assess how the subject feels about seeing themselves, some people don't like being filmed and especially for amputees are the concerns about their body image, which the augmented reality system hopefully should improve. The second question is, *the virtual prosthesis felt like a part of my own body,* which is asked to assess if the subject felt that the virtual prosthesis was a natural extension of their own body. These extra items do not belong to any subscale and their final score is calculated individually. After the evaluation of the first game, the subject will play the second game following the same procedure as for the first (e.g. training round, 3 rounds with adjusted difficulty and evaluation). For the final test setup see Figure 18.

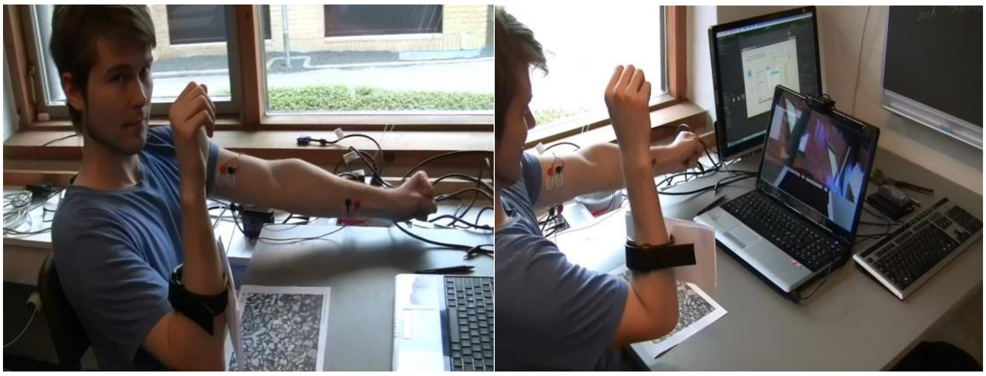


Figure 18: 2 images of the test setup with a test subject taken after the subject had completed the test.

A pilot study is conducted to verify the test methodology. A fellow 10th semester medialogy student was chosen for the pilot test as I besides testing wanted critique from a peer. The test started and the introduction to the test, as well as the fitting of the electrodes went according to plan. I decided to verify that the system was working by analysing the raw myoelectric signals in BioPatRec which was done by asking the subject to flex/extent the 4 muscle sites one by one and verify that each muscle site gave a proper response in BioPatRec. This worked well and I decided that I would add this procedure in the final test. Subsequently the training session of BioPatRec was explained and to explain the kind of wanted muscle contraction to use the subject was instructed to not contract with full strength, as this quickly causes exhaustion, but instead to contract enough to feel some muscle straining during the movement. Also, the subject was told not to contract any muscles when the system asked him to relax. During the training session in BioPatRec I instructed the subject in which movement to perform and when to perform it, even though BioPatRec shows both using images, text and progress bars, see Figure 19. A part of the reason for this was that the subject was confused about when to start the movement, as the subject already started during the movement when being prompted to prepare for it, see Figure 19.

Figure 19: 2 Snippets of the training interface in BioPatRec. The left hand side showing the prompt used to prepare the subject to perform the next movement and the right hand side showing the prompt to make the subject relax.

On the contrary, after being told only to perform the movement when the prompt showed it, the subject did not prepare to do the movement which caused him to miss the first second or so of the recording window, this was most prominent in the elbow flexion/extension movement which required a bit more movement than hand open/close. To some extent, it also happened after the prompt to relax, see Figure 19. Therefore I decided to instruct the subject in what to do during training regardless of their ability to follow the on-screen prompts.

After completing the training session, the subject was donned the marker used to display the marker on the right arm and the game, in this case the augmented reality version was started. The subject was shown that the virtual arm would be augmented on the marker and that the game world itself would be augmented on the marker on the table. The subject was instructed in the goal and the controls of the game followed by the first round of the first game. It quickly became apparent that the subject had some troubles controlling the virtual arm; especially the hand open/close movement was difficult to do for the subject. This resulted in the subject primarily doing the smash. After having played for a few minutes, the subject made a comment about that he now got his daily workout. I asked the subject if the game was exhaustive to play and the subject answered that “it would be after some time”, after which I asked that if the game was to continue for another 10 minutes, how the subject thinks that would be, after which the subject answered that it would be “very tough”. After this, I chose to switch game to the virtual reality version and let the subject play that. After the first round of the virtual reality version I asked the subject if he felt exhausted to which the subject asked that he was "a bit tired, but could go on if necessary". I chose to stop the test and ask the subject about his initial thoughts of the product and the test in general. His answers can be summed up to that 3 times 2 game rounds will be too much for most people and that it was a bit confusing to control the placement of the virtual arm with the right arm and the movement of it with the left arm. He also found the virtual reality version easier to control, but also said that it probably was due to that it was the second game.

To conclude, the following changes were made after the pilot test:

1. The signals from the subject are tested before the training session to ensure that they are of a high enough quality.
2. During the training session the subject is given instructions to supplement the instructions given by BioPatRec.
3. The number of rounds in each game is changed from 3 to 1. The easiest difficulty setting is chosen for each to certify that the game is not too hard for anyone. The game will run for 2-3 minutes before the round is ended.

The shortening of the test will probably affect the test, as shorter playtime will not give subjects enough time to master the first game before moving on to the next one, which will negatively affect the first game. However, as the first game is changed between subjects, it is believed this will cancel most of the effect. Another factor will be that the difficulty is preselected which some subjects might find to be too easy. This effect is reduced by the shortening of the test, as the subjects will probably not have enough time to master the game completely. This will however also mean that they might not enter FLOW which probably will decrease their enjoyment during play. This is unfortunate, but drive the test subjects to exhaustion could have implications as well. I would like note that the game will be far less exhaustive for the amputee subjects, as they don't have an arm that they must swing around during play.

The results from the test will be analysed in the next chapter.

Results

10 able-bodied subjects were tested; 9 males and 1 female between 20 and 27 years old all medialogy students. They all completed the test successfully and answered the questionnaires and some also gave comments which were noted and will be analysed in the end of this chapter.

The data is analysed to see if the hypothesis can be validated. The raw data located on the appendix DVD and is summarized in Table 4 and Table 5.

Subscale/Statement	Mean	Standard deviation
Interest/enjoyment	3.98571	1.05075
Perceived competence	4.74	1.48788
Perceived choice	4.76	1.28513
Pressure/Tension	3.1	0.53104
"I felt in control of the virtual prosthesis"	4.9	1.44914

Table 4: The result from the questionnaire from the virtual reality version of the game. The questionnaire was based on the Intrinsic Motivation Inventory [Ryan, 1982] and had subjects rank statements from 1 to 7 where 1 represents "not true" and 7 represents "very true. The statements belong to one of 4 categories which are averaged in the table. "I felt in control of the virtual prosthesis" is a stand-alone question.

Subscale/Statement	Mean	Standard deviation
Interest/enjoyment	4.2	0.79739
Perceived competence	4.54	1.14717
Perceived choice	4.8	0.95685
Pressure/Tension	3	0.99331
"I felt in control of the virtual prosthesis"	4.7	1.63639
"I liked seeing myself on the monitor"	5.4	1.07
"The virtual prosthesis felt like a part of my own body"	3.1	2.02

Table 5: The result from the questionnaire from the augmented reality version of the game. The questionnaire was based on the Intrinsic Motivation Inventory [Ryan, 1982] and had subjects rank statements from 1 to 7 where 1 represents "not true" and 7 represents "very true". The statements belong to one of 4 categories which are averaged in the table. "I felt in control of the virtual prosthesis", "I liked seeing myself on the monitor" and "The virtual prosthesis felt like a part of my own body" are stand-alone items.

With 2 sets of data, an *independent two-sample t-test* is used to assess if the data are significantly different. First, the distribution of the data must be assessed as the t-test requires that the distribution is not *grossly unnormal [McKillup, 2005]*. The distribution is assessed by studying the histogram of the distributions using www.wessa.net [Wessa, 2008] and all data except for the data related to the statement "I felt in control of the virtual prosthesis" for the augmented reality system is deemed not grossly unnormal.

The F-ratio is calculated for all sample sets to ensure that the variances are homogenous, as this is required to calculate the t-test correctly. The F-ratio is calculated by using the method described in chapter 9.3 of [McKillup, 2005] and can be seen in Table 6.

Subscale/Statement	F-ratio
Interest/enjoyment	1.74
Perceived competence	1.68
Perceived choice	1.8
Pressure/Tension	3.15
"I felt in control of the virtual prosthesis"	1.28

Table 6: Assessment of the F-ratio of the data to ensure the variances of the data are homogenous

As seen in Table 6, all F-ratios are below the critical value of 3.17 (2 groups with 9 degrees of freedom with a probability level of 0.05)

As the requirements are now met, a single-tailed t-test can now be performed. The test is performed using http://studentsttest.com [[] and the results can be seen in Table 7.

Subscale/Statement	p-value
Interest/enjoyment	0.30685
Perceived competence	0.37014
Perceived choice	0.46897
Pressure/Tension	0.38686

Table 7: Assessment of the P-value of the data to see if the data is statistically significant.

As seen in Table 7, all the data has a p-value below 0.95 thus there is no statistical significance between the augmented reality version and the virtual reality version.

As some of the data for the statement "I felt in control of the virtual prosthesis" is considered unnormal, this data is analysed with a Mann-Whitney U-test using http://elegans.som.vcu.edu/~leon/stats/utest.html [Avery, 2007], see Table 8.

Statement	p-value
"I felt in control of the virtual prosthesis"	0.455899

Table 8: Assessment of the P-value of the data for the statement "I felt in control of the virtual prosthesis" to see if the data is statistically significant.

As seen in Table 8, the data for the statement has a p-value below 0.95 thus there is no statistical significance between the augmented reality version and the virtual reality version.

Some subjects also gave comments during or after the test. Subject 6 commented that it was easier to use the augmented reality version, as he could see the arm-marker which made positioning of the arm easier. Subject 8 commented that it was confusing that the video feed from the augmented reality version was mirrored. Subject 9 commented that he should not have used so much force when he trained the system. A comment made by some of the subjects is they had trouble determine depth, which made it harder to position the arm correctly.

My own observations from the test are that most of the subjects had fun playing both versions. Some subject really did their best to play the games while others played it more relaxed. A few subjects did not seem to enjoy the games that much. In general, I will say there is a correlation between the subjects' mastery of the hand and their enjoyment.

Looking at the results, it's clear to see that they are very similar; the augmented reality version scored 0.2 more than the virtual reality in the interest/enjoyment score, but at the same time scored 0.2 less in the perceived competence score. The statement "I like seeing myself on the monitor" scored 5.4 (out of 7) with a standard deviation of 1.07, which indicates that the subjects liked this feature of the augmented reality version.

These results will be discussed in depth in the next chapter.

Discussion

Looking at the problem formulation presented earlier:

> *In the context of training simulators for myoelectric prosthetics, in which the patient controls a virtual prosthetic, is augmented reality superior to virtual reality?*

And the hypothesis:

> *Augmented reality will be the preferred system reality, as opposed to virtual reality, for a training simulator for myoelectric prosthetics*

From the data presented in the last chapter, it can be concluded that the hypothesis cannot be validated and therefore it seems that virtual reality is just as preferred as augmented reality in the context of training simulators for myoelectric prosthetics.

I believe there are several reasons for why the hypothesis could not be validated. The test was only conducted on a limited sample (10 subjects) that was not a part of the target group (amputees). This has several implications; firstly, the virtual arm is probably seen as a nuisance instead of a representation of how the control of ones future prosthetic is like, as the marker used to place the virtual arm is unnatural for an able-bodied subject as their real arm was “in the way”.

Another point of discussion is that if the games are too similar as the control of the games are the same. Virtual reality games that uses camera input for control exist [Sony Computer Entertainment America LLC, 2010], but they use the tracked object to perpetuate the real-life equivalent to the action in the game (e.g. swing a controller to play tennis or hold 2 controllers like a bow and arrow). The action in the presented game is controlled by the myoelectric input and the tracked marker is only used for controlling the placement of the virtual objects. It could be argued if virtual reality makes sense, when the camera input is only used for the placement of the virtual objects. The only reason that it was the case in this project was to isolate the system reality variable and avoid that control of the game could be a factor. This could easily have resulted in the same pitfall as Anderson and Bischof [Anderson and Bischof, 2012], as they made a comparison between 2 widely different systems and claimed that augmented reality was better, even though there were major differences in the controls, graphics and gameplay between the 2 systems.

I believe a natural next step would be to test the 2 versions with a head mounted display. One of the results from my previous work [Kristoffersen, 2012] gave a tendency towards that a head mounted display is more preferable in a myoelectric training system (Mean = 66, Standard deviation 18.42, p-value = 0.097)[2]. With a head mounted display I believe that augmented reality will surpass virtual reality in a game like the one presented.

Future systems should multiple games that facilitate different movements, so that each patient can find a game that suits them and their situation. Furthermore a higher degree of customisation for the arm should be possible so that it can fit both trans-radial and trans-humeral amputees. Also, the patient should be able to choose between a virtual arm that resembles a real arm or a prosthetic. The prosthetic should support different textures, so that the patient can personalize it and especially children might find it enjoyable to be able to have a cartoon arm e.g. look like Iron Man's arm which can make them feel special in a positive way. Data recording of the arms movement as well as improved high scores should also be used to spark motivation in the patients by triggering their competitive gene. Even though no data to date supports that this training decreases abandonment rates for myoelectrical prosthetics, I am a firm believer that it has a potential and I will even claim that if a new study investigating the effects of myoelectric training on abandonment rates were performed today, that it would find evidence for that it helps.

A sub-question was previously formulated:

> *Can a training simulator for myoelectric prosthetics that utilises augmented reality, in which the patient controls a virtual prosthetic, maintain accessibility and affordability?*

I would say the answer is yes. The product presented in this report only requires a laptop, a webcam and 2 markers printed on a consumer printer on A4 paper. The laptop used for the test was more than 3 years old (MSI CX620, new price in April 2010: 6,000 DKK), which I would mean constitutes a standard consumer laptop and it was able to run the game with more than 30 frames per second at all times. Even though the laptop has an integrated webcam, I chose to use an external webcam to get better tracking and to adjust the field of view, but the built-in webcam could have been used as well.

[2] Egocentric perspective (head mounted display) compared with an exocentric perspective (monitor). On a scale from 0 (not preferred) to 100 (highly preferred)

Conclusion

To summarize, this project has investigated the use of virtual reality and augmented reality in respect to training system for myoelectric prosthetics. From the general problem that a meaningful number of amputees that was fitted with a myoelectric prosthetic later abandoned it, because they did not have the motivation to learn to use it led to an initial problem statement. This initial problem statement was the centre for further analysis for the training system. An analysis was conducted to investigate rehabilitation practices for amputees as well as different reality modalities. This led up to an analysis of the state of the art after which it was clear that augmented reality had some good possibilities in this context, but that further research was required. This led to the final problem formulation which was used to design a system and to investigate if augmented reality was superior to virtual reality in a training system for myoelectric prosthetics. A game was designed as games are seen as a good way to motivate. The game was after an expert interview designed around the classic Whac-A-Mole arcade game and a modified version of the game was prototyped in both virtual reality and augmented reality. The prototypes were tested using comparative testing with a limited sample of 10 able bodied subjects, but the test did not give any significant results and a it could not be concluded that augmented reality is better than virtual reality in the context of a training simulator for myoelectric prosthetics. This is believed to due to the test not being performed on amputees and the fact the virtual reality version drew benefit of the camera-based controls of the augmented reality version which minimised the differences between the 2. There are a lot of areas for further research in this subject ranging from egocentric vs. exocentric perspective, display modalities, game types, pursued interactions, degrees of freedom and the applications for treatment of phantom limb pain using similar systems as the one presented. Immediate further work will be to test the system on amputees and or patients suffering from phantom limb pain, to verify the results from the test of the able-bodied subjects and gather more qualitative feedback which can be used in the further development of myoelectric training systems.

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