Universidade do Minho
Escola de Engenharia
Departamento de Informática

João Dias

Dissertação
Dispositivo de Realidade Virtual

para melhoria da marcha em pacientes com a doença de Parkinson

October 2017

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Master dissertation
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Cristina Santos
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ABSTRACT

In recent years there have been many improvements to medical procedures, involving the use of augmented reality technology to provide new innovative approaches to difficult tasks that are often required of the patients, requiring less physical exertion from the to achieve the same results or simply looking at the problem in a new perspective. Virtual reality technology has the capability of creating an interactive, motivating environment in which practice intensity and feedback can be manipulated to create individualised treatments to retrain movement.

Currently there is a very large amount of people suffering from minor to severe functional limitations, impairments such as loss of range of motion, decreased reacting times, disordered movement organisation, and impaired force generation create deficits in motor control that effect the personss capacity for independent living and economic self-sufficiency. The use of augmented reality is starting to be used in more medical scenario's and in the treatment of many diseases generally co-related with motor difficulties or recovery treatments.

One of the diseases that has been looked more prominently for augmented reality development is the Parkinson's disease which causes its patients to suffer severe gait constriction and whose generalised gait treatments didn't produce a significant improvement in the patients gait without the use of heavy medication.

One other important detail to take notice is that the Parkinsons disease causes the patient to abruptly enter a freezing state without any kind of warning which can lead the patient to fall and severally harm itself depending on the situation at hand.

The objective of this thesis is to explore the possibilities of the use of augmented reality in an attempt to improve gait in patients suffering from Parkinson's disease. For this purpose many augmented reality glasses were analysed selecting the best one in terms of affordability, comfort and utility. The application developed has the objective of improving the patients gait by displaying an augmented reality supper- imposed path for the patient to follow matching auditory cues with each of the patients steps and also helping the patient of he suddenly finds himself affected by a "freezing" episode.

RESUMO

Recentemente tem sido feitos vários melhoramentos nos procedimentos mèdicos, recorrendo ao uso de tecnologias como realidade aumentada para fornecer uma nova abordagem a tarefas complicadas que são frequentemente requeridas aos pacientes, requerendo um menor esforço físico e feedback imediato ou simplesmente para obter uma nova perspetiva sobre o problema em questão.

O uso de realidade aumentada tem vindo a ser cada vez maior, sendo usado em cada vez mais procedimentos e para tratamento de variadas condições principalmente focadas em dificuldades motoras e fisioterapia.

Uma das doenças que despertou maior interesse no uso de realidade aumentada no seu tratamento é a doença de Parkinson, conhecida por causa deterioramento nas capacidades motoras dos afetados causando problemas na marcha da pessoa que, afetam varias tarefas do seu dia a dia.

Outro detalhe importante da doença de Parkinson é que os afetados também tem o que são chamados de episódios de ″congelamento″ que acontecem quando o paciente de repente e sem nenhum aviso previ-o fica paralisado durante uns instantes, o que pode provocar a queda da pessoa. Estes episódios não são constantes podendo variar bastante na ocorrência e na intensidade de pessoa a pessoa.

O objetivo desta dissertação é a exploração das possibilidades do uso de realidade aumentada numa tentativa de melhorar a marcha das pessoas afetadas com a doença de Parkinson. Para este propósito muitas ferramentas de realidade virtual foram examinadas escolhendo uma que seja o menos intrusiva possível para facilitar o uso pelo paciente e que tenha as especificações necessárias para o bem funcionar da aplicação. A aplicação de realidade virtual terá então o objetivo de melhorar a marcha do paciente através do seu uso mostrando ″pégadas″ que irão servir para o paciente se orientar e ajudar o paciente quando ele estiver sobre o efeito de congelamento para evitar que cause danos graves a si próprio casa ocorra numa situação complicada.

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1

INTRODUCTION

This chapter presents the motivation for this dissertation and the objectives that must be accomplished. Furthermore, it will also describe the structure of the remaining document.

1.0.1 *Motivation*

In recent years, more and more companies and financial entities have supported the development of medical applications that make use of augmented reality technology which is mostly caused by the fact that there is a medical barrier where the medicine being prescribed to Parkinson patients is not enough to help, and Parkinson being the second most common age-related neuro-degenerative disorder after Alzheimers disease mean this problem is quite widespread, with an estimated seven million to 10 million people worldwide who suffer from this disease that affect the patients quality of life, making social interaction more difficult and worsening patients financial conditioning due to the medical expenses associated with it .
This is due to the potential augmented reality has in the treatment of various conditions, where the existing methods prove to be very intrusive on the patient daily activities or to some scenarios that the only kind of treatment can only be achieved by augmented reality applications.
Augmented reality has been explored in the use of treating various diseases that generally cause the patient to suffer in its motor functions, because of its ability to create realistic scenarios that are safe for the patient to interact with, hence its applications being used in diseases like Parkinson's that harm the gait of the patient.
Computerised technology has the capability to create an exercise environment where the intensity of practice and positive feedback can consistently and systematically be manipulated and enhanced to create the most appropriate, individualised approach. Adding the layer of three-dimensional (3D) spatial correspondence between the patients steps on the augmented reality projections and the real world objects. Studies have already been conducted to search for a way to improve the gait of patients suffering from Parkinsons disease that showed some impressive results in gait improvement from successive training in aug-

mented reality scenarios, but had limitations in terms of the usability of the augmented reality device with some patients refusing to use it and for some this approach was still too intrusive causing even more discomfort than the usual methods and in many cases not helping the patient in case he suffers from a freezing of gait episode.

Other relevant limitation is that most of these augmented reality applications had the objective of training the patient, so they can't be used to help in the patients daily activities, being that when the patient stops using the augmented reality application the improvements might end up not remaining for long.

Lastly there is no efficient help when the patient enters a "freezing" state which is the most dangerous situation the patient can find himself in being since it can severely harm the patient in some scenarios. Some attempts at "waking" the patient from this state using augmented reality have been made, ranging from small shocks and visual cues, but none proved too effective leaving this section to many improvements.

1.0.2 *Objectives*

The main focus of this work is to explore augmented reality systems that are focused on a close circuit, in which the feedback signal is to be generated in tune with the users movement in order to improve the living conditions of patients suffering from gait impairment due to the Parkinsons decease.

For this purpose a wearable augmented reality device will be used that integrates other systems that uses sensory feedback, in conjunction with other devices already in development with the aim of achieving a sensory and vibratory feedback mechanism.

This will take form of a footstep superimposed on the real world that the patient will see when moving to create a balanced gait rhythm that will adapt dynamically to the patients gait cycle. The speed of these visual cues is directly tied to the patients own motion and speed and will move toward him at the speed the user is walking.

Lastly in this work we intend to match the visual feedback of the patient wearing the augmented reality device with the vibration and sound of each step finally integrating this system with other existing systems with the purpose of creating a efficient way of "waking up" the patient from a freezing of gait episode exploring auditory/vibratory and visual cues for the effect so we can determined the best method to "wake up" the patient from a freezing of gait episode.

This will be tested in Patients suffering from Parkinson disease in an on medication state because we do not intend to make the patients suffer in the usage of this application, since patients are likely to refuse testing if that is the case. Here follows the list of all the objectives for better understanding.

1. Definition of what are the specifications to the system we want to create, the experiments to realise and the data that must be recovered and analysed in accordance to discussion with the supervisors and medics involved;
2. Select the adequate augmented reality device to acquire in order to develop the proposed system;
3. Implementation of the functional specifications in the augmented reality device.
4. Definition of the experiments and procedures to be taken in the hospital.
5. Integration of the developed system with other existing devices.
6. Execution of the clinical experiment in the hospital with Parkinson patients in the "off" state;
7. Recovery and analysis of the data obtained during each gait condition in virtual and real environments;
8. Implementation of possible system alterations according with experiment results;
9. Implementation of a tool capable of predicting patient gait by analysing previously selected bio-mechanical data;
10. Validation of the system in real time, evaluating system performance.

1.0.3 *Document Structure*

This document is organised in 5 chapters: The first chapter describes the motivation of this work, as well as the goals that are its final objective . Its main purpose is to identify the problem and set up objectives that should be accomplished.

The second chapter introduces the main concepts of the aspects of the Parkinsons disease that are important to understand the objective of this work also explaining the basics of augmented reality reasoning the decision to use augmented reality instead of another method or technology. It also describes the state of the art, focusing on the different tools and approaches that have been tried in the field and what where the benefits and limitations of each one. The third chapter is about explaining the requirements to complete the proposed objectives explaining the proposed approach to be used in this work.

The fourth chapter is where we analyse the results of the various tests and the fifth final chapter present the results discussion and analysis with the final conclusions regarding this work.

2

STATE OF THE ART

This chapter will present the current technologies and different approaches for gait improvement in patients suffering from the Parkinson's disease explaining the reason for the use of augmented reality over other technologies. Additionally, it will also detail basic concepts related to gait impairment and the Parkinson's "*freezing*" effect and Augmented Reality needed to understand the solution presented for the problem and the needs of the patients suffering from this condition.

2.1 PARKINSONS FREEZING OF GAIT

Many patients suffering from mid-stage Parkinsons decease experience "freezing". Freezing can be best described as the temporary, involuntary inability to move. Not all people with Parkinsons experience "freezing", but those who do have a much greater risk of falling. Freezing episodes can occur at any time without warning, and some people are prone to freezing episodes than others. Usually the freezing effect only last for a few seconds.

The cause of "freezing" is unknown but in patients that experience "freezing", it mostly happens when they are having an "off" period, meaning that they are in a period where they are not under the effect of Parkinsons medication, or are due to their next dose of dopaminergic medication.

Freezing episodes can happen at any time but tend to happen more often when the patient is initiating a movement or starting to move (Ex: the patient stands to start walking). The situations where the patient is more prone to having an "freezing" episode is when doing changing his current movement to start another (Ex:Turning a corner, turning around).

Freezing episodes can also be triggered during stress-full events or when surrounded by crowds. These "freezing episodes are dangerous because there is a danger of falling because the beginning and end of these episodes are unpredictable. The unpredictability coupled with exterior force, like a random person trying to help the person move may cause the person suffering from a "freezing"episode to lose balance and fall.

The general recommendations for preventing the "freezing" episodes albeit not very effective by theyre self's are walk or march in a particular rhythm like rhythmic music, and step

with the beat or imagining stepping over an imaginary line in front of you or just to avoid distraction at all costs when youre walking, just focusing on long steps.
Lastly the ways to overcome a "freezing" episode come in prompting yourself to follow a rhythm by saying aloud 'left,right,left,right' or 'one,two,one,two', trying to wake up your body by stand still and swinging your arms, or shifting your weight from foot to foot and visualising an imaginary line to step over. Other method involves the use of auditory or visual cues where visual cues provide feedback through the eyes and visual system to provide a location ro place the foot when stepping. Visual clues include: lasers on canes and U-step walkers, placing lines of tape on the floor, placing Xs of tape in a semi-circle in tight spaces, and stepping over the foot of a therapist while gait training. On the other spectrum auditory cues rely on feedback through the ears to establish a rhythm "step to the beat". These cues generally come in the form of music, counting out loud, or using a metronome, There are also applications for smart phones that can provide sounds like metronome that a therapist can demonstrate for the patient.

2.2 GAIT IMPAIRMENTS IN PARKINSONS

Gait impairments have been receiving a lot of focus in recent years since they are a common cause of disability in people suffering from Parkinsons. Various aspects of gait impairment have been fount to be affect by Parkinsons, but can be influenced and improved through the use of rehabilitation through auditory or haptic cuing. *(Maculewicz et all, 2016 (6))*
The most common of the aspects are the freeze of gait, cadence, balance, gait velocity, stride length, increased spatio-temporal variability and difficulties in gait initiation. These conditions then lead to restricted or weakened balance and mobility, and consequently a bigger risk of falling causing noticeable problems in the daily activities of patients suffering from Parkinsons.
Figure 1 illustrates the difference between a regular gait and a Parkinson's gait.

2.2.1 *Rehabilitation through Auditory Stimulation*

In this case the PD patients are usually provided with an auditory metronome, or markedly rhythmic music, and ask are required to match the consecutive footfalls matching each onset of the beat. External rhythm's presented by auditory cues may improve gait characteristics and can also be used to identify problems in gait adaptability. *(Spaulding et all, 2013 (8))* in its review he pointed that the auditory cuing elicited positive changes in gait cadence, velocity and stride length.
The aforementioned way of stimulation lack the interactivity component where the systems

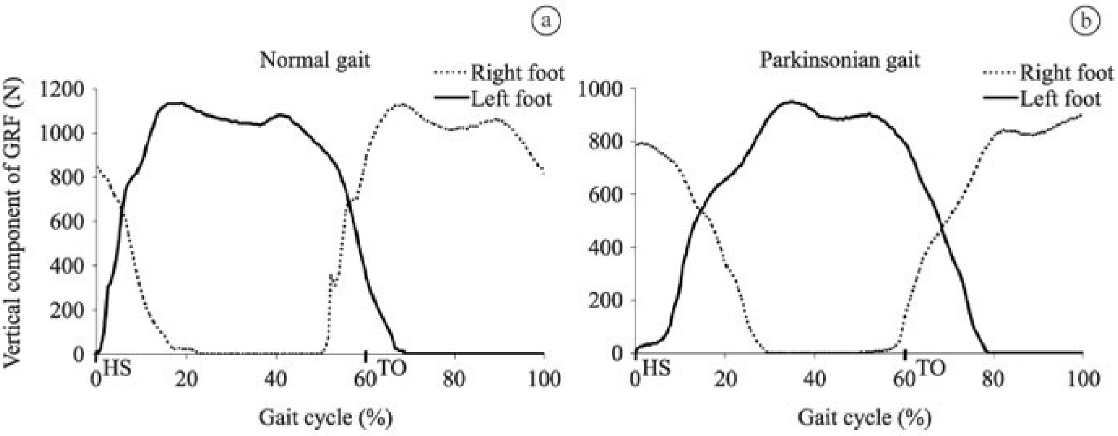

Figure 1.: Vertical component of ground reaction force (GRF) for both feet during a gait cycle(GC), a)normal gait; b) parkinsoniam gait. For normal gait stance phase (0%-60% GC) begins at left heel strike(HS) and ends with toe off(TO). Swing phases takes between 60% and 100% GC. Notice how these percentages vary for parkinsoniam gait

could adapt to the user where a close-loop system could then be used to implement mutual entrainment between the system and user to avoid constant vigilance and need of attention strategies to prevent reversion to impaired gait patterns caused by repetitive stimuli. Gait rehabilitation should lead to achieving the more stable and not random stride times structure that can be observed in normal and healthy gait. Systems based on mutual entrainment principles can provide immediate to unpredictable changes in human behaviour.

2.3 MEDICATION

Freezing of Gait is frequently considered to be one of the dopamine-resistant motor symptoms of Parkinsonism. Previous studies have demonstrated that the Off-related FOG is improved be levodopa (L-dopa) or entacapone treatment. L-dopa can decrease the duration of each FOG episode as well as its frequency. On-related FOGs are not common and difficult to diagnose.
Later when the disease has progress into its later stages it becomes resistant to treatment as many other symptoms. Off.related FOGs are likely to be improved by dopamine agonists but this has never has never been looked at systematically. Levodopa remains the most potent drug for controlling PD symptoms, yet is associated with significant complications such as the "wearing off" effect, levodopa-induced dyskinesias and other motor complications making this option not viable in the long term.

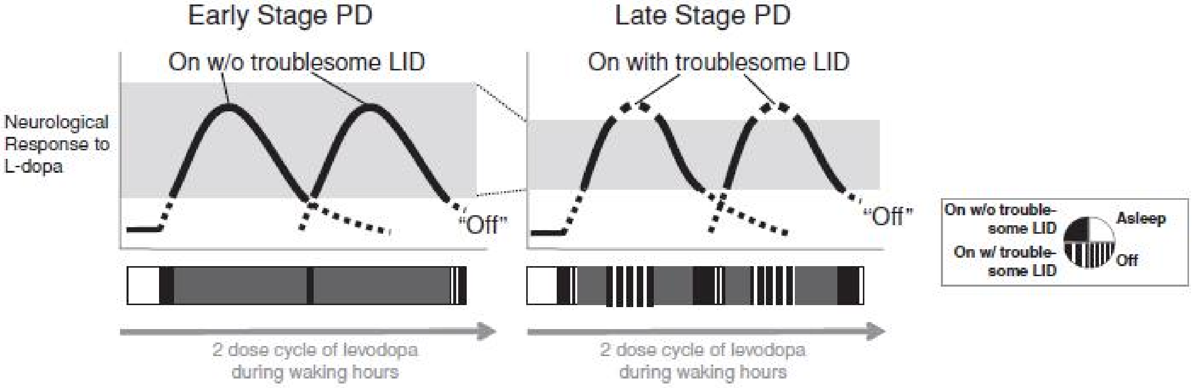

Figure 2.: Levodopa effects on the early and later stages of PD

2.4 AN INTRODUCTION TO AUGMENTED REALITY

Augmented reality is a technology that allows for virtual objects to be placed in the real world in real-time, enhancing our information about the world around us. Imagining a scenario where looking outside and seeing and seeing the weather forecast for the day appearing before the window itself. AR layers detailed information over what we see around us while still allowing us to navigate though the real environment.

Virtual Reality differs from AR in a few key areas. First, VR seeks to not just enhance reality, but to recreate reality in an immersing environment. To accomplish this user are often separated from the real world by headsets (often refered as HMDSs). HMDs completely block out the users surroundings, isolating them from the outside world. Such technology is indeed very immersive, but also limited in its applications.

This distinction between AR and VR is based on the current state of both technologies. However, the future will bring head-mounted displays that are capable of both AR and VR (well touch on that later). It is easy to imagine an HMD that allows users to see through the outside world in AR mode, then becomes opaque and switch to VR. There are no known players developing such an hybrid system at this point in time. AR and VR remain separate domains performing different functions; VR seeks to created a world of its own separate from reality, while AR seeks to increase a users experience in the real world and enhance reality.

2.4.1 *3D models and Processing*

Augmented Reality allows us to visualise 3D models in real-time and in a real environment. Before AR, 3D graphics were limited to gaming environments , architecture visualisation, engineering, and entertainment. Although 3D computer graphics continued to evolve in quality, 3D models were still used solely in immersive environments - until augmented

reality. There are two way to approach creating an AR experience: creating a 3D content or starting from already build models from a 3D library. While AR works with 2D images, AR cannot reach its full potential without a 3D model that can be rendered by any angle, thus creating a digital interface on top of the real world.
3D artists use one of several software programs to create 3D worlds. Starting with a rough sketch's of what the final model will look like, the image will typically go through an approval process that refines the idea.
The more complex the model, the longer this stage will take. A simple box shape with a only a few surfaces takes a short time to complete and a full fledged 3D character can take a very long time to finish depending on the level of detail. As AR and VR grow, the demand for 3D content for the medium grows as well and 3D content libraries which developers can use to populate their AR and VR applications will likely expand. An example of this is the virtual library *Sketchfab* that contains an endless variety of 3D objects from witch to chose.

2.4.2 *Augmented Reality SDKs*

3D content still needs an engine to bring the AR experience to fruition, and this software can be adopted through an augmented reality SDK. This SDk includes a rendering engine for the 3D model, as well as tracking detection and depth sensing to orient it in the world around it.
Some of the more important aspects that come from SDKs involve: Motion Tracking where custom sensor allow a smart phone to understand position and orientation relative to the environment. Motion tracking fives real-time information about the 3D motion of a device. This aspect is of particular importance as it is one of the objectives of the AR solution that is proposed in the study; Depth Perception where sensors can detect how far or how close objects are in relation to the device. Understanding depth helps you interact with virtual elements in the real world; Area Learning where devices can recognise the world around them. After learning the environment, the device estimates positioning and also remembers both visual and physical elements of the space around them. It appears to easily recognise surfaces and the relationships between those surfaces and the real objects around the person.

2.4.3 *How AR Tracking Works*

When a scene in a movie needs to use 3D elements mixed with live action elements, a supervisor will place tracking markers around the set in order to give the computer a sense of what the environment looks like so that the computer generated elements can move around with ease and still look realistic.

An AR SDK learns and tracks movement in the environment in real-time, creating and updating its view of the environment many times per second. The common way of achieving this result is using the *Simultaneous Localisation And Mapping (SLAM) Tracking, Depth Tracking, and Pattern Tracking*. *SLAM* tracking uses complex algorithms coupled with sensor data to build a 3D map of an environment and calculate its position within that environment. Some versions of SLAM use a 'registered object', which the computer has already measured, in order to get initial measurement of the space. From this point, sensors take over and learn the environment while the user moves within the space. An example of this effect is Googles self-driving cars that use *Lidar*, a technology similar to SLAM, that is built to generate a depth map of the surroundings using lasers and a 360 view.

Depth Tracking also uses a variety of sensors, many of which use infrared light to generate a map of the environment. This sensor data is combined with other data from various sources such as an accelerometer or GPS to update the computers vision of the world.

Pattern tracking uses infrared lasers to create a pattern of dots which bounce back to the sensor to give the device an idea of contours of surrounding area. It then keeps track of distance and orientation in space by constantly recalculating the shape and size of the pattern, If the pattern gets smaller, for instance, it knows the object has moved farther away, Similarly, it tracks the space and distance between the individual dots of the pattern to get a sense of an objects shape or to determine whether it is being moved or rotated.

2.5 MOTOR REHABILITATION USING AUGMENTED REALITY

The augmented reality environments provide a unique medium suited to the achievement of several requirements for effective rehabilitation intervention *(Šumec et all, 2015 (9))*.

In many cases therapy can be provided within a functional, purposeful and motivating context.

Many virtual reality applications present opportunities which can have a better way to communicate feedback for the analyser and a more rewarding experience for the person using it. In addition to the value of the rehabilitation experience for the user, both therapists and users benefit from the ability to readily grade and document the therapeutic intervention using a variety of different systems.

In augmented reality, similar to virtual reality the users are provided with an simulated, interactive and multidimensional environment. From this point visual interfaces such as desktop monitors and head-mounted displays(HMDs) and real-time tracking devices are used to create environments allowing users to interact with images and virtual objects in real-time through multiple sensory modalities.

In a more basic form, augmented reality overlays simple head up displays, images or text into the users field of view. More complex augmented reality applications display sophisticated 3D models rendered in such a way that lighting conditions, shadow casting and the simulation of occlusions appear indistinguishable from the surrounding natural scene. Figure 3 shows an example of a common AR system in which the video is acquired, registered and augmented. In this case the augmented reality object registered by tracking information from the video output. After rendering the 3D transformation, the real object can take any other appearance or even be transformed into a completely different object. From this position the object could then represent a variety of interactive elements such as different figures or interactive buttons. Actions made to manipulated objects and body movement through virtual space provide frameworks, that are comparable to doing the same actions in the real world without the intervention of augmented reality in the perceived real world. This type of visualisation is a powerful tool for exploring real world structures along with additional contextual information. For example, by augmenting textual descriptions or instructions, AR displays are able to provide semantics to real world objects that, by themselves, do not provide any information about how they should be used.*(Bell Boucher et all, (3))*

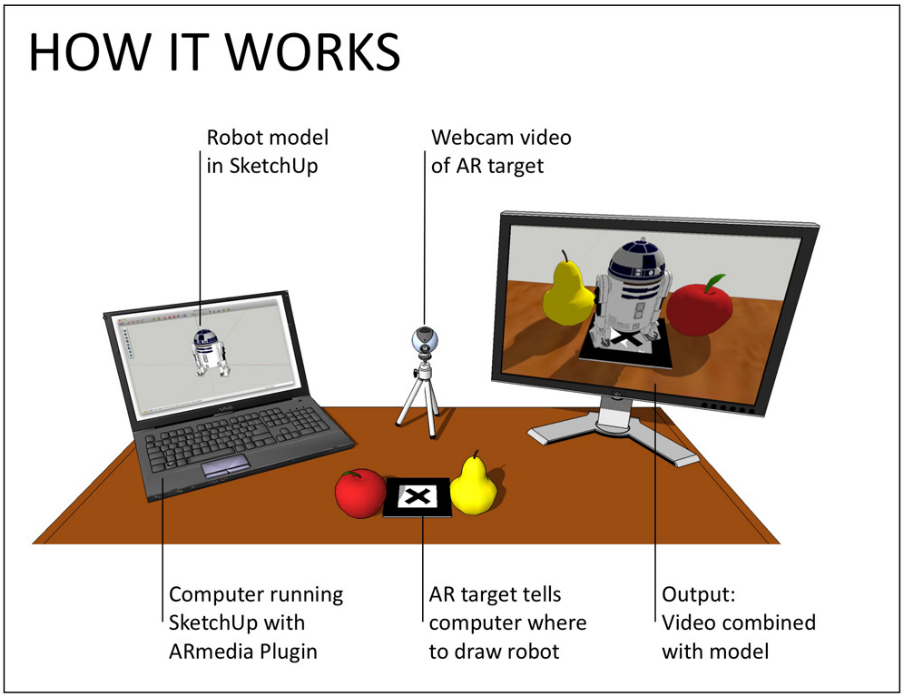

Figure 3.: Simple augmented reality example

Since virtual information does not necessarily have to follow real world physic's and convection's, augmented reality is able to present a variety of non-natural elements in a real world environment. This can translate to simple floating textual information in a real world environment to the incorporation of complex fictional characters living in the real world environment.

What all this translates to when it comes to motor rehabilitation is that augmented reality is useful to create specific environments and situations that can be tailored specifically to the users condition and objectives being more flexible in its use than its counterparts

2.6 CLOSE-LOOP VS OPEN-LOOP AUGMENTED REALITY

It is well recognised that auditory, visual, or tactile stimuli can improve gait patients with Parkinsons decease. As a result, devices that exploit the sensory cuing-related modification of gait in patients with Parkinsons have been proposed with limited success for ongoing use. These devices typically come in two forms: open-loop or closed-loop strategies.*(Espay et all, (4))* Open-loop strategies impose a sensory signal on the patient, as seen on Figure 4, generated by an external source that is not affected by the patients own motions. Examples are fixed-velocity visual cues or rhythmic auditory cues. While open-loop stimulation may offer benefits to some patients, such cues were found to cause confusion and/or exacerbate freezing of gait in others. *(Espay et all, 2010 (4))*
On the other hand it is well known that the stabilisation of open-loop dynamic systems can only be achieved through constant feedback that is closed-loop systems. The key aspect to notice here is that the role played by the sensory feedback in gait stabilisation and control. where the feedback signal is generated by the patients own motion, has been demonstrated by studies where the Parkinsons patients where provided with visual marking on the ground. *(Bell Boucher et all, 2013 (3))*
The feedback obtained from closed-loop systems increases the flexibility of the augmented reality environment being able to make adjustments on real-time to improve the users experience and respond and adapt to changes in the patients gait or posture to increase effectiveness making the closed loop systems more advantageous than the open-loop systems. The development of wearable augmented reality device driven by inertial sensors that delivers earth-stationary visual feedback cues has provided an opportunity to access a closed-loop system of sensory(visual-only) feedback stimuli to aid dysfunctional gait in patients with PD.

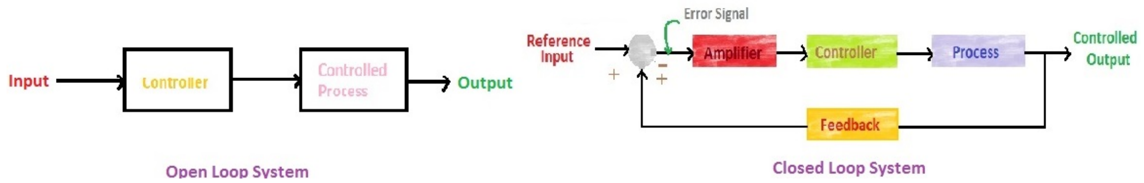

Figure 4.: Open-loop and Closed-loop basic explanation

2.7 GAIT ANALYSIS SYSTEMS

In many cases, a test environment is necessary, to analyse the patients gait in various details to be judge and evaluate patients growth or deterioration.
The validated gait analysis system (GAITRite, CIR Systems, Inc:Havertown, Pennsylvania (7)) , displayed in Figure 5, is one of the possible ways to generate these details. It consists

in a 4-meter electronic walkway that contains six sensor pads encapsulated in a roll-up carpet to produce an active area of 61cm wide and 366 cm long.

In this configuration, the active area is a grid (48 sensors by 288 sensors placed on 1.27 cm

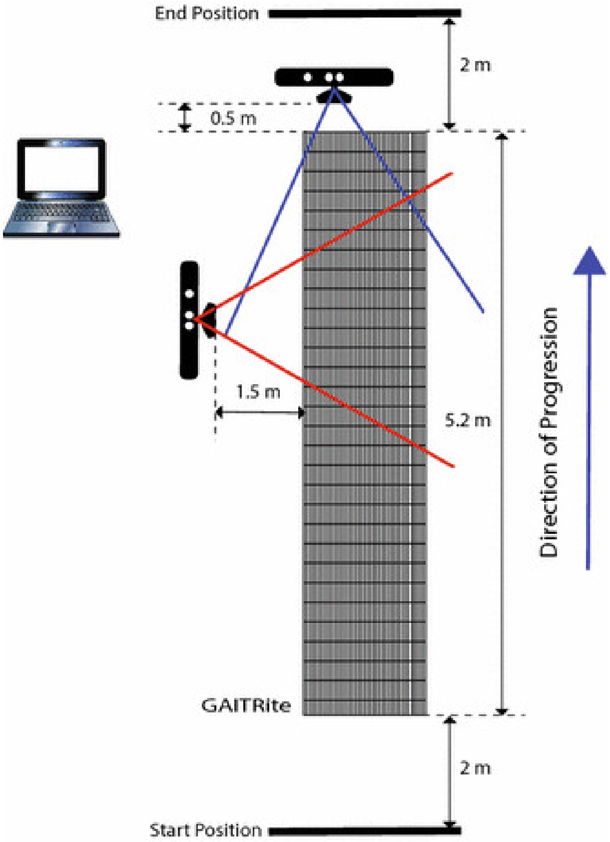

Figure 5.: GAITRite Setup

totalling in 13,824 sensors (7). This walkway is portable and can be laid over any surface with minimal setup and test time requiring no extra devices for the patient to wear. The application software controls the functionality of the walkway, processes the raw data into footfall patterns, and the computes temporal (timing) and spacial (distance) gait parameters, including stride length, cadence and velocity.

This makes the *GAITRite* system the most prevalent system to test the patients gait and obtain the details necessary as efficiently as possible.

2.8 GAIT ACCELERATION PATTERNS IN PATIENTS WITH PARKINSON DISEASE

Parkinson is very complicated disease to deal with on a daily basis and community-based studies indicate that PD is a strong independent risk factor for falls (*Mark. D et all, 2009 (14)*), and studies specifically focusing on PD populations have demonstrated fall rates of between 38% and 50% over a 6-month period (*Buckey et all, 2016 (15)*). The advancement of the disease severity appears to be the strongest predictor of falls among people suffering from PD. However, it as also been suggested that the gait pattern associated with PD can be characterised by reduced walking speed, shortened step length and increased double support time may also contribute to an increased risk of falling. In these studies the gait patterns of three distinct groups of older people where analysed: non-PD controls, older people with PD that do not fall and people with PD that fall. During these tests, variable like stride length, cadence, step timing variability and walking speed where analysed for each different population where PD nonfallers compared to the control group exhibited significantly reduced step length, walking speed and increased step timing variability. Among participants with PD, fallers exhibited significantly reduced walking speed and increased step timing variability compared to non-fallers. There were no differences in cadence between the three groups. Typical acceleration patterns obtained from accelarometry systems are show in Figure 6. Compared to controls, PD nonfaller exhibit reduced acceleration RMS in all three planes at the pelvis and head. Among participants with PD, fallers exhibited reduced acceleration RMS in the vertical and mediolateral planes at the head compared with nonfallers. What these studies where able to conclude from all this is that PD is not only associated with decreased walking speed, step length shortening, and increased step timing variability, but also with a disruption of head and pelvis accelerations. Few previous studies have evaluated the effect of PD on head and trunk stability. Conclusion of this studies also helped determine that acceleration patterns of the body during gait were found to differ between older people with and without PD and between older people with PD who do not fall suggesting that an inability to control displacements of the torso when walking may predispose falls in older people with PD.

2.9 GAIT REHABILITATION TECHNOLOGIES

This section will provide an summary of related technologies and applications that serve as a foothold for the improvements that are the objective of this work. Various different approaches have been used, from gaming relating technologies , such as Nintendo ^{TM}(Wii), for rehabilitation purposes while other studios have opted for the creation of custom programing and/or hardware or even robotics. Although this work is based of the use of specifically augmented reality technology knowing what other approaches have been made and how they work and what are theyre limitations proves valuable to take into consideration.

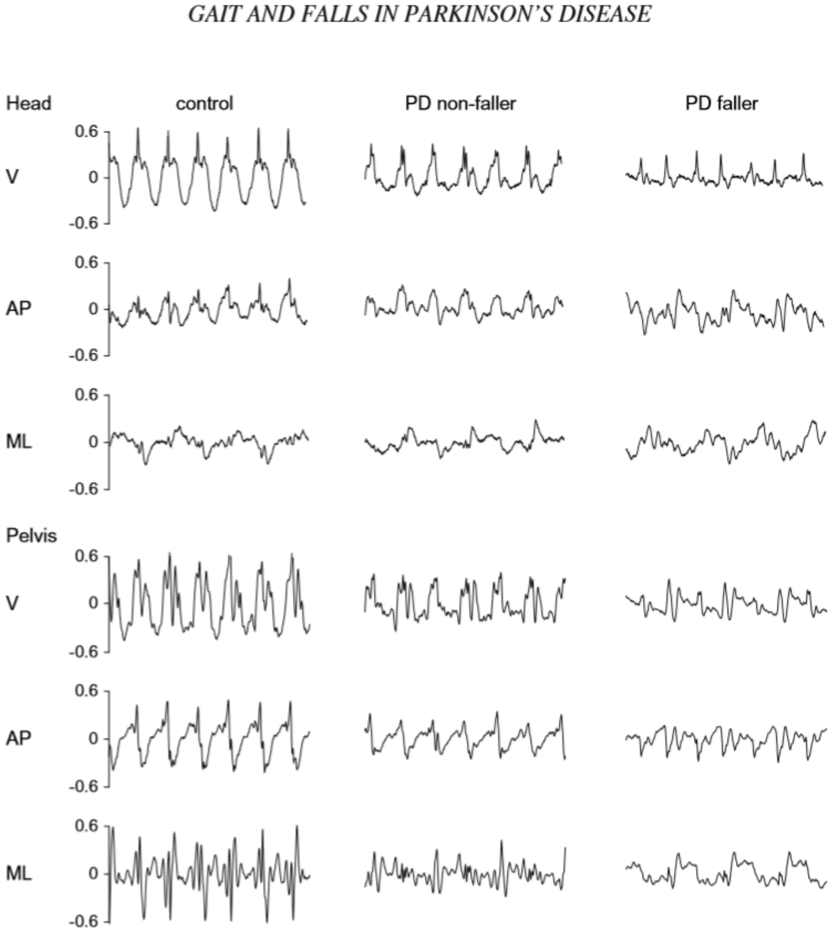

Figure 6.: Examples of accelerometry recordings in (*Buckey et all, 2016 (15)*). Each trace represents 5 seconds. Vertical scale in units of gravity(g). AP = anteroposterior; ML= mediolateral; V = vertical.

2.9.1 *Nintendo ^{TM}(Wii)*

Improvement in gait disorders in Parkinsons disease generally involves drug or rehabilitation therapy, in which physiotherapy activities a priority. Following this principle *(Barros Gonalves et all,2014 (1))* considered virtual reality through the Nintendo ^{TM}(Wii) to be a good alternative in the motor rehabilitation of individual with Parkinsons analysing the effect of virtual sensorimotor activity on gait disorder in people suffering from PD.

This study used an sample of 15 individual diagnosed with Parkinsons, presenting major gait disturbance that had been observed and monitored by medical staff. The selected participants individually performed three laps on a 3-meter track and after the laps started playing Nintendo ^{TM}(Wii) in 40 min sessions following this procedure twice a week in a total of 14 session, with two min of break between each exercise. For the program three categories of different virtual exercises were standardised: aerobics, balance and exercise plus.

1. **Aerobatics** - Consists of Free Step, Rhythmic Step and Rhythmic Boxing. Step Free Step involved stepping on and off the platform with each leg before progressing to Rhythmic Step and Rhythmic Boxing, performed by standing on one leg while the other moves in a rhythmic sequence, alternating the foot and arm movement.
2. **Balance** - Consists of Ski Slalom, Advanced Skiing, Ski Jumping, followed by Header and Jump Rope (three for each exercise).
   Ski Salom is performed by standing on both feet while the body moves side to side (as if moving forward in zigzag movements) to change direction.
   Ski Jump involves standing with your feet slightly apart, bending the knees, leaning the upper body forward, and holding the arms straight back in a straight line. The feet stay in contact with the platform. The participant straightens up the body position at the end of the "Jump", arms by the side.
   The same position is used to perform Header and Jump Rope, but with specific sensorimotor. stimulation's.
3. **Exercise Plus** - It consists of the following: Segway Circuit and Cycling. The Segway Circuit is performed standing on two legs. When a participant leans forward he or she goes faster, and upper body movements enables the player to move the handlebars and change direction.
   The Cycling activity on the other hand is performed with a sequence of steps on the platform. Upper movements, and moving the hands up and down as if beating a drum, enable the participant to change direction.
   Both exercises also have an Advanced level.

The implementation of the program developed through sensory-motor exercises specific to^{TM}(Wii Fit Plus) improved gait performance in Parkinsons patients, with an increase in stride length and gait speed, demonstrated by the analysis of images, when comparing results from before and after the program.

2.9.2 ^{TM}*(Walk-Mate)*

In recent years, robotics has been attracting attention in fields of not only industry and production but also assisting technology and rehabilitation methods. *(Uchitmoi et all,2012 (11))* has focused on cooperative gait between humans as interpersonal synchronisation, and modelled a mechanism of footstep rhythm synchronisation called ^{TM}(Walk-Mate).

The ^{TM}(Walk-Mate) is a biped virtual robot synchronising with the users footsteps via walking together setting the most adequate rhythm for the user to follow with the aim to improve upon the festinating gait (accelerating footsteps) of the patients. The results showed that the festinating gait, evaluated by stride time reduction rate, significantly stabilised and accelerated less with Walk-Mate compared to unassisted walking also revealing significant carry over effects carry over effect were observed.
An overview of the ^{TM}(Walk-Mate) experimental system is show in Figure 7. This included a cross-feedback process, whereby the footstep timing of biped virtual robot was given as an input signal to the subjects footstep timing. The rhythm generator model in the biped virtual robot had an hierarchical structure, as illustrate in Figure 7 (b). Module 1 is responsible for the mutual entrainment between the human footstep timing and the virtual robots footstep timing. Module 2 controlled the phase difference (shift in timing) between the sensory input, which is the subjectss footstep timing, and the motor input which is production of robot footstep sound stimuli to the subject, to a targeted value. More specifically, Module 1 is involved in the use of the a non-linear phase oscillator while Module 2 implemented feedback control for the phase difference in the timings of input and output of Module 1.

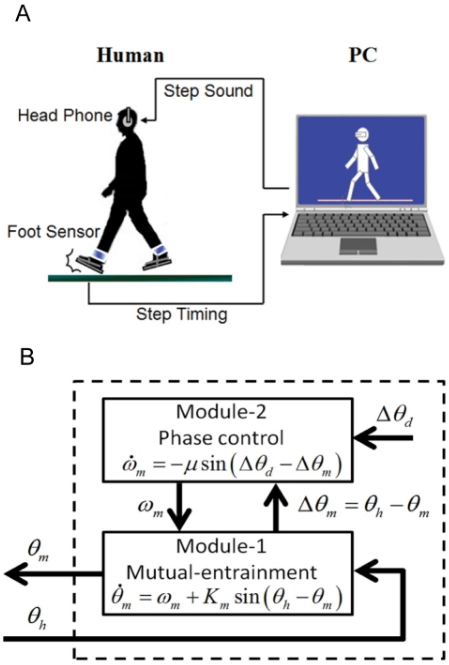

Figure 7.: An overview of the $^{\text{TM}}$(Walk-Mate) experimental system *(Uchitmoi et all,2012 (11)* . (a) Depiction of an interpersonal synchrony emulation robot named Walk-Mate. (b) Walk-Mates timing used system nonlinear oscillators and was organised hierarchically in two modules. Module 1 mutually entrained the gait frequencies of the computer and the participant. Module 2 adjusted the relative phase difference between computers auditory onset and the participant's step contact to a target phase difference.

This study provided positive results for festinating gait improvement as we can see in stride interval time and phase difference in a Parkinsons subject equipped with $^{\text{TM}}$(Walk-Mate) system as illustrated in Figure 8.

(Uchitmoi et all,2012 (11)) refers that previous research has proposed the use of fixed-tempo rhythmic auditory stimulation and floor strip patterns in gait training for Parkinsons patients but that these studies paid no attention to the dynamic stability of the earlier synchronisation between the rhythmic stimulation and the gait rhythm. By focusing on festinating gait in Parkinsons patients, this study was able to evaluate the influence of the $^{\text{TM}}$(Walk-Mate) system on rhythm formation disturbances resulting from the neurodegenerative diseases in basal ganglia.

The results also suggested that the interpersonal synchrony process was quite effective for dynamically stabilising the festinating gait. A noticeable limitation of this study is that there is no attention the freezing of gait mentioned earlier and follow up research is warranted to clarify how Walk-Mate as the interpersonal synchrony emulation robot contributes to stabilisation and improvement of human gait and other various rhythmic movements.

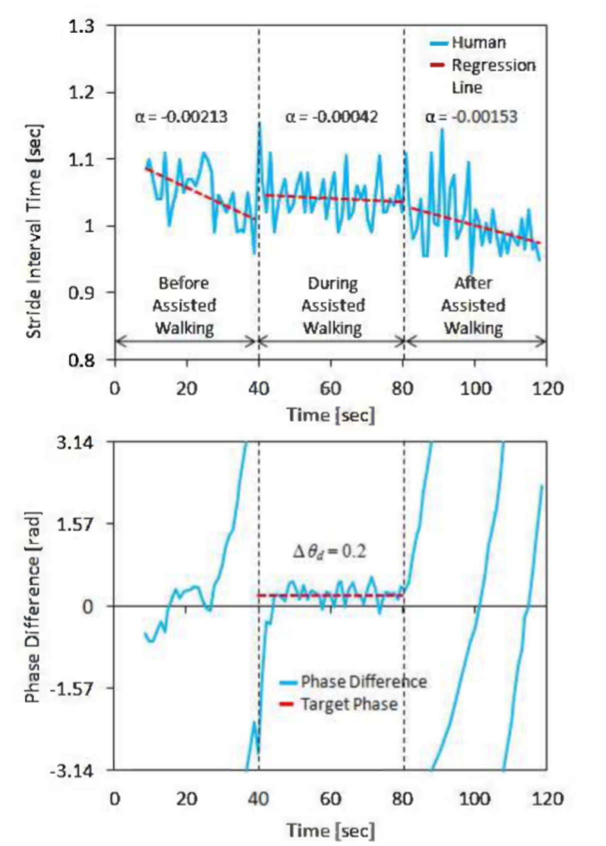

Figure 8.: Examples of a result of the time-course changes in stride time and phase difference of a subject, achieved by Walk-Mate system. This result obtained in the before assisted walking, the assisted walking and the after assisted walking are compared. In every one of theses three section, each gradient of the regression line alpfa was calculated. The festinating gait was defined as alpfa ¡ -0.001.

2.9.3 *Augmented Reality*

The two major goals of rehabilitation are the enhancement of functional ability and the realisation of greater participation in community life. These goals are achieved by intensive intervention to improve sensory, motor, cognitive and higher level-cognitive functions as well as to practice in everyday activities and occupations to increase participation. Intervention is generally based primarily on the performance of rote exercises and/or different types of purposeful activities and occupations. For many injuries the rehabilitation process is long and arduous.

Virtual reality-based therapys have been explored in various in various cases and scenarios related to various diseases that result in gait difficulties because of its ability to create environments and activities that appear to be, to various extents similar to real-world objects and events as we can see in *(Palacios-Navarro et all, 2016 (10))* .

When it comes to Parkinson there has been some exploration in the usage of virtual reality to improve the patients gait or help deal with freezing events. *(Espay et all, 2010 (4))* proved that that augmented reality can be used to reach positive results in this area and more efficiently than regular virtual reality because its less imposing on the users field of view being able to be aplied to real world scenerious and situations and can be transitioned to use in real life scenarios to prevent and deal with the $freezingofgait$. In *(Espay et all, 2010 (4))* a device that exploits the sensory cueing-related modification of gait in patients with Parkinsons that uses a closed-loop augmented reality system because then the users feedback can be used dynamically to adapt the signal displayed.

The aim of this study was to improve the gait of patients suffering from Parkinson using said device to control the patients gait showing tiles on the ground for the patient to follow matching sound cues to that adapt to the rhythm of the patient walk cycle.

In this study the key role played by sensory feedback in gait stabilisation and control, where the feedback signal is generated by the patients own motion, has been demonstrated by the gait improvements in patients with Parkinson when they are provided with visual markings on the ground.

This study was also conducted on parkinsonian gait in the ”off” state, when the magnitude of gait impairment is expected to be the largest. It is believed that the optical flow provides a reassuring feedback effect, informing the patients of motion being performed and matching visual feedback from clicking obtained from each step to help produce a balanced rhythmic walk. This works in contrast to open-loop strategies to produce and maintain a high degree of confidence, comfort and safety to create an environment where the patient using the augmented reality system will be much less likely to become stressed and suffer an episode of freezing from said system. The augmented reality system that was used in *(Espay et all, 2010 (4))* can be seen on Figure 9.

Figure 9.: Virtual (augmented) reality goggles used in *(Espay et all, 2010 (4))* containing built-in LCD screen which projects floor tiles when subjects are moving, and earphones that sound step-matched cues as determined by connected sensor strapped as belt

This device, that works in an adaptive closed-loop mode, displays a life-size virtual checker-board-tiled floor superimposed on the real world with specialised see through glasses. The closed-loop (or feedback) concept as opposed to open-loop comes from what was described in the earlier chapters where the speed of the clue is not a predefined set but an consequence of the patients walk-cycle and speed. The effect is the same as that created by walking over earth-stationary cues (i.e., a real tiled floor).Similarly, the rhythm of the auditory cues is determined by the rhythm of the steps and not the other way around. Here the user then regulates the gait pattern to create a constant optical flow and a rhythmic auditory cue. The virtual augmented floor acts as a moving visual display whose speed is controlled by the users own motion. A steady gait synchronises the patients own steps with the virtual tiles and the auditory cues, thus ”rewarding” the patients for the effort.

Most studies like this one and *(Bell Boucher et all, 2013 (3))* had subjects asked to walk at theyre usual pace on a defined path using the GAITRite walk-way beginning and ending at the same point.

In this case the subjects were asked to walk in five distinct conditions:(1) no sensory feedback(no device, baseline),(2) visual-auditory device positioned but deactivated(device off), (3) device positioned with visual feedback-only activated, (4) visual and auditory feedback activated, and (5) again with no sensory feedback (device off, immediate residual effect). Each condition was repeated three times and the average of these was used for analysis. Subjects were evaluated at two points: baseline (visit 1) and after two weeks of at-home use (visit 2). In between these clinic-evaluations patients were asked to use the virtual-auditory device while walking for no less than two 30-minute periods a day, regardless of their medication state.

The data that was analysed was the primary outcome measures (gait velocity, stride length, and cadence) to access the effect of the device under various conditions. To accomplish this, the evaluation was made under the effects of various conditions (no device, device without feedback, visual only feedback, visual auditory feedback, and no device for immediate

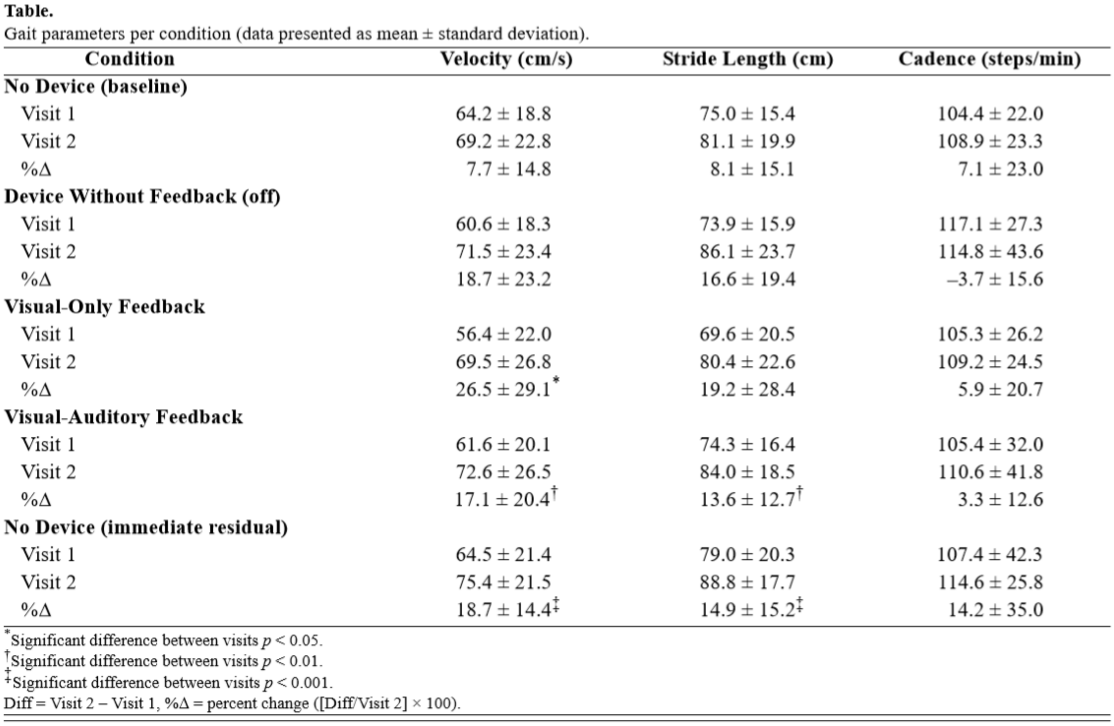

Table.
Gait parameters per condition (data presented as mean ± standard deviation).

Condition	Velocity (cm/s)	Stride Length (cm)	Cadence (steps/min)
No Device (baseline)			
Visit 1	64.2 ± 18.8	75.0 ± 15.4	104.4 ± 22.0
Visit 2	69.2 ± 22.8	81.1 ± 19.9	108.9 ± 23.3
%Δ	7.7 ± 14.8	8.1 ± 15.1	7.1 ± 23.0
Device Without Feedback (off)			
Visit 1	60.6 ± 18.3	73.9 ± 15.9	117.1 ± 27.3
Visit 2	71.5 ± 23.4	86.1 ± 23.7	114.8 ± 43.6
%Δ	18.7 ± 23.2	16.6 ± 19.4	–3.7 ± 15.6
Visual-Only Feedback			
Visit 1	56.4 ± 22.0	69.6 ± 20.5	105.3 ± 26.2
Visit 2	69.5 ± 26.8	80.4 ± 22.6	109.2 ± 24.5
%Δ	26.5 ± 29.1[*]	19.2 ± 28.4	5.9 ± 20.7
Visual-Auditory Feedback			
Visit 1	61.6 ± 20.1	74.3 ± 16.4	105.4 ± 32.0
Visit 2	72.6 ± 26.5	84.0 ± 18.5	110.6 ± 41.8
%Δ	17.1 ± 20.4[†]	13.6 ± 12.7[†]	3.3 ± 12.6
No Device (immediate residual)			
Visit 1	64.5 ± 21.4	79.0 ± 20.3	107.4 ± 42.3
Visit 2	75.4 ± 21.5	88.8 ± 17.7	114.6 ± 25.8
%Δ	18.7 ± 14.4[‡]	14.9 ± 15.2[‡]	14.2 ± 35.0

[*] Significant difference between visits $p < 0.05$.
[†] Significant difference between visits $p < 0.01$.
[‡] Significant difference between visits $p < 0.001$.
Diff = Visit 2 – Visit 1, %Δ = percent change ([Diff/Visit 2] × 100).

Figure 10.: *(Espay et all, 2010 (4))* Gait Data Evaluation Results

residual) on each outcome variables using repeated measures analysis of variance followed by post hoc multiple comparisons with $Bonferroni$ adjustment for each visit separately. The result of this evaluation can be seen in Figure 10. From this Figure we can see that in the general case in all different scenario's we can observe that there has been an improvement in all parameters (Velocity, Stride Length and Cadence) but we scenario that proved to yield the best results was the Visual-Auditory Feedback scenario concluding thus that the this is the best environment for gait improvement for gait rehabilitation from the tested scenarios. In this study, contrary to expectations, the benefits were not observable within each visit, immediately upon device activation, but as a robust immediate residual or carryover effect at the end of the last assessment. In fact nearly 70 percent of the subjects showed residual improvement of at least 20 percent in velocity, stride length, or both. One important aspect to note is that in both *(Espay et all, 2010 (4))* and *(Bell Boucher et all, 2013 (3))* patients with more advanced disease showed greater benefit after using the device, as greater baseline disability would provide the opportunity for a proportionally larger magnitude of benefit whereas small baseline disability makes it harder for the intervention to show any beneficial results.

The limitations of this study are that there was an absence of an control study given the lack of ”neutral mode” (e.g., white noise and non-tiled visual feedback), which could have served as an ”active placebo”. Secondly the lack of within-visit improvement of the patients, possibly related to the subjects cautious approach to the study hardware, argues against a placebo response although it does not rule out physiological test-retest variability in the gait of patients with Parkinson's. Lastly this study did not focus on the "freezing of gait" which if adapted into the augmented reality system could provide an even safer training environment.

Similar limitations could also be found in *(Bell Boucher et all, 2013 (3))* study but in its case the limitations revolve around the need to improve the presence of the patient in the virtual system stating that a less than optimal level of presence may have contributed to any learning effects that were observed. Another limitation to note is that the subjects were asked to perform actions in augmented reality environments and subsequently completed in the real world. This was initially done to avoid learning in the real world task that may carry over to the augmented reality performance in order to identify the effect of the system performance. However this may have affected the results as performance in the real world may be partially due to a learning effect from the first completing the task in the augmented reality environments. It is advised that future studies should randomise and alternate the order of environments in which the task are completed. Lastly it is also advised to aim for larger and equal size of groups so that the results become less skewed. This study also does not deal with improving the "freezing of gait" in the patients showing that this is a relatively unexplored area of augmented reality gait rehabilitation.

3

METHODOLOGY

This chapter characterises the requirements that should be met in this work and explains the approach that was chosen to reach and validate the proposed solution.

3.1 REQUIREMENTS

In this work we intend to explore the possibilities of closed-circuit augmented reality where the feedback signal is generated according to the user movement with the aim of developing an augmented reality system that will integrate other sensorial feedback systems already developed in order to achieve a vibrating and auditory feedback resulting from each step in the gait of the patient. In this aspect we pretend to improve on the limitation of the previous attempts that focused mostly about not addressing the issues related to what should the user do when he encounters himself in a freezing state and the use open-loop modes, where the patients gait is not considered when making calculation to the speed of the cueing, making the application not very adaptive and user friendly. Also the type of visual cue is something to note because if the visual cue is too easy to associate to a predetermined test environment it may not work so well when taken to another test in a different environment. The aim here is for the user to be able to chose where he uses the system so he feel more comfortable and less prone to stress from the environment which may induce freezing of gait. To fulfil this objective these are the proposed steps that need to be fulfilled:

1. The system must operate in an adaptive close-loop mode.
2. The system must show visual cues representing a foot in from the patients field of view.
3. The system must deliver auditory cues through earphones to the patient.
4. The speed of the cues must not be externally set but, rather the outcome of the user walking speed.

5. Similarly the rhythm of the auditory cues must be determined by the rhythm of the steps and not the opposite.
6. The virtual (augmented) cues must respond dynamically to the patients movements measured by the accelerometer.
7. The user should be able to change the shape and size of the visual cues.
8. The augmented reality interface should not be intrusive allowing the user to see real world obstacles with ease.
9. The system should be able to be integrated with other existing devices.

3.2 APPROACH

The chosen approach was the development of an augmented reality app that must follow all the previously listed requirements. For this purpose the smart glasses that were decided on where the ORA-1 smart glasses because these were the most affordable glasses that were available per amount of features and sensors. The ORA-1 (Figure 11) is equipped with a dual core processor, camera, microphone, sound, inertial sensors, WiFi, Blootooth, GPS, ambient light sensor, photochromic lenses, and a high capacity rechargeable battery. The developed application that will use this glasses must follow all the listed requirements which will be met gradually and validated periodically with its end user. It comes with an *Wikitude* development kit to facilitate its installation and use.

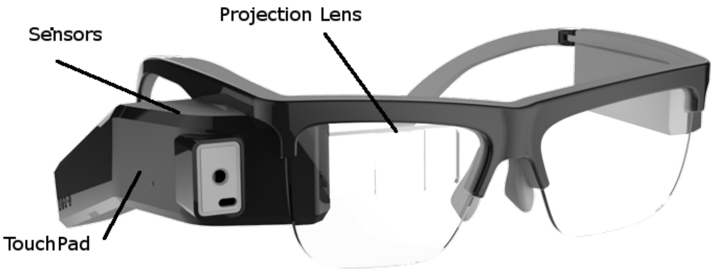

Figure 11.: *ORA-1 smart glasses*

3.3 APP METHODS

The developed app developed in the Unity Engine with a Vuforia SDK. Unity was chosen because of its ease of use of work in 3D space with the Vuforia SDK makes for a great

platform for creating augmented reality application, it was also chosen because its an environment we are familiarised with so it reduces the need of a familiarisation period with different platforms. The developed application will have to comply with the established objectives to achieve the best possible results to streamline the experience to the target audience so that its use will not cause discomfort, since the test subjects will likely belong to demographic that will be formed of ages of 30+ years in most cases, and in this particular demographic the subjects are less familiar with the new technologies and are more prone to not choose this technologies in favour of a more ″old-school″ approach.
Having this concept in mind here are presented the various components that will be part of the final product:

1. **Continuous Gait Analysis**
   The patients progress will be tracked each time he uses the app adding to his pool of data so that we can see continuously analyse the progress or regression of the subjects gait.

2. **Gait Metrics**
   The app will show data to the subject and examiner related to the patient gait like speed and steps taken in, so that it is possible to see and analyse changes in the patients gait pattern.

3. **Visual Stimulation**
   Visual Stimuli will be presented to the subject in the way of a projected footstep, which will react to each step the patient takes establishing a rhythm with the patients speed since the footstep cue will be directly related to the patients gait pattern. Visual Stimuli will be presented to the subject in the way of projected figures, for example steps, in front of the patient.

4. **Auditory Stimulation**
   Similarly to the above mentioned auditory stimuli will be presented to the subject in the form of sound associated with the patients every step again creating a rhythm that will be soothing to the patient reducing the risk of occurring ″freezing″.

5. **Personalised Training**
   The subject will be able to personalise their test environment being able to customise things like the visual stimuli presented, to the duration of the test for better adaptation and ease of use promoting a more relaxed experience to avoid ″freezing″ episodes related to discomfort caused by the use of the app.

6. **Simplified Interface**
   To minimise the occurrence of ″freezing″ episodes the interface that the patient will

interact with will be as simple as possible so that it minimise discomfort to the patient being able to be easily used by users that are not used to this kind of technologies.

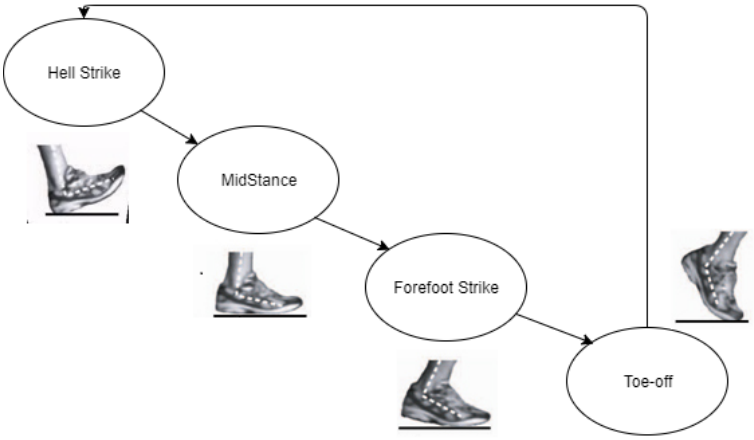

Figure 12.: State Machine representing the human gait events during one gait cycle of walking on healthy subject.

In Figure 12 we can see the states of the human gait, starting with the Heel Strike and ending with the Toe-off with when our foot starts to lift off the ground. In this approach we focus on the Heel Strike, which is the moment when the foot comes in contact with the ground, since what we want to know is when the user starts a step or takes another and then feed that information to the algorithm so that the interface can be update with each step detected to present the visual and auditory cues.

The functioning of the app is based on the step detection algorithm based on the data received from the accelerometer in relation to the Y axis from the augmented reality glasses, because what we intend to use to identify the steps taken by the subject is the oscillations from that same axis. From this data we can find the points at which a new step is started, more precisely when the heel strike happens following a set of rules for verification. The basis for the step detection algorithm is building a state machine that will to analyse the signal we receive from the accelerometer as seen in Figure 13.

This data was obtained by analysing the accelerometer y-axis when a user walks at different speeds. For this a walkway as seen in Figure 14 was utilised where we asked different people both male and female participants to walk with the glasses recording the accelerometer y-axis data at different speed settings during 40 seconds recording data at fixed intervals of 100ms which where then used to analyse the data separately so that we could prepare the application for real time usage and analyse the differences between each person gait characteristics.

Multiple stages of a step can be calculated from the data observed in the Figure mentioned before from analysing for example the Local Minimum which represents the Toe off

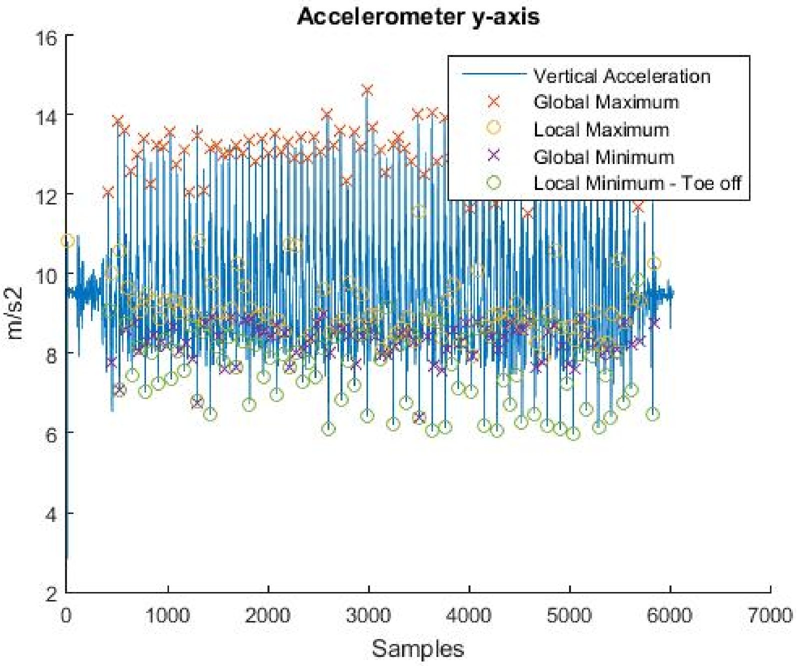

Figure 13.: Data obtained from the Accelerometer y-axis

Figure 14.: Gait Data gathering using Augmented Reality glasses on Walkway with different speed settings

event. For this application though what we use the Global Maximum because it marks the beginning of a new step. The Global Maximum peak represents the stepping down of the foot which is different for each person, some walk slower and some faster with different postures with in turn makes each step rhythm different resulting in different signals for each person.

The application starts with a simple start screen as seen in Figure 15 very simple to not complicate its usage with users not familiarised with this kind of technology which will be the case for most Parkinson patients..

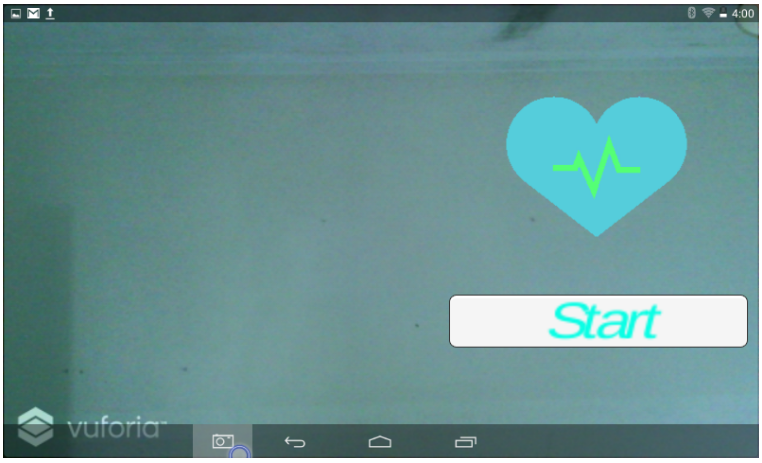

Figure 15.: *Application Start Screen*

A period of calibration is introduced before the application starts in full operation, the subject must walk some steps with a very low Global Maximum threshold which will then be replaced by an average of the Global Maximums of steps the subject took during calibration minus the standard deviation calculated from the same steps. During this time on the words "Calibration" as seen in Figure 16 and no visual or auditory cues will be activated because the purpose of the calibration is to prepare the subject for the tests and to making the algorithm adaptive so that we can achieve better results.

When the calibration ends a message on the screen appears so that he subject will then press when it is time to start application in full operation mode. The rule for each step detected is seen in the Table 1 below.

Table 1.: Proposed decision rule using adaptive thresholds for step detection

Decision Rule
(Acc(Y) >Max_threshold) AND (Derivative(n) <0) AND (Derivative(n-1) >=0) *AND (Min_Global == 0) AND (Max_Global == 0) AND (Max_Local == 0)*

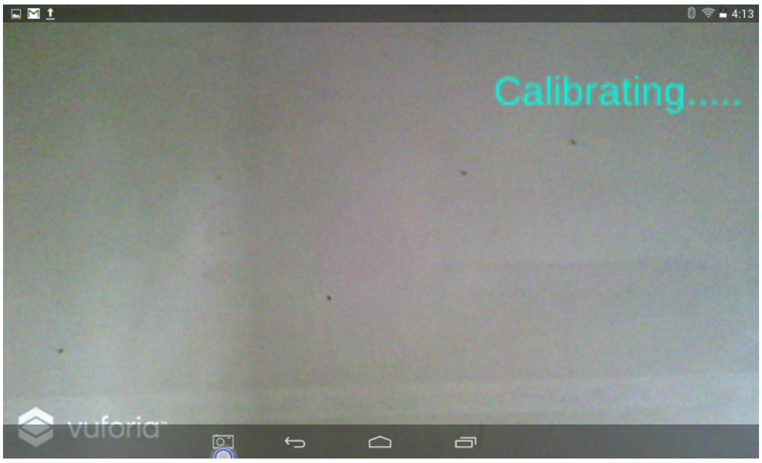

Figure 16.: Application while in Calibration Mode

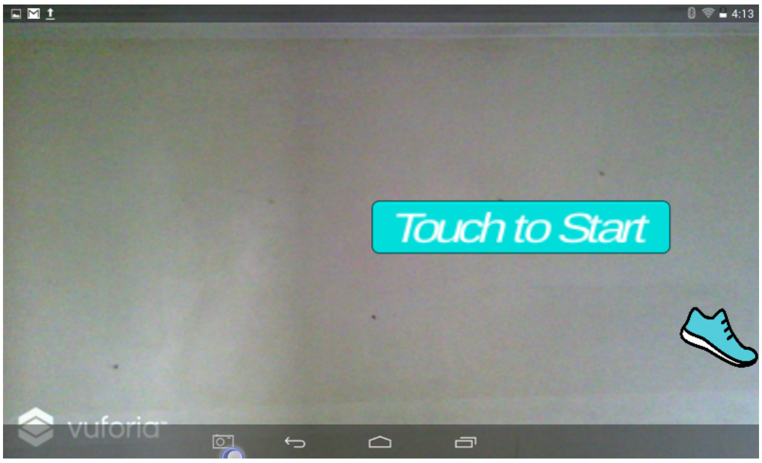

Figure 17.: Application when Calibration Mode is finished waiting for user input to resume activity

As pointed out in Table 1, the step detection is defined as: *Max_threshold*, the predefined *Max_Threshold* which is a value that is adapted from data from the first 5 steps of during the calibration stage with the purpose of changing the threshold to something more corresponding to the patients gait. The *Derivative(n)* value is determined by the acceleration values corresponding to the y-axis which must be negative and the following *Derivative(n-1)* be positive because the taking of a step in the signal is represented as we saw in the last Figure as the peak represented by the Global Maximum that then falls to the Local Minimum repeating the process for each step where the fall represents that a step has been taken.
y The variables *Max_Global*, *Max_Local* and *Min_Global* serve to store the data from the step and since what we are detecting with this rule is the beginning of a step they must all null at this point.
The next step is when the user then presses the button that says "PRESS TO CONTINUE"

were he will now see an image of a step in the right side of its field of view as seen in Figure 17, this is always moving at a fixed velocity upwards the screen where it reaches a limit that makes it turn back to its original position making it effectively stuck in a infinite loop.

Here is where the users steps will interact with the step shown before by making it return to its initial position whenever it detects a new step being made by the user, being this step left or right as the app does not distinguish left and right steps. As the user walks the step image on its right moving forward and back mimics the walking process of the user, for example a fast walker will see the step go back to its original position faster and not having time to move upwards a lot since the users walks fast, and in other circumstances a slow user will see the step being able to move upwards a lot maybe even being able to reach close to top of the screen which is where it will turn back automatically making the step rotation to the original position occur less frequently and more slowly. Here in the following Figure 18 we can see a flowchart of the proposed algorithm for the application.

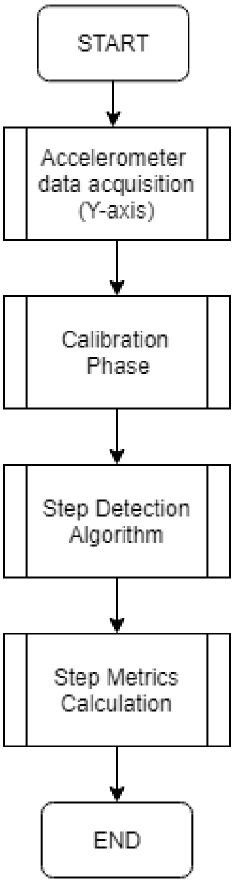

Figure 18.: *Flow chart of the proposed algorithm used for step detection*

A small consideration must be made here and that is that the speed of the step image is slow enough so that slow walkers can have enough time to trigger the step image return before it reaches it threshold but there are a lot of different gait patterns, especially when it comes to different gait patterns that from disabilities like Parkinsons disease which might necessitate a chance in the image step speed in the future.
The app the concludes with the user touching the touch-pad located in the right side of the augmented reality glasses to end the application which will result in the appearance of a pop-up window on the screen were the we can see details of the trip the user just took which are the metrics that we will use to analyse the users gait. We can see the the metrics in the following Table 2 as well as the simplified formula for their calculation.

Table 2.: Metrics Analysed

Metrics	**Method**
Steps Taken	+1 for each time DicisionRule is true
Test Duration	FrameDuration+=FrameDuration
Step Duration	TotalStepDuration/Steps
Step Length	Distance/Steps
Step Speed	Step Length/Step Duration

In Table 2 we can see five distinct metrics being those: *Steps Taken*; *Test Duration*; *Step Duration*; *Step Length* and *Step Speed*. The first one is simple enough as we have already explained the reasoning and rule behind the step detection as each time the *DecisionRule* occurs an new step is confirmed and added to the Steps Taken counter.
Test Duration was calculated using the Unity function of *time.deltatime* which represents the time in seconds it took to complete the last frame. This function is used to create a chronometer by adding to the time of all frames successively, then when a step is detected the time is saved for that specific step and the time is reset to 0 so we can restart the process for the next step. These step times are saved on a list called *StepTimes* and when the user click to screen the average step duration is calculated by averaging all step times on the list and the total test duration is calculated just adding the different frame times since the user finishes calibrating and starts the application to the time the users presses the screen to end the finish its run.
Step Length is estimated based on the test total distance covered and the number of steps taken during the test which in turn is used to calculate the users *Step Speed* from the users *Step Length* and *Step Time*. A consideration was made to calculate the values from the accelerometer to then calculate step speed but since the accelerometer cannot distinguish between gravity ($-g_z$) and and an acceleration of 1_g towards the floor making it not able to tell the difference between the gravitational acceleration and the actual acceleration in the inertial system that we want the measurement to be done in with turns this approach more complicated and prone to worse results than the method used.

3.4 METRICS VALIDATION

To metrics used were validated to ensure that the results where plausible and to ascertain the margin of error of each method. To this end the metrics were validated in different ways, in the case of the step duration and test duration the case was simple, a mock test was filmed in a controlled environment and the test duration and step timings were compared to the recorded data. In step count case it was also simple but also the most interesting, again mock tests were made in various undefined environments just asking a set of different healthy people with ages between 18-60 to walk where they wished for a few seconds. The step detector detected most of the steps in general with a margin of error of about 3 steps although this value later changed because as was refereed before, different people have different gait characteristics, some walk fast and have more stiff and composed posture and some walk more relaxed which resulted in different results and variance even after the calibration stage whereas the application had bigger margin of error in relaxed and abnormal step patterns and more consistent results in more consistent gait patterns. Finally the calculated step length was compared to an average of the person measured footsteps and stride length. Since these tests where only conducted with healthy people we can never know how sure the application will translate to usage with Parkinson patients ,which is its final purpose, since its̀ gait patterns are very irregular but basis of the approach mentioned is to make the application adaptable to various kinds of gait patterns so we speculate that the application will translate favourable to use with Parkinson patients.

3.5 TESTING SCENARIOS

To test the efficiency of the app, users will be asked to use the augmented reality glasses in scenario where they will have to partake in a set of small activity while they walk. The aim of this test is to see if different scenarios produce marginally different results and identify best combination and usage of the application. These scenarios also serve another purpose, that is to identify any shortcoming with the application, by collecting data from the subjects via the app itself and a questionnaire that subjects will be asked to fill in the end of each test to change the app accordingly.

Each user or patient will be handed a test protocol so they can understand all the steps that they are about to realise and to clarify any doubt about the nature of the test and what is asked of the user. For the obstacle course show in Figure 19 both a control test with healthy user will be conducted and a test where the users all suffer from Parkinsons disease, where the healthy users test will serve to test and validate the application before it is then used for testing in Parkinson patients.

For this purpose gait metrics will be collected from the patients to validate the results and

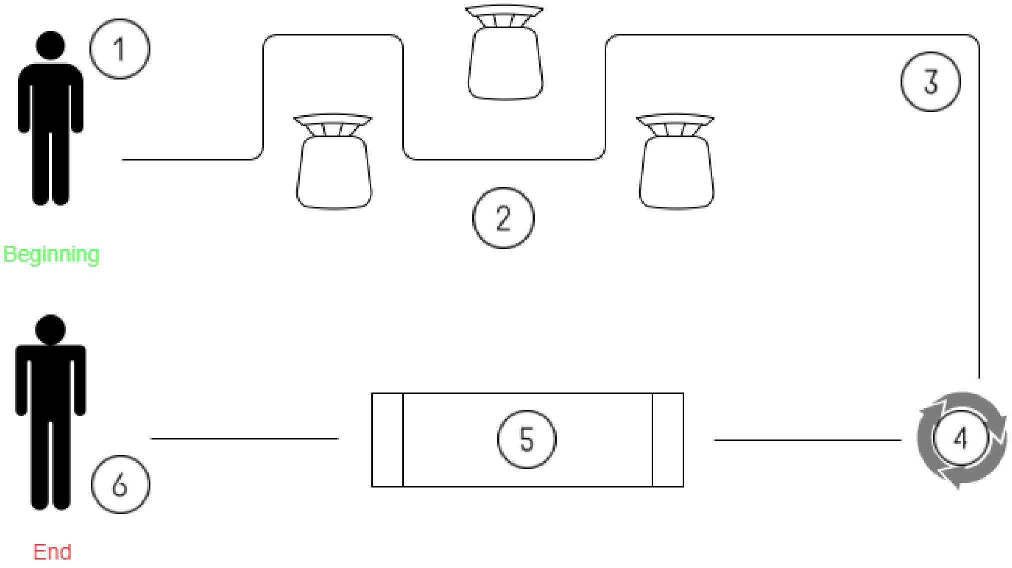

Figure 19.: Representation of the various steps of the obstacle course(15 meters): 1 - Beginning ; 2 - Passing in between a set of chairs; 3 - shifting direction; 4 - Roundabout; 5 - Walking on a carpet; 6 - Finish line

method that will then we used for the Parkinson users tests.

Both types of users will be asked to walk the course in different scenarios where we will test to see what is the best way to provide aid to the user while he walks and to see how much the usage of the glasses affect the user during the course. Below follows the testing scenarios for the user:

1. **No device**
   Patient without using the device, will serve as the baseline for the other tests.

2. **Device Offline**
   In this case the subject will wear the device but it will remain offline to identify the degree of distress that use of the device may cause to the subjects.

3. **Visual Stimuli Only**
   Here the patient will use the device with only the visual stimuli active to compare with the other methods and identify its efficiency and preference from the subjects.

4. **Auditory Stimulation** Same as before but this time only Auditory Stimuli will be available for the patient during the test

5. **Visual and Auditory Stimulation** Both auditory and visual stimuli will be active. This will be default operating mode for the application.

6. **No Device Again** After testing in the previous scenarios the subject will be asked to repeat the first scenario so that we can see any remaining effects from the use of the device.

Before the beginning of each patient or healthy user test rounds they will be asked to sign a consent where they are explained in more detail the aim of the study and objectives intend upon its completion so that the patient is clarified and responsible of its actions. The obstacle course seen in Figure 19 was reproduced in the university gym 26 because of the ease of use convenience of that location where the users where asked one by one to perform the tests shown the test protocol given to them, one for each situation where in the end of each of the tests where the glasses are online, the values of the metrics where taken at the end and then asked to respond to a brief questionnaire of the experience they had with the application. This questionnaire is composed of 10 questions related to the application they just used and about the test they completed. The questions are scored from an easy to hard, or like to dislike scenario with each question having a score of 1 - 10 points concluding with a score range of 10-100 where 10 represents that the user could not complete the tasks asked of him, found the application lacking and the glasses very bothersome and 100 where the user completed all tasks with ease, found the application useful and the glasses comfortable. A similar questionnaire was made for tests with Parkinson patients but has a total of 16 questions because of other elements we want to take into account from Parkinson patients like "Freezing of Gait". The scoring and evaluation follows the same rules as the evaluation before but now with scale of 10-160 points.

3.6 CLINICAL DESCRIPTION

Participants with Parkinsons Disease were recruited from The public Hospital of Braga. Tests with Heatlhy people were conducted from the community from friends and colleague's or parents of the same. Inclusion and exclusion criteria are in Appendix A. From the test subjects, subject with PD are to be selected from an average disease duration of 6 years (SD += 3 years), have an average Hoehn & Yahr Stage of 2.3 += 0.5. A consideration was made to ask the patients with PD involved to not take any levodopa dose before the tests but it was deemed to hurtful for the patient and so they will partake on the testing with their regular doses of ledovopa even if it may have an influence over the final results because otherwise the patients would not be willing to participate in this experiments.

4

RESULTS ANALYSIS

The augmented reality application was implemented with the intention of both tests with Parkinson patients and with a control group as described in the clinical description. Due to limitations related to schedule and permissions at this time only tests with the control group were realised, which are enough to prove the functioning of the application. The results will be presented with respect to the participant data, tolerability of the system, a test protocol and finally a presence and app questionnaire.

Although full fledged testing with the application with Parkinson patients at this stage was not possible, a small scale test with 3 patients was made in the hospital where data from the theyȓe gait was analysed which proved useful for analysing the use of the augmented reality glasses for Parkinson patients.

4.1 PARTICIPANTS

For the purposes of the control tests with the application, 14 people (10 male and four female) with an average age of 28.1 years and a standard deviation of 11.6 years with the older tester being 59 years old and the youngest 20, and with an average weight of 70.625 kilograms with a standard deviation of 10.75 kilograms, and an average height of 1.73 meters with a standard deviation of 0.075 meters. For the purposes of the making the testing easier and more concise each person was handed a Testing Protocol as seen in *Appendix E* which details the aim of the study, the objectives we aim to complete with the testing, and a detailed explanation on the tests themselves explaining the steps that will be taken for each tests and the testing environment details. Each was expected to occupy 15-20 minutes for each person.

4.2 TOLERABILITY OF THE SYSTEM

The system was well tolerated in general in the control group and in the small testing environment with Parkinson patients, with no reports of disorientation or nausea, although in one case in particular, the glasses frame was too big and caused the glasses to slide down the nose of the person making it complicated to wear the glasses.

All participants were able to complete the full protocol with no exception. Minor complains about the confort of the glasses were reported, for example a pinching sensation was described or pressure on the nose, and users posed no complains about the glasses interference with the traversing the obstacle course.

4.2.1 *Step Count*

During the tests the users were asked to walk the obstacle course show as show in Figure 19 with only the visual feedback, which is represented by the foot on the right side of the screen which will move up and down according to the users pace and in two other testing scenarios, one where only audio cues were enabled and a final one where both were enabled.

Here in the following Figure 20, we can see the results on all 3 testing scenarios in relation to steps taken through the course:

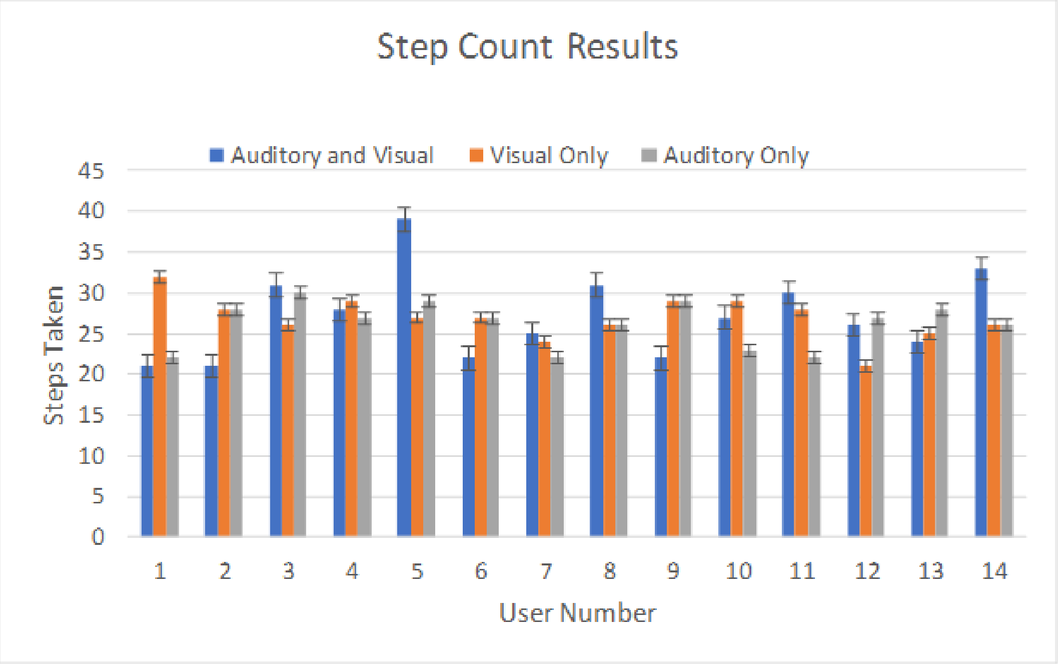

Figure 20.: Step Count Data from all testing scenarios

The average step taken to complete the 20 meter course in all 3 different testing scenarios were 25.32 steps with an standard deviation of 3.65 but as we can see in the graph above there are spikes of 39 steps and 20 steps which are related to first and foremost the users gait characteristics which cause the user to walk more slowly or faster depending on the

body type and general disposition, but it is also related to the effect of having the glasses on and having all feedback active, as since it is not an experience the users generally have dealt with some transition to more cautious step which in turn makes the user steps generally slower which is a trend we can will see in all the present graphs.
As we can see in the graph in general the use of the visual and auditory cues did not cause wild differences in the users steps since we can see a generally consistence step count rounding the 26-28 steps taken which is important to take notice there is a lot of importance in having the minimum level of discomfort in the use of the augmented reality glasses and the application. Since at this point these tests were only conducted with healthy people there is not much variance in the number of steps taken since the variances between healthy people gait are not as significant in difference between people affected with Parkinsons disease where we expect there would be a much bigger variance. With that point established there were differences in the step count average with the visual and audio and only visual coming around at an average of 26 steps and the only audio test at around 22 steps averaged. This difference is mostly due to distraction on the user during the tests where visual feedback was present because the user will pay attention to not only the path it is taking but also the foot on the left side of the screen, when visual feedback is off the user is basically going through the course with the glasses turned off as there are no interface elements on the screen at that time and so it is less likely that distraction occurs during testing.

4.2.2 *Step Lenght*

During the obstacle course the users had to perform tasks as described earlier in testing scenarios where they first walked in a straight line then turning to the side and moving in between a set of chair going through a carpet and coming around to the staring position. All this these actions affect the users step length so it was not constant during the test. With this aspect in mind here in this next Figure 21, we can see the results of Step Length in all 3 tests:

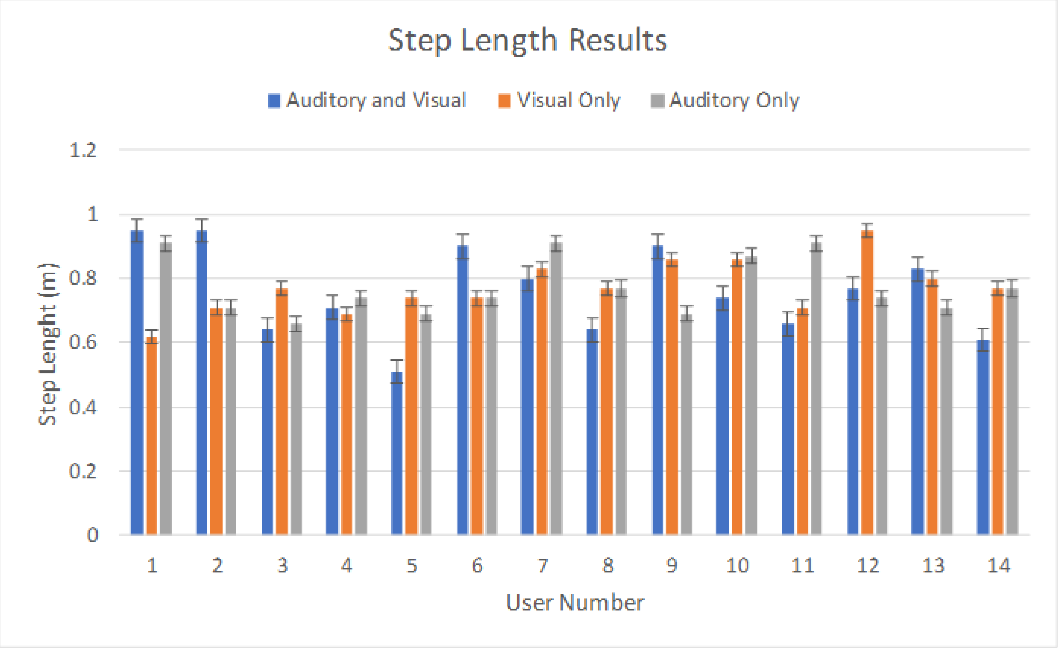

Figure 21.: Step Length Data from all testing scenarios

The average step length in all 3 tests was 70 cm with a standard deviation of 1 cm, which is a positive result since a typical male step length is around 78.74 cm and since a majority of the users were male we can conclude that application did not cause much variance in step length that might had been caused by discomfort of the glasses themselves or application. The same behaviour can be observed here once again, that is the average values have a small variance between the visual tests and the only audio one which had an average of 66 cm and 77 cm respective results. This is most likely again due to the fact that with absence of visual feedback the users are less prone to caution or distraction and feel more relaxed and confident which in turn results in bigger steps.

From the Figures above we can only conclude that the user gait was healthy and regular with only slight variances, although results from Parkinson patients are likely to produce bigger variances since their gait is not normal and will most likely be more affect by the use of the augmented reality glasses and the application than regular healthy user with an regular and healthy gait.

4.2.3 *Step Duration*

In relation to the users step duration, all the step times were taken, counting each step from the moment it is registered to the moment another step is registered making in the end the average step duration of the user. The following Figure 22, reflects the different user step duration's on all 3 tests.

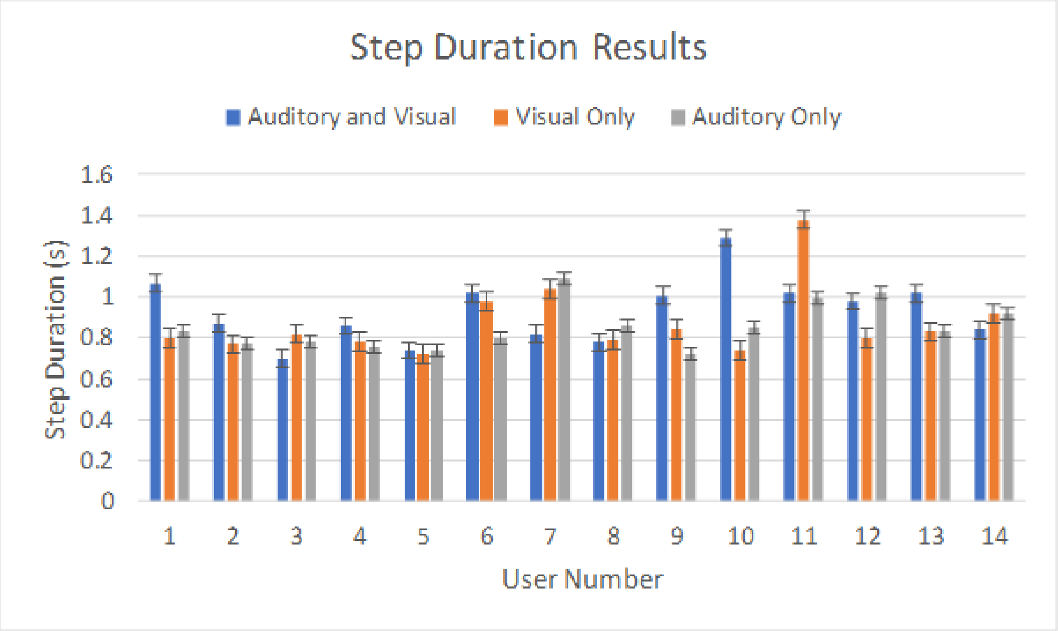

Figure 22.: Step Duration Data from all testing scenarios

Step duration is correlated to the user step length and step speed so users that have a bigger step length have a bigger step duration and inversely users with smaller step lengths will register smaller step duration's although in the case of a user with small step length and small step speed might register bigger step duration.
The average step duration during all 3 tests is 0.78 seconds with an standard deviation of 0.18 seconds that is normal by healthy user standards.
There were variances in the different test scenarios where the average step duration's in the visual and audio test fluctuated more which correlates to the same graph but for the step count in the same testing scenario where there was also more variance, and this time the visual only and audio only are very similar to each other which is a different result than the previous metrics. Step duration is a result of many different factors like step speed, step count and stride length which leads to variances in each users gait to be more pronounced

in the graphs particularly in the graph where there are more influence being held to the user in the form of the visual and audio cues.

4.2.4 *Step Speed*

User step speed is governed by the user step length and step duration, smaller average step duration's will result in smaller step speeds and bigger step length will result in bigger step speeds as the user is covering more ground with each step taking longer to do so than if he had smaller step length. The following Figure 23 represents the results of the 3 different scenarios for the users Step Speed.

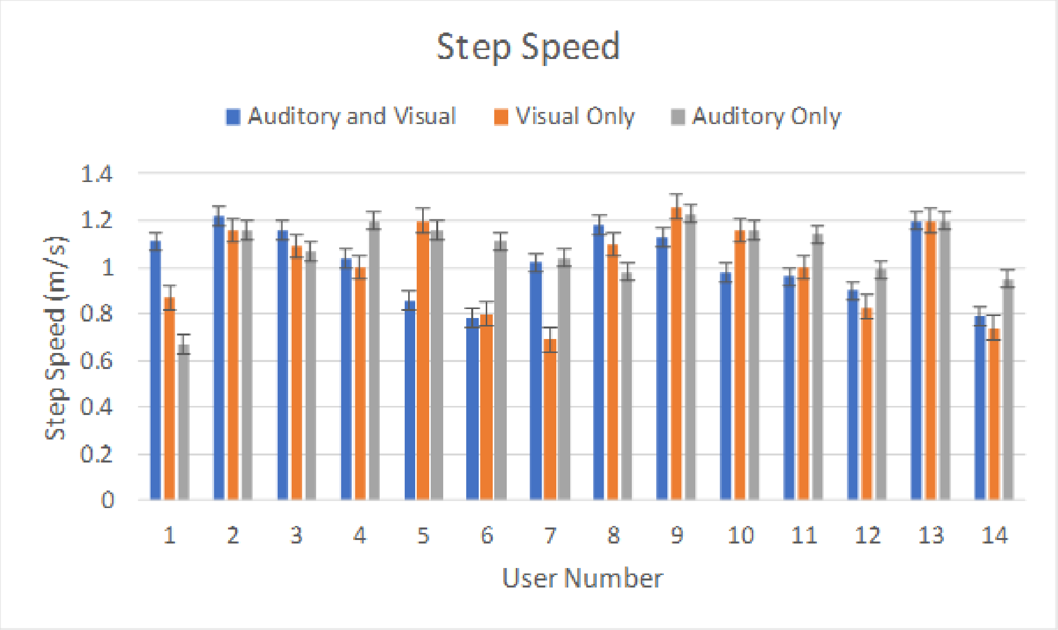

Figure 23.: Step Speed Data from all testing scenarios

The results for average step step speed from all 3 testing scenarios are 0.96 seconds per step taken with an standard deviation of 0.16 seconds. Here the results have little variance between all the tests but there is some variance to be seen in the users, where some user exhibit lower steps speeds than the others generally because of the same factors described before that resulted in low stride lengths or step duration's. This is another aspect that would have a much bigger variance from tests with Parkinson patients since the more advanced stages of gait deterioration will cause complications on their gait patterns that will have very different results in step speed.

4.2.5 *Test Duration*

Test Duration data was also retrieved with the purpose of analysing if the use of the augmented reality glasses and the application would cause discomfort or confusion on the user that would translate to increased test duration's. Here we see below in Figure 24, the results of the Test Duration on all 3 different testing scenarios.

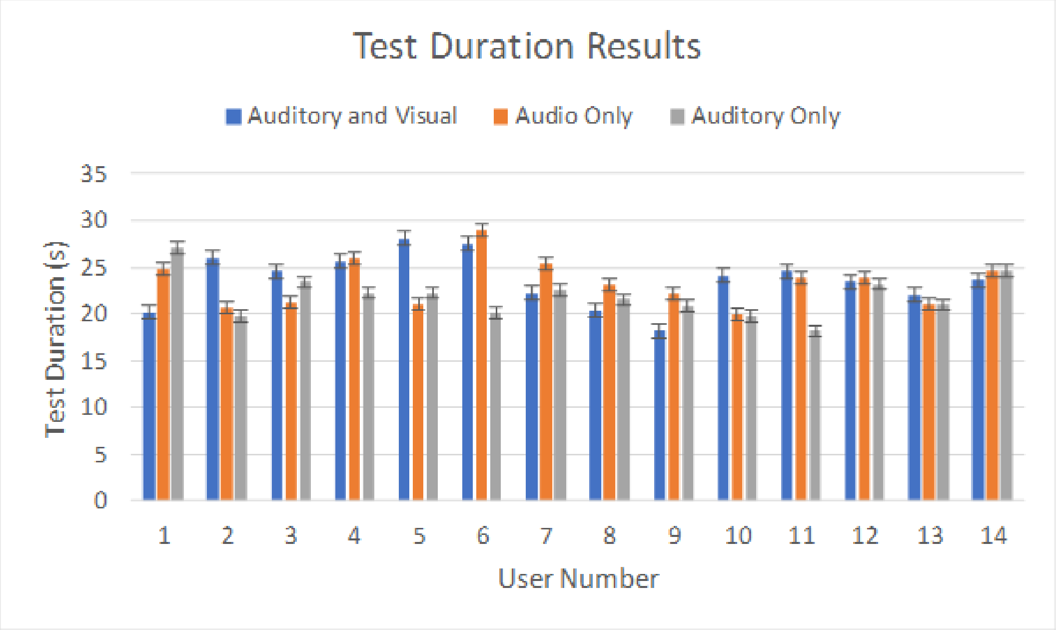

Figure 24.: Step Length Data from all testing scenarios

The average test duration was 21.99 seconds to complete the 20 meter obstacle course with an standard deviation of 2.56 seconds. Again following the patterns of the other tests large variance is not presence since all the subjects in the control group are generally healthy people, but we can see a small difference in larger average test duration of 23.36 seconds for the visual only testing, again expect to occur because of the presence of visual feedback distracting the user causing it to walk slower than usual.

Each user as seen in the Figure 24 has a faster test duration between all three tests although not one testing scenarios proved to have been completed faster by all the users since all we see the faster times distributed by the different tests.

5

RESULT DISCUSSION

In this section we will discuss the the augmented reality application developed with an open access software to successfully analyse the user gait characteristics and display audio and visual cues with the intention of helping user with abnormal gait characteristics like patients suffering from Parkinsons disease. Since at this point the only tests conducted were with a healthy control group we will discuss the performance in an attempt to better understand if and how augmented reality stimulation might alter of effect movement in control or PD groups since all that was used for the control group is aimed to be also use and adapted to user suffering from Parkinsons disease. The results will be discussed under three main sections: the augmented reality system, the Testing Environment, and questionnaire results.

5.1 IMPLEMENTATION OF THE AUGMENTED REALITY SYSTEM

One scene was successfully developed and implemented with the aim to gather data from the patients gait and using it in conjunction with visual and auditory cues to create a positive rehabilitative setting. Consistency and adaptability are key in this matter so that the application can be used by many different users and even on the same user in different scenarios and conditions. The type and quality of the augmented reality glasses take an important role in this aspect because with better performance comes a faster adaption from the application part.

Although this scene is simple and straight to the point, augmented reality is very customizable and highly flexible so it possible to adapt the form and aspect of the cues to better suit each user, but since we are talking about an augmented reality application and not an virtual reality application we must keep visual interference with the real world to a minimum so as not interfere much with the users perception of the real world. These cues must act as a extra to the real world and not be the total focus of the user to be considered safer than practising rehabilitative techniques in a hospital environment as they may also present real world dangers.

With the ability to simulate real world scenes with extra superimposed elements, movements strategies specific and functionally relevant to the user may be learned and practised. Rather than just helping the user in the background, the application could intervene in certain activities to help correct the user gait giving helpful tips.

5.2 TESTING ENVIRONMENT

The Testing Environment consisted of an gym room given by the university to conduct testing. The room provided ample space to build the simple obstacle course which consisted in the user walking a distance of 20 meters completing some simple tasks cause gait alteration with the aim to test performance of the application. The course was simple as to not pose danger to the users since the use of an augmented reality device may cause nausea or discomfort in some user which could lead to accidents like falls.
Since at this point in time only test with the control group were possible there is low variance in the results in all 3 testing conditions, but that being said the low variance is also a sign of the efficiency of the application, since the calibrations were made before each test with each user so that the application could have a better notion of what kind of gait it was dealing with. That being said the variance that existed in the control group is due to differences in the gait of healthy user duo to body structure and discomfort with the application. In general the more consistence results were achieved in the testing scenario where only audio cues were active since in that mode there are no augmented reality objects on the users field of view so they become less distracted and more likely to have a more normal gait as if they were not wearing the glasses in the first place.

5.3 QUESTIONNAIRE RESULTS

A questionnaire (appendix C) was administered to measure the subjective experience of the augmented reality environment with respect to the level of abstraction from the real world by the participants. These questionnaire were at this point only collected from healthy users where the questionnaire is more focused on the performance and comfort of the application and overall experience so it does not include questions that related to the Parkinsons disease. From these questionnaires we received valuable information, the main complaint of the application being that the visual cues were hard to see because of the low image quality, other than that all the users completed the obstacle course without difficulties as it was expected from user with normal gait. User also did not feel bothered by the audio or visual cues saying mostly that they were indifferent about them and that they did not bother them while they completed the course in general did not have trouble using the augmented reality application, both the user that already had prior experiences with augmented reality and user that had their first contact with this kind of technology.

From this point to improve the overall experience starting with healthy user experience is to use augmented reality glasses with an overall better image quality and customisation of the experience in the way of choosing different visual and audio cues both in type like so that the application can become more adaptive to the different kinds of users that will have different preferences. Another aspect to improve is the view angle and screen scale, the more area of view that can be worked in augmented reality the better the user experience will be since it will have more space to be better positioned in the user field of view and distinct enough that it is easy to identify which is the biggest complain from the testing. New augmented reality glasses being developed as it slowly becomes a more mainstream technology, because at this point it an expensive one, but the rate at which such new technology is becoming available is high, making it difficult to implement and then report the most recent technologies before a new advancement becomes available although all in all the rapid development is to our benefit because more competition will eventually bring prices down making it easier to obtain more capable technology. The overall average score in this questionnaires which ranges from 10-100 for each person resulted in an average of 82 points with a 6 point standard deviation which represents that all the users were able to complete the tasks asked of them in all tests with a small amount of complains, which are mostly related the low image quality of the glasses making it harder for some users to see the visual cues

5.4 CONCLUSIONS

Augmented reality technologies have to the potential to be adaptable to any individuals particular needs while minimising hazards typically present in daily environments. We saw in the thesis that augmented reality can be useful for the needs of physical rehabilitation, since it has major positive points like being flexible, customizable and safe.

A augmented reality application was designed and implemented in a sample of healthy people where simple tasks where completed while walking and metrics were collected as to access quantitative measures of performance were collected with the aim to test and adapt this application to be more specifically used for Parkinson disease users.

An augmented reality environment can be constructed with increasing levels of complexity and sensory inputs in order to restrain how the patients responds to various manipulations. When applied to an rehabilitation environment, this is an ideal tool since functional tasks in everyday environments can be developed with varying levels of difficulty. Augmented reality having the advantage that it can put the user in a scenario where he is safer but still in full contact with real world, so in the end it becomes easier to then translate the exercises the user does using the glasses and then out in the real world without the help of the same. Other advantages are that this kind of technology is evolving rapidly so an environment where it is possible to view what the user is viewing during testing and adapting the application in real time tailoring to different needs is very possible. This is particularly helpful when dealing with users with abnormal gait patterns since it enables a more immediate response in the case where something seems to be going wrong because it is hard to anticipate every possible dangerous scenario.

I believe that this pilot testing of the augmented reality application has confirmed the viability of this type of system for scientific investigation of clinical populations and demonstrated potential in the rehabilitation world. There are aspect that can be improved and a more complex version of occupational and physical therapy can be achieved where even the difficult task of detecting when exactly the "freezing of gait" happens in Parkinson patients which is a point that was not focused in this thesis.

5.5 LIMITATION

The results present in throughout this thesis reveal that augmented reality has a great potential for successful implementation in rehabilitation settings in different scenarios.

However there were some limitation in this study, number one being that augmented reality is, even though it is becoming more readily available technology, is a very expensive product which limited this study since more ambitious ideas where immediately blocked by hardware limitations. An example is the way the visual cues where first meant to be displayed where cues displayed directly onto the floor that reacted to the patients steps, but that idea was rejected because of the small field of view that was allowed by the glasses. This aspect was also present during testing where some users complained about the bad image quality and difficulty seeing the visual cues particularly when out in the sun where they seemed to disappear all together.

Future studies in this may not have to deal with this problem as time goes on and augmented reality becomes more cheap but as of now similar studies should know the limitations.

Other big limitation was that during the making of this study, access to testing with a large group with Parkinson disease patients was not possible making it hard to prove the application efficiency which was only able to be tested in a control group with healthy patients. Admittedly not all Parkinson patients have distorted gait characteristics but the idea is to help all but particularly those who are distorted gaits to try to improve so that they do not get worse the point of not being able to walk, although this might sound far-reaching it is the final aim of this study.

A final point is that the control group in this study was a small sample. Future studies should aim for a large and equal size of groups.

5.6 FUTURE DIRECTIONS

The purpose of this study was to test the tolerability and viability of augmented reality technology for rehabilitation purposes in a clinical population of users suffering from Parkinsons disease. At this point in time, since testing with a large number of Parkinson patients was not possible future studies should improve on the basis this thesis has created from testing on healthy patients and compare and apply to a Parkinson population which is ultimately the final aim of this study.

There is room for improvement on many aspects with respect to the programming as well as the technological aspects of the system. As new augmented reality technology is purchased more options become available such as more complex and robust visual cues, that interfere on the real world in a much larger scale and with advancements in technology maybe also find a way to resolve the most complicated issue that was not addressed in this thesis, that was the "freezing of gait" since it is so hard to identify and react to on the system side of things. Together, this aspects will substantially improve the effectiveness, applicability and viability of the augmented reality system as a rehabilitation tool and maybe in the future as so meting that the user can use to help its dally live continuously and not something they use for training.

BIBLIOGRAPHY

[1] Barros Gonçalves, G., Leite, M. A., Orsini, M.,& Santos Pereira, J. (2014). *Effects of using the Nintendo Wii Fit Plus Platform in the sensorimotor training of gait disorders in Parkinson's disease. Neurology International.*

[2] Georgy, E. (2010). *Freezing of gait in Parkinsons Disease: Impact on falls risk, walking aids utilisation, and assistance-seeking behaviour.* European Journal Of Adapted Physical Activity, 3(1), 49-59.

[3] Bell Boucher, Danielle M., *Investigating Immersive Augmented Reality as a Rehabilitation Tool for Parkinson disease" (2013). Electronic Thesis and Dissertation Repository.Paper 1588.*

[4] Espay, A. J., Baram, Y., Dwivedi, A. K., Shukla, R., Gartner, M., Gaines, L., & ... Revilla, F. J. (2010). *At-home training with closed-loop augmented-reality cueing device for improving gait in patients with Parkinson disease.* Journal Of Rehabilitation Research & Development, 47(6), 573-581.

[5] Georgiades, M. J., Gilat, M., Ehgoetz Martens, K. A., Walton, C. C., Bissett, P. G., Shine, J. M., & Lewis, S. J. (2016). *Investigating motor initiation and inhibition deficits in patients with Parkinson's disease and freezing of gait using a virtual reality paradigm.* Neuroscience, 337153-162.

[6] Maculewicz, J., Kofoed, L. B., & Serafin, S. (2016). *A Technological Review of the Instrumented Footwear for Rehabilitation with a Focus on Parkinson's Disease Patients.* Frontiers In Neurology.

[7] Nelson, A., Zwick, D., Brody, S., Doran, C., Pulver, L., Rooz, G., & ... Rothman, J. (2002). *The validity of the GaitRite and the Functional Ambulation Performance scoring system in the analysis of Parkinson gait. Neurorehabilitation*, 17(3), 255-262.

[8] Spaulding SJ, Barber B, Colby M, Cormack B, Mick T, Jenkins ME. *Cueing and gait improvement among people with Parkinson's disease: a meta-analysis.* Arch Phys Med Rehabil (2013) 94(3):562–70.

[9] Šumec, R., Filip, P., Sheardová, K., & Bareš, M. (2015). *Psychological Benefits of Nonpharmacological Methods Aimed for Improving Balance in Parkinson's Disease: A Systematic Review. Behavioural Neurology.*

[10] Palacios-Navarro, G., Albiol-Pérez, S., & García-Magariño García, I. (2016). *Methodological Review: Effects of sensory cueing in virtual motor rehabilitation. A review.* Journal Of Biomedical Informatics, 6049-57

[11] Uchitomi, H.)., Suzuki, K.)., Nishi, T.)., Miyake, Y.)., Hove, M.)., Wada, Y.)., & Orimo, S.). (2012). *Interpersonal synchrony-based dynamic stabilisation of the gait rhythm between human and virtual robot - Clinical application to festinating gait of Parkinson's disease patient. 2012 International Symposium On Micro-Nanomechatronics And Human Science, MHS 2012, (2012 International Symposium on Micro-NanoMechatronics and Human Science, MHS 2012), 460-465*

[12] Velik, R., Hoffmann, U., Zabaleta, H., Marti Masso, J., & Keller, T. (2012). *The effect of visual cues on the number and duration of freezing episodes in Parkinson's patients. Conference Proceedings : ... Annual International Conference Of The IEEE Engineering In Medicine And Biology Society. IEEE Engineering In Medicine And Biology Society.* Conference, 4656-4659.

[13] Young, W. R., Shreve, L., Quinn, E. J., Craig, C., & Bronte-Stewart, H. (2016). *Auditory cueing in Parkinson's patients with freezing of gait. What matters most: Action-relevance or cue-continuity?*. Neuropsychologia, 8754-62.

[14] Mark D. Latt, Hylton B. Menz, Victor S. Fung, Stephen R. Lord; *Acceleration Patterns of the Head and Pelvis During Gait in Older People With Parkinson's Disease: A Comparison of Fallers and Nonfallers* J Gerontol A Biol Sci Med Sci 2009; 64A (6): 700-706.

[15] Buckley, C., Galna, B., Rochester, L., Mazzà, C. (2017). Full length article: Quantification of upper body movements during gait in older adults and in those with Parkinson's disease: impact of acceleration realignment methodologies. Gait Posture, 52265-271.

A

UNIFIED PARKINSON DISEASE RATING SCALE ITEMS

The Unified Parkinson Disease Rating Scale is a commonly used tool to assess people living with Parkinson disease. It is divided into several different sections namely: I - Mentation, behaviour and mood, II. Activities of daily living, III. Motor examination, IV. Complicatons of therapy, V. Modified Hoenh and Yahr Staging, and VI. Schwab and England activities of daily living life scale. The third section used to commonly report an idea of the motor function status of people with PD.

The following items were reported as part of the participants ”motor profile”:

18. Speech

- 0 = Normal.
- 1 = Slight loss of expression, diction and/or volume.
- 2 = Monotone, slurred but understandable; moderately impaired.
- 3 = Marked impairment, difficult to understand.
- 4 = Unintelligible.

20. Tremor at rest (head, upper and lower extremities)

- 0 = Absent.
- 1 = Slight and infrequently present.
- 2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present.
- 3 = Moderate in amplitude and present most of the time.
- 4 = Marked in amplitude and present most of the time.

22 Rigidity (Judged on passive movement of major joints with patient relaxed in sitting position. Cog-wheeling to be ignored)

- 0 = Absent.
- 1 = Slight or detectable only when activated by mirror or other movements.
- 2 = Mild to moderate.
- 3 = Marked, but full range of motion easily achieved.
- 4 = Severe, range of motion achieved with difficulty.

23. Finger Taps (Patient Taps thumb with index finger in rapid secession.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definitive and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

24. Hand Movements (Patient opens and closes hands in rapid succession.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definitive and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

25. Rapid Alternating Movements of Hands (Pronation-supination movements of hands vertically and horizontally, with as large an amplitude as possible, both hands simultaneously.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definitive and early fatiguing. May have occasional arrests in movement.

- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

26- Leg Agility (Patient taps heel on the ground in rapid succession picking up entire leg Amplitude should be at least 3 inches.)

- 0 = Normal.
- 1 = Mild slowing and/or reduction in amplitude.
- 2 = Moderately impaired. Definitive and early fatiguing. May have occasional arrests in movement.
- 3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
- 4 = Can barely perform the task.

29. Gait

- 0 = Normal.
- 1 = Walks slowly, may shuffle with short steps, but no festination (hastening steps) or propulsion.
- 2 = Walks with difficulty, but requires little or no assistance, may have some festination, short steps, or propulsion.
- 3 = Severe disturbance of gait, requiring assistance.
- 4 = Cannot walk at all, even with assistance.

30. Postural Stability (Response to sudden, strong posterior displacement produced by pull on shoulders while patient erect with eyes open and feet slightly apart. Patient is prepared.)

- 0 = Normal.
- 1 = Retropulsion, but recovers unaided.
- 2 = Absence of postural response; would fall if not caught by examiner..
- 3 = Very unstable, tends to lose balance spontaneously.
- 4 = Unable to stand without assistance.

B

INCLUSION/EXCLUSION CRITERIA

Inclusion criteria where defined as: 1) diagnosis of idiopathic Parkinsons Hoehn & Yahr stage 2-3 limit disease severity thereby reducing confounding factors of dementia or motor involvement impacting testing; 2) stable Parkinsons management (has been a clinical patient for 12 months prior to enrolment) with n change in medication during the study; 3)minimum grade 10 education to reduce education variance as a factor on test performance; 4) between the ages of 40 and 80 years old to reduce any confounding ageing effects; 5) no significant wearing off or fluctuations between medication doses as cognitive fluctuations can be a component wearing off ; 6) no other neurological disease to prevent any confounding results as a result of a co-morbidity, specifically stroke, seizure disorder, brain tumour, head injury, spinal cord injury or severe peripheral neuropathy; 7) no other injuries or illness that may impair motor function such as recent fractures, dislocations, artificial limbs, recent surgical procedures or any injury or illness requiring a brace or walking aid; 8) no other psychiatric illness that may affect motor or cognitive performance.

Exclusion criteria were defined as follows: 1) freezing of gait or other gait symptoms as this could present an unnecessary risk in an unfamiliar environment; 2) on or off state dyskinesia because the current technology of the visor causes a timelage that is amplified with dyskinectic movements; 3) any neuro-opthamological condition or pathology that may effect performance, specifically convergent deficiencies and oculomotor abnormalities as determined by a neuro-opthamologist. 4) Vision not in good enough state to be able to observe the augmented reality cues;

C

PRESENCE QUESTIONNAIRE

C.1 QUESTIONNAIRE FOR PARKINSON PATIENTS

Nome: ——————————————————————-
Idade: ———-
Peso: ————
Altura: ———
Sexo:M( ) F ( )

1. Apos o uso dos Oculos ORA-2, indique o nivel de dificuldade que encontrou com o uso dos mesmo?

- Muito fácil
- Fácil.
- Aceitável
- Incómodos
- Muito Incómodos

2. Antes da realização deste teste, já tinha alguma experiência com o uso de óculos de realidade aumentada?

- Sim
- Não

3. Indique o nível de familiaridade com o uso de realidade aumentada?

- Não familiar
- Pouco familiar

- Bastante familiar

4. Indique o nível de qualidade de imagem da aplicação.

- Alta Qualidade
- Boa Qualidade
- Qualidade Aceitável
- Qualidade Baixa
- Impossível de ver

5. Qualifique a aplicação quanto á sua facilidade de uso.

- Sem Problemas
- Facil de Usar
- Aceitável
- Difícil
- Muito difícil

6. Indique o nível de desconforto com as pistas visuais/auditivas.

- Muito Incomodas
- Pouco Incomodas
- Indiferente
- Não Incomodas

7. No uso da mesma, indique a facilidade da visão das pistas visuais/auditivas.

- Sem problemas
- Fáceis de entender
- Aceitáveis
- Difíceis de entender
- Impossíveis de entender

8. Durante o uso da aplicação, qual foi o grau de ocorrência de episódios de FOG(Freezing of Gait)?

- Nenhuma Ocorrência
- Pouca Ocorrência
- Muita Ocorrência

9. Durante o seu uso com a aplicação, indique o nível de dificuldade em percorrer o percurso de obstáculos.

- Muito fácil
- Fácil
- Nem Fácil nem Difícil
- Difícil
- Muito Difícil

10. Indique o grau de influencia que a aplicação induziu sobre o sua marcha durante o percurso.

- Facilitou o percorrer do percurso
- Indiferente
- Complicou o percorrer do percurso

11. Qual o seu grau de facilidade em adaptar-se á visão de elementos de realidade aumentada?

- Fácil
- Indiferente
- Difícil

12. Durante a experiência indique o nível de sintonia das as pistas visuais e auditivas em relação a sua marcha?.

- Pouca sintonia
- Alguma sintonia
- Muita sintonia

13. Indique o nível de distração que as pistas visuais/auditivas tiveram no percorrer do percurso.

- Não distraem
- Distraem pouco
- Distraem muito

14. Quão natural foi a sua interação com o mundo real visto através de óculos de realidade aumentada?.

- Não natural
- Moderadamente natural
- Bastante natural.

15. Indique se sentiu alguma diferença na sua marcha imediatamente após o uso da aplicação.

- Senti um melhoramento
- Moderadamente natural
- Bastante natural.

16. Indique o nível de satisfação com o uso da aplicação.

- Gostei bastante
- Gostei
- Não Gostei

C.2 QUESTIONNAIRE FOR HEALTHY PATIENTS

Nome: ————————————————————————-
Idade: ———-
Peso: ————
Altura: ———
Sexo:M( ) F ( )

1. Apos o uso dos Oculos ORA-2, indique o nivel de dificuldade que encontrou com o uso dos mesmo?

- Muito fácil
- Fácil.
- Aceitável
- Incómodos
- Muito Incómodos

2. Antes da realização deste teste, já tinha alguma experiência com o uso de óculos de realidade aumentada?

- Sim
- Não

3. Indique o nível de familiaridade com o uso de realidade aumentada?

- Não familiar
- Pouco familiar
- Bastante familiar

4. Indique o nível de qualidade de imagem da aplicação.

- Alta Qualidade
- Boa Qualidade
- Qualidade Aceitável
- Qualidade Baixa

- Impossível de ver

5. Qualifique a aplicação quanto á sua facilidade de uso.

  - Sem Problemas
  - Facil de Usar
  - Aceitável
  - Difícil
  - Muito difícil

6. Indique o nível de desconforto com as pistas visuais/auditivas.

  - Muito Incomodas
  - Pouco Incomodas
  - Indiferente
  - Não Incomodas

7. No uso da mesma, indique a facilidade da visão das pistas visuais/auditivas.

  - Sem problemas
  - Fáceis de entender
  - Aceitáveis
  - Difíceis de entender
  - Impossíveis de entender

8. Durante o seu uso com a aplicação, indique o nível de dificuldade em percorrer o percurso de obstáculos.

  - Muito fácil
  - Fácil
  - Nem Fácil nem Difícil
  - Difícil
  - Muito Difícil

9. Indique o grau de influencia que a aplicação induziu sobre o sua marcha durante o percurso.

- Facilitou o percorrer do percurso
- Indiferente
- Complicou o percorrer do percurso

10. Qual o seu grau de facilidade em adaptar-se á visão de elementos de realidade aumentada?

- Fácil
- Indiferente
- Difícil

11. Durante a experiência indique o nível de sintonia das as pistas visuais e auditivas em relação a sua marcha?.

- Pouca sintonia
- Alguma sintonia
- Muita sintonia

12. Indique o nível de distração que as pistas visuais/auditivas tiveram no percorrer do percurso.

- Não distraem
- Distraem pouco
- Distraem muito

13. Quão natural foi a sua interação com o mundo real visto através de óculos de realidade aumentada?.

- Não natural
- Moderadamente natural
- Bastante natural.

14. Indique o nível de satisfação com o uso da aplicação.

- Gostei bastante
- Gostei
- Não Gostei

D

WRITTEN CONSENT

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO PARA PARTICIPAÇÃO EM INVESTIGAÇÃO

de acordo com a Declaração de Helsínquia e Convenção de Oviedo

Por favor, leia com atenção a seguinte informação. Se achar que algo está incorreto ou que não está claro, não hesite em solicitar mais informações. Se concorda com a proposta que lhe foi feita, queira assinar este documento.

Titulo do estudo: Dispositivo de realidade virtual para a melhoria da marcha em pacientes com a doença de Parkinson (Development of a augmented reality app for gait improvement in pacients suffering from Parkinsons disease).

Enquadramento: Serviço de Neurologia do Hospital de Braga/Escola de Medicina da Universidade do Minho/ Departamento de Eletrónica Industrial da Universidade do Minho.

Explicação do estudo A população alvo deste estudo será constituída por doentes com Doença de Parkinson, seguidos em consultas externas de Neurologia do Hospital de Braga. Os participantes neste estudo serão abordados na consulta de Neurologia Hospital de Braga pela Dra. Ana Margarida Rodrigues - Médica Neurologista e recrutados se preencherem os critérios de seleção necessários.
Serão realizados uma serie de testes que envolvem o uso de um dispositivo vestível de realidade aumentada, sendo que esta será o suporte das experiencias a realizar. O objetivo sendo observar se o uso desta aplicação desenvolvida num ambiente de realidade aumentada contribui para um melhoramento na marcha dos pacientes e se contribui de alguma forma para um menor número de episódios de "congelamento da marcha" também conhecidos por freezing. Este testes envolvem 5 etapas: 1) Sem o Uso do Equipamento; 2) Uso

do Equipamento num estado Offline; 3) Uso da aplicação só com estímulos visuais ativos; 3) Uso da aplicação só com o estímulos auditórios ativos; 4) Uso da aplicação com ambos os estímulos visuais e auditórios ativos; 5) Repetir passo 1). Isto num percurso predefinido com obstáculos que irá favorecer a ocorrência de eventos de freezing tais como: passagem por portas, inversão da marcha, contorno de objetos, dobrar esquinas e alteração do piso (utilização de um tapete).

Os estímulos visuais irão tomar a forma de ícones que o paciente poderá ver sobrepostos ao mundo real, neste caso pegadas, que irão servir de guia para uma marcha estável sendo que o aparecimento das pegadas está relacionado com a marcha do paciente, significando que a velocidade das mesmas depende da velocidade da marcha do paciente. O mesmo se irá verificar com os estímulos auditórios que serão pequenos sons que estarão associados a cada passada do paciente com o objetivo de ajudar a criar um ritmo da marcha tentando obter um efeito de relaxamento no paciente.

Destes testes irão ser recolhidos dados sobre a marcha como o numero de passos e a velocidade para efeitos estatísticos e para observar se houve efetivamente um melhoramento na marcha do paciente apos o uso e analisar também se ocorreram episódios de freezing durante o seu uso e se sim quantos e qual a sua intensidade.

Estes testes serão realizados em 15 indivíduos saudáveis e em 15 pacientes com Parkinson, numa fase ON (fase para a qual a medicação surte efeito) e sempre à mesma hora, após administração da medicação, de modo a garantir que os pacientes responderão sempre de igual modo e para que possa ser ignorado este parâmetro farmacológico nesta primeira fase. Também se acrescenta que estes pacientes deverão apresentar uma marcha autónoma e não devem se encontrar numa fase de demência. Acrescenta-se que todos os participantes deverão estar dentro da mesma faixa etária, visando uma melhor avaliação. No final de cada teste, os participantes deverão responder a um breve questionário. Deverá ser salientada que cada sessão experimental poderá ser filmada, sendo que as filmagens serão apenas divulgadas para fins académicos e científicos. Para obter esse resultado, o rosto não será visível para garantir o sigilo. Os resultados obtidos durante a pesquisa serão colocados em forma de gráficos e imagens.

Resumindo, um conjunto de pacientes de Parkinson recrutados nas consultas de Neurologia e cumprindo os devidos critério de inclusão do estudo, realizarão testes experimentais visando validar uma aplicação de realidade aumentada

Condições e financiamento: Este é um estudo de carácter voluntário e não existem quaisquer prejuízos, caso não queira participar. A sua aceitação ou a sua recusa em participar, ou posterior abandono não prejudicarão a sua relação terapêutica com a equipa de clínicos ou investigadores. Este estudo mereceu um Parecer favorável da Comissão de Ética do Hospital de Braga e será realizado nas instalações do Centro Clínico Académico e Serviço de Consulta externa, no Hospital de Braga. O protocolo experimental não implica a existência de efeitos secundários.

Confidencialidade e anonimato: As informações obtidas serão mantidas em sigilo e não poderão ser consultadas por pessoas leigas sem a prévia autorização por escrito do participante. As informações assim obtidas poderão ser usadas somente para fins estatísticos ou científicos, sempre resguardando a privacidade do participante.

Desde já a Dra Ana Margarida Rodrigues agradece a sua colaboração.

Assinatura: ——————————————————————————

Declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas pela pessoa que acima assina. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências. Desta forma, aceito participar neste estudo e permito a utilização dos dados que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação e nas garantias de confidencialidade e anonimato que me são dadas pela investigadora.

-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-

Nome: ——————————————————-
Assinatura: —————————————————-
Data: ——/——/———

ESTE DOCUMENTO È COMPOSTO POR 2 PÁGINAS E FEITO EM DUPLICADO: UMA VIA PARA O/A INVESTIGADOR/A, OUTRA PARA A PESSOA QUE CONSENTE

E

TESTING PROTOCOL

E.1 INTRODUÇÃO

No decorrer destes testes experimentais serão realizados uma series de testes que envolvem o uso de um dispositivo de realidade aumentada neste caso os óculos ORA-2, sendo que este será o suporte das experiências a realizar.
O objetivo destes testes ira ser observar o uso da aplicação desenvolvida num ambiente de realidade aumentada analisando se esta contribui de alguma forma para um menor numero de episódios de "congelamento da marcha" ou o melhoramento do ritmo da marcha no geral. Os testes a realizar serão os seguintes:

1. (1) Uso de equipamento offline
2. (2) Uso do equipamento apenas com estímulos visuais
3. (3) Uso do equipamento apenas com estímulos auditivos
4. (4) Uso do equipamento com ambos estímulos visuais e auditivos
5. (5) Repetir (1)

Estes testes irão ser realizados em dois percursos predefinidos, um simples e outro composto por vários obstáculos que irão compor as seguintes ações: inversão da marcha, contorno de objetos, dobrar esquinas e alteração do piso (utilizando um tapete). As métricas que se irão usar no decorrer destes teste contem: Step Counter (Numero de passos realizados), Duration (Duração do teste), Step Speed (Velocidade da passada) em m/s, Step Lenght (Comprimento dos passos), e Duration(Duração do percurso em min).

E.2 METODOLOGIA

Aqui se encontram os vários passos a realizar para uma melhor eficácia no decorrer da experiência.

1. 1 - Explicar a experiência e demonstrar como será realizada a mesma.
2. 2 - Preenchimento dos dados referentes a cada participante.
3. 3 - Explicação do funcionamento dos óculos de realidade aumentada.
4. 4 - Período de familiarização com os mesmos por parte do paciente e calibração do mesmo.
5. 5 - Selecionar o tipo de teste.
6. 6 - Recolha de maior parte dos dados será realizada pela aplicação que poderá ser consultada no final de cada teste para preenchimento de uma tabela.
7. 7 - Para cada teste, recolher dados sobre o bem-estar e confortabilidade do paciente e sobre o numero e intensidade de episódios de "congelamento da marcha" que podem ou não ter decorrido durante os testes.
8. 8 - Repetir o processo para os restantes testes.
9. 9 - Desligar os óculos de realidade aumentada.
10. 10 - Responder a um questionário sobre os testes realizados e sobre a aplicação.
11. 11 - Repetir até completar cada teste.

E.3 AMBIENTE DE TESTE

Estes testes irão ser realizados num percurso com alguns obstáculos que o utilizar ir precisar de contornar para chegar á reta final sendo estes acções: contornar objetos, contornar esquinas, inversão da marcha, passagem por um tapete. O objetivo deste percurso é alem de recolher as métricas descritas testar a fiabilidade da aplicação em relação á consistência dos dados recolhidos e em relação á sua facilidade de uso para o utilizador. Na Figura 25 temos um representação do que constitui o percurso cuja distancia total são 20 metros. O percurso demonstrado na Figura 2 tem como objetivo criar mudanças na marcha que irão servir para comprovar a eficácia da aplicação sendo os parâmetros descritos avaliados em todas as passagens pelo percurso descrito usadas criação de comprovações estatísticas.

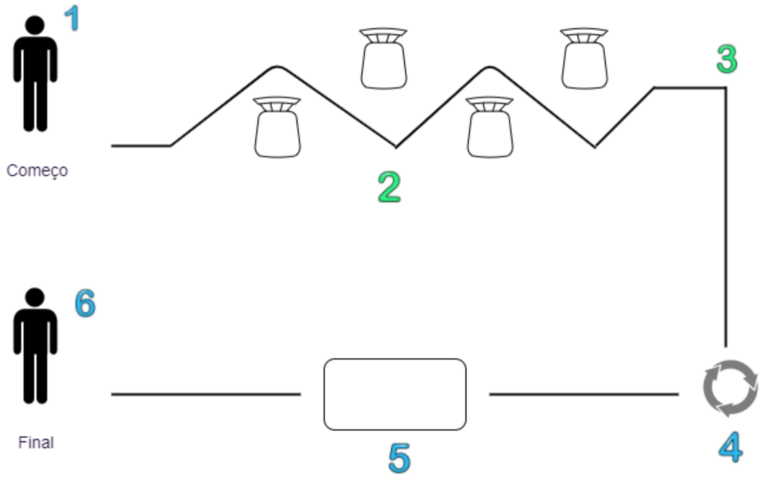

Figure 25.: Representação das varias etapas do percurso de teste com obstáculos (10 metros): 1 – Inicio da marcha, 2 – contorno de cadeiras, 3 – dobrar de esquina, 4 – inversão de marcha, 5 – passagem por tapete; 6 -Final da marcha.

DURAÇÃO ESTIMADA DO TESTE: 15 - 20 MINUTOS

Table 3.: Results table

	Step Count	**Step Lenght**	**Step Speed**	**Step Duration**	**Test Duration**
Visual Only					
Results					
Audio Only					
Results					
Audio/Visual					
Results					
Total Average					

E.4 TABELA DE RESULTADOS

F

TESTING ENVIRONMENT

Figure 26.: Testing Environment

Figure 27.: Testing Environment 2

Figure 28.: Testing Environment 3

Figure 29.: Testing Environment 4