Universidade de Aveiro
Ano 2018

Departamento de Electrónica, Telecomunicações e Informática

Anna-Khrystyna Andreikanich

Human body tracking and interactive applications for balance rehabilitation

Rastreamento do corpo humano e aplicações interactivas para reabilitação de equilíbrio

To Dubravko, for being an inspiring role model and a great leader.

2018

Universidade de Aveiro
Ano 2018

Departamento de Electrónica,
Telecomunicações e Informática

Anna-Khrystyna Andreikanich

Human body motion tracking and interactive application for balance rehabilitation

Rastreamento do corpo humano e aplicações interactivas para reabilitação de equilíbrio

Dissertação apresentada à Universidade de Aveiro no âmbito da Unidade Curricular de Dissertação realizada sob a orientação científica da Doutora Maria Beatriz Alves de Sousa Santos, Professora Associada com Agregação e do Doutor Paulo Miguel de Jesus Dias, Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro.

o júri

presidente	Prof. Doutor Joaquim João Estrela Ribeiro Silvestre Madeira professor auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro
arguente principal	Prof. Doutora Ana Isabel Barreto Furtado de Albuquerque Veloso professora auxiliar do Departamento de Comunicação e Arte da Universidade de Aveiro
orientador	Prof. Doutora Maria Beatriz Alves de Sousa Santos professora associada do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro

Agradecimentos/ Acknowledgments

First of all, a big thanks to my family; for the moral and financial support.
Second of all, I would like to acknowledge to the Doctors and therapists of Centro Rovisco Pais: Paula Amorim, Paulo Margalho, Jorge Lains, Fátima Faim, Margarida Coelho and Teresa Cardoso for their help and support along the development and test of the applications.
And to Mariana Barbosa, the coordinator of the University Gym for giving access to the equipment
To Paulo Dias for co-supervising and providing the necessary equipment.
Finally, I am extremely grateful to my mentor Beatriz Sousa Santos. For the understanding, patience, great advice and support in overcoming numeral obstacles throughout this work. Thank you!

palavras-chave Realidade Virtual, Reabilitação, Sensor de Rastreamento de Movimento, Treino de Equilíbrio Corporal Superior;

resumo

Nos últimos anos tem surgido no mercado um grande número de dispositivos de interacção, *display* e *tracking* adequados a aplicações de Realidade Virtual, a preços bastante acessíveis, que têm sido usados pela Indústria de Jogos; no entanto, a Realidade Virtual tem também grande potencial na área da Medicina de Reabilitação, podendo oferecer abordagens inovadoras no tratamento de pacientes que recuperam Acidentes Vasculares Cerebrais (AVCs) ou de lesões medulares. O principal objectivo deste trabalho consistiu no estudo da possibilidade de usar aplicações de Realidade Virtual para aumentar a motivação daqueles pacientes na realização continuada de exercícios necessários para a sua recuperação.

Este trabalho foi realizado em colaboração com o Centro de Medicina de Reabilitação da Região Centro – Rovisco Pais. Estudaram-se os desafios que os seus médicos, terapeutas e pacientes enfrentam e desenvolveu-se um mini-jogo e adaptou-se um outro para ajudar na recuperação do equilíbrio daqueles pacientes que foi testado primeiro com participantes saudáveis e depois com pacientes. Foi ainda estudada a possibilidade de utilização do sensor Kinect v2 para análise de marcha.

keywords Virtual Reality, Rehabilitation, Motion Tracking Sensor, Equilibrium Training;

abstract In recent years with the development of Virtual Reality and gaming industry, a number of Virtual Reality and Motion tracking devices have been offered on the market for an affordable price. Besides the applications in gaming, Virtual Reality potential in the medical rehabilitation was recognized as well. It offers a new approach to treatment in Stroke and Spinal Cord (SCI) Injury rehabilitation. The aim of this work is a research of the application of VR games in the rehabilitation; Identification of how they can increase the motivation of Spinal Cord Injury and Stroke patients for performing exercises relevant for their recovery.

This work was performed in collaboration with the Rovisco Pais Rehabilitation Center. Based on the case study of the rehabilitation center and consultancies with the therapists, a set of mini-games was produced. In the first produced mini-game, the aim was training of the upper limb movements for Stroke patients. The developed game yet, hasn’t been tested because of the lack of the occupational therapists. Therefore, the work continued in the direction of producing the mini-game for gait restoring. However, since the evaluation of the Kinect v2 sensor for motion tracking proved that it doesn’t have enough precision the next game developed was a trunk balance training game. The target audience of the game was SCI patients. The produced game was tested with 9 students and based on the results it was further improved and tested with 6 SCI patients. The testing’s results suggested that these types of games can be helpful in the recovery process of SCI patients and can be motivate the patients for the recovery.

Table of Contents

List of figures

List of tables

I: Introduction

Virtual Reality is a computer-generated simulation of a three-dimensional environment that can be interacted with using specific electronic equipment. Virtual Reality is primarily experienced through sight and sound, but stimuli for other human senses are becoming more often used [1].

The global Virtual Reality (VR) market was valued at approximately USD 2.02 billion in 2016 and is expected to reach approximately USD 26.89 billion by 2022[1]. Such high growth of VR industry can be explained by a growing demand for latest technologies in video games especially among the young population. Due to an increasing number of startups in the field of VR, a number of innovative software added up to the growth of the electronic games industry. The forecast for the following years of Virtual Reality market size is promising (Figure 1)

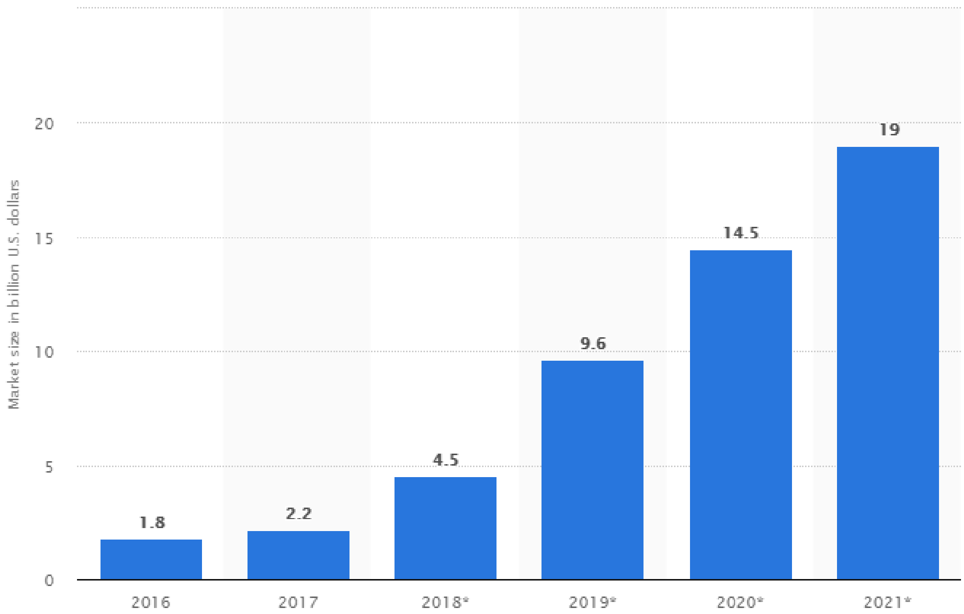


Figure 1: Worldwide Virtual Reality market size from 2016 to 2020 forecast (source: https://www.statista.com/statistics/528779/virtual-reality-market-size-worldwide/, accessed May, 2018)

Besides the gaming industry, VR applications can be found in the military, education, healthcare, entertainment, product design, scientific visualization, telecommunications, construction and multimedia industry [1]. In order to provide better and more immersive gaming experience, VR headsets and various VR motion tracking systems have been offered on the market for an affordable price. There are several types of VR tracking

[1] https://www.zionmarketresearch.com/news/virtual-reality-market (accessed May 31, 2018)

systems such as electromagnetic, ultrasonic, mechanical and optical tracking systems [1]. A popular motion tracking device currently is Kinect v2 from Microsoft. Kinect v2, which is an optical tracking device and so far, it, was the most used sensor for neurological rehabilitation [2].

1.1 Physical therapy and Virtual Reality

In physical therapy, the determinants of motor recovery are early intervention, task-oriented training and repetition intensity [3]. However, the repetition of certain actions can be daunting and boring, which results in demotivated patients. The amount of movements required to induce a significant change is measured in thousands of repetitions, but on average only 30 movements are practiced for a given movement in a traditional daily rehabilitation session [4]. The benefit of combining a rehabilitation treatment with Virtual Reality games is that it provides an immersive gaming experience and entertainment while doing motor recovery exercises [5]. Additionally, exercises that implement VR can be done both at the rehabilitation center and at home. Viau et al. [6] showed that the movements performed in a virtual environment are similar enough to the ones performed in the real world [6]. Hence, the virtual environment can provide an effective training environment for rehabilitation.
An advantage of using VR was that patient’s performance was better when immersed in a virtual environment because of a more intense focus on the task [7]. Another advantage of a virtual environment is that the games can be personalized for each patient, taking into account patients desires and giving them the ability to evaluate themselves [7]. This increases patient’s motivation to practice. The tasks can be performed at home without the supervision of a physical therapist. Patient performance data can be sent to the hospital for the medical review and tracked over time in order to observe the overall recovery. The patient's experience of the rehabilitation game can be further intensified using haptic devices and other forms of feedback. Companies like VAST Rehab[2] and VR Health[3] already offer its services and apps for rehabilitation in Virtual Reality.

1.2 Objectives

Due to the rapid growth of VR technology and new possibilities it offers in the rehabilitation settings and because of the significant number of people being affected by Stroke or Spinal Cord Injury (SCI), the goal of this work was to answer the following questions based on the literature research:

[2] http://vast.rehab/ (accessed May 27,2018)
[3] https://www.vrhealthgroup.com/ (accessed May 27,2018)

- What are the motivational concepts behind a successful game execution and how the can be implemented in the rehabilitation?
- What are the challenges in the rehabilitation that patients and therapists are facing today and how VR can solve them?

Based on the questions mentioned above the work presented in this thesis includes:

- Development of VR mini-games for SCI and Stroke patients.
- Testing's of the developed mini-games with healthy people.
- Testing of the improved mini-game with SCI patients under therapist supervision.
- Comparing obtained results with the results of the previous research in the field.
- Evaluation of further possible applications of VR in rehabilitation settings.

1.3 Dissertation outline

This dissertation is organized in six chapters:

Chapter II – Background and related work: introduces the relevant issues in the recovery of SCI and Stroke patients, as well as, the effects of the applications of Virtual Reality in the rehabilitation.

Chapter III – Technology used: presents the technology used for the creation of mini-game for SCI patients and describes the features of Unity Game Engine and Microsoft Kinect v2 sensor.

Chapter IV – Methods and work: shows a case study of the Rovisco Pais rehabilitation center and the proof of concept of the Kinect v2. In this chapter the difficulties in the game development and obstacles that lead to the development of the mini-games for trunk equilibrium training for SCI patients are elaborated. Furthermore, the designed and adapted games for trunk balance have implemented motivational concepts, such us reward and socialization.

Chapter V – Results and discussion: presents the results of the preliminary test of designed mini-game for equilibrium training, with students. Based on the test results of the created mini-game, the course of the work focused on the adaptation of the existing open source games is justified and test results of the adapted open source Unity game with SCI patients is presented.

Chapter VI –.Conclusion and future work: final remarks and contextualization on the current state of the Virtual Reality in the rehabilitation and the suggestions for possible further developments of the work.

The described work is visually presented on the diagram below (Figure 2).

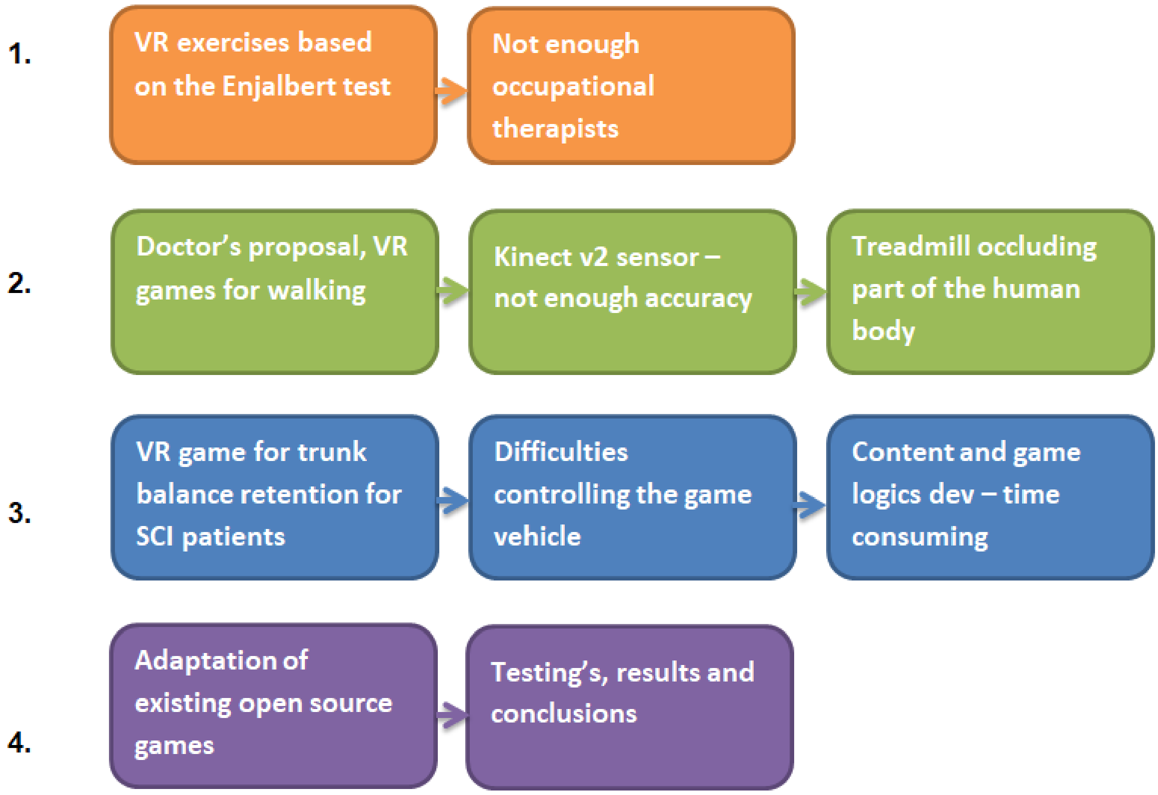


Figure 2: Thesis workflow

II: Background and related work

This chapter addresses the issues relevant for the recovery of SCI and Stroke patients. Further, the effects of the applications of Virtual Reality in the recovery process are studied as well.

Investigated topics include: the impact of physical therapy on functional outcomes after the stroke; Spinal Cord Injury and the possible applications of VR in the SCI treatments; The gait cycle parameters relevant for gait analysis; The metrics used for balance evaluation; The psychological effects produced after experiencing a stroke attack; The principals of motivation in gaming and the main concepts of game design. The review of existing games specifically designed for Rehabilitation purposes after a stroke and finally, the effectiveness of commercial games usage for Balance disorders rehabilitation.

2.1 The impact of physical therapy on functional outcomes after stroke

In a survey performed in 2013, it was estimated that around 795,000 people only in the United States have a stroke each year [8]. A stroke occurs when the flow of blood in the brain is interrupted causing neurons to die. Stroke victims suffer from disability to perform basic daily tasks. They tend to have slower reflexes, balance problems, disorganized thinking, difficulty to read and write and sometimes can be paralyzed on one side of their body. However, the human brain is neuroplastic meaning that it changes all the time and can form new neuron connections [9]. Due to that, after the stroke, the brain does not have to be permanently locked in the damaged state. In fact, by performing aerobic exercises and motor recovery exercises it is possible to enhance movement and ability to balance and improve overall motor functions [5]. Some of the common methods nowadays used in the post-stroke rehabilitation include Constraint-Induced Movement Therapy (CIMT), Body-Weight-Supported Gait Training, Functional Electrical Stimulation and Robotic-assisted therapies. Nevertheless, the methods mentioned above require patient's presence at the hospital and therapist supervision. Furthermore, the exercises must be done regularly and tracked in order to progress and heal [10]. This is often not possible because of the lack of medical staff. In order to overcome limitations and due to innovations in technology new rehabilitation methods have been invented, such as Virtual and Augmented Reality games.

It was proven that organized multidisciplinary care and rehabilitation after a stroke enhance patient survival and independence [11]. Furthermore, a number of studies showed that rehabilitation reduces the length of inpatient stay [12]. These findings support the use of physical therapy to improve the performance of daily activities after stroke, in particular when started early after the incident [13].

Programs that include muscle strengthening or muscular re-education with the support of biofeedback showed significant improvement in range of motion, muscle power and reduction in muscle tone. However, if too impairment focused, they fail to achieve greater functional improvements [14, 15].

The main goals of physical therapy for stroke patients are restoring motor control in gait, improving upper limb functions and relearning to cope with daily life activities like eating, brushing teeth, combing the hair etc.. Since walking and using hands are actions that are extremely important in daily life, it is crucial to work on them so the patients can be independent and socialize. Besides the regular physical exercises, assistive devices are used to support the treatments. For gait training, treadmills are used regularly. Furthermore, for better recovery, it is important to provide advice and instructions to the patient and his/her family. Nowadays, optimized decision-making by emphasized use of evidence from well-designed and well-conducted research is being recognized by physical therapists as a very important parameter in physical therapy rehabilitation [16].

Regarding the knowledge that rehabilitation is crucial for the recovery after the injury, there are still no standardized guidelines on how to choose an appropriate treatment. Therapists still need a better understanding of the coordination deficits nature in functional tasks after the incident. However, Virtual Reality has a potential to induce new insights in the rehabilitation settings and enrich current recovery programs.

2.2 Spinal cord injury and balance dysfunction rehabilitation in virtual environments

Spinal Cord Injury (SCI) causes serious changes in entire physical systems and functional abilities and it can result both in loss of voluntary movement (paralysis) and loss of sensation. SCI affects a relatively small number of people: each year about 11,000 people are added to the current United States´ total of approximately 230,000 people with this condition. However, it remains a prominent medical problem among rehabilitation counselors because there is currently no solution to repair the central nervous system and restore its function [17].

When the spinal cord is damaged the communication between the brain and parts of the body below the lesion is cut. The lesion may be complete meaning that no nerve fibers are functioning below the level of injury or incomplete meaning that some nervous signals are able to travel to the injured area of the cord. However, the cord does not need to be completely severed to result in a complete injury; the nerve cells may as well be destroyed as a result of pressure, bruising, or loss of blood supply. When the nerve cells die they do not have the ability to regenerate.

The amount of functional loss depends upon the level of injury. The higher the damage occurs, the more of the body is affected (for more details see Appendix IX International standards for neurological classification of Spinal Cord Injury) [18]. The majority of new SCI victims are young man. Over half of the SCI patients are in the 16-30 year age group and the average age at injury was 33 years. [44]. Most common causes of SCI are falls, road traffic accidents and sports injuries (Figure 3).

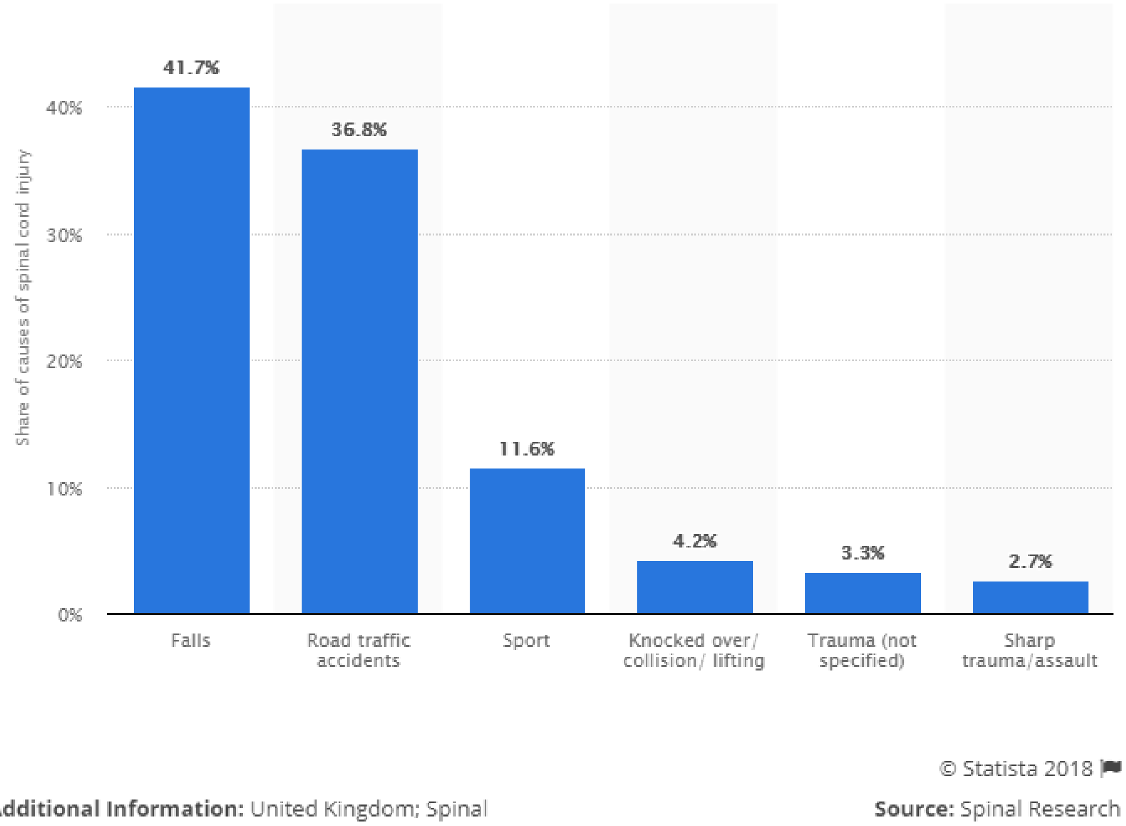


Figure 3: SCI causes (source: https://www.statista.com/statistics/448888/spinal-cord-injury-common-causes-united-kingdom-uk/, accessed May 28, 2018)

Another condition characteristic for the SCI survivors is the neuropathic pain caused by tissue injury [19]. When immersed in the Virtual Reality therapy, SCI survivors reported reduced pain and increased the duration of pain relief [20]. Huang et al reported that balance dysfunction treatments in a virtual environment of patients with spinal cord injury, cerebral palsy and other neurological impairments produced positive results and improved patients' balance control [21].

When patients exercise in Virtual Reality, the prefrontal, parietal cortical areas and other motor cortical networks are activated. This activation helps in the reconstruction of neurons in the cerebral cortex and helps in retention of motor skills, as the prefrontal cortex is one of the important brain areas in controlling human balance [22]. Stepniewska et al. suggested that visual information can provide a potent signal for the reorganization of sensorimotor circuits [23]. The observed actions may stimulate the areas in the brain responsible for the execution of these actions. The indicated happens due to the “mirror neurons” [24]. Based on the mentioned findings, it might be important to show the patient an activity he/she wants to retain.

2.3 Human gait

Being able to walk is of essential importance for everyday activities in life. Unfortunately, after a stroke walking can become a challenging task. Human walking involves movement in each part of the leg and if any segment of the body is disordered, it will have consequences on the gait pattern [25]. A gait cycle can be defined as a repetition of steps or strides. The step time is the difference between the times when one foot is touching the floor and the other foot touching the floor. A stride consists of 2 steps (Figure 5).

One gait cycle can be divided into two phases: a stance phase and a swing phase (Figure 4). The stance phase in a healthy gait takes up 60% of the gait cycle whereas the swing phase takes up 40%. The stance phase starts with the heel strike. At this moment the heel is in contact with the ground but the toes are not yet in contact. The following midstance phase is defined by the settlement of the foot at the lateral border. The midstance phase ends with the toe off phase and the swing phase begins. The swing phase is the phase between the toe off phase and the heel strike phase.

Double limb support phase occurs when the lower limb of one side of the body is beginning its stance phase while the opposite side is ending its stance phase.

During double support, both lower limbs are in contact with the ground at the same time.

It accounts for approximately 22% of the gait cycle. The double limb support phase is absent in running. Single limb support time, on the contrary, describes a period when only one extremity is on the ground [26].

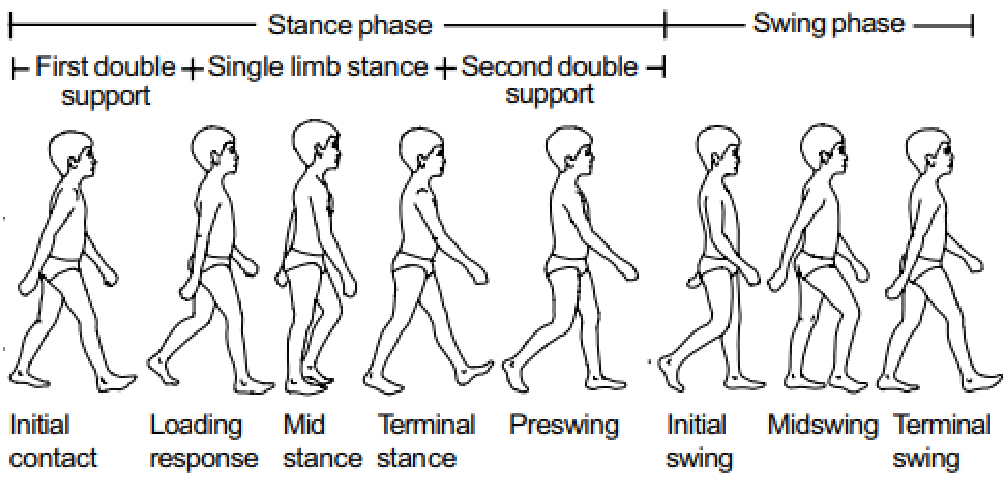


Figure 4: Gait cycle (source: [26])

Other important parameters in the gait analysis are:

- Step duration - indicates the amount of time spent during a single step (expressed as sec/step). If the limb is injured, step duration may be decreased on the affected side and increased on the unaffected side.
- Cadence - a number of steps taken by a person per unit of time, usually measured as the number of steps/second.
- Walking velocity - the rate of linear forward motion of the body, measured in meters/minute.

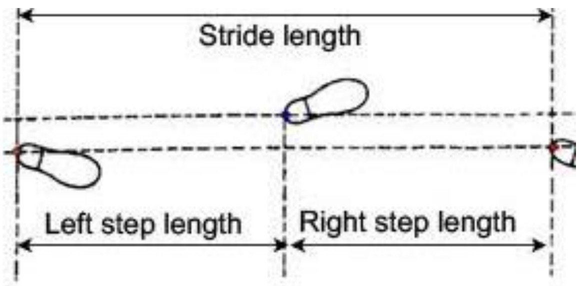


Figure 5: Left step, right step and stride length

(source: https://www.utdallas.edu/, accessed May 28, 2018)

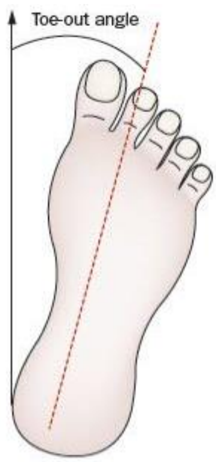


Figure 6: Toe-out angle (source: https://www.nature.com, accessed May 28, 2018)

- Degree of toe-out (DTO, Figure 6) - the angle of foot formed by each foot's line of progression and a line intersecting the center of the heel and the second toe. In a normal gait, the average DTO value is around 7 degrees. The DTO decreases as the speed of walking increases.
- Step width (Figure 7) - the linear distance between the midpoint of the heel of one foot and the same point on the other foot.

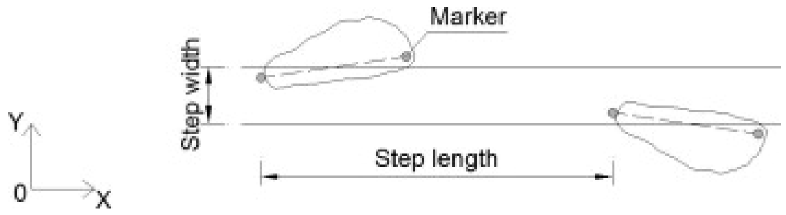


Figure 7 Step width (source: https://www.researchgate.net, accessed May 28, 2018)

- Knee flexion angle – change of the knee flexion angle during the gait cycle. In stance phase goes approximately to 20 degrees and it shortens the leg in the middle of stance phase (Figure 8).

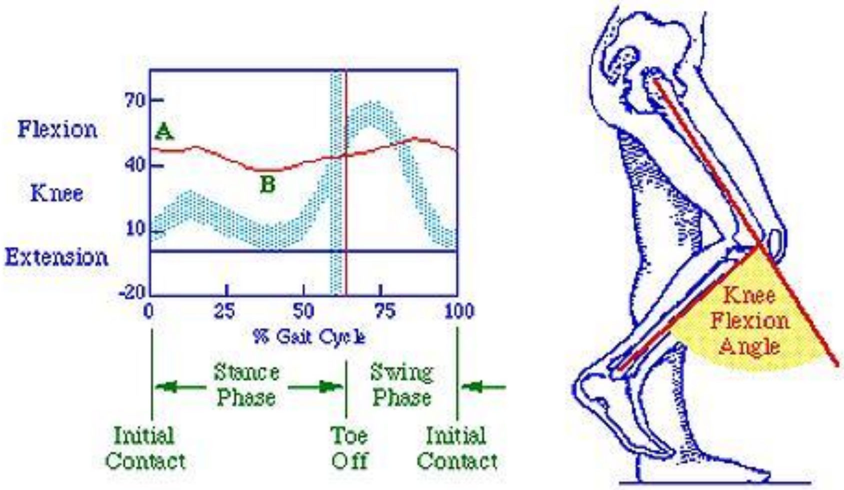


Figure 8 Knee flexion angle (source: https://www.medscape.com, accessed May 28, 2018)

The values of the described parameters can be affected by many factors such as age, gender, height, distribution of mass in body segments, joint mobility, muscle strength, psychological status and more. Every human has a unique gait cycle [26].

An altered gait pattern due to deformities, weakness or other impairments is called a pathological gait. A gait pattern characteristic for stroke is called a Hemiplegic Gait [31]. It is likely to be slow with a circular movement of the leg limbs or hip hitching of the affected limb. At the pre-swing phase of the Hemiplegic gate, stroke subjects inappropriately extended their impaired knee, while during swing they abduct their impaired leg [27].

Any gait with parameters that noticeably differ from the normal gait parameters will be considered as a pathological gait. However, using the Kinect v2 sensor, only a limited number of mentioned parameters can be tracked effectively. Xu et al. suggested that whether the Kinect sensor is sufficient for measuring gait parameters depends on the desired accuracy level of a specific task [28].

2.4 Balance control

Falls are the leading cause of nonfatal injuries and injurious death among older adults; It is estimated that 1 in 3 persons older than 65 years will fall each year [29]. Therefore, it is important to identify the probability of falling and train the balance control of elderly population to prevent the falls.

Also, gaining control through locomotor training for achieving balance and walking is critically important for SCI patients with incomplete injuries [30]. Locomotor training focused on task-specific training of the injured components, to return functioning as closely as possible to preinjury levels of neuromuscular control proved to have positive and long-lasting effects [30].

One of the tools used to measure static and dynamic balance ability is a Berg Balance Scale or BBS, developed by Katherine Berg in 1989 [31]. It is a valid instrument used for evaluation of the effectiveness of interventions and for quantitative descriptions of function in clinical practice and research.

The BBS assesses balance via performing functional activities such as reaching, bending, transferring and standing. It incorporates most components of postural control: sitting and transferring safely between chairs; standing with feet apart, feet together, in single-leg stance, and feet in the tandem Romberg position with eyes open or closed; reaching and stooping down to pick something off the floor. Each item can be ranked along a 5-point scale, ranging from 0 to 4, each grade with well-established criteria (see the Appendix II: Berg Balance Scale). Zero indicates the lowest level of function and 4 the highest level of function. The total score ranges from 0 to 56.

Depending on the scored points, the patients are categorized in one of the following groups: 41-56 = low fall risk group, 21-40 = medium fall risk group and 0 –20 = high fall risk group. The BBS scale is relevant for this work since it will allow evaluating the inclusion and exclusion conditions to use the mini-games and assess the effects of the gameplay on the balance control of patients.

2.5 Rehabilitation challenges and motivational concepts

A human-centered task-oriented approach is a significant and beneficial concept in rehabilitation [32]. Task-oriented training has also been proven to be effective in the arm-hand skilled performance of stroke patients [33]. The concept of client-centeredness integrates patient’s needs in their rehabilitation and actively involves the patient in selecting goals for their own rehabilitation process [11]. To stimulate the neuroplasticity, the goals set in rehabilitation by patients and technicians must be task specific, clearly defined, challenging, motivating and intensive [34].

One of the problems in post-stroke rehabilitation, that is rarely addressed, is the occurrence of the post-stroke depression or PSD. It is the most frequent psychiatric complication after the stroke affecting more than 40% of patients. It has strong negative effects not only on the patient social interactions and overall quality of life but also on the recovery of their motor functions [35]. Hence, depression is sabotaging the rehabilitation. The diagnosis of PSD is challenging and often depends on the interviewer. In a study performed by Schubert et al. out of 15 stroke patients, 68% was diagnosed with depression according to psychiatric interview, 50% by self-report, but not a single one of them was recognized as depressed by the rehabilitation team [35]. Patients with PSD have a higher probability of worsening of cognitive functions and poor motor recovery compared to stroke patients without PSD. Therefore, early effective treatment of PSD can not only improve the patient psychological health but also boost the rehabilitation outcome. Hence, rehabilitation teams should also concentrate on how to motivate patients for the recovery and address their mental health. Virtual Reality can help therapist to motivate patients for recovery and bring amusement in the recovery process.

When motivated, players/patients are willing to spend more time playing the game and thus perform more motor exercises, which is most relevant when they are used in rehabilitation. Video games are beneficial for cognitive and motor skill learning in both rehabilitation and experimental studies with healthy subjects [36]. Physiological data suggest that gameplay can induce neuroplasticity reorganization that leads to long-term retention and transfer of skill [36]. Furthermore, by doing mental practice of an activity or looking to the activity being performed (images or video) helps in the skills retention needed for the activity [37]. Lohse et al. took an interdisciplinary approach to find areas of overlap between game design, the neuroscience of motivation and principles of motor learning [36]. These authors extracted the key principles of effective game design that can increase the player's engagement and motivation in performing tasks or play the game. The extracted key principles are: reward, optimal challenge, feedback, choice and interactivity, clear instructions and socialization.

- Reward – It was shown by vast neuroscientific research on reward and motivation that the part of the limbic system called *nucleus accumbens* is responsible for learning new behaviors associated with reward, pleasure and addiction. Interestingly the activity in *nucleus accumbens* scales linearly to the chance of receiving a reward [38].
- Positive feedback – a positive feedback instead of the negative one motivates patients and therefore allows better future performance compared to the negative feedback [39]. Simply by concentrating on the good trails in patient performance the patient motivation increases. Hence, patients learning abilities are enhanced. In the

long run positive feedback results in overall better recovery and improved retention of skills [36].

- Clear instructions – another factor boosting the patients' motivation for recovery are communication between patient and therapist and clearly defined goal-directed tasks. It gives patient a feeling of reassurance that they are moving in the right direction and will achieve set therapy goals [36]. Contrarily, unclear goals lead to patients' frustration and decrease in the motivation.
- Choice and interactivity – data shows that players report games having higher number of options as more pleasurable. Greater engagement is achieved because of feeling of choice and interactivity [36]. Chiviacowsky and Wulf stated that by simply allowing patients to choose when to receive their performance evaluation, increased patient skill retention [40].
- Socialization – Stroke survivors with high levels of social support experience more rapid and extensive recovery than socially isolated individuals [36]. Likewise, social interactions were reported to be the primary reasons for playing online games by 39% of players in an online survey [41]. Therefore it was concluded that the design of the rehabilitation game that supports socialization, competition or cooperation between players can further boost patients' motivation for recovery.
- Optimal challenge – it is connected to a positive failure, meaning that a player fails just before the success. These way players are not discouraged to try accomplishing the mission again, since they feel capable of succeeding. Excitement during the execution brings more joy than the success of winning itself [42]. Positive failure is also correlated to being in the "flow", defined by positive psychology, where the person is completely absorbed in the activity, maintaining high focus and feeling of enjoyment during the activity [43]. Furthermore, nearly succeeding or narrowly avoiding failure is a physiologically rewarding experience [36].

2.6 Fundamentals of game design

By definition: "a game is a type of play activity, conducted in the context of a pretended reality, in which the participant(s) try to achieve at least one arbitrary, nontrivial goal by acting in accordance with rules" [1]. Every game starts with the core or its statement of purpose, the one thing that game is about. Every single feature of the game should strengthen the core and make the gameplay strong. For example, the core can be character development, role playing, racing, career development, building a business, developing cities, design apartments. Game design changes drastically with the change of the game core.

People enjoy playing games because in the game they can execute actions that are not possible or are too expensive to do in a real life [44].

The essential elements of every game are gameplay, pretending, a goal, and rules.

- Play is a participatory form of entertainment, unlike the books, film or shows where the audience has no influence on the story (presentational forms). On the other hand, in a game the player make choices that affect the course of events.
- Pretending is the act of creating a notional reality in the mind. Another name for the reality created by pretending is the magic circle (Figure 9). It defines the boundary between reality and make-believe. Within the magic circle, the players agree to attach a temporary, artificial significance to situations and events in the game. The magic circle comes into existence when the players join the game—in effect, when they agree to abide by the rules. It disappears again when they abandon the game or the game ends.

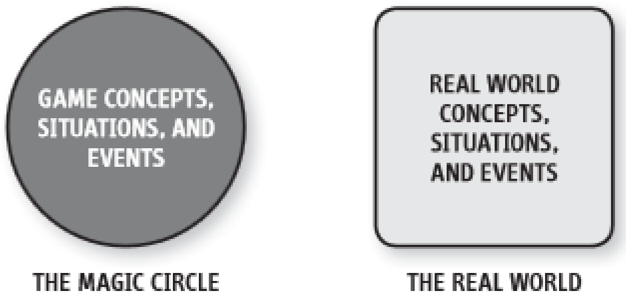


Figure 9: Magic circle (source: [44])

- A game must have at least one goal. To achieve the goal the player must overcome some level of challenge because it creates tension and drama. In other words, the goal must be nontrivial. If the goal can be achieved in a single moment, without either physical or mental effort, then the activity is not a game. [44].
- Rules are definitions and instructions that the players agree to accept for the duration of the game. They establish the goal of the game and the meanings of the different activities and events that take place within the magic circle. The rules should instruct the players which activities are permitted and which course of action will best help them achieve their goal.

Games can be played in a single-play or multi-play mode. In a multi-play mode competition occurs when players have conflicting interests. Contrarily, cooperation occurs when the players try to achieve the same or related goals by working together.

The main objective of every game should be entertainment. Although, some games can be used for training or educational purposes, they still should provide a fun experience to the players. Good games are fun and bad games are not [44].

When designing a game a first stage is to create a game concept. It is a document of few pages that describes the following:

- Concept statement (two- or three-sentence description of what the game is about)
- Player's role(s) (the player's role(s) in the game, if the game is representational enough to have roles; If the player will have an avatar, describe the avatar character briefly)
- Gameplay mode (a proposed primary gameplay mode, including camera model, interaction model, and general types of challenges the player(s) will experience in that mode)
- Genre (the genre of the game or, if you think it is a hybrid, which features it will incorporate from the different genres to which it belongs. If it is an entirely new kind of game, include an explanation of why its gameplay doesn't fit into any existing genre)
- Target audience (a description of the target audience for the game)
- Platform (the name of the machine on which the game will run and details of any special equipment the game will require (for example, a camera or dance mat))
- License (The licenses that the game will exploit, if any.)
- Competition mode (the competition modes that the game will support: single-, dual-, or multiplayer; competitive or cooperative)
- Progression loop (a general summary of how the game will progress from beginning to end, including a few ideas for levels or missions and a synopsis of the storyline, if the game has one)
- Game World (a short description of the game world)
- Unique selling points (what makes the game stand out in the marketplace, and possible marketing strategies and related merchandising opportunities)

The concepts and principles described in this chapter where taken into account when designing the mini-game and adapting existing games from Unity for SCI patients. In the mini-game and adapted games, patients are required to perform relevant movements for balance control strengthening.

2.7 Virtual Reality games and rehabilitation

Because of the large benefits of gamification in recovery treatments, a few companies build VR games with motion tracking technology for rehabilitation purposes.

One of them is VirtualRehab[4], offering a set of small mini-games each targeting distinct functions: equilibrium, coordination, weakness, fatigue and spasticity (the detailed description of the games is in the Appendix III: Virtual rehab games). The exercises provided by VirtualRehab can be adapted to the patient's disability levels and adjusted based on the patient progress. A Microsoft Kinect is used as motion tracking sensor in the games they provide.

Another company offering Virtual Reality games is Jintronix[5]. The games are designed to train balance and mobility, muscle strengthening and endurance, flexibility and range of motion, fall prevention, postural control and motor control. Games track player's movements with the Microsoft Kinect sensor and monitor the progress.

Furthermore, the games provide reports for the therapist supervision. Jintronix games can be used both as one to one session between therapist and patient, or independently, at home with remote supervision. Mixxus Studios[6] have also developed a set of games for walking and upper limb movements while Fysio Gaming[7] is another rehabilitation platform that uses Kinect sensor to offer a range of effective, personalized rehabilitation games. It offers exercise programs across 30 levels of difficulty, making the rehabilitation process more dynamic.

Apart from the mini-games specifically designed for the rehabilitation purposes, the usage of commercial VR games, such as "Kinect Adventures" and "Zen", in a few research studies[5, 45] was observed as well.

"Zen" includes movements derived from exercise programs based on Thai Chi and Yoga. In "Kinect Adventures" users play the game by performing moves such us bending, stepping side to side, jumping and standing on one foot. "Kinect Adventures" is a compilation of mini-games for the first version of Kinect, Xbox 360 and includes 5 different sets of mini-games: "20,000 Leaks", "River Rush", "Rally Ball", "Reflex Ridge" and "Space Pop" (Figure 10). It can be played by one or two people. The games can only be played in a standing position. "Kinect Adventures" provide interesting content and pleasant design In order to play it or any other commercial games designed for the Xbox 360, it is necessary to have a television screen with the HDMI audio/ video interface, an Xbox 360 and a Kinect Sensor. The feedback in a game is provided by a score a player gains when playing the game.

---

[4] http://www.virtualrehab.com/ (accessed May 27, 2018)
[5] http://www.jintronix.com/ (accessed May 27, 2018)
[6] http://www.mixxusstudio.com/ (accessed May 27, 2018)
[7] http://doctorkinetic.com/ (accessed May 27, 2018)

Beaulieu et al. stated that commercial games from Kinect Xbox 360 and other available commercial games can improve balance control [45]. However these authors' research was missing a control group, so it is not clear if the balance control improvements were caused by a gameplay or by the natural recovery process. In their study 3 patients performed a 30 min biweekly standardized sessions during 10 weeks. A Berg Balance Scale (Appendix II: Berg Balance Scale) was used to evaluate patients balance control. Furthermore, Kim et al. also tested the usability of the commercial games in balance strengthening. They used "Kinect Adventures" games as one of the games in a study and concluded that the commercial games can help in balance control [5]. The study included 36 patients, among which 18 were in a control group and 18 patients were playing the games with Kinect Xbox. Balance strengthening was evaluated using force plates and a multimodal dynamometer. Significant improvements were observed in the hip strength of the extensors, flexors, adductors and abductors. It is important to highlight that in the study by Kim et al., the exercises were performed without therapist supervision. Patients played the games 1 hour, 3 times per week during 8 weeks. In the same time, a control group did not play any games or undertake any kind of conventional therapy exercises.

Figure 10: Kinect Adventures mini-games (source: https://bitscaverna.websiteseguro.com/images_storage/14349_1.jpg, accessed May 28, 2018)

Based on the mentioned studies, commercial games like "Kinect Adventures" proved to be successful in retaining balance control of elderly people with balance disorders. The disadvantages of these games are that they cannot be customized and are not appropriate to be played in a wheelchair or seated. Because of standing position and jumping, commercial games are not applicable for Spinal Cord Injury patients. They don't include any logging information relevant for the recovery process and sometimes can be to challenging to perform. Furthermore, Stroke patients are usually an elderly population (older than 65 year). In order to keep them engaged, a specific design guideline, regarding the content and colors should be used (familiar environments with simple daily tasks like cooking, washing dishes, combing the hair and eating).

To conclude, commercial games in some cases can be used for fun and motivation but for more significant impact on the recovery patients should play the games that are specifically developed for them, taking into the account all the relevant movements and limitations (human-centered). In order to develop such games, the technology that makes it possible was studied and described in the following chapter.

III: Technology used

This chapter presents the technology used for the creation of mini-game for SCI patients. There are many game engines on the market, but because of the Unity Game Engine favorable features like easy integration with motion tracking devices and free SDKs, it was decide to use it for the game development.

In the previous work of R. Silva [46], a set of mini-games for rehabilitation purposes was developed using the Leap motion sensor[8]. Using that sensor, only the hands could be tracked and not the patient's posture, which was considered a limitation as in some situations patients would lean toward the hand not completing correctly the movement. As a next step, it was decided to move from tracking hands to tracking the whole body. Since the Kinect v2 provides the full body tracking and was available for an affordable price, it was decided to use it in this work. A detailed overview of the Kinect v2 properties is presented below.

3.1 Unity game engine

Since it offers a free student version and has an extensive documentation with a large and active online community and uses a C# language for scripting, it was reasonable to choose Unity Game engine for mini-games development.

The Unity Game Engine[9] was chosen as a solution to build the games for rehabilitation purposes in this work. Unity is developed by Unity Technologies, a company founded in Denmark in 2004. It is a multipurpose-cross platform game engine mainly used to build 2D, 3D VR and AR games. Unity Game Engine is one of the most used game engines currently on the market. It offers a number of tools and resources to build games with ease. The tools include Unity Asset Store, Unity Cloud Build, Unity Analytics, Unity Ads, Unity Every play and Unity Certification. It has a large and active online community, in which many game developers worldwide share their knowledge or ask for advice. In addition, it has an extensive documentation and information about game scripting, design and general information.

The Unity Game Engine supports more than 25 different platforms including major mobile, VR, desktop, console, TV and Web platforms. It runs on Windows and OSX and can publish to Windows, OSX, Linux, Android, iOS, Windows Phone, Blackberry, Xbox One, Xbox 360, PS4, PS3, PSP Vita, PlayStation Mobile, WiiU and Wii. For VR and AR, this Game Engine

[8] https://www.leapmotion.com/en/ (accessed May 29, 2018)
[9] https://unity3d.com/ (accessed May 29, 2018)

provides native support for Oculus Rift, Gear VR, PlayStation VR, Microsoft HoloLens, Steam VR/Vive and Google Daydream.

The Unity Game Engine contains a powerful graphics engine, 3D and 2D physics engine, scripting in C#, multiplayer and networking features, animation and audio implementation. It also contains timeline features for cinematic video creations, a UI system and a full-featured editor that supports drag and drop functionality. The general aspect of the Unity Game Engine user interface is displayed in Figure 11.

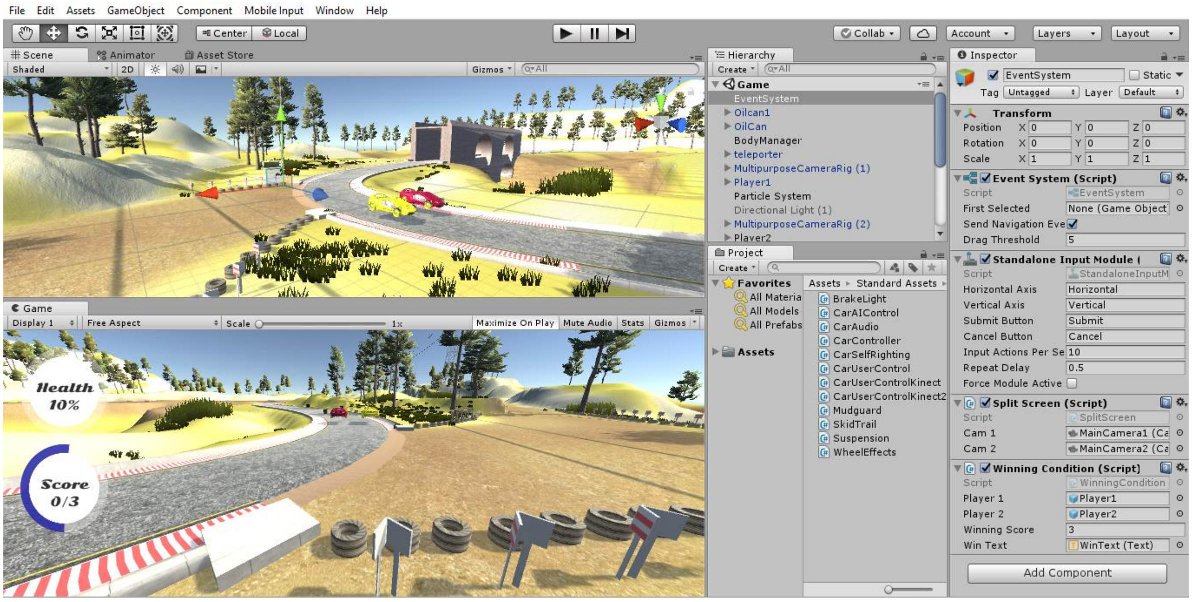


Figure 11: Unity User Interface

3.2 Unity scripting

Scripting is an essential ingredient in games. Every game needs scripts, to respond to input from the player and arrange for events in the gameplay to happen when they should. Beyond that, scripts can be used to create graphical effects, control the physical behavior of objects or even implement a custom AI system for characters in the game. Although, Unity uses an implementation of the standard Mono runtime for scripting, it has its own practices and techniques for accessing the engine from scripts. The important classes, functions and objects in Unity scripting are: “Monobehaviour Class”, “Update” and “Fixed Update” functions, “Collider” components and “Triggers” and object “Transform” properties.

The behavior of game objects is controlled by the Components that are attached to them. “Collider” components define the shape of an object for the purposes of physical collisions. “Collider” is invisible and does not need to be the exact shape as the object’s mesh. Often it is even more useful to have the collider approximately shaped as the object to which it is attached since it is more efficient and indistinguishable in gameplay. A “Collider” configured as a “Trigger” (using the “Is Trigger” property) does not behave as a solid object; instead, it allows other “Colliders” to pass through. When other “Colliders” enter its space, a “Trigger” will call the “OnTriggerEnter” function on the trigger object’s script. With this property, it is possible to call certain actions using the “OnCollisionEnter “(when 2 colliders start to touch) and “OnCollisionExit” (when 2 colliders stop to touch) functions.

The “Mesh Renderer” renders the geometry of an object at the position defined by the object’s “Transform” component. “Transform” component contains the object position as a “Vector3” component, rotation as a “Quaternion” component and a scale, also as a “Vector3” component.

To implement any kind of game behavior, the “Update” function will be called every frame, if the script is derived from the “Monobehaviour” class. For any kind of physics calculations or simulations, it is more appropriate to use a “FixedUpdate” function. When dealing with “Rigidbody” components e.g. adding a force or change other “Rigidbody” settings the changes will be applied every fixed frame rate inside “FixedUpdate” function instead of every frame inside “Update” function. A frame rate independent interval that dictates when physics calculations and “FixedUpdate” events are performed. The interval can be customized. When the “Rigidbody” component is added to an object, the object’s motion goes under the control of Unity's physics engine, meaning that it will be pulled downward by gravity and will react to collisions with incoming objects. By default, Unity scripts derive from the “Monobehaviour” base class. It offers a set of predefined lifecycle functions, like “Update” and “FixedUpdate” and many more. These lifecycle functions make the game development process easier.

3.3 Kinect v2 sensor

Kinect is a motion sensor[10] device that allows people to interact in a virtual environment. Using Kinect v2 people can perform multiple movements in a natural way without the need for an attached device or a controller. In February 2012, Microsoft released a Kinect Software Development Kit for Windows, which resulted in a large number applications being built as a consequence of the enthusiasm with the new technology. Kinect v2 is equipped with a full HD RGB camera, an infrared camera, a depth sensor and a multi-array microphone that can track the origin of a sound (Figure 12).

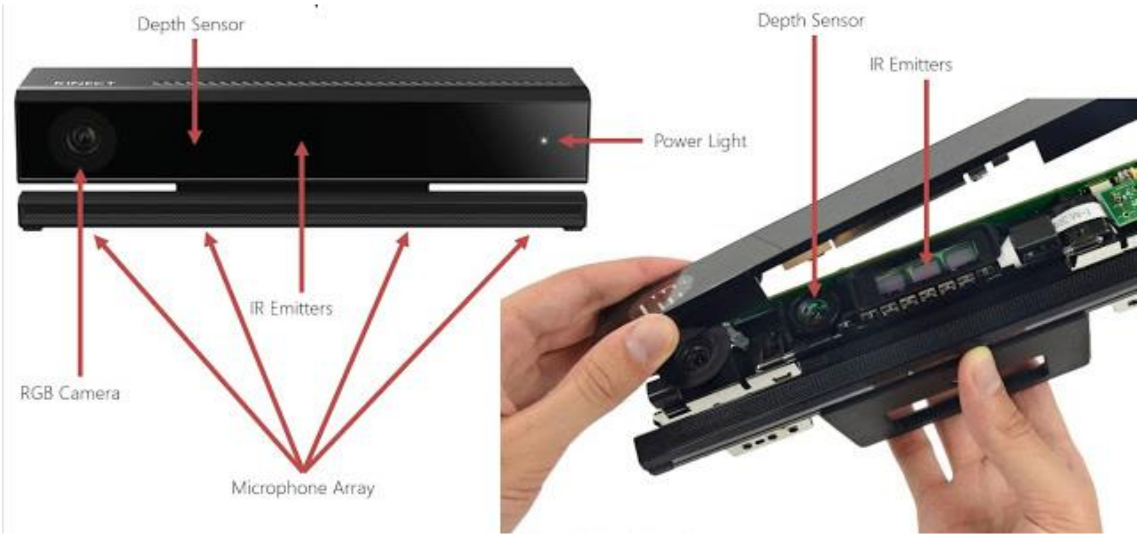


Figure 12: Kinect v2 sensor (https://www.physio-pedia.com, accessed May 17, 2018)

Instead of determining directly the body pose in this high-dimensional space, the Kinect v2 algorithm is using a per-pixel, body-part recognition as an intermediate step (Figure 13).

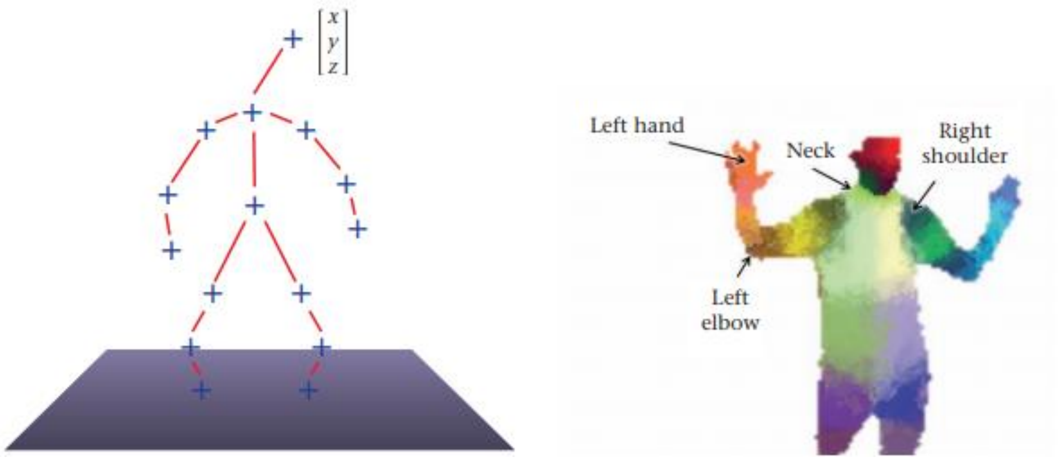


Figure 13: Kinect body-part recognition system (image source: [47])

---

[10] https://support.xbox.com/en-US/xbox-on-windows/accessories/kinect-for-windows-v2-setup (accessed May 17, 2018).

“The segmentation of a depth image as a per-pixel classification task avoids a combinatorial search over the different body joints and features yield 3D translation invariance while maintaining high computational efficiency” [47, p7].

Kinect v2 can track 25 joints on the human body and up to 6 bodies simultaneously[11]. For the full-length visibility by this sensor a person needs to stand at least 1.5 m away from it (Figure 14).

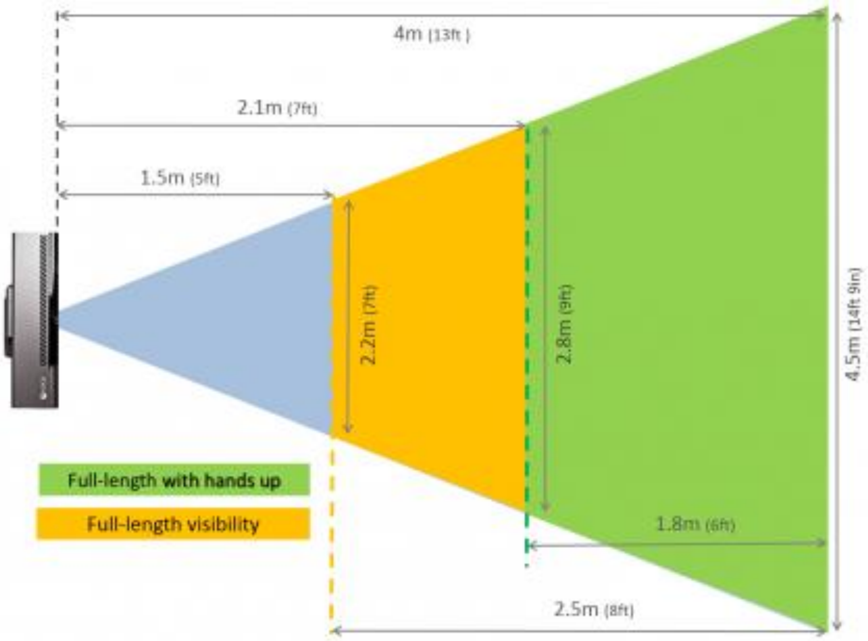


Figure 14: Body visibility by the Kinect v2 sensor (http://docs.ipisoft.com, accessed 17 May 2018)

Thumb tracking, end of hand tracking and open and closed hand gestures can be recognized by Kinect v2 sensor as well. In addition, multiple apps can utilize the sensor simultaneously. A 3-axis accelerometer configured for a 2G range (where G is the acceleration due to gravity) allows determining the current orientation of the Kinect v2 sensor. More detailed specifications of the sensor are presented in the Appendix VII: Microsoft Kinect v2 specifications.

For the purposes of this dissertation, the main focus will be on a skeleton tracking feature of the Microsoft Kinect v2. In skeletal tracking, a human body is displayed with a number of body joints (Figure 16) representing body parts.

[11] https://developer.microsoft.com/en-us/windows/kinect (accessed May 17, 2018).

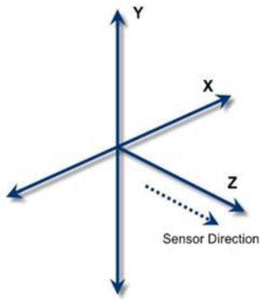


Figure 15: Kinect coordinate system (https://msdn.microsoft.com, accessed May 17, 2018)

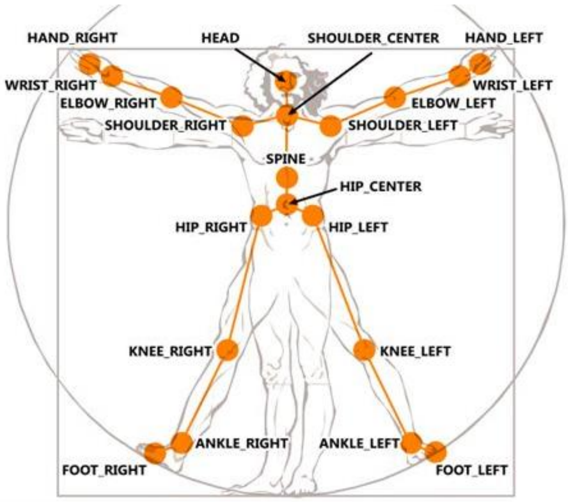


Figure 16: Kinect Skeleton (https://msdn.microsoft.com, accessed May 17, 2018)

Each joint of the human body is represented by a “Vector3” component with x, y, z coordinates in the Kinect v2 sensor coordinate system (Figure 15).

Concerning the reliability of Kinect v2 sensor, the table displayed at Figure 17 summarizes the test retest values of the studies of the motion tracking data from the Kinect v2 sensor performed by Giancola and Milano [48]. In the studies listed in the table, two separate sets of measurements using Kinect v2 sensor were performed and the values of the measured data were compared. The comparison between these 2 sets of measurements is referred as test rest values. The test retest values are reported in Intra Class Correlations (ICC). The ICC describe how strongly units in the same group resemble each other. The values are poor if the score is in the range (0-0.3), moderate (0.4-0.6) or strong (>0.7).

Author	Year	Gait	Shoulder	Elbow	Trunk	Hip	Knee	Ankle	Hand	Reported results	Int. of result
Behrens et al	2014	>.90								ICC of walking speed tests	High
Clark et al	2012				>.87	>.26	>.71	>.63	>.73	ICC of different movements	Moderate
Huber et al	2014		>.76, >.24							ICC frontal and sagittal view	High
Bonnechere et al	2013		.73	.70		.84	.66			ICC	High
Clark et al	2015	>.80								ICC of gait variables	High
Mobini et al	2015		.98, .99	.86, .94						ICC for healthy individuals and stroke	High

Figure 17: Test retest values of Kinect measurements (image source: [28])

Figure 17 shows that, depending on the joints tracked, the ICC values vary from moderate to high. Despite that study, the reliability and validity of the data the Kinect v2 sensor for rehabilitation purposes provides have been rarely investigated [49]. So far, it was concluded that the main source of errors in the Kinect v2 sensor measurements is the occlusions. They prevent from detecting the positions of a person body limbs. When one of the limbs is not perfectly visible, the posture is no longer correctly recognized and the error magnitude of the body joints positions becomes significant [28]. In case a subject is not moving, the position of the body joints is recognized within the radius of 5 mm. Dynamic measurements evidenced that if the displacement of the tracked object is less than 0,2m per second, main accuracy limit arises as the consequence of the resolution of the instrument. If the displacement is larger than 5 mm the motion reconstruction is usually correct. When the displacement is lower and/or the frequency is larger, the measured amplitude of the motion is no longer correct [28].

Therefore, the Kinect v2 can be used for motion tracking in the environment when the whole body, that is being is tracked, is visible and when the tracked movements are not too fast.

IV: Methods and work

In this chapter, first the identification of the problems that the therapists and clinicians are facing today is presented. A visit to the Rovisco Pais rehabilitation center was arranged in order to see the challenges the center is facing in the rehabilitation of Stroke and SCI (Spinal Cord Injury) patients. Additionally, possible opportunities for applying Virtual Reality and Motion Tracking equipment were investigated, in order to help overcome those challenges.
Secondly, a Kinect v2 proof of concept is presented in order to estimate its tracking possibilities. Finally, the building of a mini-game using Unity Game Engine and the code for body tracking with the Kinect v2 is described.

4.1 Rovisco Pais rehabilitation center case study

Rovisco Pais is a Rehabilitation Medicine Center of the Portugal Central Region and is an institution specialized in rehabilitation, within the scope of the network of the Portuguese National Health Service. The development and adaptation of mini-games for Stroke and SCI rehabilitation was done in the collaboration with this Center. Observing the rehabilitation environment and patients together with their therapists some of the following problems were noticed:

- In the Rovisco Pais rehabilitation center there are primarily two main types of patients: Spinal Cord Injury patients and Stroke patients.
- Usually, there is a lack of therapists. These results in large waiting lists, sometimes up to 30 patients are waiting for the start of rehabilitation. The waiting period may go up to 2 months. This is a relevant problem as for the effective recovery it is important to start the rehabilitation as soon as possible.
- Depression is another problem noticed. When depressed, patients are not motivated to perform recovery exercises. Therefore it is crucial to deal with the depression first.
- It is important to convince the patients that they can actually rehabilitate due to brain neuroplasticity (keep them motivated and informed) and with enough exercise.
- Exercises that the patients perform are often repetitive and daunting for the patient.
- The recovery exercises are in most cases performed individually, which is not as motivating as it could be if the exercises were performed in a group of 2 or more people.
- Young patients with SCI train in groups by playing handball or other types of team sports, these types of activity tend to be more fun for them.

- Therapists reported that large gym environments are distracting for the patients. Therefore small gyms with fewer people might be more favorable to produce better results.
- Visualization of an activity helps a lot for the actual performance of that activity. By visualizing, the areas of the brain responsible for that activity are activated as if the patient is performing the actual activity. Therefore visualization can lead to more effective and faster recovery.
- Because the rehabilitation may be not effective and some patients are not fully recovering or as much as they could;, this leads to their inability to lead an independent life again, which in return leads to a high cost of their maintenance or sacrifices in the family (if the patient has one).
- Slow rehabilitation creates larger waiting lists meaning that patients that are waiting for the rehabilitation will also start later and because of that have worse recovery results.

In brief the information collected during the visit is summarized and put on the diagram below (Figure 18). It allows easier visualization of the current state and fosters the possibility to get ideas regarding the type of games that would be relevant to help rehabilitation at the Center.

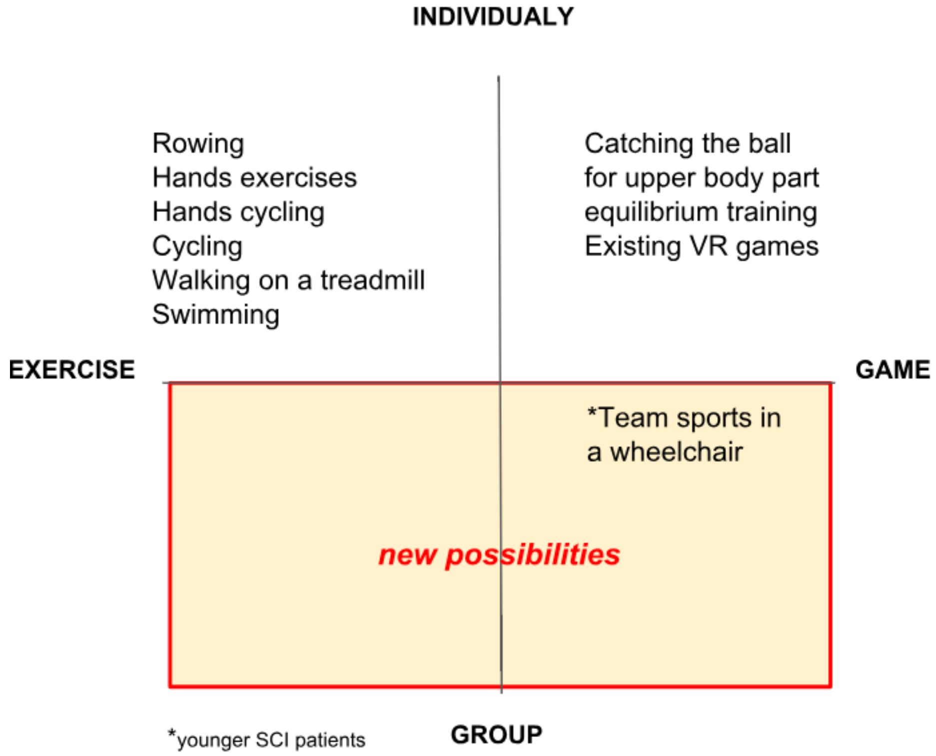


Figure 18: Cross vector insights diagram

The Y axis denotes how many people are involved when doing rehabilitation and on the X axis the used approach for a recovery; if it is performed through a game or as an instructed and repetitive exercise. As a consequence, an interesting result came up. There are currently not many solutions on the market that include VR games for rehabilitation that are performed in a group (real or virtual), therefore this area might represent an unmet needs of the patients and therefore, new product opportunities. During the visit to the rehabilitation center it was observed that, when younger SCI patients were playing group sports like basketball or football together, they enjoyed the gameplay and were motivated to win. Based on the research, it is likely that the types of games that must be played in a group could be very motivating for patients and result in better and faster recovery. Therefore this will be a main guideline for the creation and adaptation of VR rehabilitation mini-games in the scope of this dissertation.

Figure 19 - Team sports appropriate for SCI patients (source: http://www.wheel-life.org/hitting-the-field-with-wheelchair-lacrosse/, accessed May 30, 2018)

4.2 Skeleton body tracking using Kinect v2 SDK in Unity

In this section the created code for tracking information about the body skeleton posture and joints position in a 3D space to further transfer it to the Unity environment, is described. This was a pre-requirement for the remaining work.

For building any application using Unity Game Engine and Kinect v2 sensor it is necessary to use the following software assets:

- Unity 3D Game Engine
- Kinect v2 SDK
- Kinect v2 Unity Plugin

Using the Windows Kinect library from Kinect v2 Unity Plugin, it is possible to access the Kinect Sensor from Unity. A class “Body Frame Reader” was used to read the skeleton body data in order to track the skeleton. Kinect v2 can track up to 6 bodies simultaneously. To keep the track of all the bodies the array of “body data” was created. In every Unity script that is derived from the “Monobehaviour” class there are default functions of “Start” and “Update”. The “Start” function is called on the first calling of the script, while “Update” function is called every frame (25fps or 30fps, depending on the settings).

To track the body movements the “Body Manager” class was created. In the “Body Manager” class in the “Start” function the Kinect v2 sensor is accessed, and then the “Body Frame Reader” stream is opened.

Furthermore, in every frame in the “Update” function, the data from the reader is accessed to record the latest body frame data of the tracked body. In case the body is already tracked and stored in the array of all tracked bodies, the data will be refreshed with the last acquired frame.To prevent resources leaking on an application exit, it is mandatory to release all the resources and close all the streams. Therefore, before quitting the “Body Frame Reader” must be closed. After that the communication with the sensor must be closed as well. The full code of “Body Manager Script” can be viewed in the Appendix I: Skeleton tracking scripts, I.1 Body Manager Script.

When the body skeleton information is acquired, it is possible to represent the acquired data in the Unity Game Engine environment. The “Body View” script was written in order to do that. In this script the “Dictionary<key, value>” type class was created where all tracked bodies by Kinect v2 sensor can be stored. Before tracking bodies, another Dictionary “BoneMap” was created for mapping out all the bones with the two joints they are connected to. For example, the “Left Foot” is connected to the “Left Ankle”, which is further connected to the “Left Knee”, which is further connected to “Left Hip”.

In the “Update” function the “Body Manager” class is accessed in order to turn on the sensor and start reading the data. All the tracked bodies in the “Body Manager” scripts are then stored in the list of tracked bodies and updated every frame. In case one of the bodies is no longer in the Kinect v2 field of view, the body will stop being tracked and will be deleted from the list of tracked bodies.

For the remaining bodies that are tracked, the skeleton data will be refreshed every frame. In case a new body is detected, a new body instance will be created and stored in the list of tracked bodies. Each created body contains the associated "Bone Map". In this way, a position of each joint, in every frame of every tracked body, is known. Having the information, it is further possible to manipulate the data.

In the "Body View" class a primitive cube is assigned to each joint of the tracked body, with its appropriate collider and mesh renderer. All joints represented as primitive cubes are further connected with the lines in Unity Game Engine environment.

In order to know if the Kinect v2 is tracking a body, a "GetColorForStart" function was created. It returns the appropriate color of the tracking state: black by default, red if not tracked and green when tracked.

The full code of the "Body View" script can be seen in Appendix I: Skeleton tracking scripts, Body View Script.

4.3 Preliminary work

This section describes preliminary work based the work previously developed in the scope of the collaboration between the Department of Electronics, Telecommunications and Informatics of the University of Aveiro, and the Rehabilitation Center Rovisco Pais [46]. In that work a set of mini-games was developed for stroke patients based on the Enjalbert Test[12]. The Enjalbert test is used to determine the upper limb motor function of post-stroke patients and it includes five exercises:

- Lifting and holding the hand in place
- Bringing hand to mouth
- Opening and closing hand
- Executing fine pinch movements with index and middle fingers
- Executing fine pincer movements with ring and pinky fingers

In a previous work of my colleague [46], a Leap motion sensor was used to track the hand movements when doing the Enjalbert test. However, it was realized that some patients didn't maintain the correct posture while performing an exercise and Leap motion sensor couldn't detect it because it can only track the hand movements. Therefore it was decided to improve the work by developing the same types of games, but with the whole body tracking

[12] https://www.youtube.com/watch?v=05G37IhWUSs (accessed June 16, 2018)

implemented, so that the leaning of the patients can be recognized and alerted. Kinect v2 was used as a motion tracking device since it allows the full body tracking.

The mini-game to train the second exercise from the Enjalbert test listed above was developed with Kinect v2. This exercise was chosen as a result of the above mentioned previous work, since it was the most enjoyable for patients. In the mini-game the whole body is tracked to assure that the patient maintains a correct posture while performing the exercises. The last three exercises in the list were not convenient for the development with the currently used equipment since Kinect v2 can only recognize 3 states of the hand: open, closed and “lasso”.

The setup of the game is as follows: a patient is situated in a virtual dining room, with food presented on the table (Figure 20). When a patient grabs the food and puts it near the mouth he/she scores a point. The scored points are displayed in the UI bar, thus giving positive feedback. This action is further done for a predefined number of times. While performing the action of eating, the patient should maintain a straight posture and only move the affected hand. Furthermore patients, themselves can choose how many points they have to score. This feature makes a game more motivating.

Figure 20: Game UI: player seated

Posture supervision is done by tracking the z coordinates in 3D space of the “Head Joint” and “Spine Base Joint”. For posture supervision, first, a calibration is done by finding the z coordinates of two referenced joints while the patient is in a straight posture. The coordinate’s value is then subtracted and saved as a reference value. During calibration patients can be seated or in standing position. A tolerance is added to the calculated value for determining any deviation from the straight posture. This tolerance of the allowed deviation can be varied. Once the deviation exceeds the allowed tolerance a message on the screen will appear to notify the user to go back in the upright position and continue the game, visual feedback is also provided through a cactus falling animation[13].

Figure 21: Game UI: player reaching for the object (food is on the table and can be grabbed by the patient; a cactus on the right gives feedback concerning posture)

Moreover, if the patient is leaning, the food cannot be picked up from the table or eaten (Figure 21). Only if the patient posture is correct, it is possible to eat the food and score a point. The number of points patient has scored is displayed in the UI bar at the left bottom corner of the screen. When the set number of points is reached, the game is successfully completed and a motivating completion feedback is given. Patient and a therapist can set the following variables in the game: number of food instances that should be performed and a tolerance value for leaning. The created mini game was tested by 2 people and from the testing it was concluded that Kinect v2 can be used as a full body motion tracking device.
The created mini-game was tested in the lab, but couldn't be tested in the "Rovisco Pais" rehabilitation center because the center reported that they were lacking of the occupational therapist and suggested to take a different path – a development of a mini-game for gait recovery. In order to do that, first it was necessary to estimate the precision with which the motion of the body can be tracked.
Therefore the evaluation of the Microsoft Kinect v2 sensor was performed and is presented in the following chapter.

[13] https://www.youtube.com/watch?time_continue=61&v=q2uqpubxC_M (accessed June 16, 2018).

4.4 Kinect accuracy in measuring gait cycle parameters

Stroke patients in the Rovisco Pais rehabilitation center have to do every day a 30 minutes walking session on a treadmill. When patients walk on a treadmill, they are in a gym which can be very daunting and boring.

Therefore, the therapists came up with the idea of a walking game where a patient, while he/she is walking on a treadmill, is simultaneously walking in an interactive virtual environment. This type of game might distract patients from the daunting environment. Thus, before the game development itself, it was necessary to evaluate how precisely the Kinect v2 sensor can measure gait cycle parameters (step size, stride size, velocity and cadence) needed for such game. A simple experiment was performed:

The Kinect v2 was placed in an area of 4 m x2 m. The footsteps were drawn on the floor, each with the step size of 50 cm (Figure 22).

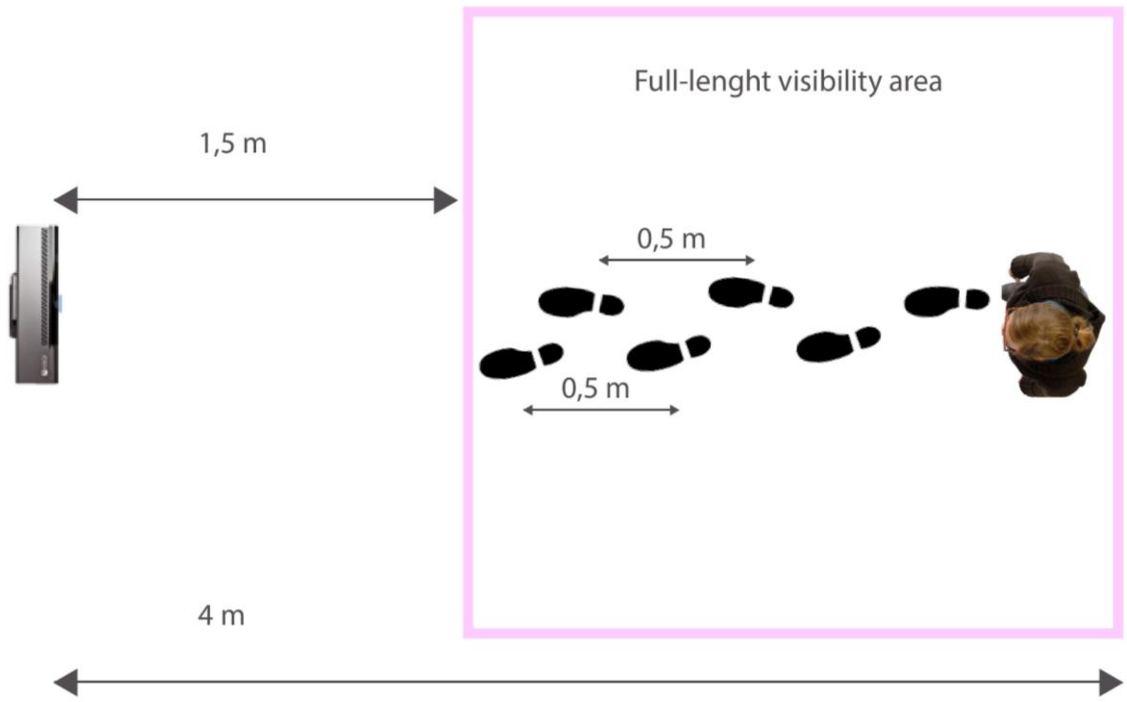


Figure 22: Experiment setup

Two people were involved in the experiment; one person would perform a walking task and the other person would take measures, taking turns on each role. The person performing the walking task was asked to first stand in a “T” pose in order to be detected by the sensor. Once the sensor managed to start tracking the body, the person was asked to put the feet on the indicated footsteps, with the left leg in front and the right leg behind the spine joint. The distance between feet was 0.5 m (the distance length was chosen arbitrarily). Once the legs were at the required position, the calibration ratio was calculated by measuring the distance between feet in the virtual world in Unity and dividing it by the distance of 0.5 m in the real world. After the calibration, the person was asked to walk on the indicated steps on the floor. The range in which the person walked was limited from 4 m to 1.5m towards the sensor. The 1.5 m was chosen as a limit because the full body length visibility starts at this distance (Figure 14).

In the specified area a person could perform 4 steps in one single measurement: 2 left steps and 2 right steps. The left step is defined as a step with the left foot in front of the spine base joint and the right step is defined as a step with the right foot being in front of the spine joint. The experiment was repeated 22 times, by the same person. Data collected by the sensor were recorded and further analyzed; the results of the experiment are shown in Table 1: Gait parameters experiment data.

Table 1: Gait parameters experiment data

	Person 1.	*Person 1.*	*Person 2.*	*Person 2.*
	Left step	Right step	Left steps	Right steps
real dist. step size [m]	0,50	0,50	0,50	0,50
measured average step size [m]	0,58	0,53	0,57	0,54
max measured step size [m]	0,80	0,74	0,70	0,72
min measured step size [m]	0,21	0,08	0,30	0,30
Deviation [m]	0,09	0,13	0,07	0,11
deviation %	15,69%	24,84%	12,90%	19,89%

From the obtained results, it can be concluded that whether the Kinect v2 can or cannot be used to determine the gait cycle parameters, like average step size, depends on the desired accuracy level. The maximum standard deviation calculated in this experiment goes up to 24.84%. For more accurate measurements of gait cycle parameters a more sophisticated device should be used since the possibilities of the Kinect v2 are limited. However, the Kinect v2 does allow the detection of the more significant anomalies in walk cycle or some serious asymmetries, which are characteristic in walk cycles of stroke patients. From the data it is also seen that the left step size detected is smaller than the right one. The reason for that is not clear. It might be due to the sensor itself, or due to the placement of the foot.

4.5 Treadmill walk cycle monitoring using Kinect v2

After the evaluation of the Kinect v2 sensor measurement abilities, the next step was to test how precisely it can monitor gait cycle parameters, when the walking is performed on a treadmill, to simulate the rehabilitation environment. Based on the literature [50], in order to perform gait analysis the following parameters were monitored:

- Bilateral parameters in absolute values and in % compared to normal walk cycle: Velocity (M/Min), Cadence (Step/Min), Stride Length (M), Gait Cycle (Sec);
- Unilateral Parameters For Right And Left Leg: Swing (%GC): Stance (%GC):

The parameters were chosen based on the limitations of the Kinect v2 sensor. In order to determine gait cycle events of heel strike and toe off, which will be further used to calculate the rest of the parameters; simple methods were used proposed by Zeni Jr. et al. [44]. Heel strike and toe off events are determined by:

$$t_{\mathrm{HS}} = (X_{\mathrm{heel}} - X_{\mathrm{sacrum}})_{\mathrm{max}}, \qquad t_{\mathrm{TO}} = (X_{\mathrm{toe}} - X_{\mathrm{sacrum}})_{\mathrm{min}}$$

In the formula, the t_{TO} represents the maximal displacement of the toe from the sacrum marker while the t_{HS} represents the maximal displacement of the heel from the sacrum marker (Figure 23). The sacrum marker is indicated with the red circle on Figure 24 (in Kinect v2 system sacrum marker is the “Spine Base Joint”).

The toe off event is determined when the displacement between the toe and the sacrum is the smallest, or maximum in absolute values. The heel strike event is determined when the displacement between the heel and the sacrum is maximum. This means that in the heel strike event the leg is in front of the sacrum and in the toe off event leg is behind the sacrum. In case of Kinect v2 sensor, the only available joints are foot and ankle. Hence, for determining the t_{TO} and the t_{HS} events, instead of the heel an ankle joint was used and instead of the toe, the foot joint was used. This approximation already adds to the error in the monitoring of gait cycle parameters.

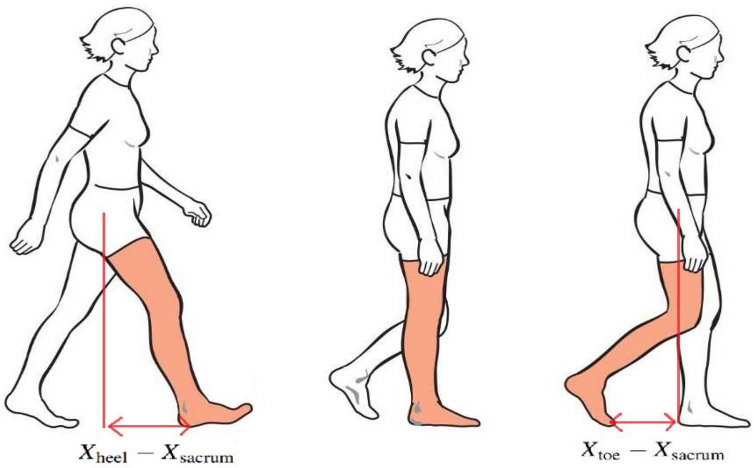


Figure 23: Heel strike and toe off events (source: http://www.flexibilityrx.com/sessions/, accessed May 30, 2018)

Several problems were encountered in measurements performed in a typical treadmill setup (Figure 25). First, the sensor did not detect all toe off events, which resulted in errors in the calculation of the duration of the swing and stance phase. Second, when part of the body is occluded, Kinect v2 can no longer provide accurate data. Because of the design of the treadmill (Figure 25), part of the body of the person walking on a treadmill is always occluded and thus, the data recorded by Kinect v2 sensor are no longer precise. Therefore, the idea of the game development for treadmill walking was abandoned.

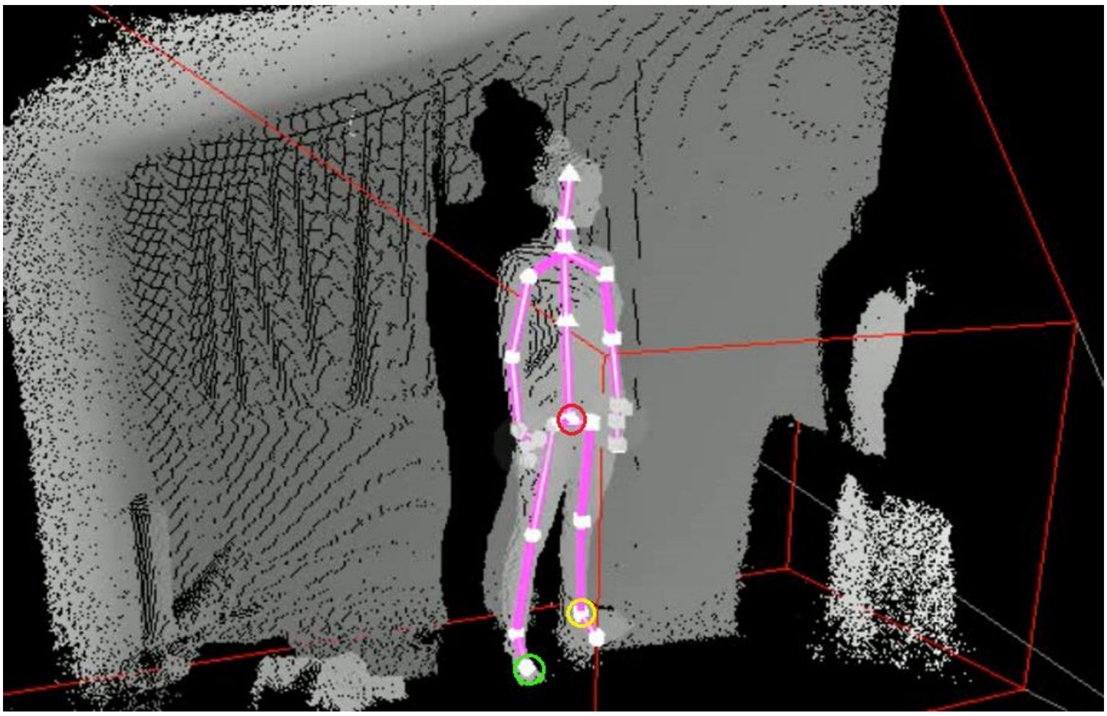


Figure 24: Spine base (red circle), ankle (yellow circle) and foot (green circle) joints

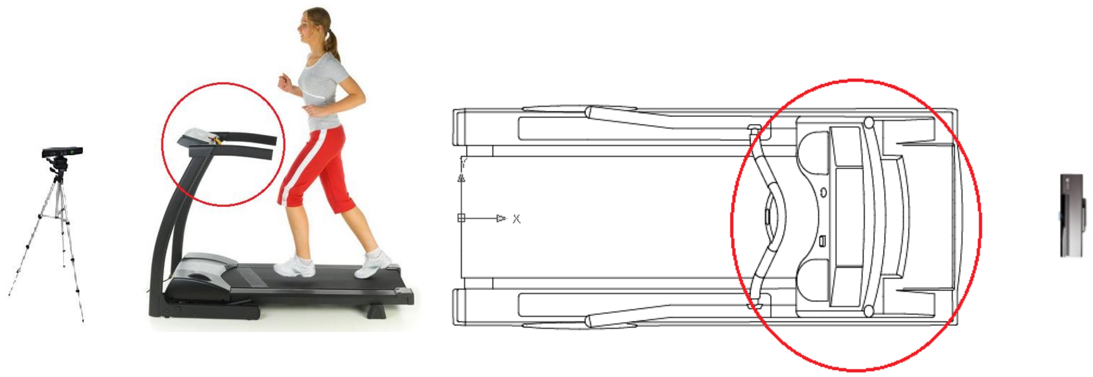


Figure 25: Experimental Setup (top view on the right)

4.6 Upper body balance training mini-game

A second visit to the Rehabilitation Center was organized in order t of the patients. The visit produced a new idea for game development (that benefits from the use of Kinect): an upper body equilibrium training mini-game for Spinal Cord Injury (SCI) patients. Taking into consideration that situation, the patients cannot perform easily in real life due to their condition, are more motivating and that many SCI patients are young, a mini-game based on a car race was developed.

The designed mini-game for upper body equilibrium training also implemented motivational concepts described in section 2.5 Rehabilitation challenges and motivational concepts:

- Reward – the winner is rewarded with flashing lights and ringing sounds
- Positive feedback – while racing, players can collect fuel tanks on the road to gain points. The number of collected points is displayed on the screen. The more points they have, the faster they can drive.
- Clear instructions – the goal of the game is to be the first one that completes the driving route.
- Interactivity – players are allowed to define themselves how many race circles they have to drive in a row to announce a winner.
- Socialization – the game can be played in two-player competitive mode, with the objective of first riding the full racing route.
- Optimal challenge – the control of a vehicle using the upper body part inclination is not trivial and requires learning.

The effects of the game on the upper body equilibrium control are measured using a questionnaire. The rules of the game are as follows: In the game the player controls a vehicle by moving his/her upper body part (Figure 26 and Figure 27). While controlling the car, hands can be in any position. Only the inclination of the upper torso matters in the control of a vehicle. If the player is leaning forward the vehicle moves forward. Leaning backward will move the vehicle backward. The same mechanism works for turning. If the player is leaning left, the vehicle will turn left. When the patient is leaning right, the vehicle turns. The described gestures were selected based on the consultancies with the therapists that trained the trunk balance of the SCI patients.

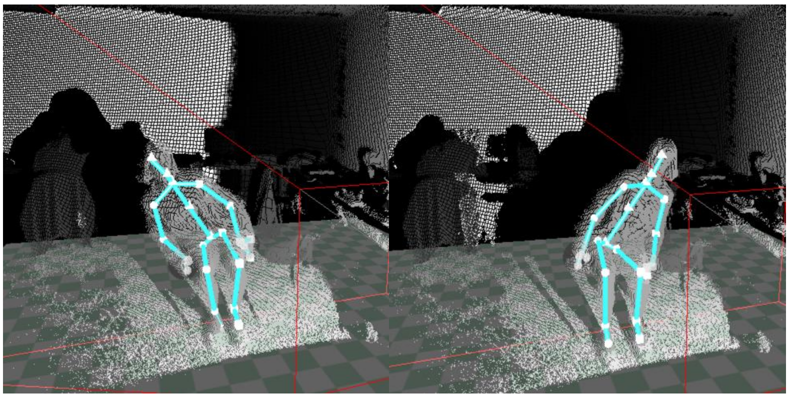


Figure 26: Side inclinations o turn left or right

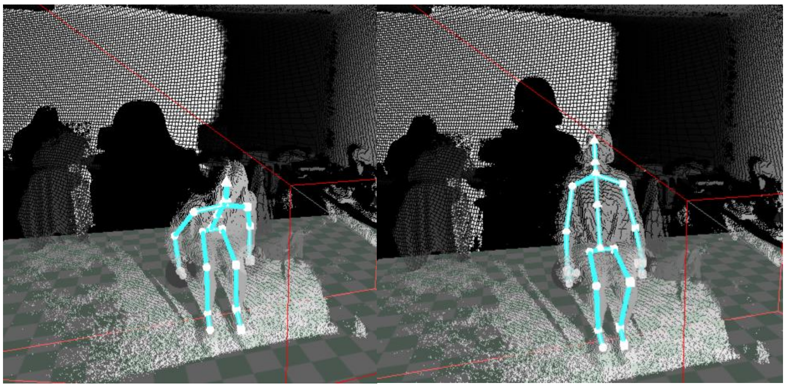


Figure 27: Forward and backward inclinations to move front or back

The more the patient leans, the faster the vehicle will go. To break, the player has to lean back. Braking won't be instantaneous. A certain amount of time will pass before the vehicle stops, in order to simulate the real world environment. In case the vehicle goes out of the road and is not possible for the player to get it back to it, the player can reset him/herself to the starting position by putting both hands above the head. The number of times the player goes out of the road is logged. Players can collect fuel tanks on the road to score the points. The more points the players have, the faster he/she can go. The game can be played as a single-player (Figure 28) or as two-player competitive (Figure 29). Players can choose how many rounds they must complete to announce the winner. The one who first drives a predestined number of rounds wins. The game can be played both in standing or sitting positions.

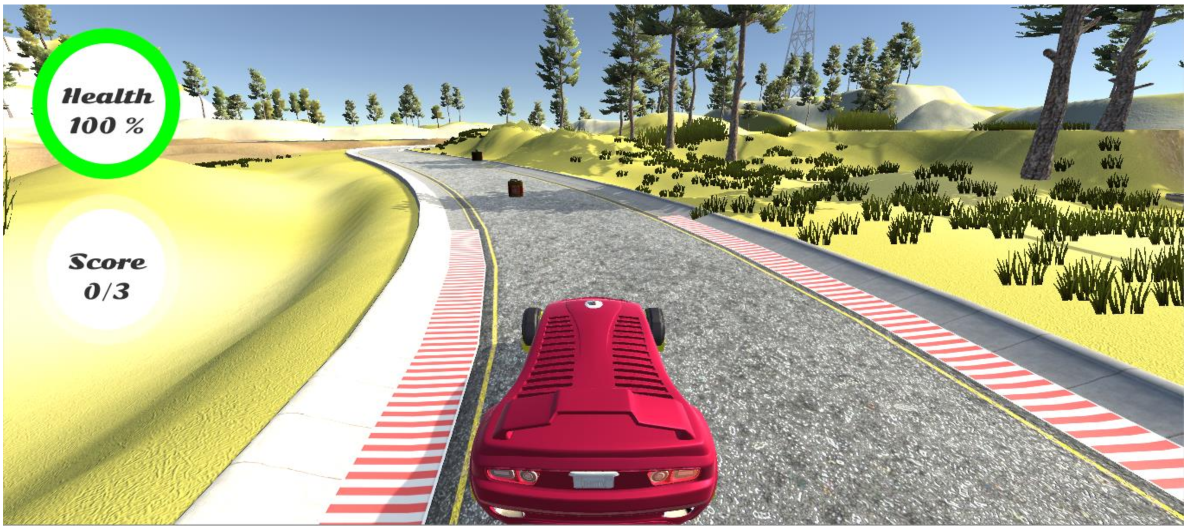


Figure 28: Single play

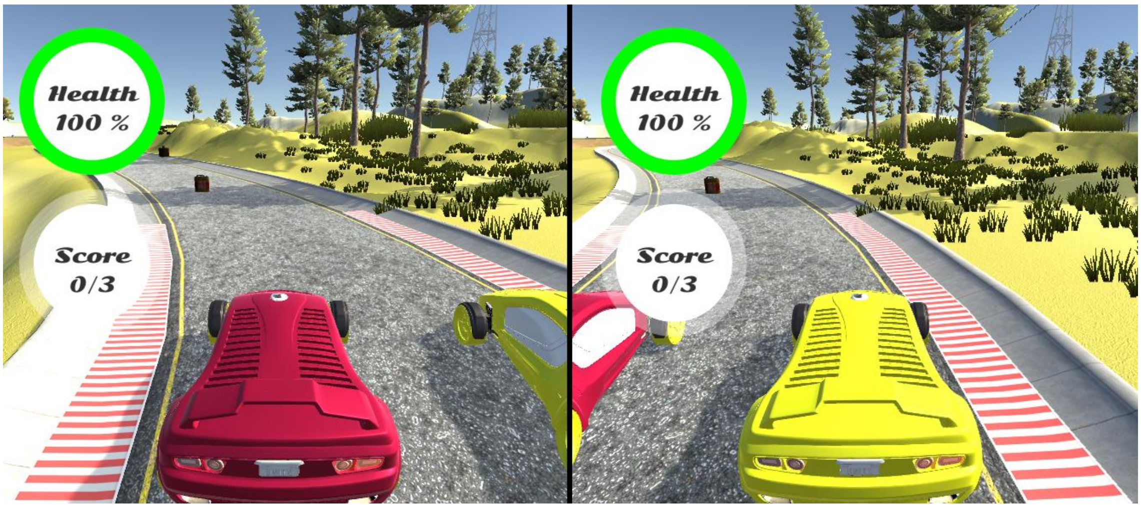


Figure 29: Two-player competition

Before the play, a player's straight posture is measured (Figure 30). That calibration procedure is needed in order to store the reference values for the calculations of leaning angles (for calibration).

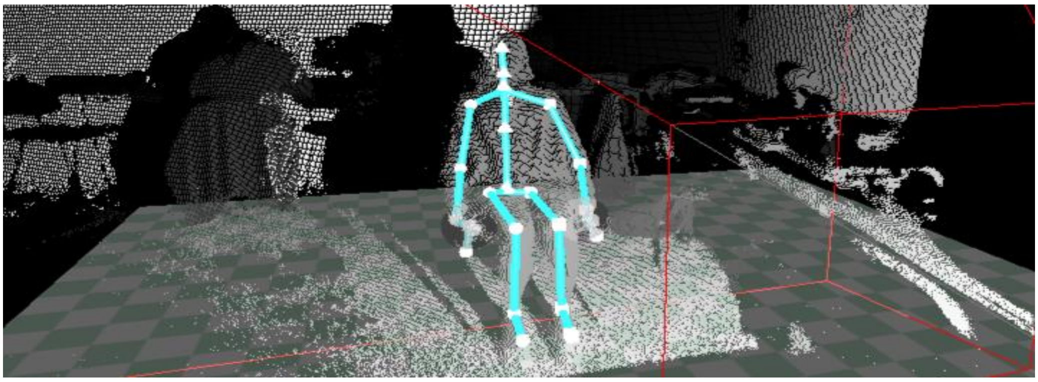


Figure 30: Calibration posture

The leaning parameters are monitored and logged. Accordingly, it is possible to measure the maximum inclination of the player in 4 directions: backward, forward, left and right.

The inclination of the upper body part is calculated by measuring the vertical Δy displacement and a horizontal displacement Δz between the Spine Base joint and Head joint. For backward and forward inclinations horizontal displacement is calculated as Δz. For the side inclinations a horizontal displacement is calculated as Δx value, with respect to the Kinect coordinate system (Figure 31).

Measured values are then used to determine the angle of the inclination, by applying a simple *tan−1* function. For side inclinations: the angle is equal to $\tan^{-1}(\Delta x/\Delta y)$ and for back and forward inclinations the angle is equal to $\tan^{-1}(\Delta z/\Delta y)$.

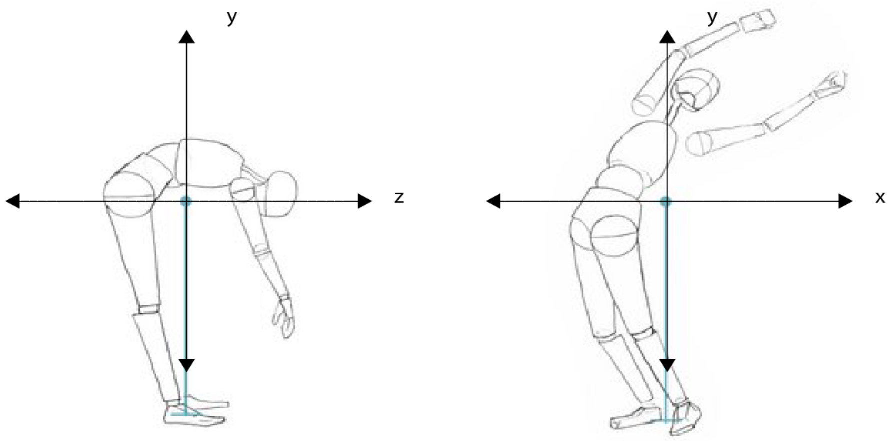


Figure 31: Body postures to control a vehicle (source: http://scienceblogs.com/startswithabang/files/2009/11/cog-poses-2.jpeg, accessed May 30, 2018)

Having determined the mini-game gameplay with the rules and winning condition, the game was further tested with healthy students.

V: Results and discussion

After the development of the mini-game for upper body equilibrium training, a preliminary test was executed with the collaboration of 9 students from the University of Aveiro. The aim of a preliminary work was to evaluate a generic usability of the game and identify the development mistakes. After the preliminary evaluation with the students and based on the gathered observations, the game was improved and tested with the patients. The results with the patients were obtained using the questionnaire and the therapist's remarks of the experiment observations. All the insight of the work is displayed arguing the possible implications of VR games in the SCI rehabilitation settings.

5.1 Evaluation with healthy subjects

For the preliminary work a questionnaire was developed to be answered by healthy players. The players were requested to fill a questionnaire after playing the upper body part equilibrium training mini-game to provide feedback on their experience in using the application.

The questionnaire (Appendix IV: Questionnaire) was divided in 5 different sections:

1. General questions focused on the patient's familiarity with computers, computer games and virtual and augmented reality. The players were requested to respond to the statements in the questionnaire with "I strongly agree / agree / neutral /disagree / strongly disagree ".
2. Questions regarding the level of satisfaction or discomfort players experienced during the game execution.
3. Questions focused on the player's opinions about the game, its usability and possibilities in rehabilitation applications.
4. Questions regarding setup of the social environment (individual or in a group
5. Open questions and suggestions for changes in the existing game.

Before answering the questions a short paragraph about the aim of the questionnaire was introduced to the players:

"This questionnaire is made to evaluate the usability of the game for equilibrium training of upper body. This game should motivate stroke and paraplegic patients to exercise more and regularly. After the initial tests with the students the game will be further tested with real patients in the Rovisco Pais rehabilitation center."

In total 9 participants (students) tested the game, of which 6 were female and 3 were male. All the testers were between 20 and 26 years old. In the testing procedure, first the game was tried as a single play, where only one person is trying to accomplish a set goal. After the single session, the players played the game once again, but this time with an opponent. When played as a competition, the winner is the one who first drives the whole driving route. Results of the questionnaire are presented below.

5.1.1 Questions focused on establishing the player's familiarity with computers

As expected all testers used the computer daily (Figure 32). Most them were also familiar with a virtual and augmented reality (Figure 34). Half of the testers were familiar with video games (Figure 33).

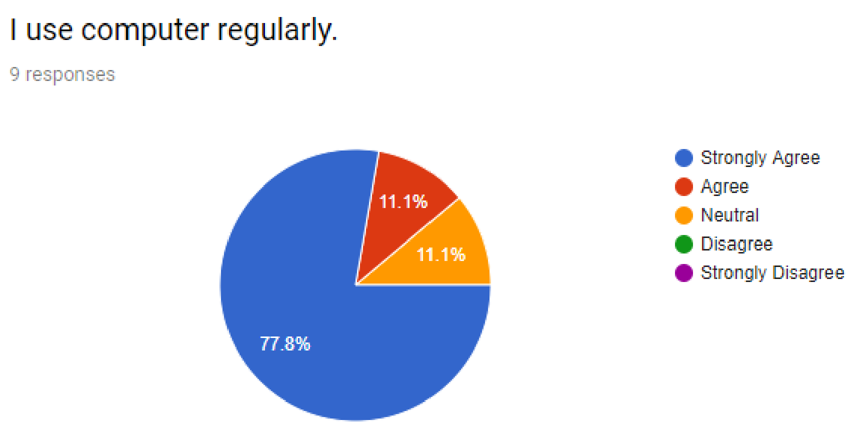


Figure 32: Computer usage results

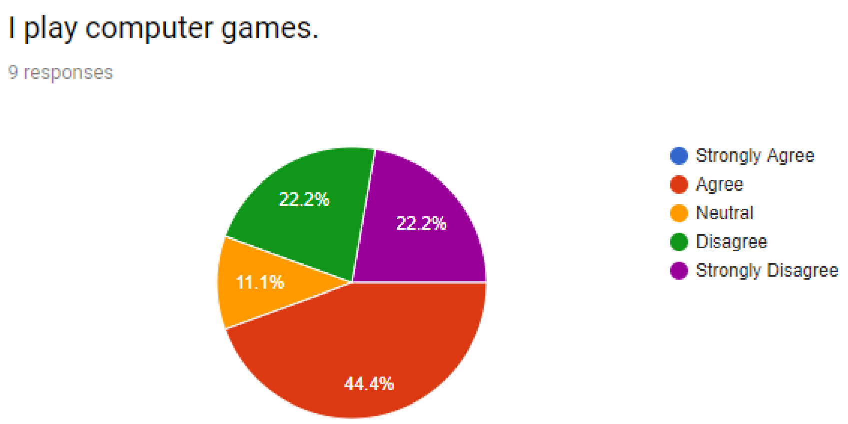


Figure 33: Gameplay results

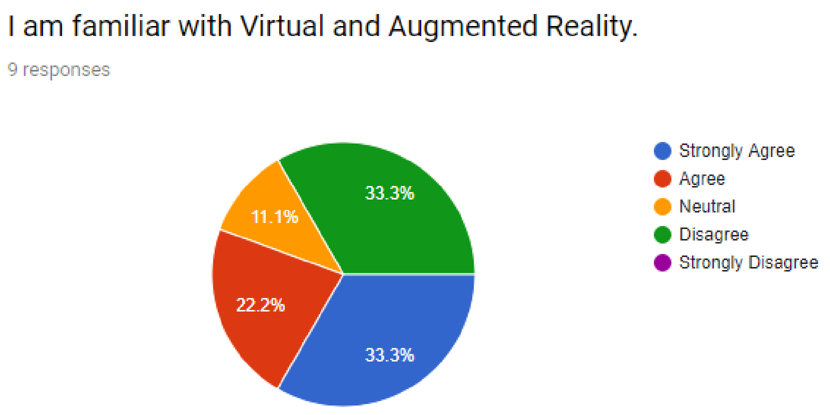


Figure 34: Familiarity with AR and VR results

5.1.2 Questions regarding the level of satisfaction

Most of the participants reported that it was not easy to control the car with their bodies (Figure 36) and suggested to implement a better and more precise control mechanism. Supposedly, because of the difficulties with the controlling the vehicle only 11% of testers reached the set target in the game (Figure 37). Players also reported a slight level of frustration (Figure 38) during the gameplay, which again can be assigned to extremely sensitive control mechanism. Players did not feel any discomfort during the gameplay (Figure 35).

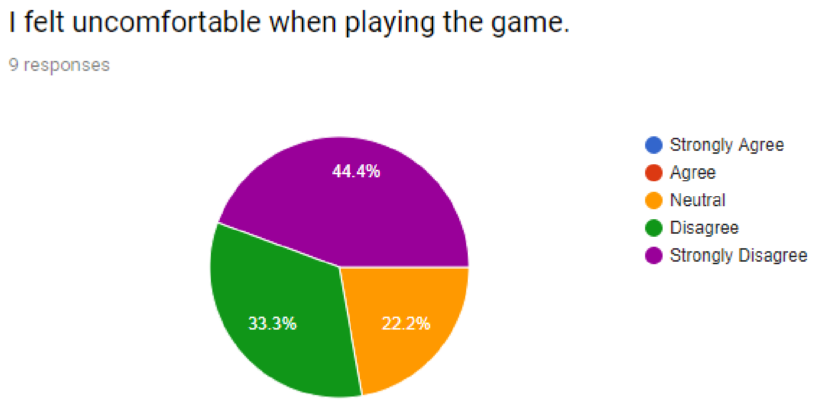


Figure 35: Comfort feeling results

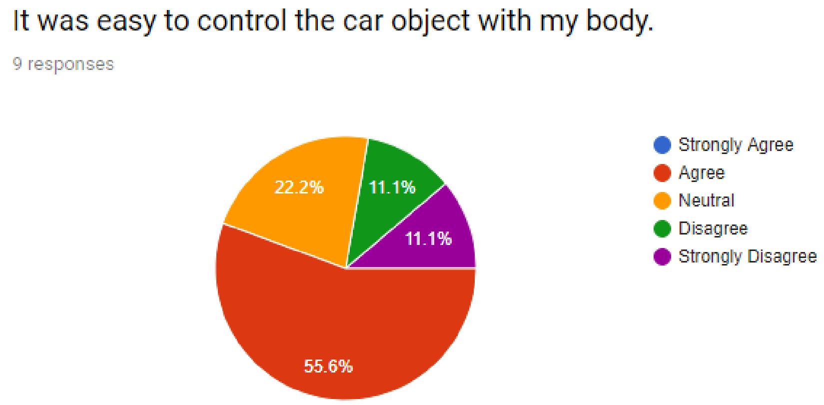


Figure 36: Ease of use results

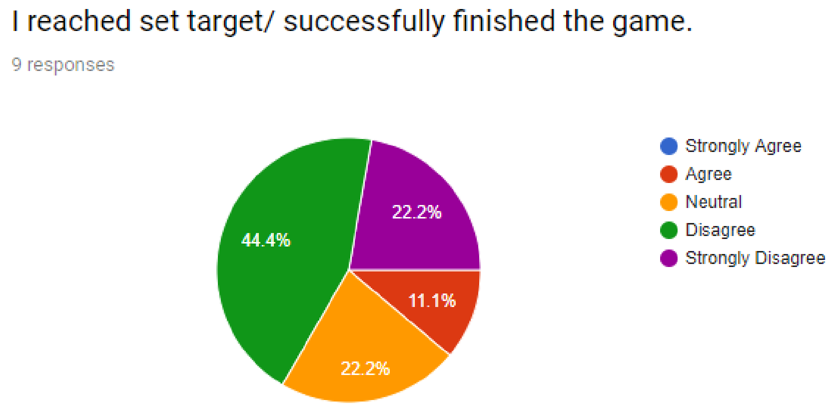


Figure 37: Success achievement results

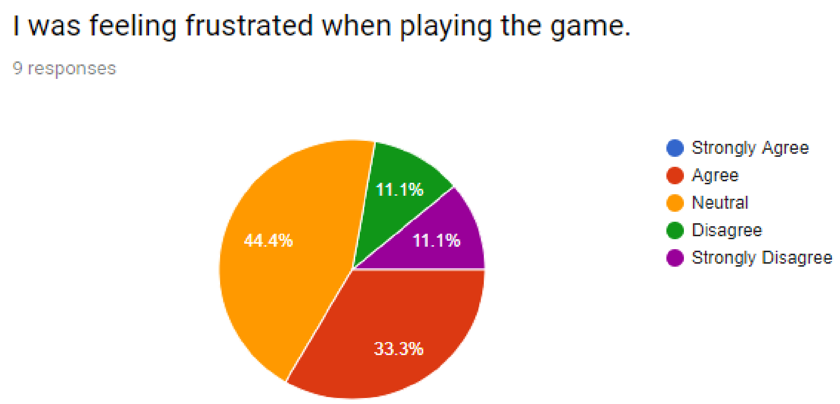


Figure 38: Feeling of frustration results

5.1.3 Questions regarding opinion about the game usability

Most of the players enjoyed playing the game (Figure 40), but they mentioned that significant modifications regarding the content should be made to make the game more interesting for play. Therefore, only half of the players stated that they would play again the game at home environment (Figure 39).

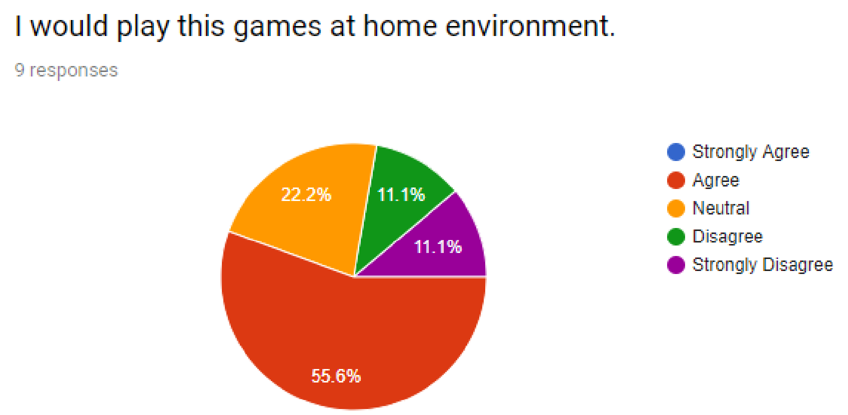


Figure 39: Engagement results

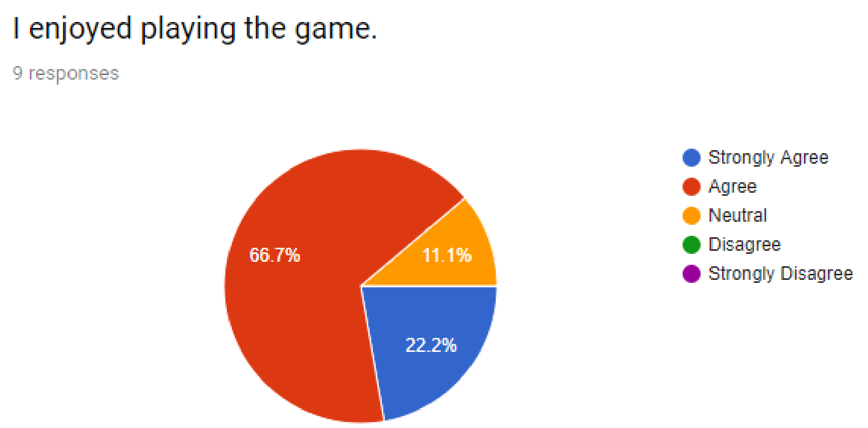


Figure 40: Enjoyment results

5.1.4 Questions regarding the social environment setup

There was consensus regarding the question about the single play versus multiplayer. All the participants reported that they enjoyed the game more when played with another person (Figure 41 and Figure 42).

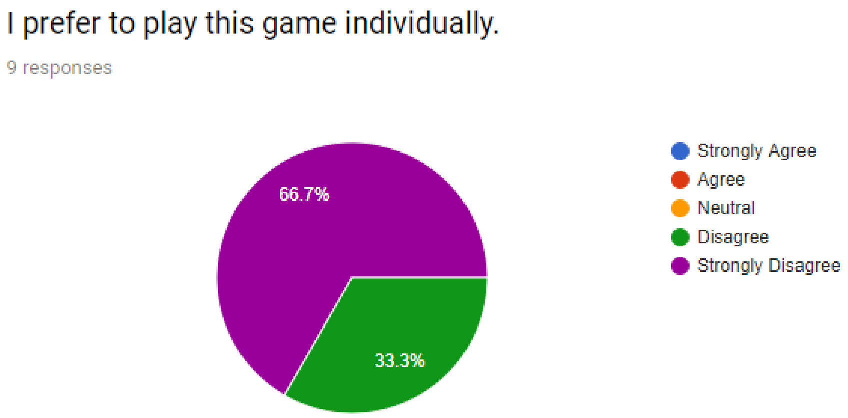


Figure 41: Single play preferences results

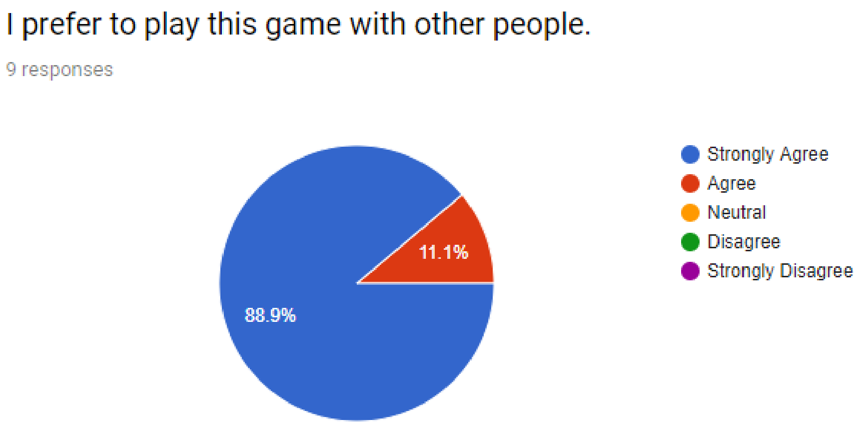


Figure 42: Multiplayer preference results

To conclude, from the questionnaire it is clear that the game is far from finished but an important notice about social setting was made. All the players prefer to play it in a social environment. Therefore it was decided to produce a new game that will be played in two-player competitive mode. The new game was adapted from the open source game called “Tanks” developed by Unity. It was decide to use that game, because it had already implemented an interesting environment and internal logics. Avatars in the game were adapted to be controlled by upper body part that is tracked with the Kinect v2.

5.2 Adaptation of the “Tanks” open source game from Unity

A detailed description of the adapted game can be seen in the Appendix X: “Tanks” adapted game. In the adapted games the players can control the avatars with the same gestures as in the upper body equilibrium training mini-game (4.6 Upper body balance training mini-game). The game is about a war in a dessert. The war is between 2 opponents. The objective of the game is to win the war. To win the war a player has to kill the opponent for a predefined number of fights. The number of winning fights can be configured by the players. The colors of the tanks can be customized by players as well.

Player in the game is a tank driver. The tanks in a game are controlled with the upper body part of the player. Player is able to drive the tank in a game by inclining the body in 4 directions: back, forward, left and right side. Furthermore, player can shoot the other player (tank) when he/she raises his left hand above the neck level. On the Figure 43 the user interface of the adapted game is displayed, where on the Figure 44 are shown the testing of the game with the patients in the rehabilitation center.

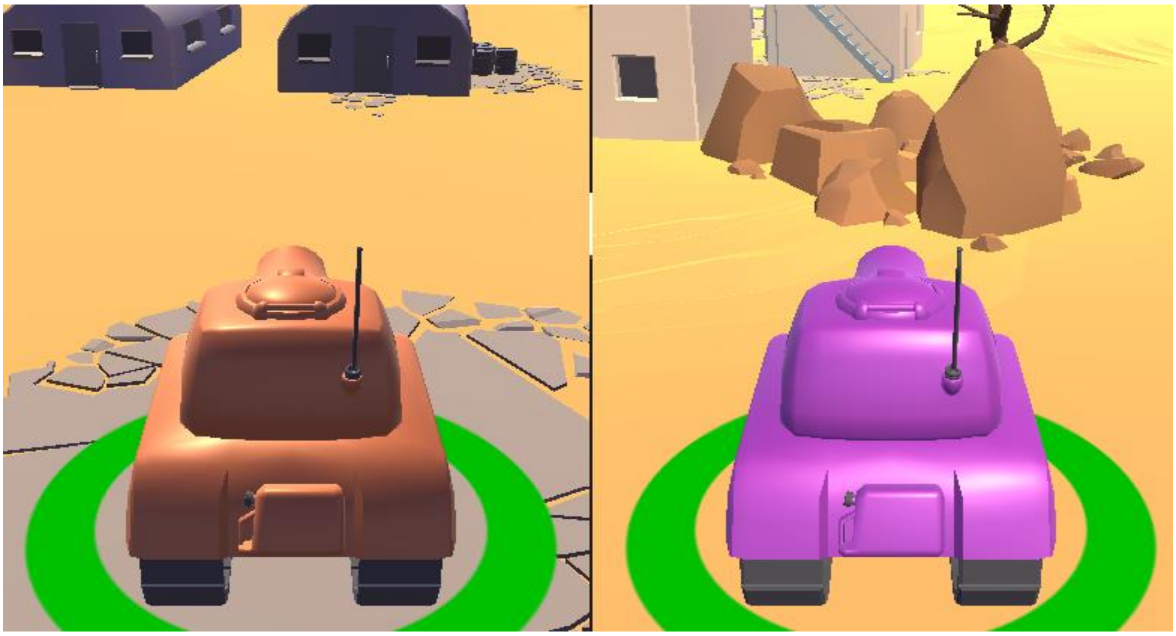


Figure 43: "Tanks" adapted mini-game

5.3 Evaluation with patients

The doctors and therapists from the Rovisco Pais rehabilitation center have agreed to evaluate the usability of the adapted mini-game “Tanks”. The game was tested by 6 male SCI patients that satisfied the inclusion criteria. The testing of the mini-game was performed with the supervision of one therapist and a doctor. Prior to the testing, an Ethics Committee (Appendix IIX: Formal Study Request to Ethics Committee) approval was obtained. The Ethics Committee ensured that the experiment and human research was carried out in an ethical manner in accordance with national and international law.

Inclusion and exclusion conditions are a fundamental issue for any application that is to be used by these patients in their rehabilitation program and thus doctors and physical therapist established the following criteria for patients' usage of such a game:
Inclusion criteria:

- patients with medullary lesions below T6, complete or incomplete
- patients with incomplete medullary lesions above T6

Exclusion criteria:

- patients with preserved torso equilibrium
- patients with complete medullary lesions above T6

For detailed explanation of the lesion levels, please see the Appendix IX International standards for neurological classification of Spinal Cord Injury.
The experiment was performed according to the protocol described in the Appendix XI: Observer guide. A game used for the experiment was adapted from the "Tanks"[14] mini-game. In the experiment, patients were asked to first, play the game alone in order to get familiar with the controls of the avatar and environment. After that, patients were instructed to play the game with the tester, in a two-player competitive mode. In the experiment, subjects were seated on the normal chair or in a wheelchair.

Figure 44: Testing of the adapted "Tanks" mini-game

After the accomplished goal of the game, patients were proposed to fill the same questionnaire as answered by the healthy subjects. The results of testing are presented below.

[14] https://unity3d.com/learn/tutorials/s/tanks-tutorial (accessed June 7,2018)

5.2.1 Questions focused on establishing the patient's familiarity with computers

Most of the patients that participated in the experiment were not at all familiar with computers (Figure 45). Two thirds of the patients had never played computer games (Figure 46). Only half of the patients were familiar with the concept of Virtual Reality (Figure 47).

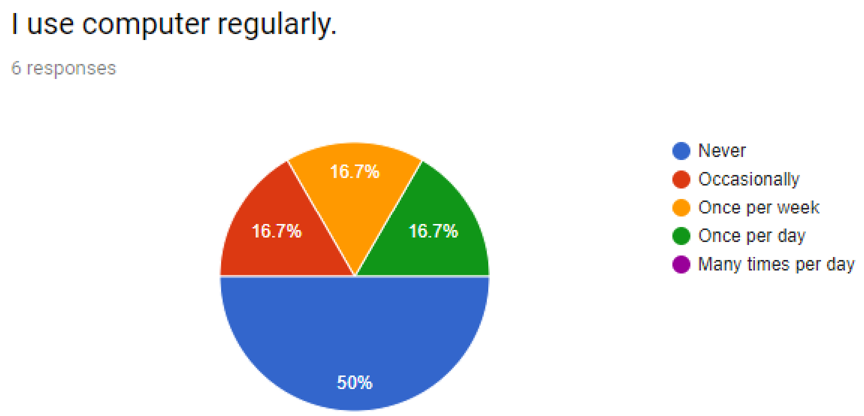


Figure 45: Computer usage results

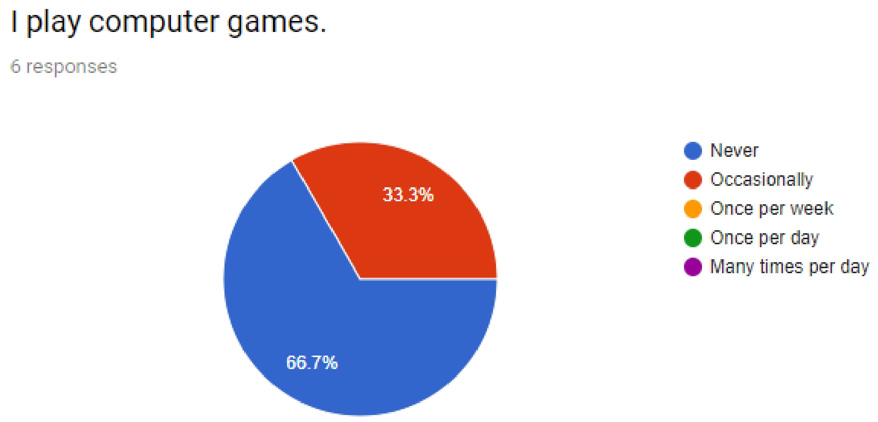


Figure 46: Gameplay results

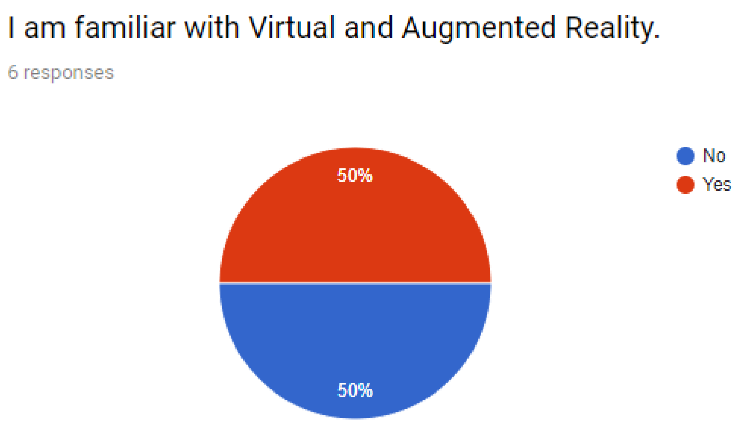


Figure 47: Familiarity with AR and VR results

5.2.2 Questions regarding the level of satisfaction

The adapted game compared to previously created mini-game was more engaging and easier to play. All the patients reported that they felt comfortable during the gameplay (Figure 48). Even though the control of the vehicle was still challenging (Figure 49), it was much better compared to the control in the previous mini-game tested by healthy subjects. All the patients reported that they had successfully finished the game (Figure 50). None of the patients reported the feeling of frustration during the gameplay (Figure 51).

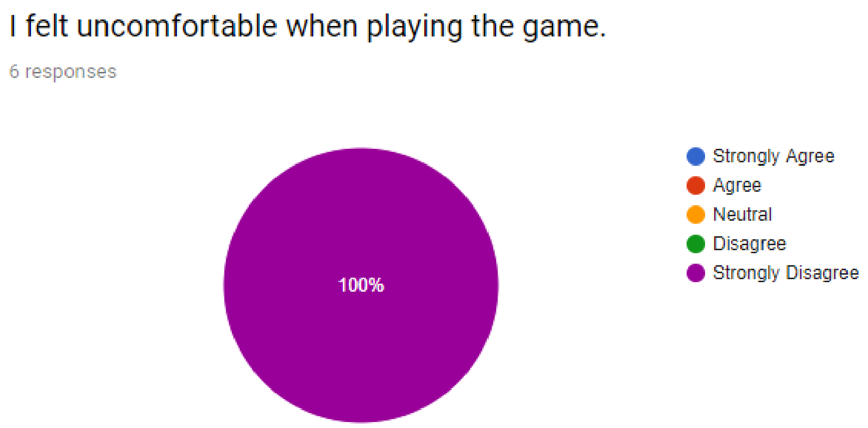


Figure 48: Comfort feeling results

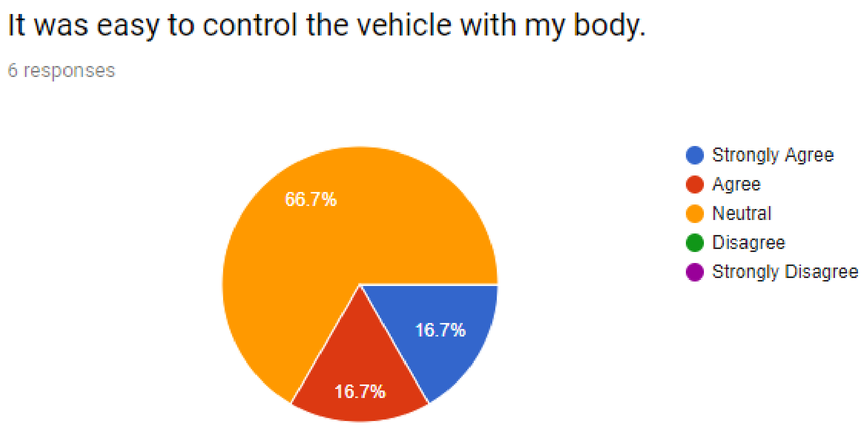


Figure 49: Ease of use results

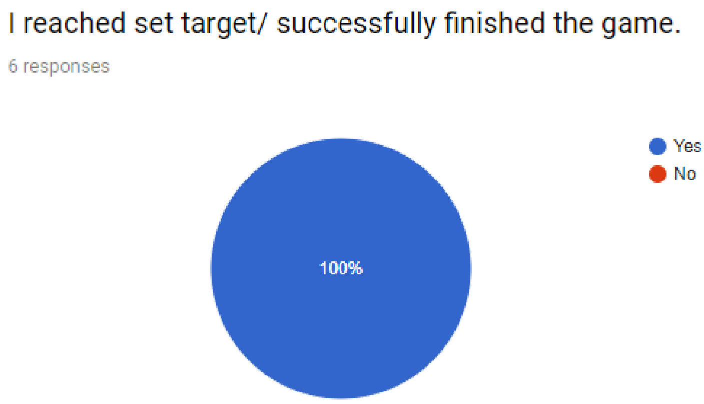


Figure 50: Success achievement results

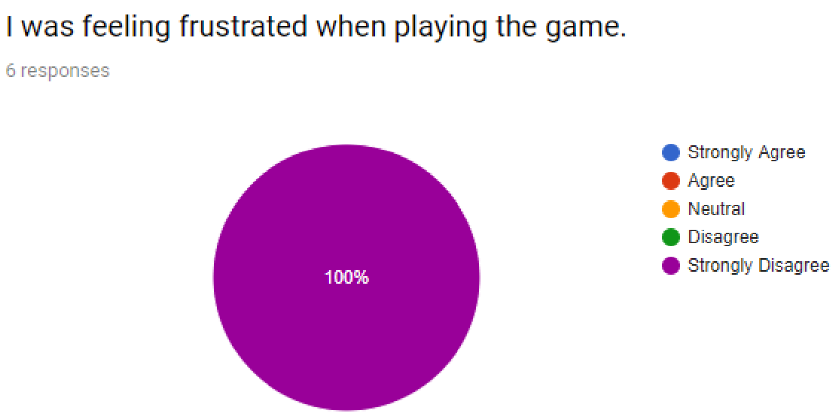


Figure 51: Feeling of frustration results

5.2.3 Questions regarding opinion about the game usability

All the patients agreed that they would play the adapted mini-game “Tanks” at home (Figure 52). All the patients reported that they enjoyed the gameplay (Figure 53) and stated that this type of game (that includes upper body part movements) can be very useful in the balance rehabilitation of the trunk (Figure 54).

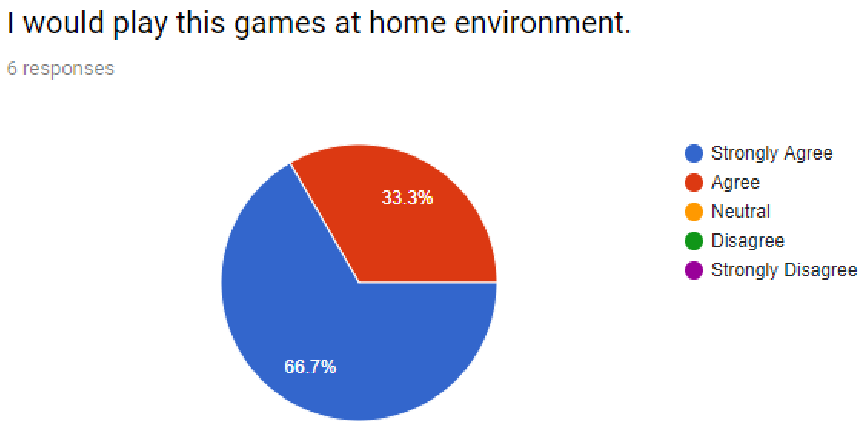


Figure 52: Engagement results

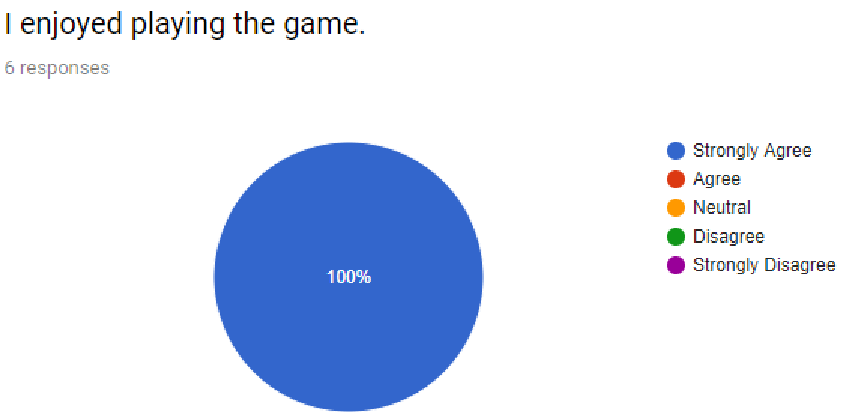


Figure 53: Enjoyment results

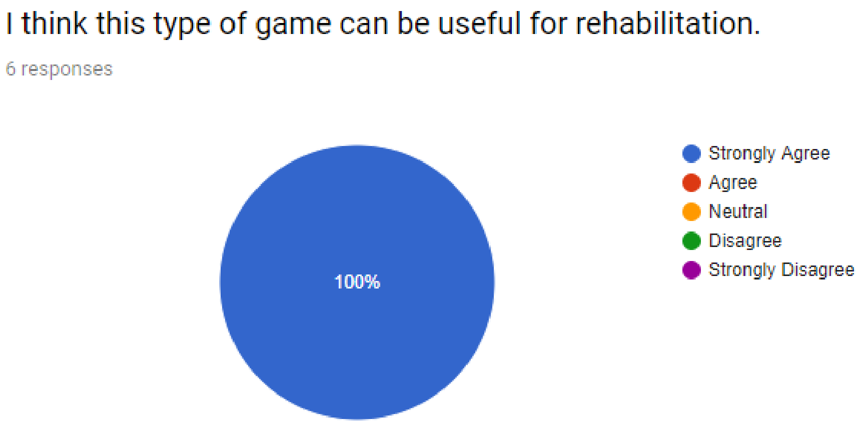


Figure 54: Opinion about usability results

5.2.4 Questions regarding the social environment setup

All the patients agreed that they prefer to play the game in the two-player competitive mode (Figure 55). The gameplay proved to be a fun and enjoyable experience for most of the patients. Some patients expressed that it would be fun to play this game online with many people (more than 2) that struggle with the SCI condition.

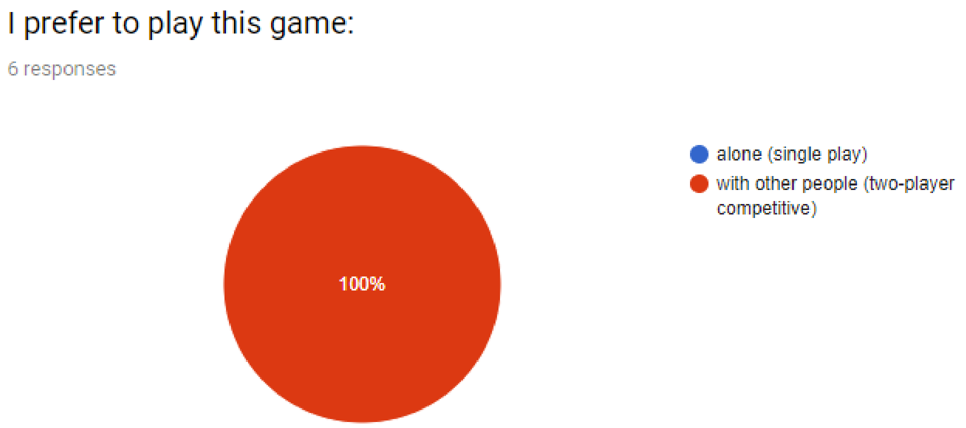


Figure 55: Gameplay mode preferences results

Therapists supervisioning the experiment proposed to create a progression loop, in the terms of the skill progression and core progression loop (2.6 Fundamentals of game design). They proposed to start the gameplay using the gestures that are easier to perform and than slightly increase the complexity of gestures. Therapists also proposed to implement a more interesting content and game levels, to make the gameplay longer and more engaiging. Furthermore, the players must be seated in a wheelchair while playing the game, since in case of balance loss, patients are secured from falls in this type of chair. Besides, therapist also proposed to use simpler gestures both with trunk or hands for the control of the avatrs in the game. Trunk gestures proved to be challanging for the patients to perform. They also proposed to implement a calibration for each patient in order to estimate his/her movements abilities and adapt the control of the avatar according to them.

5.3 Discussion

The first task in this work was the identification of the problems the therapists and clinicians are facing today in physical rehabilitation. In order to identify these problems, a case study was performed specifically for the Rovisco Pais rehabilitation center After identifying the problems, the work was focused on how to minimize them using Virtual Reality. Prior to the implementation of mini-games, a preliminary study was performed to assess the possibilities of the Kinect v2 sensor. This preliminary work confirmed that it is possible to use Kinect v2 but only in certain scenarios. For upper body equilibrium it was adequate, but for precise monitoring of a gait cycle parameters a more sophisticated device should be used.

A one day visit was arranged with the center to observe the recovery exercises the patients usually perform. Based on the study and previous research, it was concluded that a game for upper body part equilibrium training would be a good option. In the designed mini-game, a player is controlling a vehicle only using the upper body part. The designed mini-game implements the concepts of motivation: reward, optimal challenge, feedback, choice and interactivity, clear instructions and socialization and proved to be much more engaging when played in a two-player competitive. Literature confirms as well that the social aspects in rehabilitation are extremely important. In the mini-game, patients can choose themselves the target they want to reach.

A preliminary study was completed with 9 healthy people before testing the mini-game with the 6 patients. This preliminary study suggested that the control of the vehicle was hard and should be further improved. Additionally, healthy testers suggested that a more rich content would be better for the overall engagement in the game. Based on their feedback, an open source game “Tanks” from Unity was adapted to be used with the Kinect v2. The control of the vehicle in this game was improved as well. Tests of the adapted game with patients showed that they enjoyed the gameplay and had an entertaining experience. Furthermore, the patients asked if it would be possible to install the adapted game in the rehabilitation center common room space, so they can socialize and play the game in the evening hours. This proves that despite some limitations, the game was well accepted and entertaining.

VI: Conclusion and future work

From the case study of the “Rovisco Pais” rehabilitation center it was concluded that for the effective recovery, it is crucial to start the rehabilitation process, as soon as possible after the incident but because of the lack of therapists, the starting of rehabilitation treatment is often postponed. Therefore, the rehabilitation is not as effective as it would be, if it had started on time.

Based on the studied concepts of game design, it was learned that in order to produce an effective rehabilitation game, the player must be entertained. In case of long lasting games the player should have a feeling of progression through game levels or a storyline. For the development of such a game, a sufficient amount of time and work must be dedicated. Preferably a multidisciplinary team composed of a designer, developer, a doctor and a therapist should work together. Entertainment companies are not interested in the development of the rehabilitation games due to the small size of the target market (small amount of people having SCI, while Stroke patients are generally not familiar with the technology). They are generally focused on building profitable games for bigger audience.

Commercial games can be used by elderly people with balance disorders or some stroke patients for fun and as a distraction from depression. Yet, they are not appropriate for SCI patients, since they require the player to stand.

The main issue with the games designed for rehabilitation is that they are not long lasting in the terms of the attention span . These types of games are usually designed by small teams, not highly professional. Consequently, in such games the player’s interest is lost quite soon. Furthermore the VR games designed for rehabilitation are more exercises that actual games.

Socializing is very important in the recovery process. The obtained results suggest that, when the designed and adapted games in this work were played in two-player competitive mode, players were much more motivated to play.

The current designed/adapted mini-games in the scope of this work can be further improved with the help of doctors and therapist, regarding the specific movements from which the SCI patients would benefit the most. Furthermore, the development should also focus on quality gameplay development that is adapted to the patient desires. A possible direction could be as well taking successful open source games and adapting them for the Spinal Cord Injury patients. In this way it would be possible to have a good design and an engaging content but also the possibility to control the game using relevant upper body movements and implement, calibration, personalization to the patient’s needs and preferences, and logging relevant parameters for recovery monitoring.

Finally, from the performed proof of concept, it was concluded that Kinect v2 motion sensor doesn't provide with enough accuracy to reliably measure the gait cycle parameters such as step size, stride size, velocity and cadence, because of the occluded parts of the body or space limitations. However, skeleton tracking that Kinect v2 provides is good enough for interactive game design where the high accuracy is not mandatory and the person can perform the required moves in the restricted space (4x4m).
To conclude, any game should provide an entertaining experience. Therefore in the future work of this project the games build for the rehabilitation purposes should implement the game design principles and have a strong focus on the content.

References

[1] J. Jason, *The VR Book: Human-Centered Design for Virtual Reality.* Berkley, CA: 2015.

[2] E. Knippenberg, J. Verbrugghe, I. Lamers, S. Palmaers, A. Timmermans, and A. Spooren, “Markerless motion capture systems as training device in neurological rehabilitation: A systematic review of their use, application, target population and efficacy,” J. Neuroeng. *Rehabil*., vol. 14, no. 1, pp. 1–11, 2017.

[3] F. Malouin, C. L. Richards, B. McFadyen, and J. Doyon, “New perspectives of locomotor rehabilitation after strokel,” Medecine/Sciences, vol. 19, no. 10, pp. 994–998, 2003.

[4] K. Sathian et al., “Neurological Principles and Rehabilitation of Action Disorders,” Neurorehabil. Neural Repair, vol. 5, no. 5, pp. 21S–32S, 2011.

[5] J. Kim, J. Son, N. Ko, and B. Yoon, “Unsupervised virtual reality-based exercise program improves hip muscle strength and balance control in older adults: A pilot study,” *Arch. Phys. Med. Rehabil.*, vol. 94, no. 5, pp. 937–943, 2013.

[6] A. Viau, A. G. Feldman, B. J. McFadyen, and M. F. Levin, “Reaching in reality and virtual reality: A comparison of movement kinematics in healthy subjects and in adults with hemiparesis,” J. Neuroeng. Rehabil., vol. 1, pp. 1–7, 2004.

[7] H. Sveistrup, “Motor rehabilitation using virtual reality,” J. Neuroeng. Rehabil., vol. 1, pp. 1–8, 2004.

[8] K. D. Kochanek, J.Q. Xu, S. L. Murphy, E. Arias, “Mortality in the United States, 2013. NCHS Data Brief,” No. 178. Hyattsville, MD: National Center for Health Statistics, Centers for Disease Control and Prevention, Department of Health and Human Services; 2014

[9] P. Verma, G. J. Augustine, M. R. Ammar, A. Tashiro, and S. M. Cohen, “A neuroprotective role for microRNA miR-1000 mediated by limiting glutamate excitotoxicity,” *Nat. Neurosci.*, vol. 18, no. 3, pp. 379–387, 2015.

[10] N. L. Ifejika-Jones and A. M. Barrett, “Rehabilitation-Emerging Technologies, Innovative Therapies, and Future Objectives,” Neurotherapeutics, vol. 8, no. 3, pp. 452–462, 2011.

[11] P. Langhorne and P. Duncan, “Does the organization of postacute stroke care really matter?” Stroke, vol. 32, no. 1, pp. 268–274, 2001.

[12] G. J. Hankey and C. P. Warlow, “Treatment and secondary prevention of stroke: evidence, costs, and effects on individuals and populations,” Lancet, vol. 354, no. 9188, pp. 1457–1463, 1999.

[13] G. Kwakkel et al., “Effects of augmented exercise therapy time after stroke: A meta-analysis,” Stroke, vol. 35, no. 11, pp. 2529–2536, 2004.

[14] M. Glanz, S. Klawansky, W. Stason, C. Berkey, and T. C. Chalmers, “Functional electrostimulation in poststroke rehabilitation: a meta-analysis of the randomized controlled trials,” Arch. Phys. Med. Rehabil., vol. 77, no. 6, pp. 549–553, 1996.

[15] Y. Tekeolu, B. Adak, and T. Göksoy, “Effect of transcutaneous electrical nerve stimulation (TENS) on Barthel Activities of Daily Living (ADL) Index score following stroke,” Clin. Rehabil., vol. 12, no. 4, pp. 277–280, 1998.

[16] M. B. Holm, “Our Mandate for the New Millennium: Evidence-Based Practice Evidence-Based Practice,” Am. J. Occup. Ther., vol. 54, no. 607, pp. 575–585, 2000.

[17] J. W. McDonald, D. Becker, and J. Huettner, “Spinal Cord Injury,” in Handbook of Stem Cells, Elsevier, 2013, pp. 723–738.

[18] A. Piccoli et al., “Immersive Virtual Reality for individuals with spinal cord injuries,” Syst. Appl. Technol. Conf. (LISAT), 2017 IEEE Long Isl., pp. 1–10, 2017.

[19] N. M. Crewe and J. S. Krause, “Spinal Cord Injury,” in *Medical, Psychosocial and Vocational Aspects of Disability Third Edition,* Athens: Elliott & Fitzpatrick, Inc., 2009, p. 299.

[20] M. Roosink and C. Mercier, "Virtual feedback for motor and pain rehabilitation after spinal cord injury", Spinal Cord, vol. 52, no. 12, pp. 860-866, 2014.

[21] D. Huang, Y. Mao, P. Chen, and L. Li, “Virtual reality training improves balance function,” Neural Regen. Res., vol. 9, no. 17, p. 1628, 2014.

[22] D. A. E. Bolton, K. E. Brown, W. E. McIlroy, and W. R. Staines, “Transient inhibition of the dorsolateral prefrontal cortex disrupts somatosensory modulation during standing balance as measured by electroencephalography,” *Neuroreport*, vol. 23, no. 6, pp. 369–372, 2012.

[23] I. Stepniewska, P.-C. Fang, and J. H. Kaas, “Microstimulation reveals specialized subregions for different complex movements in posterior parietal cortex of prosimian galagos,” Proc. Natl. Acad. Sci., vol. 102, no. 13, pp. 4878–4883, 2005.

[24] V. Gallese, M. N. Eagle, and P. Migone, “Intentional Attunement: Mirror Neurons and the Neural Underpinnings of Interpersonal Relations,” *J. Am. Psychoanal. Assoc*., vol. 55, no. 1, pp. 131–175, 2007.

[25] D. Shi, “Effect of anterior cruciate ligament reconstruction on biomechanical features of knee level in walking: a meta-analysis,” *Chinese Medical Journal,* vol. 123, no. 21, pp. 3137-3142, Nov 2010.

[26] C. L. Vaughan, B. L. Davis, and J. C. O’Connor, *The Three-Dimensional and Cyclic Nature of Gait*. 1999.

[27] N. D. Neckel, N. Blonien, D. Nichols, and J. Hidler, “Abnormal joint torque patterns exhibited by chronic stroke subjects while walking with a prescribed physiological gait pattern.,” *J. Neuroeng. Rehabil*., vol. 5, p. 19, 2008.

[28] X. Xu, R. W. McGorry, L. S. Chou, J. hua Lin, and C. chi Chang, “Accuracy of the Microsoft Kinect TM for measuring gait parameters during treadmill walking,” *Gait Posture*, vol. 42, no. 2, pp. 145–151, 2015.

[29] J. M. Fabre, R. Ellis, M. Kosma, and R. H. Wood, “Falls risk factors and a compendium of falls risk screening instruments,” *J. Geriatr. Phys. Ther.*, vol. 33, no. 4, pp. 184–197, 2010.
[30] H. P. von Schroeder, R. D. Coutts, P. D. Lyden, E. Billings, and V. L. Nickel, “Gait parameters following stroke: a practical assessment.,” *J. Rehabil. Res. Dev.*, vol. 32, no. 1, pp. 25–31, 1995.
[31] S. Downs, “The Berg Balance Scale,” *J. Physiother.*, vol. 61, no. 1, p. 46, 2015.
[32] A. A. A. Timmermans et al., “T-TOAT: A method of task-oriented arm training for stroke patients suitable for implementation of exercises in rehabilitation technology,” 2009 IEEE Int. Conf. Rehabil. Robot. ICORR 2009, pp. 98–102, 2009.
[33] R. P. Van Peppen, G. Kwakkel, S. Wood-Dauphinee, H. J. Hendriks, P. J. Van der Wees, and J. Dekker, “The impact of physical therapy on functional outcomes after stroke: what’s the evidence?” *Clin. Rehabil*., vol. 18, no. 8, pp. 833–862, 2004.
[34] G. Saposnik and M. Levin, “Virtual reality in stroke rehabilitation: A meta-analysis and implications for clinicians,” *Stroke,* vol. 42, no. 5, pp. 1380–1386, 2011.
[35] D. S. P. Schubert, C. Taylor, S. Lee, A. Mentari, and W. Tamaklo, “Detection of Depression in the Stroke Patient,” *Psychosomatics*, vol. 33, no. 3, pp. 290–294, 1992.
[36] K. Lohse, N. Shirzad, A. Verster, N. Hodges, and H. F. M. Van der Loos, “Video Games and Rehabilitation,” *J. Neurol. Phys. Ther*., vol. 37, no. 4, pp. 166–175, 2013.
[37] K. E. Hinshaw, “The Effects of Mental Practice on Motor Skill Performance: Critical Evaluation and Meta-Analysis,” *Imagin. Cogn. Pers.*, vol. 11, no. 1, pp. 3–35, 1991.
[38] S. N. Haber and B. Knutson, “The reward circuit: Linking primate anatomy and human imaging,” Neuropsychopharmacology, vol. 35, no. 1, pp. 4–26, 2010.
[39] S. Chiviacowsky and G. Wulf, “Feedback after good trials enhances learning,” *Res. Q. Exerc. Sport*, vol. 78, no. 2, pp. 40–47, 2007.
[40] [1] S. Chiviacowsky and G. Wulf, “Self-controlled feedback is effective if it is based on the learner ’ s performance .(Motor Control and Learning) Self-controlled feedback is effective if it is based on the learner ’ s performance .(Motor Control and Learning),” *Res. Q. Exerc. Sport* ,vol. 76, no. March, pp. 1–8, 2005.
[41] F. Seay, W. J. Jerome, K. S. Lee, and R. E. Kraut, “Project Massive: A Study of Online Gaming Communities,” Ext. Abstr. 2004 Conf. Hum. factors Comput. Syst. - CHI ’04, p. 1421, 2004.
[42] N. Ravaja et al., “The psychophysiology of video gaming: Phasic emotional responses to game,” DiGRA 2005 Conf. Chang. ViewsWorlds Play, no. January 2005, pp. 1–13, 2005.
[43] M. Csikszentmihalyi, I. Csikszentmihalyi, “Beyond Boredom and Anxiety.” San Francisco, CA, Jossey-Bass Publishers, 1975.
[44] M. Wyndaele and J. J. Wyndaele, “Incidence, prevalence and epidemiology of spinal cord injury: What learns a worldwide literature survey?,” *Spinal Cord*, vol. 44, no. 9, pp. 523–

529, 2006. [45] L. Beaulieu, “Balance Rehabilitation using Xbox Kinect among an Elderly Population: A Pilot Study,” *J. Nov. Physiother.*, vol. 05, no. 02, pp. 2–6, 2015.

[46] R. Silva, “Virtual Reality in post-stroke upper limb rehabilitation: serious games using Hand Tracking,” MSc Dissertation, University of Aveiro, 2017.

[47] Z. Zhang, “Microsoft kinect sensor and its effect,” IEEE Multimedia., vol. 19, no. 02, pp. 4-10, 2012.

[48] S. Giancola and P. Milano, “Accuracy of the Microsoft Kinect System in the Identification of the Body Posture,” Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering book series (LNICST), vol. 192, pp 289-296, 2016.

[49] K. Thomson, A. Pollock, C. Bugge, and M. Brady, “Systematic review Commercial gaming devices for stroke upper limb rehabilitation: A systematic review,” *International Journal of Stroke,* vol. 9, no. June, pp. 479–488, 2014.

[50] H. P. von Schroeder, R. D. Coutts, P. D. Lyden, E. Billings, and V. L. Nickel, “Gait parameters following stroke: a practical assessment.,” *J. Rehabil. Res. Dev.*, vol. 32, no. 1, pp. 25–31, 1995.

Appendices

Appendix I: Skeleton tracking scripts

I.1 Body Manager Script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Windows.Kinect;

public class BodyManager : MonoBehaviour {


    private KinectSensor _Sensor;
    private BodyFrameReader _Reader;
    private Body[] _Data = null;

    public Body[] GetData()
    {
        return _Data;
    }
    // Use this for initialization
    void Start () {
        _Sensor = KinectSensor.GetDefault();

        if (_Sensor != null)
        {
            _Reader = _Sensor.BodyFrameSource.OpenReader();

            if (!_Sensor.IsOpen)
            {
                _Sensor.Open();
            }
        }
    }
```

```
        // Update is called once per frame, getting data from the sensor
        void Update () {
        if (_Reader != null)
        {
            var frame = _Reader.AcquireLatestFrame();
            if (frame != null)
            {
                if (_Data == null)
                {
                    _Data = new Body[_Sensor.BodyFrameSource.BodyCount];
                }
                frame.GetAndRefreshBodyData(_Data);

                frame.Dispose();
                frame = null;
            }
        }
    }
    void OnApplicationQuit()
    {
        if (_Reader != null)
        {
            _Reader.Dispose();
            _Reader = null;
        }

        if (_Sensor != null)
        {
            if (_Sensor.IsOpen)
            {
                _Sensor.Close();
            }

            _Sensor = null;
        }
    }
}
```

I.2 Body View Script

```
using System.Collections.Generic;
using UnityEngine;


public class BodyView : MonoBehaviour
{

    public Material BoneMaterial;
    public GameObject BodyManager;
    //create a Dictionary<key, value> type class to store the bodies that are tracked
    //ulong ,range: 0 to 18,446,744,073,709,551,615 definition:Unsigned 64-bit integer
    private Dictionary<ulong, GameObject> _Bodies = new Dictionary<ulong, GameObject>();
    private BodyManager _BodyManager;
    //map out all the bones by the two joints that they will be connected to
    private Dictionary<Windows.Kinect.JointType, Windows.Kinect.JointType> _BoneMap =
new Dictionary<Windows.Kinect.JointType, Windows.Kinect.JointType>()
{
    { Windows.Kinect.JointType.FootLeft, Windows.Kinect.JointType.AnkleLeft },
    { Windows.Kinect.JointType.AnkleLeft, Windows.Kinect.JointType.KneeLeft },
    { Windows.Kinect.JointType.KneeLeft, Windows.Kinect.JointType.HipLeft },
    { Windows.Kinect.JointType.HipLeft, Windows.Kinect.JointType.SpineBase },

    { Windows.Kinect.JointType.FootRight, Windows.Kinect.JointType.AnkleRight },
    { Windows.Kinect.JointType.AnkleRight, Windows.Kinect.JointType.KneeRight },
    { Windows.Kinect.JointType.KneeRight, Windows.Kinect.JointType.HipRight },
    { Windows.Kinect.JointType.HipRight, Windows.Kinect.JointType.SpineBase },

    { Windows.Kinect.JointType.HandTipLeft, Windows.Kinect.JointType.HandLeft }, //Need
this for HandSates
    { Windows.Kinect.JointType.ThumbLeft, Windows.Kinect.JointType.HandLeft },
    { Windows.Kinect.JointType.HandLeft, Windows.Kinect.JointType.WristLeft },
    { Windows.Kinect.JointType.WristLeft, Windows.Kinect.JointType.ElbowLeft },
    { Windows.Kinect.JointType.ElbowLeft, Windows.Kinect.JointType.ShoulderLeft },
```

```
    { Windows.Kinect.JointType.ShoulderLeft, Windows.Kinect.JointType.SpineShoulder },

    { Windows.Kinect.JointType.HandTipRight, Windows.Kinect.JointType.HandRight }, //Needthis for Hand State
    { Windows.Kinect.JointType.ThumbRight, Windows.Kinect.JointType.HandRight },
    { Windows.Kinect.JointType.HandRight, Windows.Kinect.JointType.WristRight },
    { Windows.Kinect.JointType.WristRight, Windows.Kinect.JointType.ElbowRight },
    { Windows.Kinect.JointType.ElbowRight, Windows.Kinect.JointType.ShoulderRight },
    { Windows.Kinect.JointType.ShoulderRight, Windows.Kinect.JointType.SpineShoulder },

    { Windows.Kinect.JointType.SpineBase, Windows.Kinect.JointType.SpineMid },
    { Windows.Kinect.JointType.SpineMid, Windows.Kinect.JointType.SpineShoulder },
    { Windows.Kinect.JointType.SpineShoulder, Windows.Kinect.JointType.Neck },
    { Windows.Kinect.JointType.Neck, Windows.Kinect.JointType.Head },
};
    private object body;

    // Update is called once per frame
    void Update()
    {
        //int state = 0;

        if (BodyManager == null)
        {
            return;
        }

        _BodyManager = BodyManager.GetComponent<BodyManager>();
        if (_BodyManager == null)
        {
            return;
        }

        Windows.Kinect.Body[] data = _BodyManager.GetData();
        if (data == null)
        {
            return;
```

```
}
// get the amount of bodies in the list of tracked bodies
List<ulong> trackedIds = new List<ulong>();
foreach (var body in data)
{
   if (body == null)
   {
      continue;
   }

   if (body.IsTracked)
   {
      trackedIds.Add(body.TrackingId);
   }
}
List<ulong> knownIds = new List<ulong>(_Bodies.Keys);

// First delete untracked bodies
foreach (ulong trackingId in knownIds)
{
   if (!trackedIds.Contains(trackingId))
   {
      Destroy(_Bodies[trackingId]);
      _Bodies.Remove(trackingId);
   }
}

foreach (var body in data)
{
   if (body == null)
   {
      continue;
   }

   if (body.IsTracked)
   {
      if (!_Bodies.ContainsKey(body.TrackingId))
```

```
            {
                _Bodies[body.TrackingId] = CreateBodyObject(body.TrackingId);
            }

            RefreshBodyObject(body, _Bodies[body.TrackingId]);

         }
      }
   }
   private GameObject CreateBodyObject(ulong id)
   {
      GameObject body = new GameObject("Body:" + id);

      for (Windows.Kinect.JointType jt = Windows.Kinect.JointType.SpineBase; jt <=
Windows.Kinect.JointType.ThumbRight; jt++)
      {
         GameObject jointObj = GameObject.CreatePrimitive(PrimitiveType.Cube);

         LineRenderer lr = jointObj.AddComponent<LineRenderer>();
         lr.SetVertexCount(2);
         lr.material = BoneMaterial;
         lr.SetWidth(0.05f, 0.05f);
         jointObj.transform.localScale = new Vector3(0.3f, 0.3f, 0.3f);
         jointObj.name = jt.ToString();
         jointObj.transform.parent = body.transform;
      }
      return body;
   }

   private void RefreshBodyObject(Windows.Kinect.Body body, GameObject bodyObject)
   {
      for (Windows.Kinect.JointType jt = Windows.Kinect.JointType.SpineBase; jt <=
Windows.Kinect.JointType.ThumbRight; jt++)
      {
         Windows.Kinect.Joint sourceJoint = body.Joints[jt];
         Windows.Kinect.Joint? targetJoint = null;
```

```
            if (_BoneMap.ContainsKey(jt))
            {
                targetJoint = body.Joints[_BoneMap[jt]];
            }

            Transform jointObj = bodyObject.transform.Find(jt.ToString());
            jointObj.localPosition = GetVector3FromJoint(sourceJoint);
            LineRenderer lr = jointObj.GetComponent<LineRenderer>();
            if (targetJoint.HasValue)
            {
                lr.SetPosition(0, jointObj.localPosition);
                lr.SetPosition(1, GetVector3FromJoint(targetJoint.Value));
                lr.SetColors(GetColorForState(sourceJoint.TrackingState),
GetColorForState(targetJoint.Value.TrackingState));
            }
            else
            {
                lr.enabled = false;
            }
        }
    }

    private static Vector3 GetVector3FromJoint(Windows.Kinect.Joint joint)
    {
        return new Vector3(joint.Position.X * 10, joint.Position.Y * 10, joint.Position.Z * 10);
    }
    private static Color GetColorForState(Windows.Kinect.TrackingState state)
    {
        switch (state)
        {
            case Windows.Kinect.TrackingState.Tracked:
                return Color.green;

            case Windows.Kinect.TrackingState.Inferred:
                return Color.red;

            default:
```

```
            return Color.black;
        }
    }
}
```

Appendix II: Berg Balance Scale

Berg Balance Scale

The Berg Balance Scale (BBS) was developed to measure balance among older people with impairment in balance function by assessing the performance of functional tasks. It is a valid instrument used for evaluation of the effectiveness of interventions and for quantitative descriptions of function in clinical practice and research. The BBS has been evaluated in several reliability studies. *A recent study of the BBS, which was completed in Finland, indicates that a change of eight (8) BBS points is required to reveal a genuine change in function between two assessments among older people who are dependent in ADL and living in residential care facilities.*

Description:
14-item scale designed to measure balance of the older adult in a clinical setting.

Equipment needed: Ruler, two standard chairs (one with arm rests, one without), footstool or step, stopwatch or wristwatch, 15 ft walkway

Completion:

Time: 15-20 minutes

Scoring: A five-point scale, ranging from 0-4. "0" indicates the lowest level of function and "4" the highest level of function. Total Score = 56

Interpretation:
41-56 = low fall risk
21-40 = medium fall risk
0 –20 = high fall risk

A change of 8 points is required to reveal a genuine change in function between 2 assessments.

Berg Balance Scale

Name: ______________________________ Date: ____________________

Location: ____________________________ Rater: ____________________

ITEM DESCRIPTION	SCORE (0-4)
Sitting to standing	________
Standing unsupported	________
Sitting unsupported	________
Standing to sitting	________
Transfers	________
Standing with eyes closed	________
Standing with feet together	________
Reaching forward with outstretched arm	________
Retrieving object from floor	________
Turning to look behind	________
Turning 360 degrees	________
Placing alternate foot on stool	________
Standing with one foot in front	________
Standing on one foot	________

Total ________

GENERAL INSTRUCTIONS
Please document each task and/or give instructions as written. When scoring, please record the lowest response category that applies for each item.

In most items, the subject is asked to maintain a given position for a specific time. Progressively more points are deducted if:

- the time or distance requirements are not met
- the subject's performance warrants supervision
- the subject touches an external support or receives assistance from the examiner

Subject should understand that they must maintain their balance while attempting the tasks. The choices of which leg to stand on or how far to reach are left to the subject. Poor judgment will adversely influence the performance and the scoring.

Equipment required for testing is a stopwatch or watch with a second hand, and a ruler or other indicator of 2, 5, and 10 inches. Chairs used during testing should be a reasonable height. Either a step or a stool of average step height may be used for item # 12.

Berg Balance Scale

SITTING TO STANDING
INSTRUCTIONS: Please stand up. Try not to use your hand for support.
( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or stabilize
( ) 0 needs moderate or maximal assist to stand

STANDING UNSUPPORTED
INSTRUCTIONS: Please stand for two minutes without holding on.
( ) 4 able to stand safely for 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unsupported

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL
INSTRUCTIONS: Please sit with arms folded for 2 minutes.
( ) 4 able to sit safely and securely for 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

STANDING TO SITTING
INSTRUCTIONS: Please sit down.
( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assist to sit

TRANSFERS
INSTRUCTIONS: Arrange chair(s) for pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.
( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cuing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

STANDING UNSUPPORTED WITH EYES CLOSED
INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.
( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays safely
( ) 0 needs help to keep from falling

STANDING UNSUPPORTED WITH FEET TOGETHER
INSTRUCTIONS: Place your feet together and stand without holding on.
( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand 1 minute with supervision
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds

Berg Balance Scale continued…

REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING
INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

( ) 4 can reach forward confidently 25 cm (10 inches)
( ) 3 can reach forward 12 cm (5 inches)
( ) 2 can reach forward 5 cm (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/requires external support

PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION
INSTRUCTIONS: Pick up the shoe/slipper, which is in front of your feet.

( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5 cm(1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING
INSTRUCTIONS: Turn to look directly behind you over toward the left shoulder. Repeat to the right. (Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.)

( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

TURN 360 DEGREES
INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cuing
( ) 0 needs assistance while turning

PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED
INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps in > 20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete > 2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

STANDING UNSUPPORTED ONE FOOT IN FRONT
INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width.)

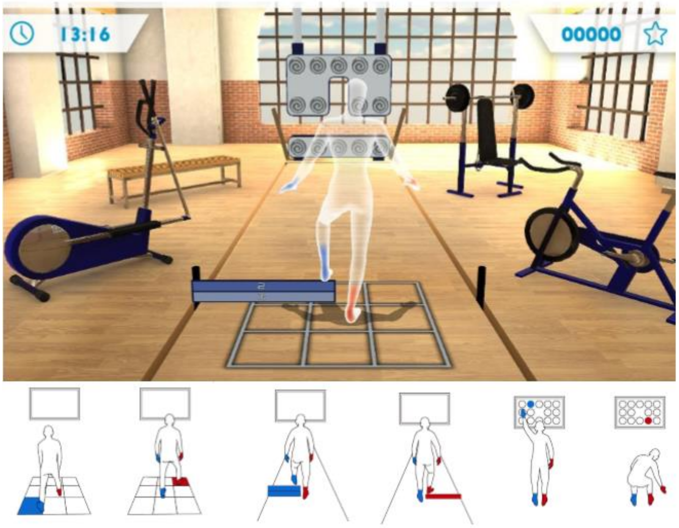
( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds
( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

STANDING ON ONE LEG
INSTRUCTIONS: Stand on one leg as long as you can without holding on.

( ) 4 able to lift leg independently and hold > 10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold ≥ 3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently.
( ) 0 unable to try of needs assist to prevent fall

( ) TOTAL SCORE (Maximum = 56)

BULLSEYES & BARRIERS



The user must intercept the objects that appear on screen with their upper limbs. They must avoid the lower obstacles by raising their feet and they must step on the indicated tiles.

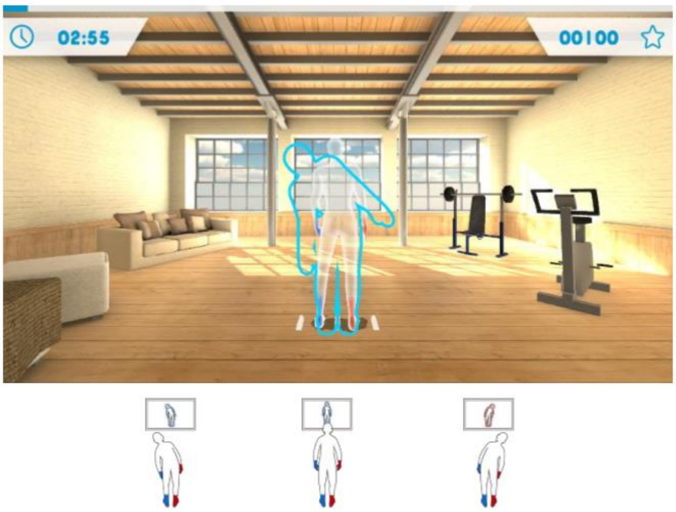
OBJECTIVES

- Balance whilst sitting and standing.
- Load transfer.
- Reaching objects.
- Alignment

MOVEMENT TYPE

- Lateral Trunk inclination
- Elbow and shoulder extension
- Reaching different distances and heights using upper limbs.
- Crossing legs and leg extension

FIT IN THE FIGURE



The user must ensure the avatar shape (aligned with their body) matches the shape shown on screen.

The system forces the user to adopt a vertical position after each movement.

OBJECTIVES

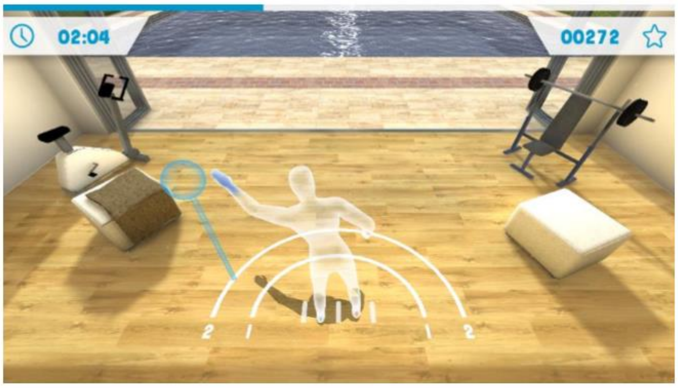
- Balance
- Standing position
- Alignment
- Flexibility
- Load transfer

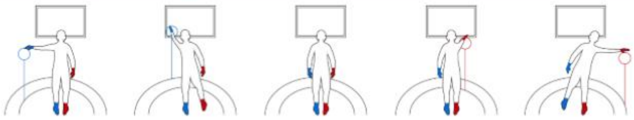
MOVEMENT TYPE

- Lateral Trunk inclination

REACH FOR BALLOONS

VirtualRehab





The user must intercept the balloons across different planes and distances. The balloons follow a colour code which indicates which hand must be used. Can be done sitting or standing.

OBJECTIVES

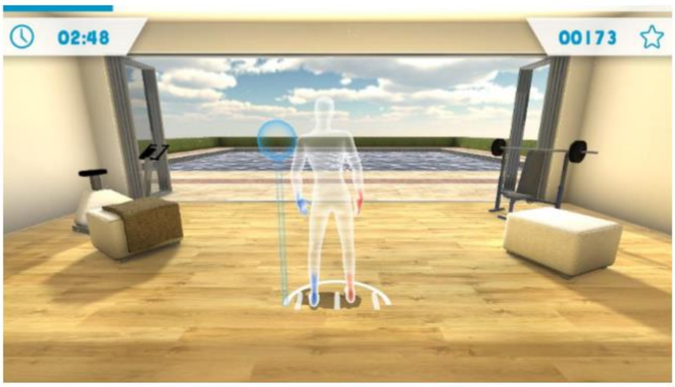
- Balance whilst standing and sitting down, as appropriate.
- Trunk control
- Laterality, body scheme (colour code).
- Load transfer, reaching objects
- Flexibility.
- Hand-eye coordination
- Thrust inhibition.
- Alignment

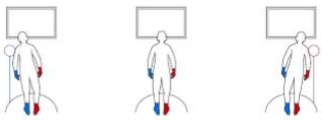
MOVEMENT TYPE

- Lateral Trunk inclination
- Shoulder flexion
- Elbow and shoulder extension

REACH WITH SHOULDERS

VirtualRehab





The user must intercept the balloons which appear on screen using their shoulders. They appear either on the right or the left-hand side, in only one position. There is no colour code

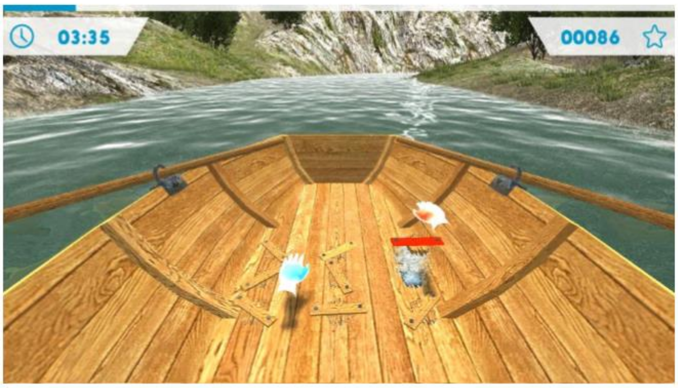
OBJECTIVES

- Similar to the previous exercise, for hemiplegics.
- Specifically helps to work on reaching objects when the arms cannot be moved by using the shoulder to reach the object

MOVEMENT TYPE

- Trunk inclination
- Trunk extension

PLUGGING HOLES IN BOAT



The user only sees the position of their hands. They have to cover the holes that appear in the boat. Both hands are moved independently. There is a colour code.

OBJECTIVES

- Trunk control
- Laterality
- Body scheme (colour code).
- Reaching objects
- Hand-eye coordination

MOVEMENT TYPE

- Reaching different distances and heights with the upper limbs

ROW THE BOAT

The user must row and move their hands in a coordinated and parallel fashion. There is no colour code.

OBJECTIVES

- Bilateral Arm Training (BAT).
- Repeated flexion-extension movements on a horizontal plane with both upper limbs to activate both cerebral hemispheres.
- The patient can use a bar to facilitate the movement of the unaffected upper limb.

MOVEMENT TYPE

- Shoulder flexion and elbow flexion-extension movements coordinated with both upper limbs

BAIL OUT THE WATER

The user must bail the water out of the boat using the pump, which is activated by moving the hands in a parallel but inverted fashion. There is no colour code.

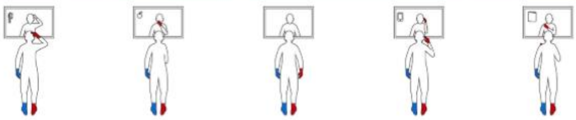
OBJECTIVES

- Trunk control.
- Laterality
- Body scheme(color code)
- Reaching objects.
- Hand-eye coordination.

MOVEMENT TYPE

- Bilateral Arm Training (BAT).
- Repeated flexion-extension movements on a horizontal plane with both upper limbs to activate both cerebral hemispheres. One arm is extended and the other one is flexed.

PLACE OBJECTS



The user can see themselves in the mirror and must place the objects that appear on screen in the correct targets located at head height.

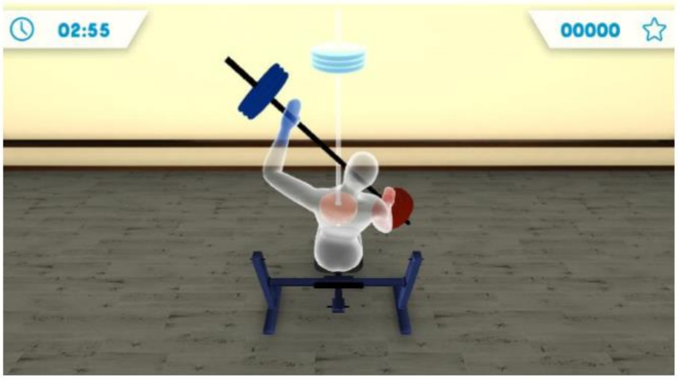
OBJECTIVES

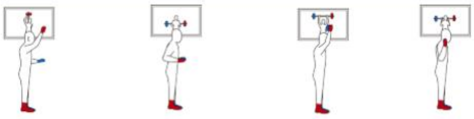
- Arm functions

MOVEMENT TYPE

- Hand.-mouth
- Hand-shoulder
- Hand-ear
- Hand-head

WEIGHTLIFTING





The user must intercept the objects that appear on screen with their upper limbs. They must avoid the lower obstacles by raising their feet and they must step on the indicated tiles.

OBJECTIVES

- Balance whilst sitting and standing.
- Load transfer.
- Reaching objects.
- Alignment

MOVEMENT TYPE

- Lateral Trunk inclination
- Elbow and shoulder extension
- Reaching different distances and heights using upper limbs.
- Crossing legs and leg extension

Appendix IV: Questionnaire

Racing Game Feedback

A questionnaire made to evaluate the racing game for rehabilitation.

1. **I use computer regularly.**
   Mark only one oval.

   - Strongly Agree
   - Agree
   - Neutral
   - Disagree
   - Strongly Disagree

2. **I play computer games.**
   Mark only one oval.

   - Strongly Agree
   - Agree
   - Neutral
   - Disagree
   - Strongly Disagree

3. **I am familiar with Virtual and Augmented Reality.**
   Mark only one oval.

   - Strongly Agree
   - Agree
   - Neutral
   - Disagree
   - Strongly Disagree

4. **I felt uncomfortable when playing the game.**

Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

5. **It was easy to control the car object with my body.**

Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

6. **I reached set target/ successfully finished the game.**

Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

7. **I was feeling frustrated when playing the game.**

Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

8. **I think this type of game can be useful for rehabilitation.**
Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

9. **I would play this games at home environment.**
Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

10. **I prefer to play this game individually.**
Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

11. **I prefer to play this game with other people.**
Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

12. **I enjoyed playing the game.**

Mark only one oval.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

13. **What would you change in a game to make it more comfortable to play?**

14. **What would you add to the game to make it more fun and engaging?**

15. **Any additional comments are welcome.**

Appendix VI: Functional reach test and modified functional reach instructions

Functional Reach Test and Modified Functional Reach Instructions

General Information: The Functional Reach test can be administered while the patient is standing (Functional Reach) or sitting (Modified Functional Reach).

Functional Reach (standing instructions):

- The patient is instructed to next to, but not touching, a wall and position the arm that is closer to the wall at 90 degrees of shoulder flexion with a closed fist.
- The assessor records the starting position at the 3rd metacarpal head on the yardstick.
- Instruct the patient to "Reach as far as you can forward without taking a step."
- The location of the 3rd metacarpal is recorded.
- Scores are determined by assessing the difference between the start and end position is the reach distance, usually measured in inches.
- Three trials are done and the average of the last two is noted.

Modified Functional Reach Test (Adapted for individuals who are unable to stand):

- Performed with a leveled yardstick that has been mounted on the wall at the height of the patient's acromion level in the non-affected arm while sitting in a chair
- Hips, knees and ankles positioned are at 90 degree of flexion, with feet positioned flat on the floor.
- The initial reach is measured with the patient sitting against the back of the chair with the upper-extremity flexed to 90 degrees, measure was taken from the distal end of the third metacarpal along the yardstick.
- Consists of three conditions over three trials
    - Sitting with the unaffected side near the wall and leaning forward
    - Sitting with the back to the wall and leaning right
    - Sitting with the back to the wall leaning left.

Name:____

Instructions:

Instruct the patient to "Reach as far as you can forward without taking a step"

Score Sheet:

Date	Trial One (Practice)	Trial Two	Trial Three	**Total (average of trial 2 and 3 only)**

Appendix VII: Microsoft Kinect v2 specifications

Table 2: Sensor Hardware Specifications (source: https://docs.microsoft.com)

Depth Sensor	Consists of an infrared (IR) emitter and an IR depth sensor. The emitter emits infrared light beams and the depth sensor reads the IR beams reflected back to the sensor. The reflected beams are converted into depth information measuring the distance between an object and the sensor. This makes capturing a depth image possible. Depth resolutions is 512x424;
RGB Camera	Full HD resolution 1920x1080
Frame Rate	60 fps
Latency	60 ms
Multi- array microphone	Contains four microphones, which enables to record audio as well as find the location of the sound source and the direction of the audio wave.

Table 3: Sensor Spatial Specifications (source: https://docs.microsoft.com)

Detection range	0.5 m - 4.5 m
Viewing angle	43° vertical; 57° horizontal
Spatial resolution	3mm (@ 2m distance)
Depth resolution	1cm (@ 2m distance)

Table 4: Required computer capabilities to run the Kinect v2 (source: https://docs.microsoft.com)

64- bit (X64) processor 17 3.1 GHz (or higher)
4 GB RAM
Built – in USB 3.0 host controller.
DX11 capable graphics adapter.

Table 5: Software Requirements (source: https://docs.microsoft.com)

Windows 8 (x64) or higher OS
Visual Studio 2012 or higher
Kinect for Windows SDK 2.0

Table 6: Kinect for Windows SDK key features (source: https://docs.microsoft.com)

Skeleton tracking and hand gestures recognition
Facial tracking
Voice tracking

Appendix IIX: Formal Study Request to Ethics Committee

Rovisco Pais
Centro de Medicina de Reabilitação da Região Centro

Comissão de Ética para a Saúde

1. IDENTIFICAÇÃO DO PROJECTO

a) Nome do Investigador principal Anna Andreykanich

b) Título do Projecto

Realidade Virtual para Reabilitação como complemento no treino de equilíbrio em doentes tetraplégicos

c) Serviço hospitalar / Instituto ou Laboratório onde o projecto será executado
CMRRC-RP

d) Existem outros centros, nacionais ou não, onde a mesma investigação será feita?

Sim ☐ Não ☒

Em caso afirmativo indique-os:

e) Descreva sucintamente os objectivos da investigação:

Estudo de aplicações de Realidade Virtual para treino de equilíbrio.
Tem como objectivo a avaliação da utilização de aplicações de Realidade Virtual e sensores de monitorização de postura (Kinect) no processo de reabilitação de pacientes no contexto de sessões de fisioterapia.

A Investigação proposta envolve:

a) Exames complementares – indique o tipo, frequência a natureza da amostra. Especifique se estes exames são feitos especialmente para esta investigação ou se serão executados no âmbito dos cuidados médicos habituais a prestar aos doentes:

Serão utilizados como complemento em doentes com os critérios estabelecidos

Quinta da Fonte Quente • 3060-673 TOCHA • Telef. 231 440 900 • Fax 231 440 902

f) Questionários

- A quem são feitos? Pacientes, fisioterapeutas e médicos
- Como será mantida a confidencialidade? Identificação do paciente por número e nunca por nome

(Nota: Junte 1 exemplar do questionário que será utilizado)

2. ENSAIOS CLÍNICOS DE NOVOS FÁRMACOS

a) Tipo de Ensaio:

Fase III ☐ Fase IV ☐ Marketing ☐

b) Tipo de Fármaco:

- Nome(s) Genérico(s) ____________________
- Grupo farmacológico ou terapêutico ____________________
- Aprovação noutros países ____________________
- Aprovação pelo INFARMED
  - Fármaco: Aprovado ☐ Não Aprovado ☐
  -
  - Forma Medicamentosa: Aprovada ☐ Não Aprovada ☐

- Indicação terapêutica contemplada na investigação:

  Aprovada ☐ Não Aprovada ☐

- Posologia contemplada na investigação:

  Aprovada ☐ Não Aprovada ☐

- Via de administração contemplada na investigação:

  Aprovada ☐ Não Aprovada ☐

- Tipo de Ensaio
  - Comparação com placebo ☐
  - Comparação com fármaco padrão ☐
  - Ensaio com dupla ocultação randomizado ☐
  - Ensaio aberto ☐
  - Outro tipo (especifique) ______________________________

  ____

(Nota: 1 – No caso de medicamentos já aprovados oficialmente junte a bula oficial do produto comercializado.

2 - No caso de medicamentos ainda não aprovados, junte documento do fabricante, certificando a segurança do produto no qual conste a posologia e vias de administração recomendadas, bem como as indicações terapêuticas.)

3. **JUSTIFICAÇÃO CIENTÍFICA DA INVESTIGAÇÃO** - descreva sucintamente os fundamentos científicos da investigação. Indique, em particular, se a investigação já foi feita anteriormente com seres humanos, se o problema foi devidamente estudado a nível experimental de modo a optimizar os aspectos analíticos e técnicos e a avaliar os possíveis efeitos adversos.

   Este estudo tem por objectivo testar a usabilidade de aplicações de Realidade Virtual utilizando sensores óticos de monitorização de movimentos com um conjunto de pacientes tetraplégicos com capacidade de treino de equilíbrio dinâmico em posição sentada. O desenvolvimento foi acompanhado por médicos do Centro de Reabilitação e foram previamente feitos testes com alunos da Universidade de Aveiro. As aplicações testadas serão fornecidas gratuitamente ao Centro de Reabilitação de forma a poder ser usada como parte de rotina de reabilitação dos pacientes caso se considere haver benefícios na sua inclusão em sessões de fisioterapia.

   ,

4. **DOENTES ABRANGIDOS NA INVESTIGAÇÃO**
   . Número 4 a 6
   . As mulheres grávidas são excluídas? Sim [x] Não [ ]
   . Indique como se processará o recrutamento dos doentes

   Critérios de exclusão: Ter alterações cognitivas ou comportamentais que impeçam a compreensão dos jogos, ausência completa de equilíbrio de tronco (sem equilíbrio estático nem dinâmico – lesões medulares muito altas), equilíbrio de tronco (estático e dinâmico) preservado.

   Este ensaio, em princípio, ajudará a estabelecer critérios de inclusão e exclusão mais específicos.

5. **CONTROLES**
   . Número ____________

. Indique como serão escolhidos ____________________________

____

____

6. **DESCRIÇÃO RESUMIDA DO PLANO DA INVESTIGAÇÃO**
Em cada sessão de teste dois pacientes testarão as aplicações; depois do teste cada paciente responderá a um questionário relativo à satisfação na sua utilização e opinião quanto à sua inclusão na rotina de reabilitação. Os médicos e terapeutas responsáveis pelo paciente preencherão também um questionário relativo à condição actual do paciente e às circunstâncias do teste. Em anexo encontram-se os questionários a utilizar para obter a visão do paciente e do profissional de saúde.

7. **ENUMERAÇÃO DOS PROCEDIMENTOS, EXAMES OU SUBSTÂNCIAS QUE IRÃO SER ADMINISTRADAS AOS DOENTES** (dietas especiais, medicamentos, radioisótopos, etc.)

____

____

____

8. **RISCO/BENEFÍCIO**
a) Que riscos ou incómodos podem ser causados aos doentes pelo estudo?

Possibilidade de desconforto causado pela utilização da aplicação de Realidade Virtual: estes efeitos poderão incluir sensações de desequilíbrio, dor de cabeça ou náuseas e estão relacionados com a exposição a movimento. No entanto, este tipo de desconforno não é esperado e caso se verifique a sessão será interrompida.

____

b) Que benefícios imediatos poderão advir para os doentes pela sua anuência em participar no estudo?

Aumento da motivação e proporcionar ambiente rico em estímulos para a realização dos exercícios de reabilitação, aliando o objetivo terapêutico ao aspecto lúdico.

Espera-se que a componente lúdica e a motivação sejam aumentadas pelo facto do jogo ser realizado por dois pacientes em simultâneo.

c) Considera que os meios utilizados no estudo podem violar a privacidade do doente?

Sim ☐ Não ☒

Em caso afirmativo, indique que medidas serão tomadas para assegurar a confidencialidade.

d) Os doentes que não aceitarem participar no estudo ficarão, por esse facto, prejudicados em termos de assistência médica, relativamente aos participantes?

Sim ☐ Não ☒

9. CONSENTIMENTO

a) A expressão do consentimento informado terá forma escrita, conforme a Lei.
Junta-se cópia do seu texto, a ser assinado pelo doente ou pelo seu representante legal.

b) Descreva resumidamente o conteúdo da informação a transmitir.
O doente irá participar num jogo de computador em que poderá controlar vários elementos através da inclinação do corpo podendo interromper o jogo em qualer altura.

c) A investigação ou estudo envolve:

. Menores de 14 anos Sim ☐ Não ☒

. Inimputáveis Sim ☐ Não ☒

Em caso afirmativo que medidas estão previstas para respeitar os seus direitos e obter o seu consentimento esclarecido ou dos seus representantes legais?

10. RELATIVAMENTE AO ESTUDO

a) Data prevista do inicio 1/6/2018

Data prevista da conclusão 1/7/2018

b) Pagamento aos doentes:

. Pelas deslocações Sim [ ] Não [x]

. Pelas faltas ao Serviço Sim [ ] Não [x]

. Por danos resultantes da sua participação no estudo Sim [ ] Não [x]

Em caso afirmativo especifique a identidade que assume a responsabilidade das indemnizações:

Outros pagamentos (especifique):

c) Do estudo que espécie de benefícios, financeiros ou outros resultarão para o investigador e/ou instituição? Especifique em caso afirmativo.

Apenas benefícios académicos, de enriquecimento do conhecimento científico, não havendo contrapartidas financeiras de qualquer natureza.

d) Os dados obtidos constituirão propriedade exclusiva da companhia farmacêutica ou outro entidade?

Sim [ ] Não [x] Que entidade? ____________________

11. TERMO DE RESPONSABILIDADE

Data do pedido de aprovação ___/___/___

Eu abaixo assinada, Anna Andreykanich

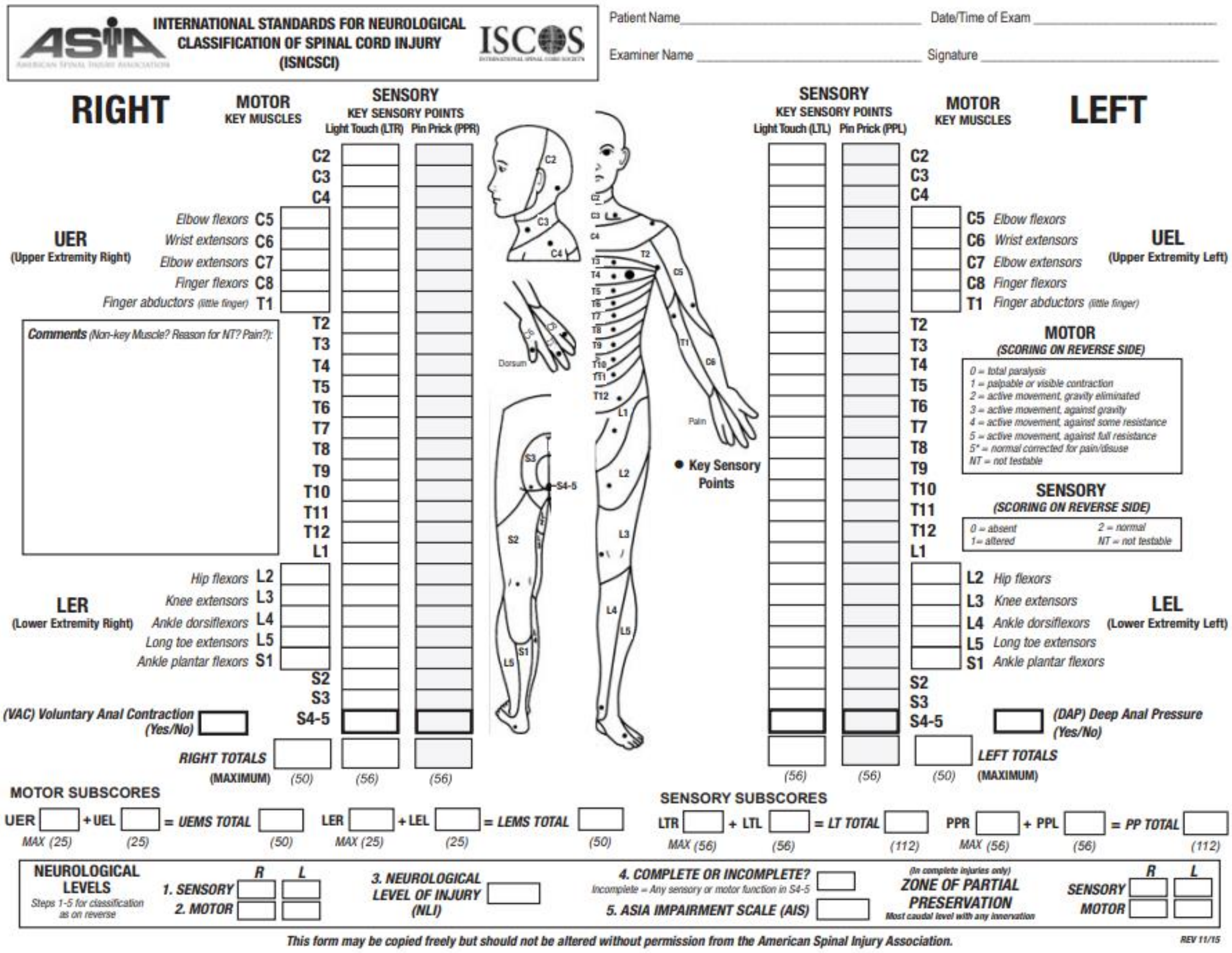
Na qualidade de investigador principal, declaro por minha honra que as informações prestadas neste questionário são verdadeiras. Mais declaro que, durante o estudo, serão respeitadas as recomendações constantes da Declaração de Helsínquia II e da Organização Mundial de Saúde, no que se refere à experimentação que envolva seres humanos.

Declaro ainda que, será entregue no prazo de 30 dias o estudo final, de preferência em suporte digital na vossa Instituição.

A. Andrei

(O investigador)

Appendix IX International standards for neurological classification of Spinal Cord Injury



INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY (ISNCSCI)

Patient Name ______ Date/Time of Exam ______

Examiner Name ______ Signature ______

RIGHT

MOTOR KEY MUSCLES

SENSORY KEY SENSORY POINTS Light Touch (LTR) Pin Prick (PPR)

C2
C3
C4

UER (Upper Extremity Right)

Elbow flexors C5
Wrist extensors C6
Elbow extensors C7
Finger flexors C8
Finger abductors (little finger) T1

Comments (Non-key Muscle? Reason for NT? Pain?):

T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1

LER (Lower Extremity Right)

Hip flexors L2
Knee extensors L3
Ankle dorsiflexors L4
Long toe extensors L5
Ankle plantar flexors S1

S2
S3
S4-5

(VAC) Voluntary Anal Contraction (Yes/No)

RIGHT TOTALS (MAXIMUM) (50) (56) (56)

• Key Sensory Points

LEFT

SENSORY KEY SENSORY POINTS Light Touch (LTL) Pin Prick (PPL)

MOTOR KEY MUSCLES

C2
C3
C4

UEL (Upper Extremity Left)

C5 Elbow flexors
C6 Wrist extensors
C7 Elbow extensors
C8 Finger flexors
T1 Finger abductors (little finger)

T2 … L1

MOTOR (SCORING ON REVERSE SIDE)

0 = total paralysis
1 = palpable or visible contraction
2 = active movement, gravity eliminated
3 = active movement, against gravity
4 = active movement, against some resistance
5 = active movement, against full resistance
5* = normal corrected for pain/disuse
NT = not testable

SENSORY (SCORING ON REVERSE SIDE)

0 = absent
1 = altered
2 = normal
NT = not testable

LEL (Lower Extremity Left)

L2 Hip flexors
L3 Knee extensors
L4 Ankle dorsiflexors
L5 Long toe extensors
S1 Ankle plantar flexors

S2
S3
S4-5

(DAP) Deep Anal Pressure (Yes/No)

LEFT TOTALS (MAXIMUM) (56) (56) (50)

MOTOR SUBSCORES

UER + UEL = UEMS TOTAL MAX (25) (25) (50)

LER + LEL = LEMS TOTAL MAX (25) (25) (50)

SENSORY SUBSCORES

LTR + LTL = LT TOTAL MAX (56) (56) (112)

PPR + PPL = PP TOTAL MAX (56) (56) (112)

NEUROLOGICAL LEVELS Steps 1-5 for classification as on reverse

1. SENSORY R L
2. MOTOR R L

3. NEUROLOGICAL LEVEL OF INJURY (NLI)

4. COMPLETE OR INCOMPLETE? Incomplete = Any sensory or motor function in S4-5

5. ASIA IMPAIRMENT SCALE (AIS)

(In complete injuries only) ZONE OF PARTIAL PRESERVATION Most caudal level with any innervation

SENSORY R L
MOTOR R L

This form may be copied freely but should not be altered without permission from the American Spinal Injury Association.

REV 11/15

Muscle Function Grading

0 = total paralysis

1 = palpable or visible contraction

2 = active movement, full range of motion (ROM) with gravity eliminated

3 = active movement, full ROM against gravity

4 = active movement, full ROM against gravity and moderate resistance in a muscle specific position

5 = (normal) active movement, full ROM against gravity and full resistance in a functional muscle position expected from an otherwise unimpaired person

5* = (normal) active movement, full ROM against gravity and sufficient resistance to be considered normal if identified inhibiting factors (i.e. pain, disuse) were not present

NT = not testable (i.e. due to immobilization, severe pain such that the patient cannot be graded, amputation of limb, or contracture of > 50% of the normal ROM)

Sensory Grading

0 = Absent

1 = Altered, either decreased/impaired sensation or hypersensitivity

2 = Normal

NT = Not testable

When to Test Non-Key Muscles:

In a patient with an apparent AIS B classification, non-key muscle functions more than 3 levels below the motor level on each side should be tested to most accurately classify the injury (differentiate between AIS B and C).

Movement	Root level
Shoulder: Flexion, extension, abduction, adduction, internal and external rotation **Elbow:** Supination	**C5**
Elbow: Pronation **Wrist:** Flexion	**C6**
Finger: Flexion at proximal joint, extension. **Thumb:** Flexion, extension and abduction in plane of thumb	**C7**
Finger: Flexion at MCP joint **Thumb:** Opposition, adduction and abduction perpendicular to palm	**C8**
Finger: Abduction of the index finger	**T1**
Hip: Adduction	**L2**
Hip: External rotation	**L3**
Hip: Extension, abduction, internal rotation **Knee:** Flexion **Ankle:** Inversion and eversion **Toe:** MP and IP extension	**L4**
Hallux and Toe: DIP and PIP flexion and abduction	**L5**
Hallux: Adduction	**S1**

ASIA Impairment Scale (AIS)

A = Complete. No sensory or motor function is preserved in the sacral segments S4-5.

B = Sensory Incomplete. Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-5 (light touch or pin prick at S4-5 or deep anal pressure) AND no motor function is preserved more than three levels below the motor level on either side of the body.

C = Motor Incomplete. Motor function is preserved at the most caudal sacral segments for voluntary anal contraction (VAC) OR the patient meets the criteria for sensory incomplete status (sensory function preserved at the most caudal sacral segments (S4-S5) by LT, PP or DAP), and has some sparing of motor function more than three levels below the ipsilateral motor level on either side of the body.
(This includes key or non-key muscle functions to determine motor incomplete status.) For AIS C – less than half of key muscle functions below the single NLI have a muscle grade ≥ 3.

D = Motor Incomplete. Motor incomplete status as defined above, with at least half (half or more) of key muscle functions below the single NLI having a muscle grade ≥ 3.

E = Normal. If sensation and motor function as tested with the ISNCSCI are graded as normal in all segments, and the patient had prior deficits, then the AIS grade is E. Someone without an initial SCI does not receive an AIS grade.

Using ND: To document the sensory, motor and NLI levels, the ASIA Impairment Scale grade, and/or the zone of partial preservation (ZPP) when they are unable to be determined based on the examination results.

INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

Steps in Classification

The following order is recommended for determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.
The sensory level is the most caudal, intact dermatome for both pin prick and light touch sensation.

2. Determine motor levels for right and left sides.
Defined by the lowest key muscle function that has a grade of at least 3 (on supine testing), providing the key muscle functions represented by segments above that level are judged to be intact (graded as a 5).
Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level, if testable motor function above that level is also normal.

3. Determine the neurological level of injury (NLI)
This refers to the most caudal segment of the cord with intact sensation and antigravity (3 or more) muscle function strength, provided that there is normal (intact) sensory and motor function rostrally respectively.
The NLI is the most cephalad of the sensory and motor levels determined in steps 1 and 2.

4. Determine whether the injury is Complete or Incomplete.
(i.e. absence or presence of sacral sparing)
If voluntary anal contraction = ***No*** *AND all S4-5 sensory scores =* ***0***
AND deep anal pressure = ***No,*** *then injury is* ***Complete.***
Otherwise, injury is ***Incomplete.***

5. Determine ASIA Impairment Scale (AIS) Grade:

Is injury Complete? **If YES, AIS=A** and can record ZPP (lowest dermatome or myotome on each side with some preservation)

NO ↓

Is injury Motor Complete? **If YES, AIS=B**

NO ↓ (No=voluntary anal contraction OR motor function more than three levels below the motor level on a given side, if the patient has sensory incomplete classification)

Are at least half (half or more) of the key muscles below the neurological level of injury graded 3 or better?

NO ↓ **AIS=C**

YES ↓ **AIS=D**

If sensation and motor function is normal in all segments, AIS=E
Note: AIS E is used in follow-up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

Appendix X: “Tanks” adapted game

Concept statement
The game is about a war in a dessert. The war is between 2 opponents. The objective of the game is to win the war. To win the war a player has to kill the opponent for a predefined number of fights. The number of winning fights can be configured by the players. The colors of the tanks can be customized by players as well.

Player’s role(s)
A tank driver(soldier in a war)

Gameplay mode
Driving and shooting with the tanks, 3rd camera view, interaction with the environment using the body gestures, a challenge is to kill the opponent.

Control gestures
The avatars in a game are controlled with the upper body part of the player. Player is able to drive the tank in a game by inclining the body in 4 directions: back, forward, left and right side. Furthermore, player can shoot the other player(tank) when he/she raises his left hand above the neck level.

Genre
Action game

Target audience
Spinal Cord Injury patients

Required equipment
PC, Kinect v2 and a Projector (not mandatory)

License
Designed for the PC, no license is required

Competition mode
Two-player competitive local

Progression loop
NA

Game World (a short description of the game world)
A battlefield in a dessert

Appendix XI: Observer guide

Observer Guide

Usability Evaluation of "Tanks" and "Explorer" Interactive mini-games

Coordinator: Anna Andreikanich

The game presented in this experiment: "Tanks"[1] was developed by the official Unity team. The code of the game is adapted to be used with the Kinect v2, so the players can control the avatars with the upper body part.

Equipment needed: PC, Microsoft Kinect v2, Projector;

Experiment setup: The games should be projected on the white wall (preferably) in a room that can be darkened. The space needed for the experiment: 2,5m x 2,5m (Figure 1).

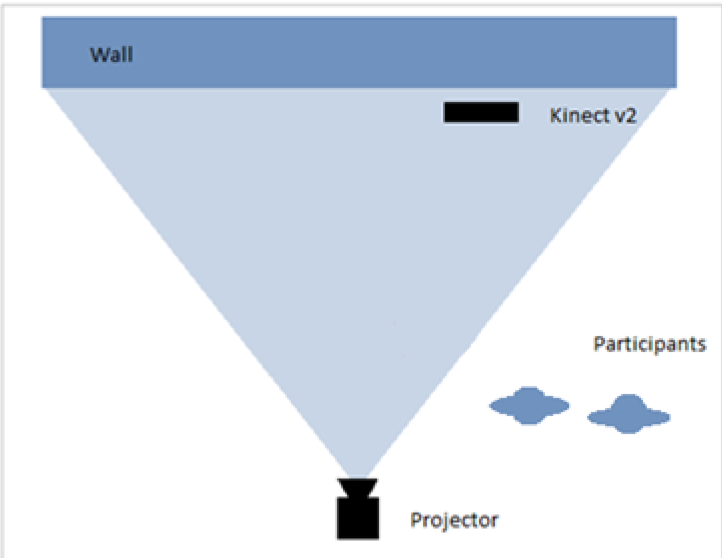


Figure 1: Experiment setup

[1] https://unity3d.com/learn/tutorials/s/tanks-tutorial

instituto de engenharia electrónica
e telemática de aveiro
ieeta

Tanks (action game for 2 people)-two-player competitive mode

This game should be tested with 2 participants at the same time.

Step	Action	Completed
0	Express the aim of the experiment and the project the participants are taking part in; describe which two games will be tested.	
1	Introduce the main aspects of the game "Tanks": what game is about, the player's role in a game, the interaction model, the gestures that control the vehicle, challenges presented in the game and the goal.	
2	Describe which parameters the users can define themselves (number of winning rounds, colors of the tanks)	
3	Demonstrate the game	
4	Let the participants to freely explore the game.	
5	Ask the participants to play the game in two- player competitive mode and ask how many winning rounds they like to play in order to announce the winner.	
6	Let the participants play the game	
7	Direct the participant to the questionnaire, describe what is the questionnaire about (do not start answering yet)	
8	Let the participant to undisturbedly fill the questionnaire	

Appendix XII: Questionnaire prepared by the clinicians

GOVERNO DE PORTUGAL | MINISTÉRIO DA SAÚDE

Rovisco Pais
Centro de Medicina de Reabilitação da Região Centro

Projeto Realidade Virtual (RV) no treino de equilíbrio na Lesão Medular

Nº de processo	**Género**		**Idade**	**Classificação da Lesão**	
	F	M		AIS	
				Nível neurológico	

Jogos terapêuticos realizados:	**Sensor de RV utilizado**:

1. HUMOR

Está deprimido?	Não		Sim		

As alterações de humor interferem com a realização dos jogos de RV?

○ Nada ○ Pouco ○ Muito ○ Impossibilita a sua realização

2. **COGNIÇÃO** (Mini mental scale – MMS)

Tem alterações cognitivas?	Não		Sim		

As alterações da cognição interferem com a realização de jogos de RV?

○ Nada ○ Pouco ○ Muito ○ Impossibilita a sua realização

Nota: é critério de exclusão os doentes que apresentam patologia do foro comportamental, de comunicação ou cognitivo que impeçam de compreender e participar no jogo

3. VISÃO

Tem alterações da visão?	Não		Sim		Quais?

As alterações visuais interferem com a realização de jogos de RV?

○ Nada ○ Pouco ○ Muito ○ Impossibilita a sua realização

4. **FUNCIONALIDADE - SCIM**	

5. **EQUILÌBRIO DE TRONCO** Escala Berg: Escala de Desempenho toracolombar: Functional Reach test/modified functional reach test:
As alterações do equilíbrio interferem com a realização a realização de jogos de RV? Nada — Pouco — Muito — Impossibilita a sua realização
6. **DOR**

Tem Dor?	Não		Sim		Localização: Qual a intensidade de 1-10 (escala visual analógica):

A dor interfere com a realização de jogos de RV? Nada — Pouco — Muito — Impossibilita a sua realização
7. **ALT. NA HARMONIA DO GESTO – DISCINÉSIAS (EX: TREMOR, DISTONIA, MIOCLONIA), ATAXIA,..**

Tem alterações na harmonia do gesto tais como tremor, distonia, ataxia, …?	Não		Sim

As alterações na harmonia do gesto interferem com a realização de jogos de RV? Nada — Pouco — Muito — Impossibilita a sua realização
8. **TÓNUS MUSCULAR NO TRONCO** (assinalar a opção que se aplica ao quadro clínico do doente)
HIPOTONIA

HIPERTONIA	ESCALA DE ASHWORD MODIFICADA:
ESPASMOS	ESCALA DE FREQUÊNCIA DE ESPASMOS:

As alterações do tónus muscular interferem com a realização de jogos de RV? Nada — Pouco — Muito — Impossibilita a sua realização
9. De que forma os jogos de RV beneficiam o programa de reeducação do equilíbrio deste utente? Em que medida beneficiou? Nada — Pouco — Muito

10.**LIMITAÇÕES VERIFICADAS DURANTE OS JOGOS DE RV**					
11. EFEITOS 2ºS VERIFICADOS DURANTE OS JOGOS DE RV					
Data de preenchimento do formulário: …../…../20….		Médico (nome e nº mec)		FT (nome e nº mec)	
Datas da realização das sessões e nome e nº mecanográfico do Fisioterapeuta					
Data					
Nome/nº mecanográfico					

Outras observações:

Médico: identificação do doente, classificação e localização da lesão e avaliação clínica dos itens 1 a 9
FT: sensor e jogos utilizados, escala de Likert nos itens 1 a 8, limitações (10) e os efeitos 2ºs (11) e registo das sessões

Quinta da Fonte Quente, apartado 3
3060-908 Tocha
www.roviscopais.min-saude.pt

T 231 440 900
@ cmrrc@roviscopais.min-saude.pt

Inovação e Qualidade em Reabilitação