Universidade de Aveiro Departamento de Comunicação e Arte
2018

José Eduardo Rodrigues Dias

Um Jogo Digital em Ambientes Imersivos no Apoio às Vítimas do Acidente Vascular Cerebral

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Comunicação Multimédia, realizada sob a orientação científica da Doutora Ana Isabel Barreto Furtado Franco de Albuquerque Veloso, Professora Auxiliar do Departamento de Comunicação e Arte da Universidade de Aveiro, e sob a coorientação da Mestre Tânia Cristina Ferreira Ribeiro, do Departamento de Comunicação e Arte da Universidade de Aveiro.

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“The important thing is not to stop questioning.
Curiosity has its own reason for existing.”

Albert Einstein

o júri

presidente

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palavras-chave Jogos Digitais, Acidente Vascular Cerebral, Reabilitação, Interação Humano-Computador, Imersividade.

resumo

A sociedade moderna está a testemunhar um aumento do envelhecimento médio populacional, graças à melhoria da qualidade dos serviços de saúde e de medicação. No entanto, o envelhecimento cria outros problemas como doenças físicas ou mentais com grandes taxas de incidência. O acidente vascular cerebral (AVC) é uma das doenças que afeta sobretudo a população idosa, e o processo de reabilitação é doloroso e difícil de percorrer, sendo que a forma mais eficaz de tratar o doente é na atuação rápida e eficaz da fisioterapia. O consumo de videojogos pela população sénior está a aumentar, sendo que é cada vez mais viável a introdução de novos artefactos digitais no processo de recuperação cerebral e motora pela vítima de AVC.

Os programas tradicionais de recuperação para um paciente que tenha sofrido um AVC são organizados em tratamento fisioterapêutico longo e monótono, com a possibilidade de envolver tarefas domésticas desmotivadoras. No entanto existem soluções tecnológicas que monitorizam as tarefas repetitivas de movimento. O aparelho de monitorização aliado a um jogo digital tem a possibilidade de estimular o paciente nas melhorias motoras e cognitivas como uma alternativa ao tratamento fisioterapêutico tradicional. As soluções desenvolvidas até ao momento são escassas, sendo que existe uma grande margem para mudar essa realidade.

O principal objetivo desta pesquisa é o de explorar caraterísticas relacionadas com o display, interface gestual, narrativa, género, estilo gráfico, dificuldade, e linguagem que um jogo digital possa ter, para complementar as sessões de fisioterapia na recuperação do AVC pela população sénior, através da criação de um protótipo experimental.

Esta investigação empírica tem um carácter exploratório e tem como base a metodologia *Development Research* (Van den Akker, Branch, Gustafson, Nieveen, & Plomp, 1999).

Os resultados indicam que o controlador de movimento – *leap motion* – é um dispositivo que pode ser adaptado à fisioterapia orientada ao AVC, através de movimentos específicos e contextualizados no ambiente de jogo. Adicionalmente, foi possível observar uma rejeição elevada no uso de *Head Mounted Displays* devido a dores oculares e perda de orientação.

keywords Digital Games, Stroke, Rehabilitation, Human-computer Interaction, Immersion

abstract

Modern society is witnessing a general population ageing increase in average life expectancy thanks to better health services and medication. However, ageing creates life quality problems, such has several disabilities, diseases, or mental illness with high incidence rates. Stroke patients are a main concern for such ages, and the rehabilitation process is painful and shows very small recovery improvements over time, unless treated in a fast manner. The consumption of videogames by the senior population is increasing, and it is feasible to introduce new digital artefacts for the process of recovering from brain damage and low motricity for the stroke victim.
Typical rehabilitation programs for stroke patients are organized in long and monotonous physiotherapy treatment, with the possibility of involving domestic tasks, which can increase the risk of treatment withdrawal derived from low motivation. However, there are some technological solutions that can effectively help in the supervision of those repetitive tasks. A monitoring device connected to a digital game can effectively stimulate a person in cognitive and physical improvements as an alternative to traditional physiotherapy treatment. There is room for improvement in order to change the reality of stroke rehabilitation.
The main objective of this research is to explore characteristics related to display, gesture interface device, narrative, genre, game art design, difficulty, and language that can be included in a digital game to complement physiotherapy sessions for stroke rehabilitation, through the creation of a functional prototype.
The empirical research has an exploratory character and is based on the methodology “Development Research” (Van den Akker et al., 1999).
The results indicate that the motion controller - *leap motion* - is a device that can be adapted to stroke-oriented physiotherapy through specific movements and contextualized in the game environment. Additionally, it was possible to observe a high rejection in the use of Head Mounted Displays due to ocular pain and orientation loss.

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LIST OF ACRONYMS

API	Application Programmer Interface
AT	Assistive Technology
AVC	Stroke
BAT	Brightness acuity tester
CLI	Command Line Interface
CRT	Cathode Ray Tube
DES	Digital Eye Strain
DGS	Portuguese General Health Department
EU	European Union
FIM	Functional Independence measure
FOV	Field of View
FPS	First Person Shooter/Frames per Second
GUI	Graphical User Interface
HMD	Head Mounted Display
HMM	Hidden Markov Model
ICF Core Set	International Classification of Functioning, Disability and Health
IDE	Integrated Development Environment
IMU	Inertial Measurement Unit
IPS	In-plane switching
IR	Infrared Light
LCD	Liquid Crystal Display
LOD	Level of detail
MHP	Model Human Processor
MR	Mixed Reality
NUI	Natural User Interface

OECD	Organization for Economic Co-operation and Development
OLED	Organic light-emitting diode
PC	Personal Computer
PvE	Player vs Environment
SCI	Spinal Cord Injury
SDK	Software Development Kit
SG	Serious Games
TN	Twisted Nematic
TOF	Time of Flight
TRC	Tone Reproduction Curve
VA	Vertical Alignment
VR	Virtual Reality
VSync	Vertical Synchronization
WHO	World Health Organization
Wi-Fi	IEEE 802.11 technology
WIMP	Windows-Icons-Menus-Pointer - A style of graphical user interface for widgets

INTRODUCTION

The stroke is a very frequent neurological disorder in the world that may alter cognitive, motor and behavioural functions. The types of impairment are diversified, and the physiotherapy treatments are not always effective for a full recovery.

Using serious games for rehabilitating the stroke patient can be an opportunity, instead of more traditional rehabilitation plans that are characterized by their repetitive nature. Digital games are so popular that we are witnessing the arising of new audiences that before were turned off for the most traditional games. According to Rego, Moreira, & Reis (2010) the *Wii System* from *Nintendo* is played abroad a wider demographic audience that deviate from *hard-core* players, which can contribute to increase motivation in rehabilitation sessions. The authors also state that low motivation is one of the major problems in therapy sessions.

This dissertation describes an exploratory research project that proposes a solution to support the recovery of the stroke patient, through a digital game with the use of two devices, the motion tracking device – *Leap Motion* – and a *Head Mounted Display* (HMD). In order to achieve the implementation of a functional prototype, a theoretical framework will be generated based on referenced authors, and used to pinpoint some characteristics that can be embedded into the final solution, based on the *Research and Development Methodology* (Van den Akker et al., 1999). Results show that it is possible to include the *Leap Motion* device into a digital game for the purpose of stroke rehabilitation, through specific movements and contextualized in the game environment. Additionally, it was possible to observe a high rejection in the use of HMD due to ocular pain and orientation loss.

The Research Problem

The increasing population ageing raises new challenges. The European Union (EU) projections show a growing number of seniors (aged 65 and over), and a particularly rapid increase in the numbers of very old people (85 and over). While it is positive that life expectancy continues to increase, it is not so clear that additional years of life are welcome if characterized by several disabilities, diseases, or mental illness. Despite the value for such longevity, and the benefits it can bring to society, the demographic implications can be referred to government finances and the different type of health care requirements (Eurostat, 2015).

For the 20th century, younger adults would take care of senior parents in most of the cases, however modern-day society lifestyle trails new challenges for health caring. In the western world, most seniors end up living alone or in nursing homes. The situation ends up degrading social connections, which directly reflects on health. The main challenge is to keep the senior occupied with stimulant activities that can actively work cognitive and motor functions during its stay in the nursing home (Castilho et al., 2013) .

In Portugal, the main cause of death is pointed to diseases of the circulatory system, with 29.8% of registered deaths. From all diseases of the circulatory system, the stroke represents 10.8% of all deaths in the country. Deaths by cerebrovascular diseases is most common within women, with a relation of 75.2 male deaths against 100 women (INE, 2017). The prevalence of the stroke between 2011 and 2015 in Portugal has been diminishing (39%), thanks to new types of anticoagulants and the improvement of stroke treatment units, however it is still a social and demographic problem for the Portuguese Society (SNS & DGS, 2017). More recently, the Portuguese General Health Department (DGS) has planned, in Portugal, a National Program for Healthy Food Promotion between 2017-2018. The main objective of this program is to reduce the consumption of salt through legislative measures, promoting communication campaigns with younger audiences by emphasizing salt as a risk factor for brain and cardiovascular diseases, and other supplementary measures.

The average age for stroke patients is 70 years, however, this average cannot be fully generalized, since there is some discrepancy between data across countries from EU (Truelsen, Ekman, & Boysen, 2005). It can be stated with enough scientific consensus that the stroke is most prevalent among senior citizens, although there is also a risk for younger demographics.

Some actions, such as sedentary lifestyle, improper feeding habits, lack of exercise, or hereditary factors might lead to cerebrovascular accidents such as the stroke. This disease is recognized to alter the physical and emotional condition of an individual, while affecting everyday tasks. Such condition not only affects the individual, but all the family that needs to take permanent care, which can lead to family repercussions (Castro, 2012).

While in some cases it is possible to have a quick and effective recovery for the walking functionality after a stroke, only 50% of patients recover the upper-limb motricity with deficits that persist after six months (Soares, Morais, Melo, Pereira, & Figueiredo, 2017). Normally, stroke rehabilitation starts in a hospital where the patient is required to travel between specialised units for supervised therapy. Eventually, home-based programmes allow the person to develop skills in their home environment, with regular advice and objective definition by a professional that works closely with the stroke survivor. An early and intensive therapy of functional task repetitions results in a more positive scenario for upper limb rehabilitation. Although the rehabilitation therapy should start as soon as possible, most patients carry major trauma from partial body paralysis, difficulty speaking, and difficulty in executing everyday tasks that have been taken for granted. The rehabilitation program attempts to stimulate the person in a variety of exercises, however it is not uncommon that people develop depression under a stroke condition (Burke et al., 2009).

The Research Question

Considering the stroke problematic for the senior citizen and based on the goal of developing a digital game to support the stroke patient, it was outlined the following research question, while retaining aspects like feasibility, pertinence, and clarity (Quivy & Campenhoudt, 1992).

Which recommendations can be included into an immersive game environment, to be played as a support in the rehabilitation of the stroke patient?

The main question will address the following sub questions:

1. Which stage of treatment is indicated to prescribe the game?
2. Is it feasible to use low-cost HMD during gaming sessions, as an alternative for the rehabilitation of the stroke patient?
3. Are there alternatives to the identified recommendations?

This research intends to create game recommendations based on game characteristics. Those characteristics will be referenced through literature review, while being applied to a functional game prototype. Further considerations will be highlighted after the analysis of the empirical evaluation, to answer the main question and sub-questions.

The Research Plan

The objective of this research is organized as follows:

1) Literature review regarding the following topics:
    - Stroke patient characterization;
    - Identify therapeutic exercises for the stroke patient rehabilitation based on related work;
    - Digital games and game design;
    - Understand the main game preferences of senior citizens;
    - Analyse similar projects and/or digital games for stroke recovery, and HMD feasibility for the senior citizen;
    - Analyse available hardware solutions for motion tracking and HMD;

2) Conceptualize and report all the involved steps for the game planification;

3) Search for adequate software and implement the game prototype;

4) Evaluate the prototype with physiotherapists and senior citizens;

5) Report the success of the chosen characteristics and suggest improvements over the final prototype.

The list considered the establishment of reasonable and realist objectives, while also considering their feasibility based on time and logistics. It should be highlighted that the most important topic in this research will be the selected recommendations based on game characteristics through the implemented game.

Methodology

The adopted methodology will follow the *Development Research* method (Van den Akker et al., 1999). The reason that led to this type of research was the ability to initiate and develop complex and innovative tasks for which only few validated principles are available. In this situation, the impact of the research is unclear and focus on realizing limited but promising results, without implementing complete interventions. The process is often cyclical and iterative until a satisfying balance is achieved between ideals and execution.

Although the methodology is originally focused for education and training purposes, the envisioned prototype is expected to have some Instructional Design Characteristics, according to the intention of re-teach movements to senior citizens that suffered hemiparesis and lost the ability to execute certain upper limb movements. From this perspective, the prototype can be viewed as a learning rehabilitation tool.

Using the Development Research methodology allows to develop technological products in the form of a prototype and generating empirical evidences for its efficiency and methodological direction for design and product evaluation (Van den Akker et al., 1999). It also allows for a degree of freedom regarding the search for game characteristics that the final prototype should have in order to create adequate therapeutic properties.

The methodology is divided in four different stages according to Van den Akker et al., (1999):

(1) Preliminary Investigation – Systematic preliminary investigation regarding state-of-the-art knowledge from literature. The main topics are defined according to the keywords of the research.

(2) Theoretical Embedding – Conceptualize and design a digital game based on state-of-the-art knowledge to complement the rehabilitation of a stroke patient, for the upper limb movements. To validate the concept in a technological platform, it is expected the creation of a functional prototype.

(3) Empirical Testing – The proposed prototype will have 2 stages of evaluation. **(a)** During the development stage, a demo will be presented to an expert physiotherapist, under the semi-structured interview technique. The primary objective is to validate the potential of the chosen kinetic movements for the stroke patient, and to identify the recommended stage of recovery for this treatment. **(b)** The final version of the prototype will be evaluated on the field. The primary objective is to determine the relevance of the prototype considering the context of stroke patients, and to evaluate the performance of the proposed kinetic movements. Considering budget, time, and logistic limitations, a convenience sample of physiotherapists and senior citizens is to be gathered, to validate the game proposal. The chosen techniques for collecting data are semi-structured interviews, the observation method, and an online questionnaire.

(4) Documentation analysis, and reflection on process and outcomes – After considering all the previous methodological stages, it is presented the discussion and conclusion of the results. The disclosure will be fully written and detailed in this research, and briefly through the elaboration of a written paper in the proper channels of scientific dissemination.

Analysis Model

The following analysis model in Table 1 aims to pinpoint the most important concepts, which were based on the research question and are used to systematize data collection and analysis (Quivy & Campenhoudt, 1992).

Table 1 - Analysis Model

Concepts	*Dimensions*	Indicators
Stroke (Klijn & Hankey, 2003; Putrino et al., 2017; Teasell & Mbbs, 2013)	*Paralysis*	Partial Paralysis Full Paralysis
	Rehabilitation	Movement Therapy Neuromuscular
Digital Games (Adams, 2010; Kerr, 2006; Salen & Zimmerman, 2004)	*Type/Taxonomy*	Exergaming Casual
	Game Design	Interaction Rules Objectives Challenges Story
	HCI	Head Mounted Display Body Tracking Devices Feedback Gestural Interface Usability Software & Hardware Virtual Reality
	Game Experience	Comfort Execution Immersion
Patient (Goldstein, 2008; Kleim & Jones, 2008; Thompson & Ryan, 2009)	*Physical*	Recovery Mobility Health
	Cognitive	Depression Social Isolation

Motivations

Humanity has the right for health protection, and the duty to promote it and defend it (ONU, 1948). In Portugal, the National Health System provides basic healthcare for its citizens, but due to some financial and structural limitations, cannot respond to all the population needs.

The overcoming of physical and cognitive limitations is an enormous battle that should not be seen as a burden. It is in our hands to change that paradigm through the creation of synergies between the patients and communities. Technology can have a decisive role in that manner, by bringing universities, companies, governments, and people together. My role is to share this research through public channels and to directly intervene between institutions to raise the awareness about the stroke patient.

In a more personal side, my grandfather suffered a stroke three years prior to this research work and developed several limitations in terms of motricity and cognition. Although his injuries were too big to expect some recovery, his condition inspired me to create a device that could help other people in the same situation.

The Dissertation Structure

The dissertation has six chapters between the introduction and conclusion. This introduction begins with the preliminary information that motivates this research. After identifying the main problematic for the EU and Portuguese society, it is defined the research question, main objectives, motivations of the author and lastly the structure of the dissertation.

Chapter 1 to 4 contain the main theoretical framework, where the main concepts are contextualized according to the objectives and research question.

Chapter 1 introduces the stroke scenario for the senior population, while defining and identifying the current types of stroke and main consequences. The chapter ends with the description of some rehabilitation tools and neurological rehabilitation.

Chapter 2 theorizes the human condition on playing and defines digital games in our society. It is explained the cultural aspects of gaming through the globalization phenomenon, while identifying different types of game genres. There is also a small preview about the basics of designing a digital game, while highlighting design aspects for the senior citizen audience, and some visual symptoms from extended exposure to multimedia displays.

Chapter 3 focus some core aspects of HCI, namely the immersion definition, interaction models, NUI and WIMP interfaces, body and hand-tracking solutions, and Head-Mounted Displays.

Chapter 4 compiles some projects that take advantage of digital games for health recovery, and the feasibility of virtual reality systems for the senior citizen. It is also retrieved some upper-body movements for stroke recovery.

Chapter 5 reports the empirical research and states all the practical work that was created such as concepts for the game, coding strategies, searched software and data collection instruments.

Chapter 6 explains all the results that were obtained through quantitative and qualitative methods and discusses the conditions on how that data was retrieved.

Lastly, the conclusion chapter will answer to the research question and will reflect on the prototype limitations and highlight improvements based on all the retrieved data.

This document was fully written in English, while all data collection instruments were translated from Portuguese to English. The APA 6th edition (American Psychological Association) citation method was chosen for its international recognition.

All the ethical issues have been considered during this research.

CHAPTER 1: STROKE PATHOLOGIES

Cardiovascular diseases are the main cause of death in Portugal and are one of the most important causes of incapacity that reduces the lifespan of the human body. The Organization for Economic Co-operation and Development (OECD) refers that cardiovascular deceases are the main cause of death for EU members, adding to 36% all deaths in 2010. Cardiovascular diseases have a range of diseases related to the circulatory system, namely ischemic heart disease, and the stroke, which correspond to 60% of all cardiovascular diseases (SNS & DGS, 2017).

This research studies the stroke pathology but does not intervene in other diseases. It is required to define and classify the stroke. For that purpose, the chapter is organized as follows: Section 1.1 focus on the target audience with statistical results of the affected countries; Section 1.2 defines the existing types of stroke and describes the brain injury; Section 1.3 describes the main consequences in human motricity and cognitive functions; Section 1.4 states some rehabilitation tools to classify the disease and exemplifies some actions that can be taken to improve neural plasticity after a stroke.

1.1 Target Audience

"The stroke is the leading cause of permanent motor disability in adults, and the number of stroke survivors is projected to increase significantly to almost 80.000.000 by 2030" (Putrino et al., 2017, p. 295). The stroke statistical data states the increased stroke prevalence with age. There is a bigger incidence in men of younger age groups, but several studies reported that women had the highest stroke prevalence rates in older age groups. Rates increased from approximately 5000/100 000 in subjects aged less than 75 years to 10 000 or more per 100 000 in those with 80 or more years (Truelsen et al., 2005).

With the growing world-wide burden of stroke, there is a continued need to understand the characteristics of the disease and its impact in various countries. The International Journal of Stroke (Thrift et al., 2017) searched for the incidence rate of this disease and compiled all the existing information from a group of 192 members of the World Health Organization (WHO). Countries that reported their annual data where included in Figure 1, that presents an increase of stroke incidence according to the increase of age.

A more detailed assessment per country has also been disclosed about incidence and mortality of the stroke around the world in Figure 2. Incidence rates between figures, highlight different aims of data interpretation: The Global Burden of Diseases (Figure 1) provides estimates according a systematic approach and enables comparison across diseases, but the Global Stroke Statistics (Figure 2) identifies countries with the most recent data on stroke incidence, and highlights countries where data is lacking or is out of date. There is a relation between high income countries, and stroke prevalence, although there are some exceptions of low-income countries, such as Belarus, and Iran (Thrift et al., 2017).

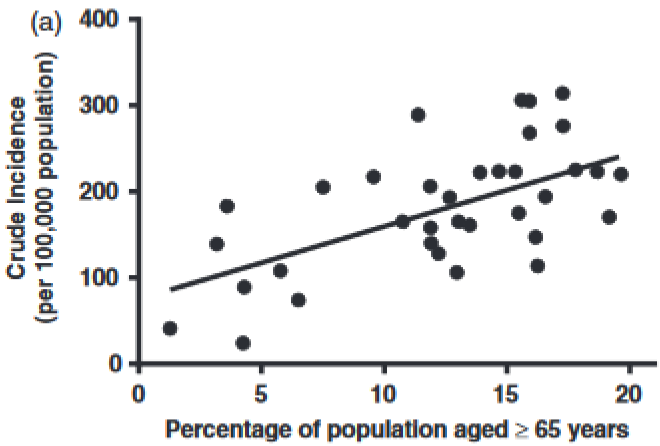


Figure 1- Information regarding stroke incidence according to age > 65 years – Retrieved from: Thrift et al., 2017

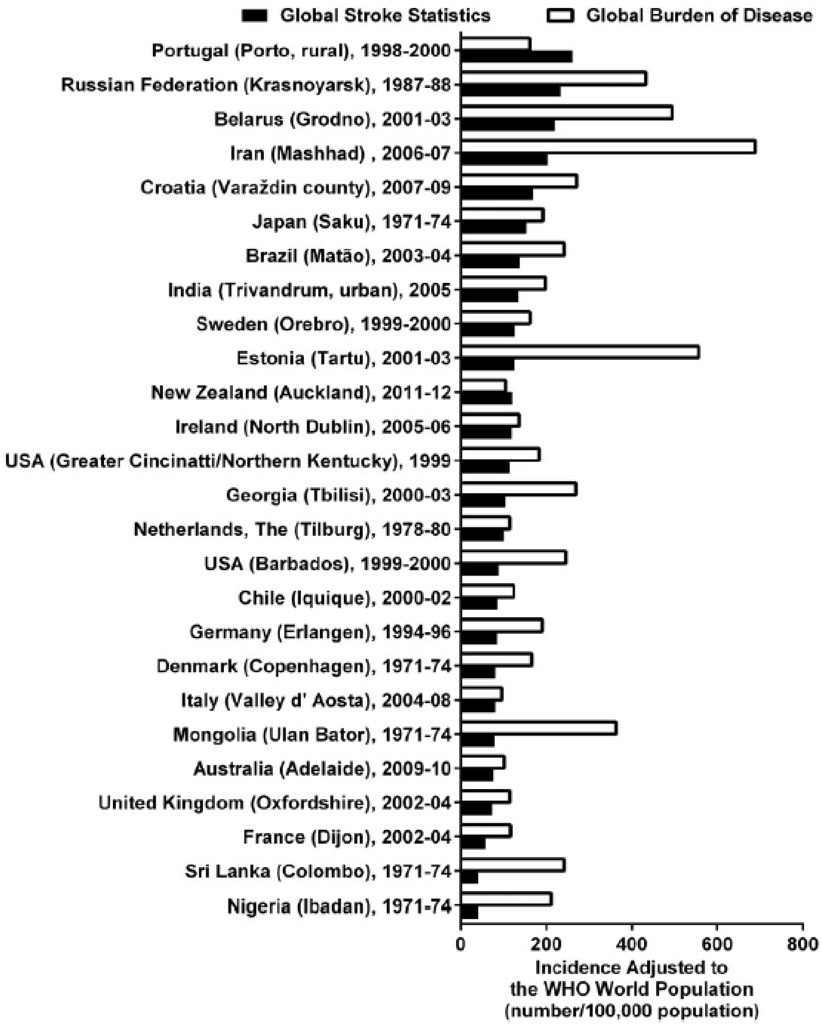


Figure 2 - Comparison of incidence rates and age between the Global Stroke statistics and the Global Burden of Disease – Retrieved from: Thrift et al., 2017

1.2 Stroke Definition

A stroke is characterized as a neurological deficit attributed to an acute focal injury of the central nervous system. Blood interruption in the irrigation of the brain is caused by a clot blockage or a rupture of a blood vessel. The absence of oxygen and nutrients causes damage to brain tissue. The obstruction or haemorrhage of an artery, when involving the cerebral hemisphere or brainstem, causes specific neurological deficits, depending on the brain affected area. Since each brain area has a specific body function, clinical outcomes may vary vastly (Klijn & Hankey, 2003).

According to Caplan (2009), depending on the affected brain area of the stroke, it is possible that the opposite side of the body can be affected, resulting in muscle spasticity, which reflect on muscle contraction. Strokes can be classified in two categories: ischemic and haemorrhagic. Ischemic stroke is caused by clot blockage of a blood vessel. The ischemic stroke can occur due to (1) thrombosis, (2) embolism, or (3) hypoperfusion:

(1) Thrombosis refers to a local obstruction of an artery. The obstruction may be due to arterial wall disease such as arteriosclerosis, dissection, or fibromuscular dysplasia.

(2) Embolism occurs due to blockage of the arterial access of a region of the brain by debris particles.

(3) Hypoperfusion is a circulatory problem through all the organism, that can manifest itself in other organs.

Haemorrhagic stroke occurs when the blood vessel breaks, causing internal brain bleeding. This type can be classified as intracerebral or subarachnoid. In the first subtype, haemorrhage occurs directly to the cerebral parenchyma, and in the second subtype the haemorrhage occurs to the subarachnoid space, mixing with the cerebrospinal fluid.

1.3 Stroke Consequences

The stroke is a big health problem, resulting in devastating sequelae, which can lead to considerable changes in an individual life. Taking care of a person after a stroke is often a long-term commitment for family members. This traumatic brain injury is caused by vascular disorders such as cerebral infraction, intracerebral haemorrhage and subarachnoid haemorrhage, which can occur when blood flows are interrupted. Brain damage results in changes for neurons and non-neuronal brain cells that alter learning processes, with the loss of tissue at the primary site of the injury, while adding neurodegenerative and neuroplastic changes in connection regions. Neurons undergo regenerative and degenerative responses to the injury. (Kleim & Jones, 2008).

The *Canadian Partnership for Stroke Recovery* divides the stroke consequences by brain areas. The stroke can occur in the cerebral hemispheres (Figure 3) or the brainstem (Figure 4). The cerebral hemispheres are divided in (1) Anterior Cerebral Artery, (2) Middle Cerebral Artery, (3) Right and Left Hemispheres. The following text will divide the consequences according to the location of the stroke in the human brain:

(1) **Anterior Cerebral Artery:** Contralateral weakness/sensory loss, mutism, urinary incontinence, contralateral grasp reflex and paratonic rigidity, transcortical motor aphasia on the left side, and gait apraxia.

(2) **Middle Cerebral Artery:** Contralateral hemiparesis/hemiplegia, contralateral sensory loss, contralateral homonymous hemianopsia. The left hemispheric area causes aphasia, and the right hemispheric area causes visual perceptual deficits including left neglect.

(3) **Right Hemisphere**: Visual spatial perceptual disorders, emotional disorders, and communication disorders. **Left Hemisphere**: Aphasia, apraxia, and emotional disorders.

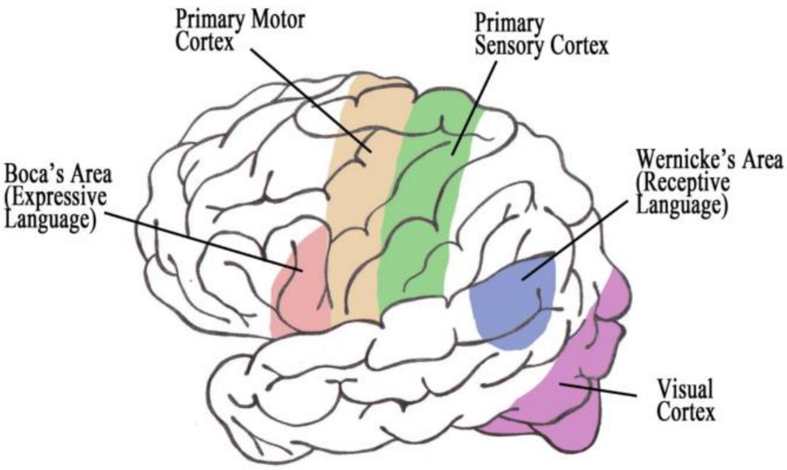


Figure 3 - Cerebral Hemispheres - Retrieved from: Teasell & Mbbs, 2013

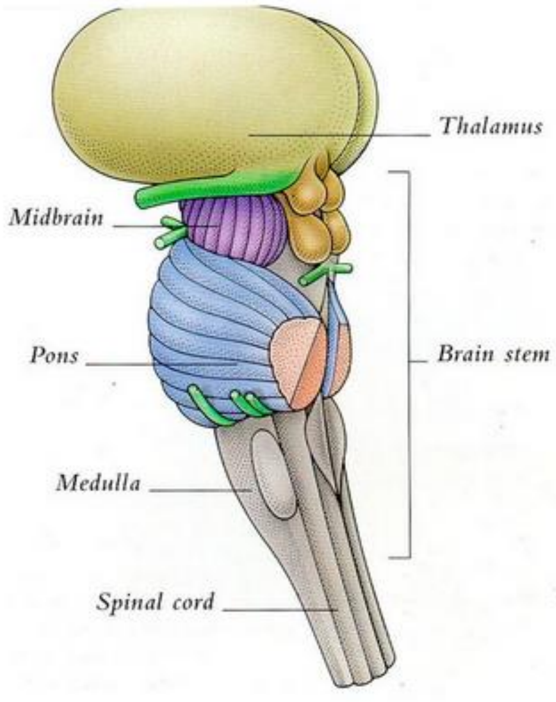


Figure 4 - Lateral View of the Brainstem
Retrieved from: http://physiologyplus.com/brainstem/

Each right and left hemisphere is responsible for the motor activity while receiving information from the opposite part of the body. Each side is specialized for a specific task, however an activity requires the integrated function of both sides. None of the sides is dominant. Based on the functions of the left and right hemisphere it is common to neglect more the left side, since the right side has a bigger influence at the attention and arousal of the visual field. The right side is more capable of compensating for the left hemisphere.

The brainstem consequences can be resumed in bilateral visual and cranial nerve problems, vertigo, dysphagia/dysarthria, diplopia, facial numbness, hemiparesis, ataxia, hemi or bilateral sensory loss.

Furthermore, the previous description of the stroke consequences by the *Canadian Partnership for Stroke Recovery* is stated in this document briefly, and does not describe the full complexity of the human brain (Teasell & Mbbs, 2013).

Putrino et al. (2017) references that the major consequences from a stroke are loss-of-motor function, with 70%-85% of strokes leading to impairments in voluntary movement. About 60% of chronic stroke survivors report significant upper limb impairments that interfere in daily life, are associated to decreased quality of life, and suffer from increased anxiety.

The reported stroke consequences in Ribeiro (2016) research are incontinence, paralysis, spasticity, vision problems and others. The consequence with bigger impact in motricity is hemiparesis. Hemiparesis is a muscle weakness from one side of the body. You can still move the affected part, with reduced muscular strength.

Furthermore, Thompson & Ryan (2009) reported emotional manifestations between stroke patients and spousal relationships. Anger proneness and irritability has been reported by the patients, while being aware of being less tolerant with their spouses. Despite being conscious, the patients were unable to prevent such behaviour when communicating. This condition generates a feeling of guilt and further increases low self-esteem and despair. There are also feelings of frustration while performing daily routine tasks, because the patient is dependent of others. Sexuality is also affected, as several patients reported changes in the dynamics of spousal relationship after the stroke. There is also the problem of personal hygiene and outward physical appearance (facial asymmetry and drooling) In terms of cognition, stroke patients can have many cognitive symptoms that can include dementia, memory problems, and many communication challenges.

According to Pancioli et al. (1998), public awareness of monocular visual losses as a manifestation of the stroke or transient ischaemic attacks, seems to be low despite the permanent disabilities of visual loss it may cause.

Table 2 systematizes all the previous referenced consequences in three different domains: Physical, Cognition, Emotional.

Table 2 - Systematized stroke consequences according to a specific domain.
Based on: Pancioli et al., 1998; Putrino et al., 2017; Ribeiro, 2016; Thompson & Ryan, 2009

Domain	Consequences
Physical	Reduced motricity, paralysis, incontinence, spasticity, reduced vision, facial asymmetry, drooling
Cognition	Changing of learning processes, dementia, memory problems, communication problems
Emotional	Anxiety, guilt, reduced self-esteem, despair

1.4 Stroke Rehabilitation

According to Goldstein (2008), effective stroke rehabilitation must occur as soon as possible, be intense and repetitive, which can lead to problems with patient motivation and engagement. Before formulating a correct working plan, the paralysis must be evaluated in terms of location and percentage of impairment. There are medical assessment tools that can resume the stroke patient diagnosis, which can then be analysed for a correct therapy. The following section resumes assessment tools for the stroke recovery, and cognition recovery aspects.

1.4.1 Rehabilitation signals and assessment tools

The recovery from psychological impairments (motor deficits, abnormal sensation, aphasia, visuospatial neglect) can lead to a recovery from stroke disabilities (walking, dressing, bathing) and ultimately a reduction of stroke handicaps. The process of recovery reflects three different processes according to Duncan et al. (1994) research: (1) resolution of acute pathological sequelae of stroke, (2) intrinsic neuroplasticity, and (3) behavioural compensation. Superficial measurements with exclusive focus to the monitoring of the disability recovery, does not give the entire picture of the recovery process.

Considering the recovery pattern of stroke recovery, it is difficult to define specific time zones due to the discrepancy between stroke cases. For example, Goldstein (2008) refers the most rapid period of recovery is over the first 30 days and continues over the next 60 days. Individuals may improve over longer periods of time, even over years. Parker, Wade, & Hewer (1986) refer that the recovery of the hemiplegic arm can continue up to 6 months after the stroke. It is acknowledged based on these examples that the treatment should start as soon as possible for optimal recovery.

The two best indicators of recovery from impairments are the initial severity of the neurological deficits and the early patterns of improvement. Patients who experience quick changes in motor function, can potentially achieve a better recovery (Parker et al., 1986).

To evaluate the stroke patient impairment, the doctor can use several types of evaluation scales. The following text will explain in detail the Fugl-Meyer assessment scale, the ICF Core Set and the FIM (Functional Independence Measure).

The Fugl-Meyer assessment test (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975), is a quantitative assessment of physical performance, based on statistical analysis for both research and clinical work. The assessment method is a cumulative numerical scoring system for measurement of motor recovery, balance, sensation, and joint range of motion in patients who suffered a cerebrovascular accident. Coordination and speed tests are also included, while the functions of wrists and hand are assessed separately. Fugl-Meyer demonstrated the validity of this assessment method by graphically plotting the order of development of the sequential stages of motor return for the arm and leg. Using a sample of 60 hemiplegic patients who were investigated one year after a stroke, it was found a high correlation between the motor score and activities of daily living capacity. However, one major weakness of the Fugl-Meyer assessment is that intratester and intertester reliability is yet to be established. The list for the upper-limb is comprised in 33 different items (Table 3).

According to Singer & Garcia-Vega (2017), the Fugl-Meyer Upper Extremity Scale is widely used and is a highly recommended stroke-specific, performance-based measurement of impairment. The Scale comprises 33 items each scored from 0 to 2, where “0=cannot perform”, “1=performs partially” and “2= performs fully”. The total motor score of the upper extremity is 66 points. Duncan, Propst, & Nelson (1983) also state that the Fugl-Meyer assessment of physical performance is extremely reliable when performed repeatedly by one examiner on the same patient and can be performed in approximately 30 minutes.

Table 3 - Fugl-Meyer Upper Extremity Scale – Retrieved from: Fugl-Meyer et al., 1975

A – Shoulder/Elbow/Forearm	
I – Reflex Activity	Flexors Extensors
II – a) Shoulder	Refraction Elevation Abduction Outwards Rotation
II – b) Elbow	Flection
II – b) Forearm	Supination
II – b) Shoulder	Inward rotation
II – b) Elbow	Extension
II – b) Forearm	Pronation
III – Hand to lumbar spine	
III - Shoulder	Flexion 0º - 90º
III – Elbow 90º	Pronation/Supination
IV - Shoulder	Abduction 0º - 90º Flection 90º - 180º
IV – Elbow 0º	Pronation/Supination
V – Normal reflex - activity	
B - Wrist	
Elbow 90º	Wrist Stability
Elbow 90º	Wrist flexion/extension
Elbow 0º	Wrist Stability
Elbow 0º	Wrist flexion/extension
Circumduction	
C - Hand	
Fingers	Mass flexion
Fingers	Mass extension
Grasp a,b,c,d,e	
D – Coordination/Speed	
Tremor	
Dysmetria	
Time	

According to Geyh et al. (2004), the ICF Core Set is a globally agreed framework and classification that defines the spectrum of problems of a stroke patient. The main challenge of the ICF Core Set is to select a sufficiently small number of categories in a condition with great variability and complexity such as the stroke. The included body functions namely, body, mental, neuromusculoskeletal, movement, and sensory functions, and pain are covered in great depth. There are two types of list: Brief ICF Core Set and Comprehensive ICF Core Set containing some other categories. Table 4 selects the category of body functions.

Table 4 - Comprehensive ICF Core Set for body functions after a stroke – Retrieved from: Geyh et al., 2004

ICF Code	ICF Category title	ICF Code	ICF Category title
B110	Consciousness functions	B310	Voice functions
B114	Orientation functions	B320	Articulation functions
B117	Intellectual functions	B330	Fluency and rhythm functions
B126	Temperament and personality functions	B410	Heart functions
B130	Energy and drive functions	B415	Blood vessel functions
B134	Sleep functions	B420	Blood pressure functions
B140	Attention functions	B455	Exercise tolerance functions
B144	Memory functions	B510	Ingestion functions
B152	Emotional functions	B525	Defecation functions
B156	Perceptual functions	B620	Urination functions
B164	Higher-level cognitive functions	B640	Sexual functions
B167	Mental functions of language	B710	Mobility of joint functions
B172	Calculation functions	B715	Stability of joint functions
B176	Mental function of sequencing complex movements	B730	Muscle power functions
B180	Experience of self and time functions	B735	Muscle tone functions
B210	Seeing functions	B740	Muscle endurance functions
B215	Functions of structure adjoining the eye	B750	Motor reflex functions
B260	Proprioceptive function	B755	Involuntary movement reaction functions
B265	Touch function	B760	Control of voluntary movement functions
B270	Sensory functions related to temperature and other stimuli	B770	Gait pattern functions
B280	Sensation of pain		

Table 5 exemplifies b110 ICF code regarding the consciousness function. The scale can go from 0 (no impairment) to 4 (complete impairment).

Table 5 - ICF Core SET Table Example
Retrieved from: https://www.icf-core-sets.org/

BODY FUNCTIONS Physiological functions of body systems (including psychological functions) ***How much impairment does the person have in ...***		No impairment	Mild impairment	Moderate impairment	Severe impairment	Complete impairment	Not specified	Not applicable
		0	**1**	**2**	**3**	**4**	**8**	**9**
b110	**Consciousness functions**	☐	☐	☐	☐	☐	☐	☐
	General mental functions of the state of awareness and alertness, including the clarity and continuity of the wakeful state. Inclusions: functions of the state, continuity and quality of consciousness; loss of consciousness, coma, vegetative states, fugues, trance states, possession states, drug-induced altered consciousness, delirium, stupor Exclusions: orientation functions (b114); energy and drive functions (b130); sleep functions (b134)							
	Sources of information: ☐ Case history ☐ Patient reported questionnaire ☐ Clinical examination ☐ Technical investigation							
	Description of the problem:							

The Functional Independence Measure (FIM) is an instrument that measures functional restrictions of diverse origin. Its main activities focus on self-care, locomotion, sphincter control, communication, and social cognition, which includes social interaction and problem solving. Each activity is evaluated with a score between 1 (total dependence) and 7 (total independence). Total score varies from 18 to 126 (Riberto et al., 2004).

1.4.2 Neurological Rehabilitation

During rehabilitation, neuroscientists are commonly asked what type of specific therapies should be included in clinical treatment programs. Unfortunately, animal models of neurological disorders cannot be directly applied to humans. However, the neurological phenomenon has been studied to identify primary principles that guide in the recovery process. Following Kleim & Jones (2008) research, it has been verified the adaptable capacity of the central nervous system (neural plasticity). Existing data suggests that neurons, among other brain cells, possess the remarkable ability to alter their structure and function in response to a variety of internal and external pressures. Neural plasticity is the mechanism by which the brain encodes experience and learns new behaviours. It is also the mechanism by which the damaged brain relearns lost behaviour in response to rehabilitation. The basic principles of neural plasticity (intact and damaged brain) can drive the recovery process, if critical behaviour and neurological symptoms are identified correctly.

Improving functions after brain damage falls into two categories according to Kleim & Jones:

(1) Efforts to limit the severity of the initial injury to minimize loss function;

(2) Efforts to reorganize the brain to restore and compensate for a function that has already been compromised or lost.

To apply those improvements, there is a need to understand our brain structure. While it is not possible to place new neurons and neural connections in the damaged areas, it is possible to create appropriate neuronal connections through learning. There are substantial evidences that the human brain continuously remodels its neural circuitry to encode new experiences and change behaviours (Kleim & Jones, 2008).

The previous research can highlight 10 different principles of experience-dependent plasticity, that can improve the recovery process which are:

1. **Use it or lose it -** Neural circuits not used in task performance for extended periods of time start to degrade. This loss can be prevented, and functional reorganization is promoted because of rehabilitative training in skilled reaching tasks.
2. **Use it and improve it** – Neural plasticity can be induced within specific brain regions through extended training.
3. **Specificity** – Training a specific modality may change a limited subset of the neural circuitry involved in the more general function and influence the capacity to acquire behaviours in nontrained modalities.
4. **Repetition matters** – Repetition of a newly learned (or relearned) behaviour may be required to induce lasting neuronal changes. Plasticity brought through repetition makes the acquired behaviour resistant to decay in the absence of training.
5. **Intensity matters** – Low-intensity stimulation can induce a weakening of synaptic responses whereas higher intensity stimulation will induce long-term potentiation.
6. **Time matters** – Neural plasticity is a process, rather than a single event. Some forms of plasticity depend upon others.
7. **Salience matters** – Goes by the definition that needs to exist a system to place weight and importance of any given experience, so it can be encoded.
8. **Age matters** – An aged brain has less neuroplastic responses, derived from neuronal and synaptic atrophy.
9. **Transference** – The ability within one set of neural circuits to promote concurrent or subsequent plasticity. For example, training on a fine digit movement task induces an increase in corticospinal excitability and an expansion of hand muscle representation in primary motor cortex.
10. **Interference** – Plasticity is broadly seen as good, when described in the context of recovery of function. However, plasticity can also impede the induction of a new plasticity within the same circuitry.

CHAPTER 2: DIGITAL GAMES

Upper limb (arm) problems are common after a stroke and the recovery is commonly limited. Improving the upper limb function is therefore a main element of rehabilitation, to maximize patient outcomes while reducing the affected paralysis. The treatment must be applied as soon as possible, however due to low motivation and depression states, it is hard to engage the patient in physiotherapy sessions (Coupar, Pollock, La, Sackley, & P, 2012). Digital games are an emerging approach for the upper limb stroke treatment, with the potential to provide rehabilitation services and improving motor function at a cost and quality that is the same or superior to traditional therapy (Putrino et al., 2017).

This chapter is divided as follows: Section 2.1 explains the relation between “game and play”; Section 2.2 defines a digital game, introduces the culture of videogames as a global phenomenon, and features a diversified library of game genres according to two authors; Section 2.3 refers to fundamental game design; Section 2.4 specifically identifies game design for the senior citizen; Section 2.5 explains visual symptoms from extended exposure to multimedia displays.

2.1 Definition of Game and Play

It is difficult to define “game” and “play” due to involving psychological and physiologic phenomenon’s, that go beyond physical activities. The definition generates room for discussion from different perspectives and there are several authors that create their definition (Salen & Zimmerman, 2004). The following Section selects some referenced authors with their perspective by the following order: (1) What is “play” and what is “game”; (2) Gaming as a form of play; (3) Definition of a generic game.

(1) Adams (2010) states that games arise from the human desire to play, and from our capacity to pretend. To “play” is a recreational human activity with social meaning, that distances itself from the real world. The pretender creates, changes and abandons the generated world at will. Although we use the word “play” to describe the entertainment through toys we do not engage in the same way for different types of entertainment. These types of “play” are differentiated through presence and absence of rules and goals. Adams definition of game is not rigorous due to the existence of a broad class of human behaviours where counterexamples are easy to find. The definition used by Adams is as follows: “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” (Adams, 2010, p. 3). By the definition, the essential elements of a game are play, pretending, goal and rules.

(2) Johan Huizinga (1980) sees gaming as a form of play. But what is playing? The author states that we should understand human play not as a biological phenomenon but as a cultural phenomenon. The non-materialistic quality of play extends beyond a purely physical or biological act and into the world of signs – thoughts, representations, messages, and communication all accomplishments of higher levels of embodied thinking or abstraction. Play is comprised within the socio-cultural world of communicative experience that joins body and mind. Thus, play is understood as a social construction, thus giving significance in daily life as an accomplishment of communicative exchange. Playing represents freedom, which implies its voluntary nature. It is emphasized the fact that there is “sense” to play, meaning that there are key aspects of play and play’s participation in the creation of meaning.

(3) According to Kriz (2016) a game is an activity that involves one or more individuals who assume roles while trying to achieve an objective. Rules determines boundaries within the game and determine what players can or cannot do. Playing a game means to use a game artefact to simulate system processes of a complex and dynamic reference system. A game reconstructs important aspects of the reference system, and is an abstract model of the reality with reduced complexity. This definition embodies all types of games, not just digital games.

2.2 Digital Games & Genres

The previous section does not make a distinction between digital games and non-digital games. Digital games are a complex toy that is vastly more responsive than conventional toys, such as card and board games. The unique characteristics of digital games brings unique qualities and concerns to the practice of game design. Salen & Zimmerman (2004) defines a game as a system with four elements which are objects, attributes, relationships, and an environment. For example, "*Tetris*" is a digital game from the *Nintendo Game Boy* handheld platform that can be viewed as a system of cultural context, such as fan magazines, marketing, manufacturing, and economics. The hardware and software are relevant but do not explain all the context if analysed in isolation. The rules of *Tetris* are composed of a mathematical system of the game that is embedded into the code, but there are external factors such as the human input (pressing a button) that needs to exchange information between the game and the environment. The role of the game designer in this case is not to create technology, but to create an experience to design meaningful play.

As described by Adams (2010), a digital game is a subset of the universe of all games, and is mediated by a computer. The computer can have any size and enables digital games to borrow entertainment from other types of media, such as books or movies.

Kerr (2006) defines a digital game to refer to the entire field of arcade, computer, console and mobile games. For this author, digital games are not one medium but many different types of media. While digital games are available on several platforms, they are composed of numerical representations, in order to be easily ported between platforms. PC games refer to the personal computer platform, while consoles refer to dedicated hardware to run digital games.

The first digital games emerged from the United States of America during the Cold War (late 1960). At the time, there was a sustained growth in service industries (private and public). The workforce suffered from structural shifts, and evolved to self-servicing domestic work, transport and entertainment. According to Kerr (2006), the first commercial digital games were launched on two different platforms: The *Baer/Magnavox Odyssey* console with tennis and hockey games and *Nolan Bushnell's/Atari* game named *Pong*. These games ended up developing the first sports games. The decline of *Atari* in the late 1970's opened the door to other companies to enter the market such as *Nintendo* and *Sega*.

The term "cultural industry" emerged to describe the industrialization of culture in the USA in the 1940's (Adorno & Horkheimer, 1977). The industrialization of culture was the opposite of what culture was meant to do. It was believed that culture was meant to offer a critique of everyday life. Over time, the concept of the "cultural industry" has become pluralised and shifted away from the industrialization perception.

Kerr (2006) states that cultural industries traditionally refer to media industries of television, radio, books, newspapers, magazines, films and music. More recently we have the internet and digital games. By definition, a cultural product is a public good that is not destroyed during use and can be reused by others.

The country of South-Korea is a good example of gaming as a cultural phenomenon, specifically online gaming. According to Jin (2010) games are broadcasted on television, and professional gamers are seen as celebrities. The rapid grow of broadband subscribers allowed a unique growth of online games market. Online gaming became a way to socialize for human relationships. The South-Korean gaming industry has been a pioneer at eSports (electronic sports and leagues), with the support of the South-Korean government that encouraged online gaming as a cutting-edge business and a cultural touchstone. The globalization aspect of this culture propagated to other countries and are not exclusive to young audiences.

Digital games are a billion-dollar business that has grown through the years (Statista, 2018). The timeline in Figure 5 forecasts the value of the digital game industry in the United States between 2011 and 2020. Every year the market experiences a low in the summer months, and then is revived at the holidays season. The majority of revenues in the USA in 2016 were generated by digital PC and console games, while the second highest share goes to mobile games.

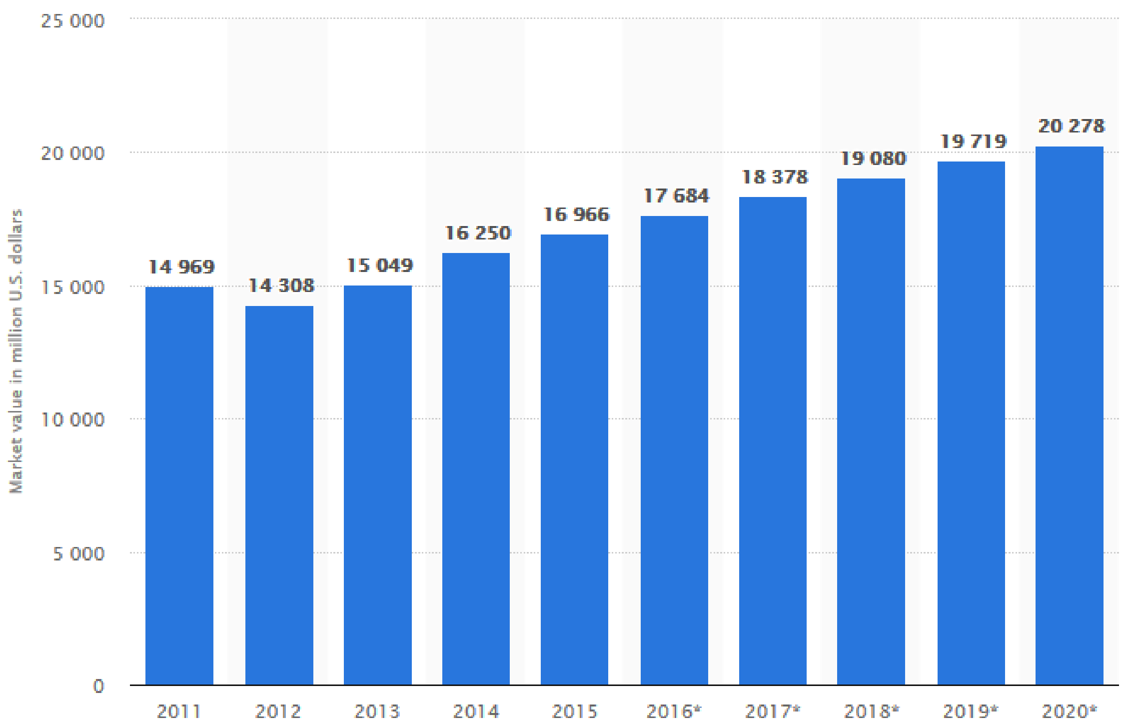


Figure 5 - Digital Game Market in the USA between 2011 and 2015 – Retrieved from: Statista, 2018

A game genre is a specific category of digital games related by similar gameplay characteristics. Genres can encompass a wide variety of games leading to a more specific classification, such as subgenres. For almost two decades, studies have looked at different type of digital games, resulting in a wide range of categorization. According to Elliott, Ream, Mcginsky, & Dunlap (2012), there is no standard list for game genres. For example, "*Gamespot.com*" or "*Metracritic.com*", which disseminate game information on the web, have different genre attributions. The author recommends the "*Gamefaqs.com*" database, which is the most comprehensive database of its type. Table 6 synthetizes all the genres.

Table 6 - Game Genres – Retrieved from: Elliott et al., 2012

Genre	Description
Action-Adventure	A broad category of games oriented toward action and exploration, mostly in third person perspective.
MMO Role-Playing	Massively multiplayer online role-playing games in which players develop a character and interact collaboratively and competitively with other players in a shared online world.
Other Role Playing	Games rich in narrative, usually single player. Success depends largely on building a sufficiently powerful party of characters to achieve objectives.
First-Person Shooter	Kill-or-be-killed in fast, violent action, usually with military or sci-fi themes.
Other Shooter	Shooting type games in third-person perspective.
Gambling	Primarily simulations of Poker, Black Jack, and Slot Machine gambling.
Real-Time Strategy	Strategic combat-oriented games from an aerial perspective with no wait between moves.
Other Strategy	Turn-based (i.e., waiting on the player to act) and other forms of strategic simulation.
Board/Card	Simulations of primarily classic games without gambling.
Sports General	Primarily interactive motion-controlled sports and workout games.
Sports	Realistic simulations, primarily of team sports.
Puzzle	Games involving matching, logic, deductive reasoning, and other puzzles.
Rhythm	Music and dance themed games often involving a unique controller like a guitar or dance pad.
Driving	Primarily car racing games.
Platformer	Games in two or three dimensions in which players contend with enemies in an environment requiring precision movement and jumping to achieve objectives.
Other Genres	Titles that were distinct but did not belong to categories large enough for valid analyses. Categories large enough for valid analyses (e.g., fighting, survival-horror).

The described perspective from Adams (2010) states that the game's gameplay determines the genre, regardless of the settings. For example, a medieval role-playing game is different from a medieval war game. The genre list from Adam's has some similarities if compared to Elliot's genres (Table 6 and 7). For example, Action, Sports, Puzzle, Driving, and Online Games are common genres between the authors.

Table 7 - Game Genres – Retrieved from: Adams, 2010

Genre	Description	Commercial Examples
Action Game	Most of the challenges test the player's physical skills and coordination. It is common to find puzzle-solving, exploration, and tactical conflict. There are some sub-genres such as Shooters, Platform, Fighting, Fast Puzzle, Action-Adventure, Music, Dance, Rhythm.	Call of Duty, Quake
Strategy Games	Challenges the player to achieve victory through planning a series of actions against one or more players.	Age of Empires, Civilization
Role-Playing Games	Interact with a game world through an avatar whose skills and power grow as time goes on.	Final Fantasy, Zelda
Sports Games	Sports Games simulate a real-world sports scenario.	FIFA, Pro Evolution Soccer
Vehicle Simulations	Creates the feeling of driving or flying a vehicle.	Gran Turismo
Construction and Management Simulations	Build things, while operating with economics constraints.	SimCity, Settlers
Adventure Games	Typically, an interactive story about a character whom the player controls.	Tomb Raider
Artificial Life	Modelling biological processes to simulate the cycles of living things.	The Sims, FreeCell
Puzzle Games	Solve puzzles within a storyline.	Puzzle Bobble, Candy Crush
Online Gaming	Multiplayer distributed games in which the player's machines are connected by a network.	World of Warcraft, League of Legends

From both tables (Table 6 and 7), it is possible to search for game preferences focused on the senior citizen, according to a specific context and region of the world, since it cannot be generalized. However, it can give some hints about the type of game that has the biggest probability to be accepted among senior communities. The research written by Schutter (2014), evaluates a survey of 124 people between 45 and 85 years about their favourite game genres. Regarding platform and genre preferences, it is concluded that the respondents can mainly be classified as casual gamers (80% of the sample) who chooses the PC platform, with a preference for traditional and puzzle games. The author acknowledges that the study has some flaws owing to a small sample size and the issues concerning Internet sampling and self-selection. It is stated that the older audience of digital games is a difficult audience to study because digital games are not always socially accepted in the context of senior players. Another research by Flores et al. (2008) for the ElderGames project suggest that seniors prefer simplistic puzzle and quiz games. This conclusion is similar to Schutter (2014) survey.

But is it feasible to use potential health care applications, while using a virtual world environment such as Second Life? According to Cook & Winkler (2016) pilot studies the senior citizens that are technologically savvy and more confident in their ability to learn about the second life virtual world are more prone to successfully complete training programs, if compared to less confident senior citizen individuals. For this case, the training program involved getting new friends, finding places to visit, using the teleport feature, shopping, changing the avatar appearance, and participate in sports activities. It was registered between the participants, a perceived usefulness of virtual worlds in terms of health, managing health, overall usefulness, and boosting the quality of life. Although the results are positive, the use of virtual worlds among senior citizens is low, but it is expected to increase over the years (Siriaraya & Ang, 2012; Siriaraya, Ang, & Bobrowicz, 2014).

2.3 Fundamentals of Game Design

The following fundamentals on Game Design are based on Adam's book "Fundamentals of Game Design" (Adams, 2010).

Game design is the process of imagining a game, defining how it works, describing the elements that are in the game, and articulate the information across the development team. This last task is ignored since this research only has one developer. The following design approach is called player-centric game design.

Interactive entertainment is a collaborative art form where different designers and developers include both artistic and functional elements that are aesthetically pleasing, work well, and are enjoyable to play. The player-centric game design is a philosophy of design that envisions a representative player of a game. The duty of the designer is to entertain and empathize. The first duty to entertain the target audience takes priority over the designer's desire to express himself about his own desires. The second duty requires the designer to place himself in the position of a representative player and imagine what it is like to play the game. The most important aspect is to ask about the player's desires and preferences about digital entertainment. The process of empathizing is differentiated from other types of media. Books, paintings, music and movies are artistically virtuous to create, without worrying about how it is received. For digital games, it is required to consider the players feelings about the game, due to the participation factor.

In terms of structure, the gameplay modes and shell menus must establish a relationship that collectively creates the structure of a game. Typically, a game moves along its shell menus in response to the players actions. During actual play, a game can change from one gameplay to another in response to the player actions, or if the circumstances of the game require that change.

The stages of a design process cannot be generalized for all types of games, due to their diversity. Typically, large games must be designed and constructed in an iterative process, with repeated playtesting, and changes to the design. However, the choice of concept, audience, and genre, should not change after being decided. The process can be divided in three parts: (1) the concept stage; (2) the elaboration stage; (3) the tuning stage.

(1) **The concept stage** allows to establish things about the game that are essential. To get a concept, you need a general idea of how it is intended to entertain the player, and why it is believed that the experience is compelling. After defining the experience, it is required to define an audience and the player's role. The player must believe in that game world, the avatar, and the situations the game puts to the player.

(2) **The elaboration stage** starts from moving theoretical aspects to the concrete. It usually begins with a prototype of the game in the form of a technical demonstration. The validation of this step allows to proceed for the full product. During the elaboration stage, there are some areas that need attention, specifically defining the primary gameplay mode, designing the protagonist, defining the game world, designing the core mechanics, creating additional modes, design levels and writing the story. Digital games must be prototyped before they can be built for real, and they must be tested along the way.

(3) **The tuning stage** is directly affected by the schedule. It blocks any new features to the game and allows to make small adjustments to the levels and core mechanics.

According to Csikszentmihalyi & Nakamura (2014) there is a model inside the theory of flow, that gives a comprehension from experiences during which individuals are involved in the present moment. The theory of being "*in the flow*" is the way people describe the subjective experience of involving individuals in manageable challenges, approaching objectives, and processing feedback continuously about its progress. Under these conditions, the experience develops through time, and the subject feels a subjective state with the identified characteristics:

- Peak concentration and focus in the individual current action;
- Fusion of action and awareness;
- Loss of reflexive self-consciousness (loss of self-awareness as a social actor);
- Feeling that you can control the other person action, which implies that you can deal with a situation because you know how to respond to whatever situation is presented;
- Distortion of temporal experience (time passes faster than usual);
- Experience a rewarding activity, so that the ultimate goal is just an excuse for the process.

Games, Sports, and other activities can provide enough feedback to create *flow* (Csikszentmihalyi & Nakamura, 2014). Although, it can be found in any activity, depending on the individual history with the activity, it can bore or create anxiety. *Flow* is experienced when the perception of opportunities to act are balanced with the ability perceived by the actor. The first mapping of the perceived challenges and skills identified three regions of experience: a region of boredom, anxiety, and a flow channel (Figure 6). The model was not consistent due to certain activities where it is provided minimal opportunities for action (watching TV) that do not lead to a *flow* state. The model was redefined were the balance of challenges and skills are above average levels for the individual. Figure 7 differentiates the challenge/skill terrain into eight different channels. The quality of experience intensifies within a certain channel as challenges and skills move away from the person average levels. A bad player confronted with big challenges is going to feel anxiety, worry and apathy for the game, while a good player confronted with an easy challenge is going to be bored and get apathetic. *Flow* occurs when the challenge is high, but the level of skill is also high.

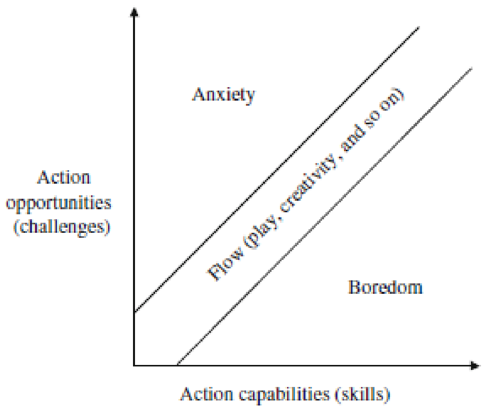


Figure 6 - First model of the flow state - Retrieved from: Csikszentmihalyi & Nakamura, 2014

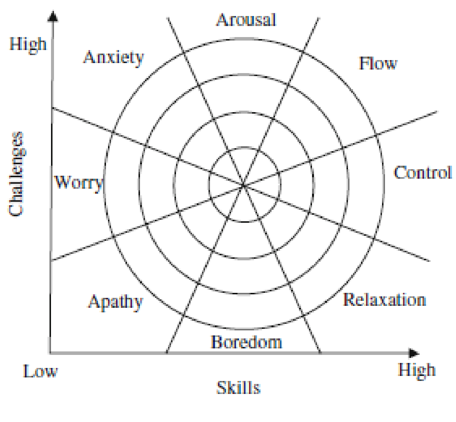


Figure 7 - Final model of the flow state - Retrieved from: Csikszentmihalyi & Nakamura, 2014

The consequences of the "flow" state is persisting during the activity and constant returns to the experience, due to experiential rewards that induce the growth of skills over time. This statement is key to understand why a player commits to the game experience for long periods of time.

This theory was developed under the investigation of intrinsically motivated activities, such as interviewing chess players, rock climbers, dancers, and others who searched for enjoyment as the main reason to pursue an activity. The same analysis can be done to digital games.

2.4 Game Design for Senior Citizens

According to Gerling, Schulte, & Masuch (2011) the engagement with digital games has a positive impact on the emotional and physical well-being of the senior in nursing homes, however commercial games are almost entirely not suitable for them. The core aspects that might help the engagement for the seniors in the use of digital games as leisure will allow for a better focus while producing games for this specific population. The following list identifies sensory decrements with aging that game designers should be aware while developing their games such as:

- Cognitive impairments, which affect problem solving skills, information processing and result in a reduced attention span when working on complex tasks
- A decline of motor skills, which includes a decrease in fine motor skills, changes in posture and balance, and negatively affect motor learning
- Chronic illness, which range from arthritis to severe heart condition, and which have an impact on physical abilities and mobility

In the early 80's, Weisman (1983) introduced digital games to institutionalized senior citizens. Based on observations, it is claimed that games with an adaptable level of difficulty are advantageous, because they support individual preferences and sensory motor skills. The use of large and well-defined visual symbols and clear auditory feedback is recommended to address visual and auditory impairments. The most important idea to be aware, is the use of visually adjustable games (regarding the font, window-size, colours and contrast) that deliver multimodal feedback relying on more than one communication channel and develop basic user interfaces with low complexity. Other features such as keeping the design with appropriate cognitive challenges with the potential of keeping the senior with high interest, can be highlighted on the following list (Gerling et al., 2011):

- Reduction of necessary steps to complete tasks
- Reduction of cognitive load

- Availability of immediate feedback
- Adaptation of digital systems to the user's goals
- System consistency
- Fault tolerance
- Genre

These design guidelines are issued on a meta-level and do not give detailed information on the impact of age on structural elements of games.

2.5 Digital Eye Strain

Section 1.3 identified the main consequences of a stroke, and it was stated that vision can be affected (Teasell & Mbbs, 2013; Ribeiro, 2016; Pancioli et al., 1998). It is relevant to highlight some common problems due to the extended use of multimedia artefacts among this target group.

In the modern world, the extended use of electronic displays is a common fact for daily life at home or at work. The use of desktop, laptop, and tablet computers, smartphones, HMD have become almost ubiquitous. The number of hours that individuals use electronic screens can be easily extended, thus, it is unknown the possible manifestation of ocular and visual symptoms. The following list from Rosenfield (2016) addresses specifically the digital eye strain (DES) during the prolonged use of digital devices:

Gaze Angle: The specific adopted angle when viewing digital devices. Desktop and laptop computers are most commonly viewed in primary and down gaze, respectively, although it may vary with multiple monitors. Hand-held devices such as tablet computers and smartphones may be positioned in almost any direction, sometimes even being held to the side, thereby requiring head and/or neck turn.

Text Size: The size of text may be small, especially on hand-held devices. Higher font values may be necessary for older adults, or individuals with visual abnormalities.

Glare: It is important to have appropriate lightning and the use of windows shades, as well as proper screen and operator positioning. Reflections on the display may result in a loss of work efficiency, due to strain factors. For older patients with less transparent ocular media, the effects of glare may be more disabling. For these individuals, a clinical test can be executed to detect such abnormalities such as the Marco brightness acuity tester (BAT).

Correcting refractive errors: Required working distances may vary from 70cm (for a desktop monitor) to 17.5cm for a smartphone.

Dry Eyes: Longer periods of computer work are associated with a higher prevalence of dry eyes. These ocular surface-related symptoms may result from environmental factors, such as low ambient humidity, high forced-air heating, airborne contaminants, and others, or increased corneal exposure derived from higher gaze angles. Dry eyes increase with age and is higher in women. Lastly, systemic diseases and medication such as arthritis, allergy or thyroid disease not treated with hormones, antihistamines, antianxiety medications, antidepressants, oral steroids or vitamins, as well as those with poorer self-rated health can increase the incidence of dry eyes.

Blink Rate: Can be affected with dry eye prevalence. Several investigations have reported that the blink rate is reduced during computer operation.

CHAPTER 3: HUMAN COMPUTER INTERACTION

Human Computer Interaction focuses on the design of computer technology and the interaction between humans and computers. It groups multiple disciplines such as computer science, cognitive science, and human-factors engineering (Interaction Design Foundation, 2018). However, with recent advancements in technology like the Internet and Smartphones, it has encompassed more fields including information visualization, or social computing.

This chapter limits the field of HCI into the following order: Section 3.1 follows the immersion keyword and defines its view from different authors; Section 3.2 states some interaction models that can be applied to learning or other purposes; Section 3.3 explains types of interfaces; Section 3.4 focus on Body and Hand Tracking Hardware that enables the virtualization of the human body; Section 3.5 relates immersion with the size of the monitor display.

3.1 Immersion

Immersion is used to describe games, but it is not always clear how its use is consistent among people. Following the gaming community perspective, immersion is used when talking about digital games with or without the use of HMD (*Head-Mounted Displays*). Typically, there are some references about game reviews and most importantly, the realism of the game world (Walton, 2014). The experience of immersion is mentioned as critical for game enjoyment and can be destroyed or enhanced by game characteristics.

An outcome of a game should be uncertain in order to be enjoyable (Caillois, 2001; Costikyan, 2013). Some digital games are regarded as popular games that have a certain level of uncertainty. For example, *Mario Kart* has an uncertainty level during acceleration for getting the best start leading point, and *Hearthstone* keeps players engaged by giving some random effects on cards, or defining strategies depending on the other players deck card. Uncertainty, in the context of play, can limit the players' information and showcase their feelings. This level of control attempts to manipulate the degree of immersion (Kumari, Power, & Cairns, 2017).

Douglas & Hargadon (2000) discusses the structure of schemas in narrative, and claim that structural differences differentiate between immersion and *immersion from flow*. This definition might be considered different from gamers, which makes immersion difficult to define.

Virtual Reality (VR) added an interesting perspective on immersive experiences. VR is a computer-simulated environment that gives the user the ability to explore 3D environments. VR can give a virtual presence to oneself while providing immersion of vision but also of sound and tactile feedback. Immersion is defined on 2 main components (Desai, Desai, Ajmera, & Mehta, 2014): (1) depth of information; (2) breadth of information.

(1) **Depth of information** includes resolution, quality and effectiveness of audio visual.

(2) **Breadth of information** is the number of sensory present at a time.

VR has found applications in different areas such as automotive, industry, architecture, medicine and education. However, VR does not necessarily imply immersive stereoscopic visualization: many VR apps are desktop based (Santos et al., 2009).

Virtual Reality research (Malloy & Milling, 2010) references immersion to the concept of presence, which is defined as the extent to which a person's cognitive and perceptual systems are tricked into believing they are somewhere other than their physical location. Patrick et al. (2000) follows the idea that movies and computer games do not provide immersion to its public, which causes divergent meanings of immersion.

Brown & Cairns (2004) references immersion as "being in the flow", which is similar to Nakamura & Csikszentmihalyi (2002) *Concept of Flow* (Section 2.3). In this case, attention defines immersion. Any distraction from the task causes the feeling of flow to be erased. Flow has some similarities with immersion in the fact that attention is needed, the sense of time is changed, and the sense of self is altered.

The immersive experience is not exclusive to VR and monitors in terms of displays. Milgram refers Mixed Reality (MR) to a merge of real and virtual worlds. The *virtuality continuum* in Figure 8 is a mixture of classes. The left side of Figure 8 consists solely on objects that can be exemplified as video displays of a real-world sense, while the other side consists solely on virtual objects that can be exemplified as conventional computer graphic simulation (Milgram & Kishino, 1994).

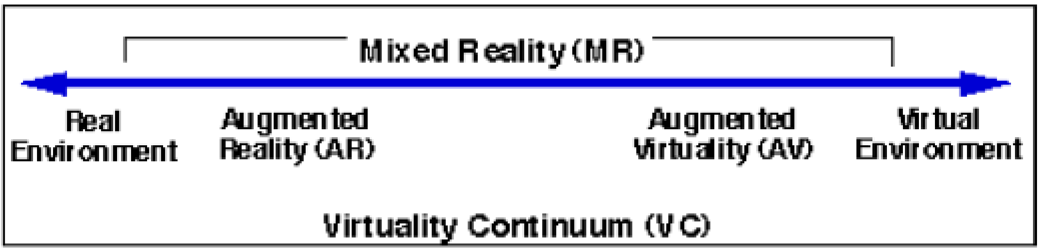


Figure 8 - Simplified representation of a virtuality continuum. Retrieved from: Milgram & Kishino, 1994

Milgram makes a distinction between the real and the virtual according to 3 different views: (1) The real objects are any objects that have an actual objective existence, while virtual objects are any objects that exist in essence or effect. Briefly, real objects can be observed directly or can be sampled and resynthesized via some display devices. The virtual object must be simulated in order to be viewed because in essence it does not exist; (2) Image quality is different from reflecting reality. Just because an image looks real, does not mean that the represented object is real; (3) A real image as any image has some luminosity at the location it appears to be located. A virtual image is an image that has no luminosity at the location it appears, and includes examples such as holograms, mirror images, and stereoscopic displays. Stereoscopy for each left or right eye images are real but the consequent fused percept in 3D space is virtual.

3.2 Interaction Models

Mayer (2001) presents questions about the role of a theory for learning in multimedia design. It is affirmed that the design of multimedia environments should be compatible with learning. However, it is necessary to understand how the human mind processes information while it is being stimulated through multimedia artefacts. Learning in multimedia starts in the capacity of memory of an individual. Memory is used temporarily to store and manipulate information in a state of active conscience. This type of processing in which a person is conscient, takes place in working memory. Figure 9 represents schematically this cognitive theory:

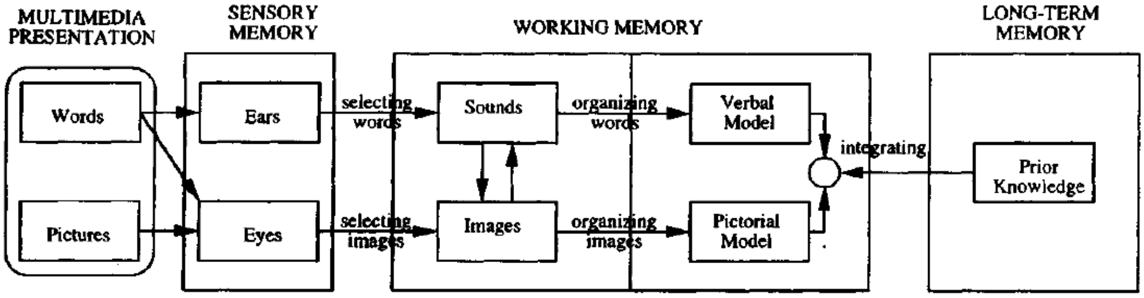


Figure 9 - Cognitive theory of multimedia learning – Retrieved from: Mayer, 2001

At the *Working Memory* area in Figure 9, it is represented raw information like images and sound. Multimedia representation such as words and pictures enter our brain through our ears and eyes, and then they are selected. The biggest capacity area for processing in multimedia learning occurs in words and images selection. Long term memory stores information during long periods of time, however this area is accessed through the working memory area.

Card, Moran, & Newell (1983) described the Model Human Processor, which is a simplified way of viewing the interactions of humans with a computer. That system is called the MHP and is separated in three sub-systems: (1) perceptual system; (2) motor system; (3) cognitive system. It is important to define how these systems are used and how they interact. To maintain an interaction with a computer, the human input is the data output by the computer and vice-versa.

(1) **Perceptual system:** The senses - vision, hearing and touch - are the most important senses in HCI. While making movements, several stimuli are received through sensory receptors and transmitted to the brain, which processes the information and tells the muscles how to respond.

(2) **Motor system:** There are two ways to measure motor skills: Movement time which depends on physical attributes and accuracy. A fast response does not always mean a less accurate response.

(3) **Cognitive system:** For the last sub-system of MHP, the human memory can be partitioned in three different types: (a) Sensory memory; (b) Short-term Memory; (c) Long-term memory.

Following Dix, Finlay, Abowd, & Beale (2003) interaction with computers can happen in different ways according to the type of device, and the type of users. Some examples can be found such as text-entry devices. In this category, it is possible to identify the typical alphanumeric keyboard, handwriting recognition or speech recognition. Other types of interaction involve the mouse, touchpads, trackballs, joysticks, touch-sensitive screens, light pens or eye gaze.

3.3 User Interfaces

Communicating with a computer has evolved over the years. Initially, HCI embedded interfaces with perforated card and printers (Batch Interface) to execute code. Later, CLI (Command Line Interfaces) appeared, being a more effective way to control the computer. A kind of interactive dialogue can be established and understood by the human and the machine. From the 60's with the development of integrated circuits, better displays, and the creation of the mouse, the GUI (graphical user interface) appeared. Its main features are the desktop metaphor, WIMP interfaces and "*What you see is what you get*" also known as visual operations (W. Liu, 2010).

According to Shneiderman & Plaisant (2005), there are three main group theories that can be applied for WIMP interfaces which are: (1) motor-task performance; (2) perceptual activities; (3) cognitive aspects.

(1) Predictions for motor-task performances such as pointing with a mouse can be used to predict keystroking or pointing times.

(2) Perceptual theories predict reading times for lists, free text, formatted displays, and other visual or auditory tasks.

(3) Cognitive theories that involve short-term, working and long-term memory, for problem solving.

The main challenge for designers is to understand tasks well enough to design a large website where users can find their way around, to arrive at a right destination in three or four clicks. The same principles can be applied for games such as game menus or inventory selection.

A tool for understanding the relation between the human and the computer is a taxonomy, which can be a part of a descriptive or explanatory theory (Shneiderman & Plaisant, 2005). A taxonomy sets order by classifying a set of phenomena into understandable categories. For example, it is possible to create a taxonomy for input devices (direct *versus* indirect, linear *versus* rotary). The taxonomy facilitates comparison, while also organizing topics for newcomers, help designers and can act as indicators for new products. For virtual reality systems, a good taxonomy is intrusive immersion (HMD) versus non-intrusive immersion (traditional screen), which enables a development team to address specific features to increase immersion while also attending to ergonomics in major audience.

Steinberg (2012) states that the natural user interface (NUI) is a computer interaction focused on human abilities such as touch, vision, voice, motion and higher cognitive functions such as expression, perception and recall. NUI allows for a wider breadth of communication through physical interaction. The interface as the name implies, is natural to use, which means that the user is able to use the interface with little to no training. Nevertheless, according to Norman (2010) the

"Natural User Interfaces Are Not Natural" because the user has to learn the gesture beforehand, to use the application properly.

Steinberg (2012) data explains some interaction types for NUI. Interaction techniques are important because there is a risk that users become impatient due to unintuitive and unnatural interfaces. The following five examples suggest some natural and easy to use interfaces.

(1) **Pan and Zoom on wall displays:** Three main factors are involved in this type of motion which are: Hands, Gestures and Degrees of Freedom. Hands have two main modes (unimanual – using one hand, bimanual – using both hands). Gestures have two main modes (linear and circular). Degree of freedom is identified with three main modes (1DPath, 2DSurface, 3DFree). The slowest combinations are both unimanual and circular, which are slow to execute and less natural to use. The fastest combinations are both bimanual and linear. These techniques should be used whenever possible, because they are intuitive and fast.

(2) **Rubbing and tapping on Touch Screens:** Two techniques are identified for interaction with touch screens: rubbing and tapping. Rubbing is a gesture where you touch the screen and move your finger up and down. Tapping is a gesture where you tap on the object you want to zoom or resize and move your other finger up or down to resize it. Times of completion are similar for both interactions, but rubbing is more natural.

(3) **Physical Navigation on Large Displays**: Physical navigation is an interaction to visualize the space the user is navigating. Some general rules facilitate the use of this technique: Wireless devices for more freedom, having a clear room with a large screen, and having the room contextualized with the virtual world. Physical navigation helps with the user performance and allows them to visualize the problem from a better perspective. Some devices such as the *Wii*, *Kinect* or *Move* are becoming more important to discover what is more natural to the user.

(4) **Tactile Feedback for Large Displays**: It is tested whether tactile feedback increases user performance with big monitors. It was hypothesized that tactile feedback will increase performance of users, because it is more natural to use. Results showed identical performance for tactile and non-tactile performance

(5) **Direct and Indirect Input using a stylus:** For this interaction, it is tested direct versus indirect input using a stylus. Direct input is where the stylus is touching the user interface. Indirect input is where the stylus is touching a touch screen, but the user interface is on another screen. Tactile feedback seems to outperform non-tactile feedback for direct input. Tactile feedback seems to not make a difference when using indirect feedback.

3.4 Body and Hand Tracking Devices

Modern daily devices such as smart TVs, gaming consoles or PC can integrate and recognize hand gestures and voice commands. Based on a specific interaction it is possible to trigger specific actions. A user can also control multiple devices with a universal device. Modern game consoles and accessories can support motion detectors, 3D depth sensors while players interact hands-free (Hasan & Yu, 2017).

There are three types of optical 3D sensors according to three different principles: (1) Structured Light; (2) Time of Flight; (3) Stereo-Vision (Weichert, Bachmann, Rudak, & Fisseler, 2013).

(1) **Structured light** sensors are composed by a set of cameras and a set of light sources, and they analyse the distortion of a known pattern onto an unknown surface to determine the three-dimensional shape. One example is the Microsoft *Kinect* (Microsoft, 2018) and *Asus Xtion Pro* (Asus, 2018).
(2) **Time of flight** (TOF) principle uses 3D cameras while measuring the distance to an object by emitting modulated infrared light and determining the phase shift between the emitted and reflected light such as the *CamCube 3.0* (PMD, 2018).
(3) **Stereo vision** cameras such as the *Bumblebee*2 sensor consists of two optical 2D cameras which determine depth while searching corresponding points in both 2D images (FLIR, 2018).

This type of sensors give room for Gesture Input Devices from two different types: (a) Incorporating a device where the user must physically hold it; (b) Hands/body free methods (Guna, Jakus, Pogačnik, Tomažič, & Sodnik, 2014).

3.4.1 HTC Vive

The *HTC Vive* uses wand-controllers and employs a structured light approach. It can track the HMD using two base tracking stations (Figure 10). The system works by sweeping an area with multiple synchronized light pulses and laser lines from the base tracking stations and paired with inertial measurement units on each controller (Meira, 2017). Figure 11 summarizes technical aspects of the *HTC Vive*. More recently, the *HTC Vive Pro* was released with better screen resolution, and optimized ergonomics.

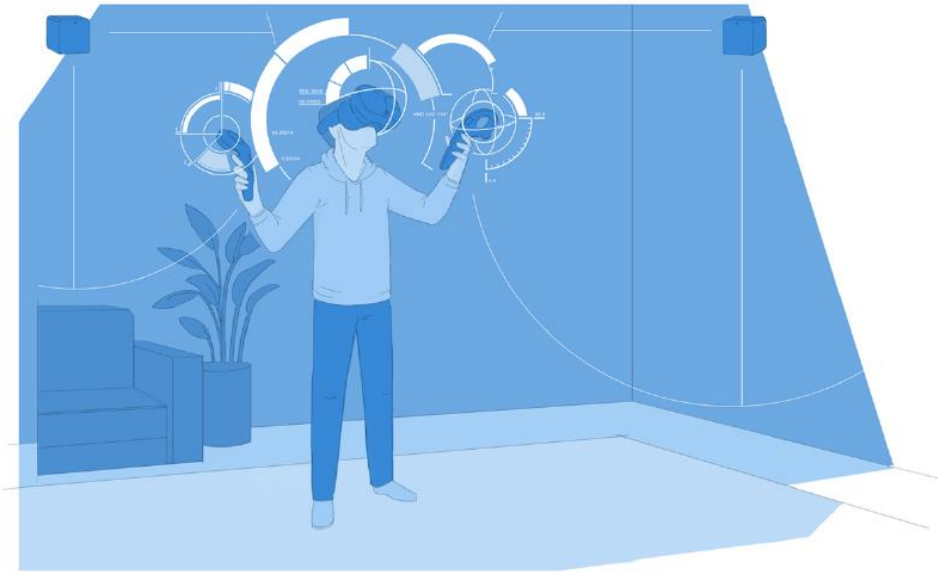


Figure 10 - HTC Vive and wand-controller usage – Retrieved from: Steam, 2018

The *HTC Vive* HMD consists of two LCD screens mounted in a glasses-like device and fixed to the wearer's eye position while showing a virtual world by obtaining the user's head orientation, from a tracking system. The HMD can present the same image to both eyes or be stereoscopic, while offering different resolutions according to the field of view (FOV) (Santos et al., 2009).

The *HTC Vive* was specifically developed for digital games, while allowing physical movement within an area that is limited to 4 x 4 m. The system provides position and orientation data and the controller allows to interact and play with the virtual world (Niehorster, Li, & Lappe, 2017).

	HTC Vive
Screen Resolution	2160 x 1200
Pixel Layout	-
Organic LED Displays	Yes
Screen Size	-
Latency	-
Low Persistence	-
Rotational Tracking (Inertial)	Yes
Positional Tracking (Optical)	Yes
FOV	-
Weight	-
Refresh Rate	90 Hz
Stereophonic Headphones	No

Figure 11 - Technical aspects of the HTC Vive – Retrieved from: Ferreira, 2015

3.4.2 Oculus Rift

The *Oculus Rift* is a direct competitor for the *HTC Vive*, while also allowing for modern VR/AR content. In terms of software, Oculus provides a proprietary *Software Development Kit* (SDK) for content creation that integrates some of the most popular game engines, allowing an easier use by creators that do not know how to code specifically for this platform (Desai et al., 2014). The evolution of the Oculus has brought to the market several hardware improvements since the first prototype (DK1), until the final version (*Oculus Rift*) as depicted in Figure 12.

It is common to find games built for VR on the *Steam Store* with compatibility between several types of HMD, which suggests that the *SDK* for each device allow for a robust integration between platforms.

	DK1	DK2	Rift
Screen Resolution	1200 x 800	1820 x 1080	2160 x 1200
Pixel Layout	Red-Green-Blue (RGB)	Pentile	-
Organic LED Displays	No	Yes	Yes
Screen Size	17.8 cm	14.5 cm	-
Latency	50 – 60 ms	20 – 40 ms	-
Low Persistence	No	Yes	Yes
Rotational Tracking (Inertial)	Yes	Yes	Yes
Positional Tracking (Optical)	No	Yes	Yes
Field Of View (FOV)	110°	100°	110°
Weight	380 g	440 g	-
Refresh Rate	60 Hz	90 Hz	90 Hz
Stereophonic Headphones	No	No	Yes

Figure 12 – Technical comparison between Oculus Rift version – Retrieved from: Ferreira, 2015

3.4.3 Leap Motion

The *Leap Motion* uses *Stereo Vision Cameras* that operate on known external conditions, combined with the current Application Programmer Interface (API), and delivers positions in Cartesian space (X,Y,Z) of predefined objects like finger tips or pen tips. The received coordinates are relative to *the Leap Motion* controller's centre point. Figure 13 illustrates the controller, which consists of three Infrared light (IR) emitters and two IR cameras. The device functions with a USB connector, and the reduced size makes it suitable for integrating a head-mounted setup. The majority of applications for the *Leap Motion* controller are gesture-based user interfaces, and its accuracy of measurement for the human hand motion is the most relevant factor (Weichert et al., 2013).

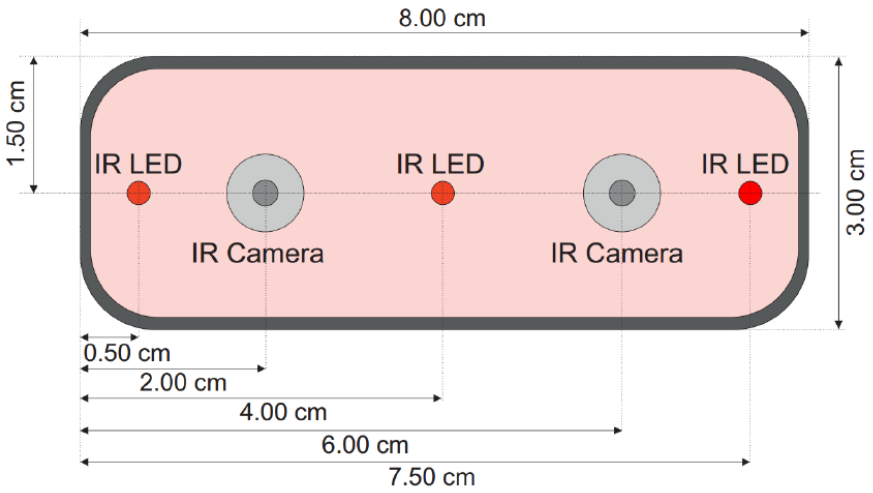


Figure 13 - Leap Motion Schematic - Retrieved from: Weichert et al., 2013

The Leap Motion can be integrated with low cost HMD such as the *google cardboard* device. *Google* concept for this device is to use the smartphone as a substitute for a traditional and more expensive HMD. The only requirement is a cardboard folded in a way to deny the entry of light around the user's vision and put two plastic lenses. The smartphone is placed in a compartment in front of the lenses (Pase & Rocha, 2017). Figure 14 exemplifies the setup.

Figure 14 - Leap Motion and Google Cardboard Integration
Retrieved from: http://www.samlcheng.com/kemstree

3.4.4 XSens

Roetenberg, Luinge, & Slycke (2013) identified the *XSens* as a system composed of a suit and several sensors placed at specific points in the body. A module that collects all information related to the inertia of the body interconnects these sensors. The computer connects to a router on a local network, thus allowing a 3D representation of the body and implement an integrated VR solution in *Unity*. Its major advantages over the *Kinect* or other tracking devices is that the accuracy of the equipment is much higher and there are no body occlusions since the system does not use a camera. This allows full movement, within the maximum capture distance of the router (+ 7 meters). The big disadvantage of this system is the periodic recharging of the battery, the high price (+ € 11,000) and the need to wear and undress the suit.

3.5 Monitor Displays

This section characterizes large displays as key factors to determine users interactive and immersive viewing experiences. Previous studies from Reeves, Detenber, and Steur (1993) founded that larger screens generated a greater level of attention, sense of reality, and presence. Similar research from Lombard (1995), also found that the exposure to bigger screens creates greater enjoyment, arousal, and the content is more easily remembered. High-resolution displays can also contribute to a greater presence (as cited in Kim & Sundar, 2011).

According to Hou, Nam, Peng, & Lee (2012), screen size is influential in affecting physical presence, self-presence, and impression on game characters and the players mood. Display size directly influences the players feeling of involvement and participation in the game play setting, more identification with the game avatar, and produces higher sense of being part of the game environment. There is also a more favourable evaluation of the characters when playing computer games with a large screen. This specific research from Hou, Nam, Peng and Lee add empirical evidence that the effect of a large screen size on emotional and behavioural responses in traditional media can be extended to digital games.

In recent years, Shama, Jindal, Goyal, Sharma, & Goyal (2016) reviewed the monitor and TV display as a specialised input/output device that has evolved over the years in terms of visual quality, angle views and refresh rates. Figure 15 represents how the monitor surface adapts to the eye field of view according to different models and associated technology.

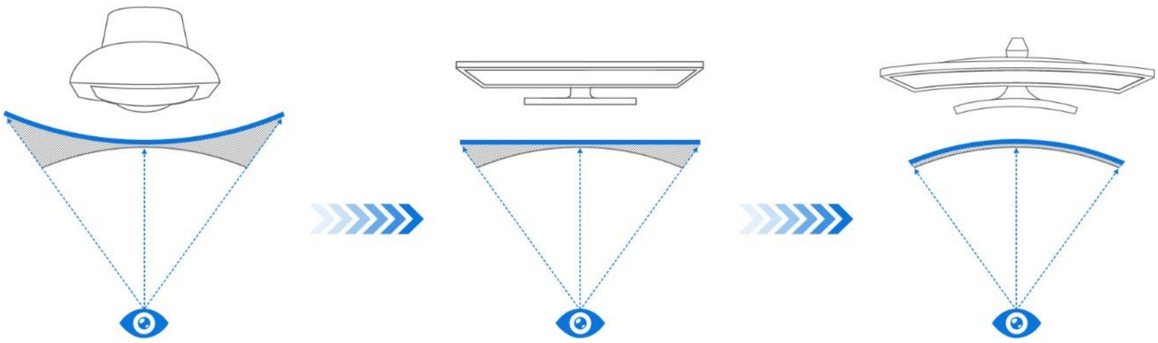


Figure 15 - Monitor Evolution - Retrieved from: Samsung, 2018

The Cathode Ray Tube (CRT) belongs to the first generation of monitor displays. The device contains a set of electron guns and a phosphorescent screen that is used to display images. It modulates, accelerates, and deflects electron beams onto the screen to create images. The Tone Reproduction Curve (TRC) of red, blue and green channels and a transformation matrix from linearized RBG values to tri-stimulus values can describe CRT monitor characteristics.

Due to the fact that CRT monitors emit X-Ray band radiation in small amounts, are heavy, and occupy a lot of space, the CRT has been replaced by new display technologies such as the LCD, LED, and OLED, which have lower manufacturing costs, power consumption, and weight (Shama et al., 2016).

Following Katoh, Deguchi, & Berns (2001) an LCD can have 3 different types of panels: (1) Twisted Nematic (TN); In-Plane Switching (IPS); (3) Vertical Alignment (VA).

(1) **The Twisted Nematic** provides the fastest response time and is typically used for First-Person-Shooters (FPS). They have also high brightness and draw less power than other technologies, while being cheap to mass-produce. The biggest drawback is the colour shifts that occur at wider angles.

(2) **IPS panels** have better colour reproduction and better viewing angles. The downside is the difficulty to emphasize blacks, which in turn means problems with contrast, and slower response times. They are also more expensive than TN counterparts.

(3) **Vertical Alignment** panels offer a solid medium between TN and IPS panels. VA was created to combine the advantages of IPS and TN panels.

Conclusions regarding the three types of panels reveal that VA has more advantages over TN panels, with better colour reproduction, higher maximum brightness, and better viewing angles. VA panels have the best contrast ratios of all panels, but they also have the worst response time (VA vs IPS vs TN). There is no single type of LCD that is good at everything and the type of panel to be selected, must have a compromise based on its use (Kerns, 2015).

CHAPTER 4: RELATED WORK

Digital games can provide a way of engaging senior citizens in social and physical activities. It is possible to use digital games as a rehabilitation tool to support the senior citizen after a stroke (Gerling et al., 2011). The use of HMD can also be effective in therapeutic applications for pain management, psychiatric disorders, and rehabilitation (Amin, Tong, Gromala, & Shaw, 2017).

This chapter states some related work in the following order: Section 4.1 compiles some digital games for health recovery; Section 4.2 compiles the feasibility of using HMD for the senior citizen; Section 4.3 compiles upper-body recovery movements for the stroke pathology; Section 4.4 states the final comments of the Theoretical Framework.

4.1 Digital Games for Health Recovery

a) Project InMind

According to Amin et al. 2017), virtual reality (VR) has been used effectively in therapeutic applications such as psychiatric disorders, rehabilitation and pain management. Over the last two decades it has been reported many successes for using VR as a distraction for acute pain. The main challenge from previous research is to use VR in a longer-term period to help manage prolonged chronic pain (CP). CP can be defined as a pain that persist for more than 6 months, is not associated to physical pain, and can be influenced by psychological factors based on brain processes and patient perception to pain.

There is not much information about using VR to mitigate pain. Small research studies used high-end HMD for that purpose, but there is not enough evidence that CP patients might benefit from using immersive VR applications, like their acute pain counterparts.

The InMind Project collected thirty adults (17 males, 13 females) all with CP, that played *InMind* using *Google Cardboard* and *Oculus Rift*. Patients easily susceptible to nausea or motion sickness, patients who had severe pain in the regions where the HMD needed to be fitted on the person, or patients who did not have physical pain at the time of the study were not eligible to participate. Conclusions about the research, suggest that the simplicity of *Cardboard VR* coupled with carefully designed pain management VR game can ensure the ease of use for CP patients, while being very easy to use, and affordable which suggests potential for massive impact as an alternative for CP patients. The results demonstrate that cardboard VR is not as effective as the traditional HMD in pain distraction for chronic pain patients, nevertheless, it is capable of immerse the player to a certain extent, providing an analgesic effect that is significantly higher than the no-VR or Pre-VR condition. Therefore, traditional HMD are more useful in hospitals and clinics, while Cardboard or other forms of mobile VR are more convenient at home (Amin et al., 2017).

b) Serious Games for Physical Rehabilitation in Morocco

This research from Bonneche, Vooren, Jansen, & Sint (2017) intends to determine whether serious games (SG) specifically customized for physical rehabilitation can be used in daily clinics with patients that are not familiar with informatics, technology, and if such a clinical approach is feasible and culturally accepted within the North African population.

The use of technology in SG is becoming more popular in the rehabilitation field. Although the efficacy of such kind of intervention is still not fully validated and further clinical trials are needed, it is important to understand if technology can be well accepted in patients living in emerging countries with relatively low levels of education, if compared with Western countries. Most of the studies presented are done in developed countries, where technology is omnipresent, but little is known about other countries where there is a potential use of SG as an alternative to compensate for the lack of health experts in remote areas.

This research gathered a convenience sample of 21 patients from the department of ambulatory rehabilitation. A set of mini-games has been developed for physical rehabilitation with the use of the *Kinect Sensor* and *Wii Balance Board*. The game was chosen according to the patients' needs and abilities (Figure 16).

The patients suffered from: (1) low level of education of the participants (school until 10 years old); (2) lack of experience with digital games (only 28% have already played digital games); (3) low access to computer and/or Internet at home (67% and 62%, respectively). Most of the patients where enthusiastic with the game experience, and were not afraid, despite the technological novelty.

Results from the research suggest that there are no risks for accidents or the potential risk of fall, associated with the use of SG. The possibility of implementing SG at home, depends on the ability of patients to perform the game alone, while configuring and launching the games, and be confident enough to move without help. Although the results of this research should be interpreted carefully, SG can offer new tools for physical rehabilitation in remote areas where there are no physiotherapists, but solutions must be developed to offer this kind of intervention in small centres or hospitals, for patients who do not have a computer at home (Bonneche et al., 2017).

Figure 16 – Moroccan resident playing games with the Kinect and Wii Balance Board – Retrieved from: (Bonneche et al., 2017)

c) Exergaming for Individuals with Spinal Cord Injury

Rosly et al. (2017) state that the availability of commercial exergames for wheelchair-bound individuals with spinal cord injury (SCI) are insufficient. The research intends to identify exergames for individuals with SCI that can bring health benefits.

Spinal Cord Injury may lead to profound disabilities, with negative psychological consequences and few employment opportunities, even after community reintegration. The global incidence of SCI is estimated to range between 8 and 246 cases per 1 million individuals, with prevalence being dependent on factors such as epidemiological diversity, acute medical care, and post-traumatic rehabilitation in different countries. Most patients have a sedentary lifestyle. SCI wheelchair users' activities during everyday life is insufficient to show health and fitness benefits. Approaches to increase participation in exercises can be challenging as upper body exercises are often perceived as boring, and facilities are often inaccessible to wheelchair users.

The *Nintendo* company massified the use of movement-controlled interfaces for their seventh-generation game console that enabled several sport-like physical activities in the context of "exergaming" with the use of the *Wii Mote*, while the competition followed by creating other movement-controlled devices. Exergaming has been referred to allow a simulation for their real sport counterpart while adding perceptual enjoyment in improved playing engagement at home or in physiotherapy centres. The research intends to investigate commercially available and ''affordable'' exergaming modalities for exercise among SCI wheelchair users, at an intensity that provides health benefits. This research sought to determine the physiological and perceived exertional responses of several types of exergaming activities while being suitable for exercise in a sitting position. Three types of exergaming (Move Tennis, Move Boxing, and Move Gladiator Duel) were identified and compared, while a fourth was adapted (Move Kayaking) specifically for SCI users. All the games utilized a PlayStation 3 with 2 PlayStation Move Controllers and a Sony Eye Camera. The games belong to the PlayStation 3 library.

Six participants with SCI were recruited and received physician's clearance before study participation, with an age between 18-65 years and had either a traumatic or nontraumatic SCI for more than 2 years, while required to have no cognitive problems and that could follow verbal instructions. All three exergaming activities were performed on separate days. The order of exergaming sessions was randomized, and the time between sessions was set at a minimum of 1 day and a maximum of 14 days. Each participant passed through a small briefing session and 10-20 minutes of practice before the exercise sessions, to familiarize themselves with the equipment and exergames.

The intensity classification while playing Move Tennis, Move Boxing, Move Gladiator Duel and Move Kayaking reported adequate exercise intensity as prescribed by exercise guidelines.

Bilateral upper limb exergaming activities produced higher energy expenditure, if compared to unilateral upper limb exergaming. The results are from a convenience sample and may not be reflected on future studies. Further work to establish the potential of these exergaming activities in increasing cardiovascular fitness in individuals with SCI is justifiable (Rosly et al., 2017).

4.1.1 Digital Games for Stroke Recovery

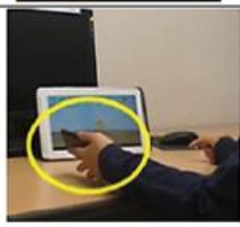
a) Project Mou-Rehab

Following Choi, Ku, Lim, Hyung, & Paik (2016) the recovery from damages after a stroke is frequently incomplete and approximately 50% of the patients are left with sequelae. The upper limb dysfunction makes stroke survivors dependent on others for daily living. Despite having no locomotion due to no bilateral lower extremity, patients can perform daily living activities with unilateral upper extremity movement. It is also stated that it is more difficult to recover from upper extremities than lower extremities.

The objective for the Mou-Rehab Project was to develop a mobile game-based upper extremity VR program for patients who have experienced a stroke and evaluate its feasibility and effectiveness. 24 participants were recruited from hospitals and the inclusion criteria were a diagnosis for ischemic stroke, the ability to follow a one-step command, clinical stability allowing participation in active rehabilitation, and upper extremity impairment. Patients were excluded if they had symptoms of delirium, confusion, suffered from uncontrolled medical conditions, were unable to follow commands because of severe cognitive impairment, had visual diseases or disturbances, and had poor sitting balance.

The rehabilitation program consisted of 10 sessions of daily therapy five days per week for two weeks. Each session required 1h per day while using *Mou-Rehab* mini-games (using a tablet and smartphone). The patient received visual and sound feedback from the tablet, and the communication module connected the tablet with the smartphone. The smartphone was responsible for validating the required movements for each mini-game. Table 8 depicts each mini-game with the target movement.

Table 8 - Collection of games and applied movement in Mou-Rehab – Retrieved from: Choi et al., 2016

	Game application	Target movement	Activities
Honey Pot Guard		Elbow Flexion/ Extension	
Protect the Bunny		Shoulder Abduction/Adduction	
Put Out Fire		Shoulder Abduction/Adduction, Flexion/Extension	
Flower Splash		Shoulder Abduction/Adduction, Elbow Flexion/Extension, Wrist Pronation/Supination	

It was concluded that *Mou-Rehab* effectively promoted upper extremity recovery in patients with a stroke. When comparing *Mou-Rehab* with conventional therapy, *Mou-Rehab* showed better improvement in motor function of hemiparetic arm (FMA-UE), B-stage (upper extremity recovery stages), and arm and hand function activities (MMT) by the Fugl-Meyer assessment of the upper extremity. Depressive mood was also reduced, and the effects lasted 1-month after evaluation (Choi et al., 2016).

b) Project GesAircraft

Putrino et al. (2017) intends to determine if therapy enjoyment is related to clinical improvement after upper limb rehabilitation and to verify the feasibility of a therapy gaming system. Despite the importance of upper limb recovery, knowledge about how to optimize rehabilitation on the upper limb in chronic stroke patients is scarce. There is not a consensus about a single therapeutic approach that is effective for upper limb recovery after chronic stroke.

This research investigates the feasibility and clinical outcomes of a novel digital therapy gaming system of upper limb function and to explore a correlation between therapy engagement and recovery in chronic stroke survivors. The subjects were selected using the following criteria: **(1)** diagnosis of unilateral ischemic or haemorrhagic stroke 6 months prior to the experiment; **(2)** residual motor impairment of the left or right upper limb; **(3)** at least 10 degrees of active wrist extension and supination; **(4)** the ability to follow instructions. The system uses a custom-designed game called "*GesAircraft*" and puts the player in a digital gaming environment that trains three upper limb joint movements: wrist flexion/extension, ulnar/radial deviation, and forearm pronation/supination. The objective of the game is to use the designated movements to control the airplane avatar through ring-shaped obstacles. Task difficulty is calibrated according to the individual's wrist and forearm Range of Motion (ROM). The *Leap Motion* controller identifies hand movement and uses it to control the game's avatar (Figure 17).

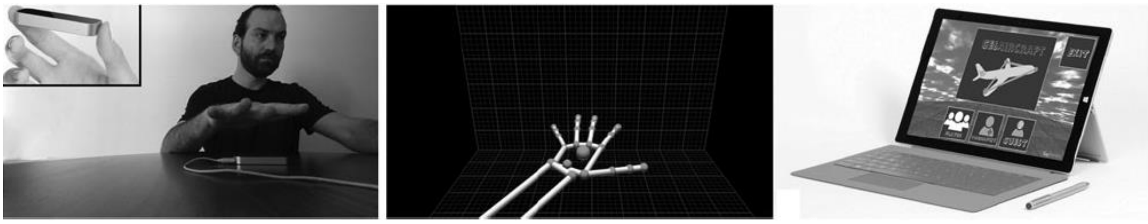


Figure 17 – Leap Motion hand detection – Retrieved from: (Putrino et al., 2017)

Subjects participated in 30 minutes, 3 times a week, for 6 weeks. Although the system can be used at home, participants attended the clinic for this pilot study. The 30-minute therapy session was broken into two 15-minute component: (1) training wrist flexion/extension; (2) forearm pronation/supination.

Results indicate that *GesAircraft* system is safe, usable, and enjoyable to treat upper limb impairment for an average population of 69.5 years old. The gaming interface was appropriate and usable for stroke rehabilitation, and there was a correlation between therapy enjoyment and gains seen in motor function. It is claimed that this research is the first to demonstrate a therapeutic enjoyment and outcome in chronic stroke survivors (Putrino et al., 2017).

c) Project PhysioFun

PhysioFun is an interactive low-cost game created by Ribeiro (2016) and is to be used at physiotherapy centres or at home. The primary motor-task performance are upper limb movements, to recover from deficits in fine and gross motor control. The effective recovery is dependent of high volumes of movement repetition to promote neural plasticity.

Game conceptualization of *PhysioFun* involves specific game design in different domains, and with the intervention of clinical experts in the field of stroke recovery, that specify physiotherapy needs and recommendations for the final product. Target group involves people over 55 years. The game is divided in 6 levels, in which players execute different movements, with an ascended scale of difficulty.

In order to track movement, a specific bracelet device was developed with a microcontroller (*Genuino micro*), connected to an Inertial Measurement Unit (IMU), that has the ability to report body’s force, angular rate, and magnetic fields around the body, using an accelerometer, gyroscope, and magnetometer.

Six different levels were designed with different movement interactions, and related to aircraft history, according to target audience main preferences. The implemented level has a cart that follows the movement of the player’s wrist, which must put the cart in the right place to avoid the death of the birdman. Coin collection can be achieved by rotating the arm with higher amplitude, thus winning extra points (Figure 18).

Figure 18 - The Birdman level - Retrieved from: Ribeiro, Veloso, & Costa, 2016

d) Virtual Reality Therapies Based on Robotic-Assisted Neurorehabilitation for Post-Stroke Patients

Lledó et al. (2016) states that post-stroke rehabilitation based on virtual therapies are performed through repetitive actions that are displayed on a screen. Currently it is possible to have two forms of visualization (1) 3D; (2) 2D spaces. (1) In 3D space there is a realism determined by resolution, image fidelity, and the spatialization of tasks. (2) In 2D, the virtual environment represents a task with a low degree of realism through two-dimensional environments. The type of visualization can influence the quality of the task perception, affecting the patient's motor performance.

In this research, the horizontal arm movement was used for reaching specific targets depending on the virtual environments. In total, 9 patients were analysed by the following parameters: maximum speed, reaction time, arm path length, and initial movement.

The success rates were very similar for the horizontal arm movement in 2D and 3D environments. However, it is concluded that the 2D task in a virtual environment may be more adequate, comfortable and the accuracy in which the patient makes the movement is much higher, so his recovery time theoretically is higher (Lledó et al., 2016).

4.2 Feasibility of Virtual Reality on the Senior Citizen

a) Highly realistic image-based rendering for senior citizens

Benoit et al. (2015) research evaluated the acceptability for senior citizens for a VR experiment using the image-based rendering virtual environment (IBVE) approach and test the hypothesis that visual cues using VR may enhance the generation of autobiographical memories.

Eighteen volunteers with an average of 68.9 years with memory complains and no history of neuropsychiatric diseases were included. Participants were asked to perform an autobiographical fluency task in 4 conditions. (1) A baseline grey screen, (2) photograph of a location in the participant’s home city (FamPhoto), (3) display of a familiar image-based virtual environment (FamIBVE) consisting of an image-based representation of a known landmark square in the centre of the city of experimentation; (4) unknown image-based virtual environment (UnknoIBVE), which was captured from an unidentified public housing neighbourhood. Figure 19 depicts the hardware setup for this experiment.

Figure 19 - Hardware setup for image-based rendering environment – Retrieved from: Benoit et al., 2015

Conclusions suggest that VR is possible with senior citizens without any significant fatigue, and that VR using IBVE stimulates autobiographical memory and conveys familiarity of a given scene, which is an essential requirement for the use of VR during reminiscence therapy. (Benoit et al., 2015).

b) DriVR

Following L. Liu, Watson, & Miyazaki (1999), one of the primary concerns in any application of VR technology is simulator sickness. The sickness is originated from differences between the perceptual display offered by the VR, and the input that is expected by the brain perceptual system. When the mismatch between display and expected input is particularly strong, symptoms of sickness appear. Susceptibility for sickness varies from gender, experience with the interface, field of view, feedback delay and illness.

In total, 148 users were grouped by age and balanced by gender. They participated in a driving assessment in a low-cost PC based virtual environment known as *DriVR*, with the use of a Virtual I/O i-glasses, and 30-degree horizontal field of view. The display was used in a biocular mode (same image sent to each eye), and with three degrees of freedom (yaw, pitch, and roll). It was used a *Sound Blaster* card for audio display for earphone output. The evaluation was divided in quantitative and qualitative data. Quantitative data was retrieved from automatic procedures and observation, while qualitative data measured difficulty, comfort visual clarity, delay and simulator sickness. *DriVR* provided 10 testing scenarios which appear in a continuous sequence as the participant drives through a small town.

Results indicated that the use of VR with the senior is feasible, and there is a relation between complaints about using glasses with the HMD and age. It was more appreciated good responsiveness instead of better visual quality (L. Liu et al., 1999).

Although this research is outdated, there is a relevance for sickness symptoms with HMD displays for the senior citizen. Still, it is not possible to predict how newer systems such as the HTC Vive or the Oculus Rift would work for this age. The greater immersion produced with newer systems can create other types of problems not recorded in the exposed article.

4.3 Compilation of Upper-body Recovery Movements

The process of recovery through motor-task performance can be achieved through an interactive game. The digital artefact can give a clear incentive to the patient for executing long physiotherapy sessions and alleviate some of the pain derived from muscle atrophy. The game tasks must have a primary therapy objective while specifying the stroke patient needs (Ribeiro et al., 2016).

This section summarizes the previous related work regarding upper-body recovery movements that are eligible for the present research work in Table 9, 10 and 11.

Table 9 - Upper-Body Recovery Movements

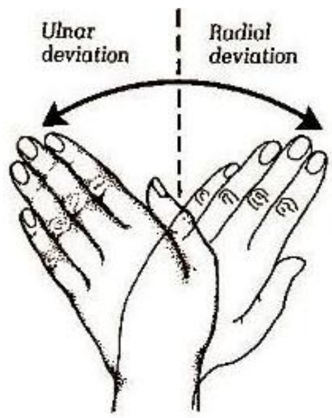
Movement Identification	Image	Related Work
Ulnar/Radial Deviation	 Retrieved from: http://biokineticgolfswing.blogspot.com/2012/02/	GesAircraft

Table 10 – Upper-body Recovery Movement

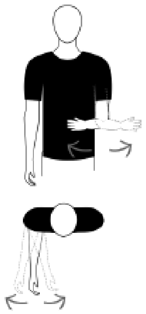
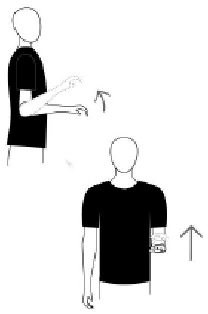
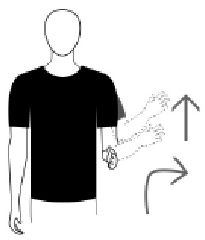
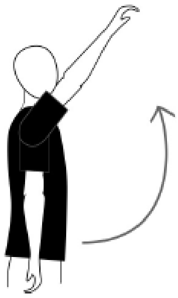
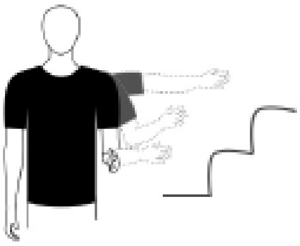
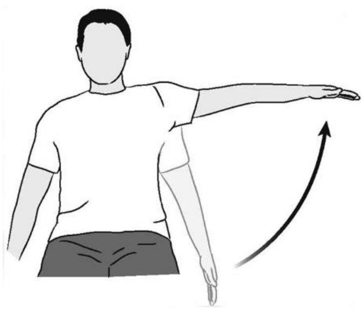
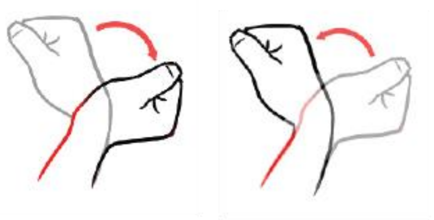
Movement Identification	Image	Related Work
Horizontal movement	 Retrieved from: Ribeiro, 2016	PhysioFun, Virtual Reality Therapies Based on Robotic-Assisted Neurorehabilitation
Elbow Flexion/Extension	 Retrieved from: Ribeiro, 2016	PhysioFun, Mou-Rehab
Elbow flection with external shoulder rotation	 Retrieved from: Ribeiro, 2016	PhysioFun
Flexion of the elbow with supination of the forearm	 Retrieved from: Ribeiro, 2016	PhysioFun

Table 11 – Upper-body Recovery Movements

Movement Identification	Image	Related Work
Shoulder flection	 Retrieved from: Ribeiro, 2016	PhysioFun
Flexion and abduction of the shoulder, with extension of the elbow	 Retrieved from: Ribeiro, 2016	PhysioFun
Shoulder Abduction/Adduction	 Retrieved from: https://orthoinfo.aaos.org/en/recovery/shoulder-surgery-exercise-guide/	Mou-Rehab
Wrist Pronation/Supination	 Retrieved from: http://www.pt-helper.com/wrist--elbow.html	Mou-Rehab, GesAircraft

4.4 Final Comments of the Theoretical Framework

The stroke is a global neurological disorder that increases with age (Putrino et al., 2017). The major consequences can be related to physical, cognition and emotional conditions that degrade the life of those affected by the disease. Depending on the stroke location, different types of effects can manifest itself.

The brain is a very complex organ that can adapt and alter its main structure in response to internal and external conditions. Neural plasticity is the mechanism that encodes experience and learns new behaviours. It is also the mechanism by which the damaged brain relearns lost behaviour in response to rehabilitation (Kleim & Jones, 2008).

According to the theoretical framework, it was identified three types of assessment tools that can determine the percentage of impairment for the upper and lower limb: (1) Fugl-Meyer Assessment Scale; (2) ICF Core Set; (3) FIM. The identification of the impairment is helpful to determine a correct rehabilitation plan.

Effective stroke rehabilitation must occur early, be intense and repetitive. However, most patients carry major trauma from partial body paralysis, difficulty speaking, and difficulty in executing everyday tasks that have been taken for granted. The rehabilitation program attempts to stimulate the person in a variety of exercises, however it is not uncommon that people develop depression under a stroke condition (Goldstein, 2008; Burke et al., 2009).

Games are a form of play that is engraved in our cultural system (Huizinga, 1980), and are a viable option to complement typical rehabilitation sessions for the stroke recovery. The implementation of digital games based under a training program can positively affect the motivation and be used as a complementary tool to be used at home or in a physiotherapy centre (Burke et al., 2009).

A digital game is a digital artefact bounded by rules and is created with the objective of being fun to play. A game genre is a specific category of digital games related by similar gameplay characteristics (Elliott et al., 2012).

Typical commercial games are almost entirely not suitable for the senior. According to Gerling et al. (2011) there are some core aspects that must be taken into account for the engagement of the senior by the design team, before developing a game. Section 2.4 synthetizes some of the core features that a digital game should have for the senior citizen.

Human-Computer Interaction focus on the design of computer technology and the interaction between humans and computers. Section 3.1 contributes to the discussion of immersion as a definition that can have a broad way of interpretation and there is not a definitive description of what it is, and how it is created. Some clues refer to levels of attention, sense of time, and altered sense of self, regardless of the type of display. All human senses can contribute to the feeling of immersion and it is the combination of each of these elements that can contribute to an immersive experience (Brown & Cairns, 2004; Csikszentmihalyi & Nakamura, 2014).

Table 12 briefly identifies some HMD that can be used to produce a digital game. From all the depicted devices, the Google Cardboard is the most likely candidate. It is intended to use low-cost equipment that can be easily used at nursing homes, rehabilitation centres or patients' homes.

Table 12 – Head-Mounted Displays

HMD	Description	Quality Build
Google Cardboard	HMD made of plastic or cardboard	Low
Oculus Rift	Professional HMD	High
HTC Vive	Professional HMD	High

Table 13 summarizes hardware for motion tracking. Each device is identified with the physical principle that is used, price, and description. Since price is an important characteristic, the *Leap Motion* is the most likely candidate. The main disadvantage of Stereo Vision Cameras (*Leap Motion*) are occlusions of certain detected areas. The *Leap Motion* is also exclusively focused for the hands, is bounded by an interaction area, and many of the identified upper-body recovery in the previous section are not compatible (movement is out of boundaries of detection). Its main advantages are good compatibility with *Unity Game Engine* and allowing for HMD integration.

Table 13 - Hardware for Motion tracking

Tracking Devices	Description	Price	Principle
Leap Motion	Gesture-based user interfaces, with accurate measurement for the human hand motion	70€	Stereo Vision Cameras
HTC Vive	A virtual reality headset allowing the user to move in 3D space and use motion-tracked hand helm controllers to interact with the environment	approximately 800€	Structured Light
Oculus Rift	A virtual reality headset allowing the user to move in 3D space and use motion-tracked hand helm controllers to interact with the environment	approximately 600€	Structured Light
Xsens	3D motion capture product	approximately 11000€ depending on licenses	Inertial Sensors
Kinect	Motion sensing input device produced by Microsoft	100€	Structured Light
Asus Xtion Pro	Motion sensing input device produced by Asus	unknown	Structured Light
Camcube 3.0	Motion sensing input device	unknown	Time of Flight
Bumblebee2	Motion sensing input device	approximately 1600€	Stereo Vision Cameras

Monitor displays are an important part of immersive environments (Kim & Sundar, 2011). There is a relation between the size of the screen and the feeling of involvement and participation according to (Hou et al., 2012). Currently the market can offer several types of displays with different technology. Section 3.5 highlights LCD display technologies since it’s commonly used among gamers and is the cheapest, if compared to LED or OLED displays.

Section 4.1 compiles relevant work in the field of motion tracking for health & stroke recovery, and section 4.2 selects some research cases that use immersive virtual reality for distinct purposes. The most important information that can be recovered from those researches are the senior citizen acceptance for new technology, and the motivational benefits that a stroke patient can experience for its rehabilitation program under the use of digital games. Scopus, Google Scholar, and ResearchGate were used and with the following keywords: stroke; virtual reality; rehabilitation; digital games; senior citizen.

CHAPTER 5: EMPIRICAL RESEARCH

The empirical investigation includes the description of two methodological steps: Theoretical Embedding and Empirical Testing, according to the *Development Research* methodology (Van den Akker et al., 1999).

Section 5.1 reviews the methodological approach; Section 5.2 selects the game characteristics to be used in the conceptualization stage; Section 5.3 states all the game design choices; Section 5.4 presents all the implementation work regarding gestures, optimization techniques, physics, and others; Section 5.5 compares the game to a therapy game model, to ascertain the coherency of the game design choices; Section 5.6 states the variables for each type of samples (physiotherapists and senior citizens) that are to be analysed with questionnaires and semi-structured interviews; Section 5.7 explains the data collection stages for the research, states the medical evaluation for the demo, and the collection of evaluation materials for the final prototype evaluation.

5.1 Methodology

The adopted methodology follows the *Development Research* method (Van den Akker et al., 1999). The reasons for picking this approach is fully explained in the Methodology section under the Introductory Chapter. Table 14 describes all the methodological stages systematically.

Table 14 - Methodology Scheme and Schedule

Stages	Date	Activities	Documental Analysis
1st Stage: Preliminary Investigation	December 2017 until February 2018	State-of-the-art survey regarding: (1) Stroke patient characterization; (2) Explore HCI under the immersion concept, NUI interfaces, motion tracking, HMD; (3) Define digital games and understand main game preferences for older adults; (4) Gather design theories for the construction of interfaces; (5) Report state-of the art digital games for health recovery based on several types of displays and motion tracking devices; (6) Identify exercises with therapeutic properties for the stroke patient;	Systematic
2nd Stage: Theoretical embedding	March 2018 until July 2018	Conceptualize, design and prototype a digital game.	Empirical Research
3rd Stage: Empirical testing	May 2018 until September 2018	(1) Create evaluation tools for the physiotherapists and senior citizens; (2) Validate the selected movements with an experienced physiotherapist; (3) Evaluate the final prototype with physiotherapists and senior citizens;	Semi-structured interviews, online questionnaire, performance sheet
4th Stage: Documentation, analysis, and reflection on process and outcomes	October 2018	Discussion and conclusion of the results.	Empirical Results

5.2 Game Conceptualization

According to the main proposed objectives and methodological framework, it is required to conceptualize a digital game that supports the rehabilitation of the stroke victim, and to build a working prototype based on the design documentation. However, to answer the main research question, there is a necessity to identify and justify the primary characteristics that should be included in the digital game. The chosen characteristics are described in Table 15.

Table 15 - Game Conceptualization Characteristics

Type	Sub-type
(1) Display	HMD Computer Monitor
(2) Gesture Interface Device	Leap Motion
(3) Genre	Adventure
(4) Game Art Design	Low Poly
(5) Narrative	Historical Approach
(6) Difficulty	Variable
(7) Language	Portuguese

(1) **Display:** Based on the theoretical framework, the immersion of a digital game can be affected according to the type of input device. However, eye health is a sensitive subject if the stroke pathology is to be considered (Teasell & Mbbs, 2013). Based on that premise, the research intends to validate 2 different approaches: (1) A device that minimizes eye discomfort and is capable of high-quality images without straining the human eye (LCD Monitor); (2) A device that increases immersion but is limited to short term use and is prone to eye stress (HMD).

(2) **Gesture Interface Device**: Motion tracking devices allow the virtualization of the human body, which is essential to monitor the performance of the senior for the proposed exercise during the game. As represented in the related work, it is required to use a device that mediates the interaction between the user performance during the exercise and the game. The *Leap Motion* was selected as stated in the final comments of the theoretical framework, for its easy integration with different types of displays, reduced price, and robust motion tracking for the hands. The related work also contains some use cases with the *Leap Motion* (GesAircraft). There are also advantages of setup in rehabilitation centres due to the *Leap Motion* small size and easy setup. The use of pre-

manufactured devices is an advantage if compared to crafted devices, due to the absence of welding electronic parts and picking fragile design options.

(3) **Genre:** There is a necessity to understand senior gaming preferences before any actual implementation. As stated in Costa & Veloso (2016), there are only a few studies that investigate game preferences for older adults, suggesting that this specific target group is not very attracted to violence in games. Instead, there is room for adventure games with historical settings with *Player versus Environment* (PvE) mechanics. Thus, the Genre for the prototype will be an adventure game and the Narrative will be based on historical events.

(4) **Game Art Design:** *Game Art Design* is a direct subset of game development. It includes the artistic aspect for a digital game. While the studies from Pearce (2008) and Schutter & Vandenabeele (2008) state a preference in realism between senior casual gamers, the *Low Poly* art style was selected for its lower impact in hardware performance according to the Unity Optimization Guide for VR (Unity, 2018) that advices for the creation of objects with simple geometry. *Low Poly* is a representation of geometric solids without realism. This characteristic requires less polygons and consequently less calculation power from the graphics card. Since it is expected to use a HMD through stereoscopy, it is important to guarantee fluent frames-per-second (FPS) to avoid dizziness, while having low computer system requirements.

(5) **Narrative:** Stated in the *Genre* characteristics.

(6) **Difficulty:** The player-centric design (Adams, 2010) requires the designer to place himself into the position of a representative player and to imagine how to play the game. For the stroke citizen, the type of impairment defines the reaction time. Two properties were defined for this characteristic: (a) The player should be able to choose the pace of the game (slow or fast); (b) calibrate the sensitivity of the *Leap Motion* inside the game. Calibration involves different stages of detection and validation for the movement in play in terms of speed and distance.

(7) **Language:** According to Costa (2013) the illiteracy rates of senior citizens is high. The evaluation stage will be executed in Portuguese health facilities, and the digital game requires the comprehension and reading of instructions and the main narrative. The first prototype will be developed for the Portuguese audience, but future prototypes should have the possibility of language selection.

After confronting all the previous characteristics, the concept of the game is inspired on the “Hugo” franchise. The ballooning mini-game is an adventure game, were the player must steer a balloon to avoid canyons, spikes and collapsing cliffs (Figure 20). When the balloon punctures, the player has to control it through a tunnel without hitting walls. This specific mini-game was launched in Hugo 4, Hugo Platin and Hugo Classic 2 for the PC.

Figure 20 - Hugo Balloon Game
Retrieved from: https://bit.ly/2CO5fho

The research prototype must resonate with the senior citizen audience while stimulating cognitive and motricity aspects. The final idea was to create a priest avatar, while the player must control a balloon through the *Leap Motion*. The player has to catch stars, deviate from obstacles, and pick a direction after intersections.

5.3 Game Design

Following the *Concept of Flow* and the *player-centric game design* main aspects (Csikszentmihalyi & Nakamura, 2014; Adams, 2010), the game takes into account the reality of the senior citizen, by balancing the skills of the player and the environment challenges. The balloon must have an adequate speed while moving forward, and the distance between objects must be adequate in terms of reaction time while changing the balloon direction to the left or to the right.

The proposed rehabilitation plan in the game is divided into 2 modes (easy and hard). Easy mode forces the balloon to travel slowly while hard mode forces bigger speed into the balloon. The distance between obstacles in the two modes is the same since speed directly affects reaction time. The player will need to spend approximately 25 minutes to complete the game while hard mode is completed in approximately 15 minutes. The player should choose easy mode if the upper-limb impairment is high, and hard mode is suitable for an almost fully recovered upper limb. Ideally, the system should be able to determine the difficulty based on a prior calibration scene or using saved data from previous game sessions, however due to a limited time of development, a manual setup for the difficulty allows for better time management in other areas, such as game art design, and level design diversity.

From an outsider perspective, the game system can be characterized as very slow paced, and the movements are very easy to control, which will increase the boredom levels (Csikszentmihalyi & Nakamura, 2014). It is expected to achieve the proper balance specifically for the stroke patient, while ignoring other types of audience.

Since the motivation levels in a stroke scenario are relatively low (Goldstein, 2008; Burke et al., 2009), the game must be permissive about human error while motivating the patient to achieve an high score. If the balloon collides with an object or terrain, the game should give the proper feedback from the collision, and the progression should be paused until the player is able to continue. It was decided that the score system would register any collision, while penalizing the player by subtracting 100 points to the overall score. However, there is no *life* system, and the progression is always in a forward way.

The main objective of the game is to catch stars to achieve the highest score. Each star adds 100 points. The number of stars is in a proportion that allows room for reaction time while giving the player a challenge. The score is a direct reflection of the player performance during the game. Since there are more stars than obstacles, the final score should remain positive, even if the player goes in a straight line. At the end of the game, the player can check for its score, separated by levels, and a final parameter with the sum of all levels.

Another aspect of the game is to stimulate cognitive aspects through short-memory. It was envisioned that the balloon will have several levels, and that at the end of each level, the player must decide a path in a cross zone (left or right). At the beginning of the game, the player is presented with a map that indicates the correct path between several possibilities. The map can be consulted if a specific action is triggered, however there must be a penalty for using the map feature. The penalty is specifically losing visibility of the obstacles by placing the map in front the game without pausing the game. If the player needs to see the map, he must be agile to open, memorize, and close it. Hitting a wrong cross-zone does not penalize the player for points. It only repositions the balloon before the cross zone and with proper warning feedback.

5.3.1 Level Design

The game is divided in 2 levels: (1) lifting the balloon for altitude; (2) driving the balloon in different biomes (two types of forest, ice, and two different deserts). The biomes are associated to a country depending on the colour pallet (Brazil, Canada, Egypt, Antarctica, Mexico). For better identification, levels will be addressed as level 1 and level 2, while biomes will be referred to the associated country.

In level 1, the player is responsible to lift the balloon into the air (Figure 21)**,** through repetitions of pronation/supination movements. A sequence system was also included exclusively for this level in order to minimize pauses between movement. The basics for this system is a counter that resets to zero if there isn't any movement executed during five seconds. Each sequence (pronation/supination) triggers an animation if two or more sequences are executed. In total there are 21 sequences for this level. The red height meter references the actual height of the balloon, and the completion of the meter skips the level for the next challenge. For the difficulty of the level, no penalty is added if there is no interaction, although it would made sense that gravity would push the balloon back to the floor. Since the sequence system can work with or against the player, no other penalty was required.

Figure 21 - Lifting the balloon – Game Scene

In level 2, a balloon can be positioned in three different areas (left, right and centre) while deviating from obstacles, catching starts, or deciding a direction at the end of the level (Figure 22) by mimicking a horizontal swipe motion. The beginning of each level starts with an automatic countdown before the actual start of the game. After this step, the gesture recognition is activated.

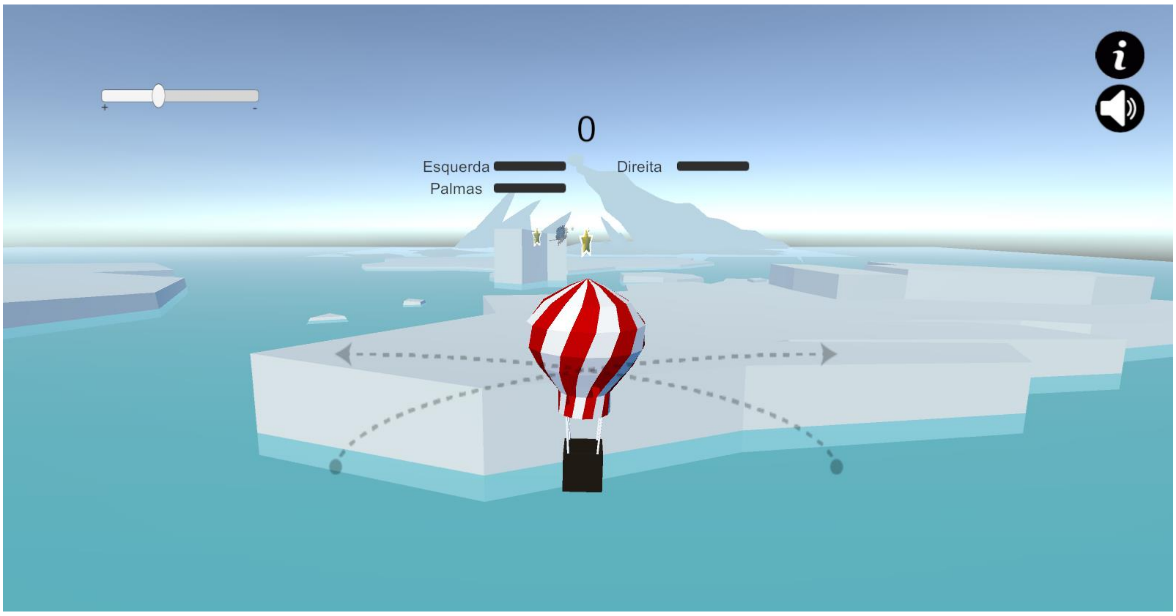


Figure 22 - Driving the balloon - Game Scene

According to Costa & Veloso (2016), memory games are popular among senior citizens. The game map for level 2 was developed to stimulate the player memory by suggesting a correct path between multiple possibilities during the flight (Figure 23). The map is fully randomized, meaning that each replay loads a different order between the biomes and cross-zones direction. The map always activates at the beginning of a level 2 biome but is automatically closed before the balloon starts progressing. The “Clapping hand” motion allows previewing the map again if desired, but without pausing the game.

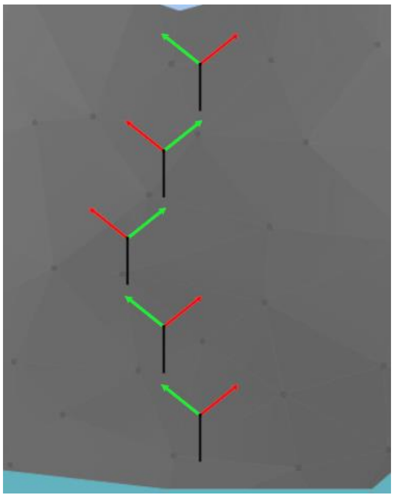


Figure 23 - Random Map with defined junctions (left or right) – Game Scene

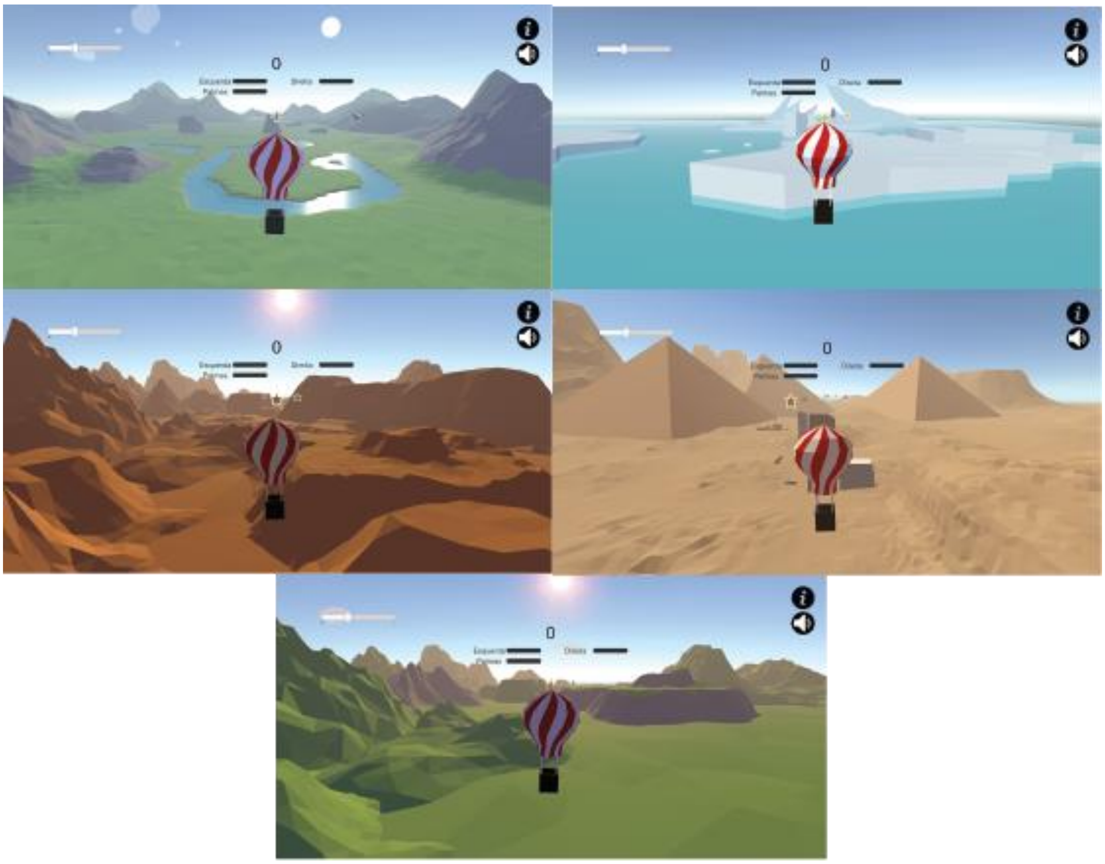


Figure 24 – Biomes – Game Scene

The creation of different biomes (countries) allows for more diversity in the scenery. It is expected that more diversity will increase the lifespan of the game during a stroke recovery program. The following Figure 24 portrays the biome representation with different colours, stars and object positioning.

As stated in the previous section, the distance between obstacles and star catching is related to reaction time. It was defined an average of 18 changes of direction (left, centre, right) and a two second delay for animating the balloon during the motion. Since it is defined a 2 second delay while changing between game areas (left, centre, right), the average number of turns is defined as 18 per minute. These values were defined to keep a balance between challenge and feasibility.

Obstacles are a common existence within the game. There are three types of obstacles in Figure 25: (1) terrain; (2) bird; (3) stone.

(1) **Terrain:** Colliding with terrain will relocate the balloon a few meters before the obstacle while pausing the progression. To continue, the player must turn to the left or to the right. In terms of percentage, about 80% of the obstacles belong to the terrain type. The balloon blinks for a few seconds if a collision is detected.

(2) **Bird:** Colliding with a bird destroys the obstacle. Birds have a specific back and forward route with random velocities.

(3) **Stone:** The stone type is a falling rock that is supposed to hit the balloon unless the player moves to safety. The balloon blinks for a few seconds if a collision is detected.

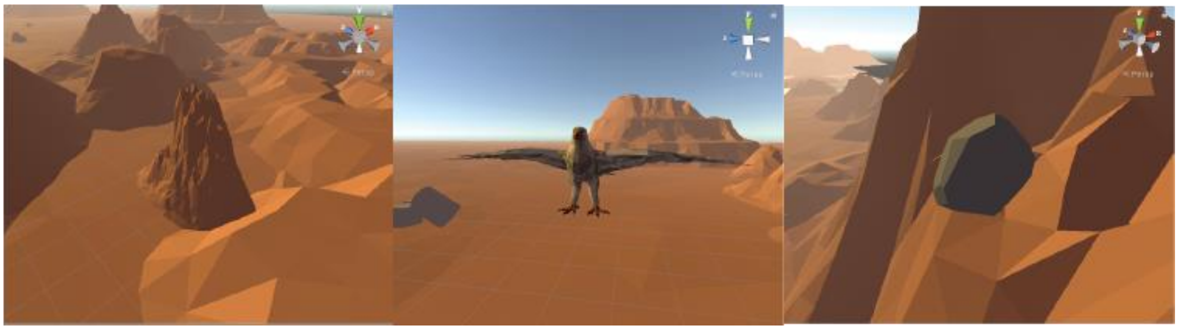


Figure 25 – Obstacles – Game Scene

5.3.2 Legibility and Aesthetics

Communication through text is a requirement to interact with menus and to get the appropriated help information. Typography defines legibility through the course of the game. It is important to have in mind some factors such as font type, variant style, body, and size. According to Bernard, Liao, & Mills (2001); Fonseca, Amado, & Costa (2014) the Arial font is adequate for Online Text Reading. The same approach was used for the game dialogues (Figure 26). In order to give more relevance to clickable areas, buttons have a distinct colour (black or white) and have a clickable area. All the icons can be found in Figure 27.

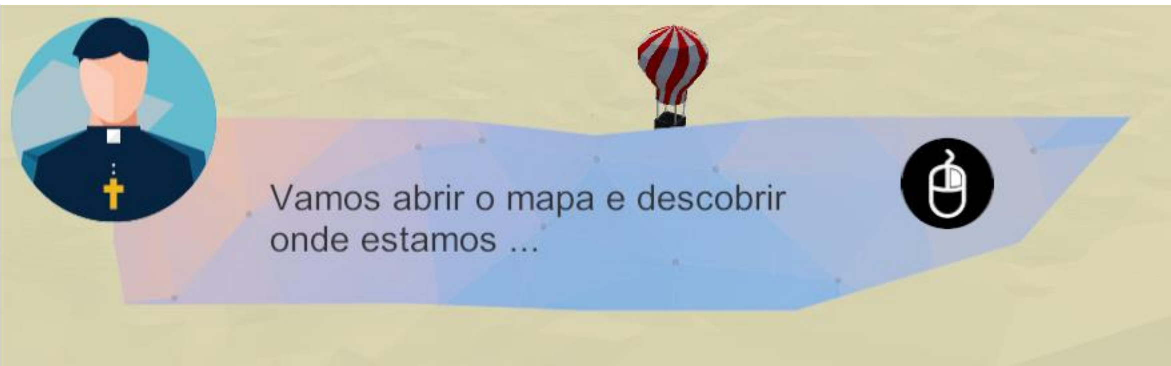


Figure 26 - Arial font – Game Scene

Figure 27 - Game Icons

A traditional game normally has a help button on the start screen to guide the user and an in-game tutorial. Quake Champions is an online game with this approach (Figure 28). This organization requires memory and can be hard to use for the senior population.

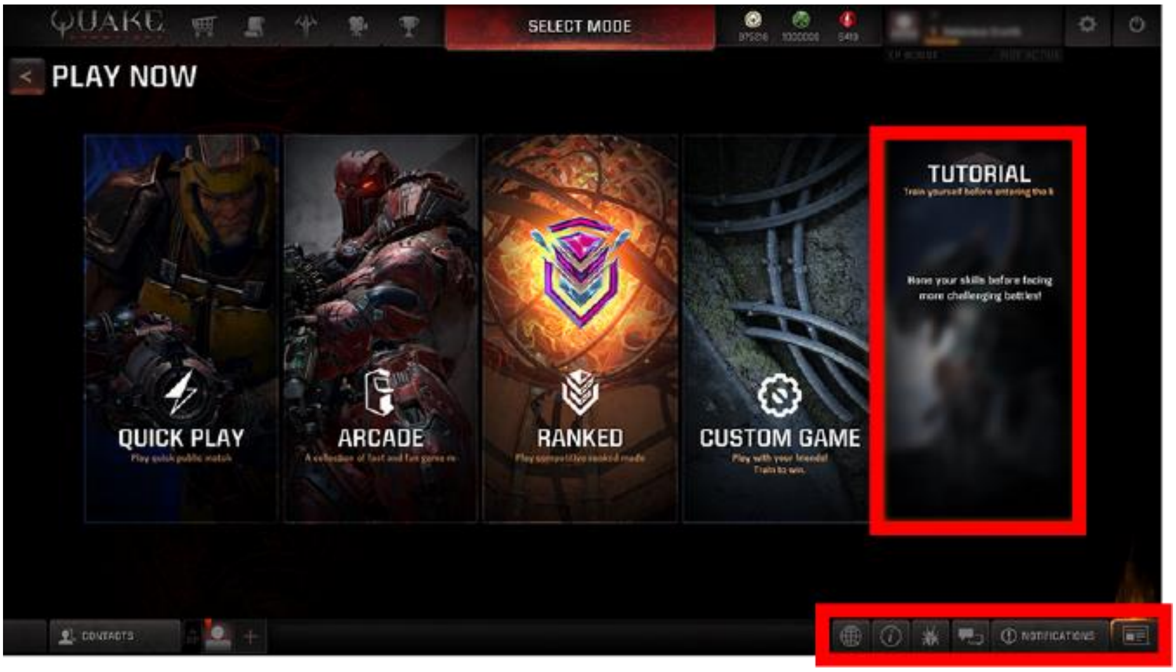


Figure 28 - Quake Champions button disposition
Retrieved from: https://quake.bethesda.net/pt

For the actual game of the research, if the player needs to perform an action, a blinking textual area will appear at the lower centre of the screen (Figure 29). Buttons are always placed on the upper-right corner. The information button gives extra information to the user if clicked (Figure 30).

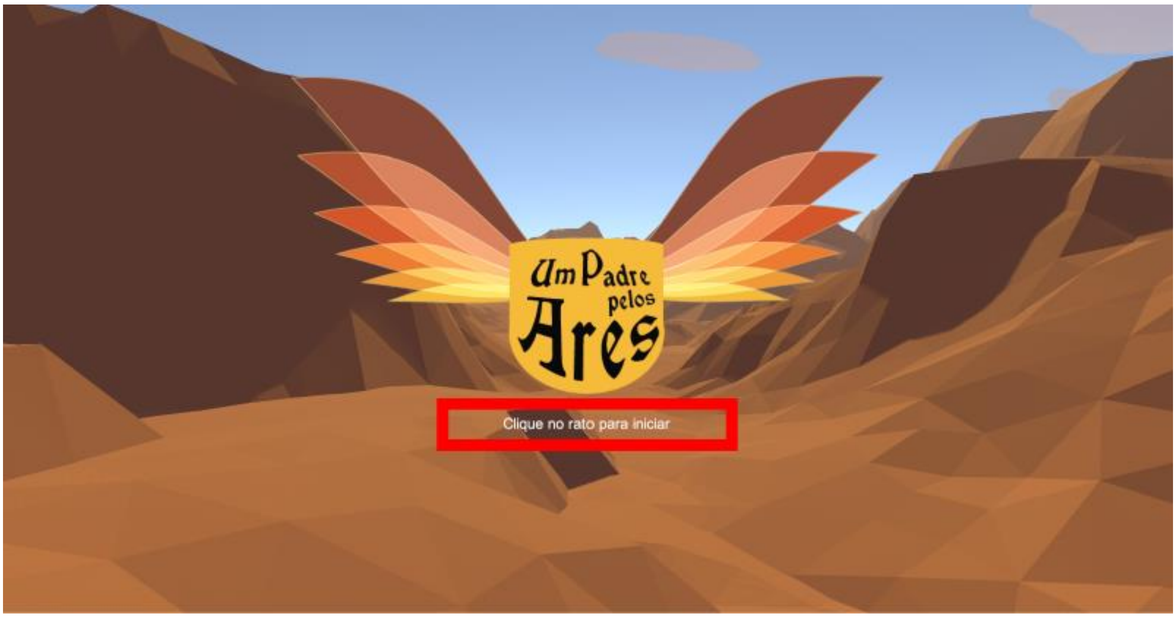


Figure 29 - Textual Information at the start screen – Game Scene

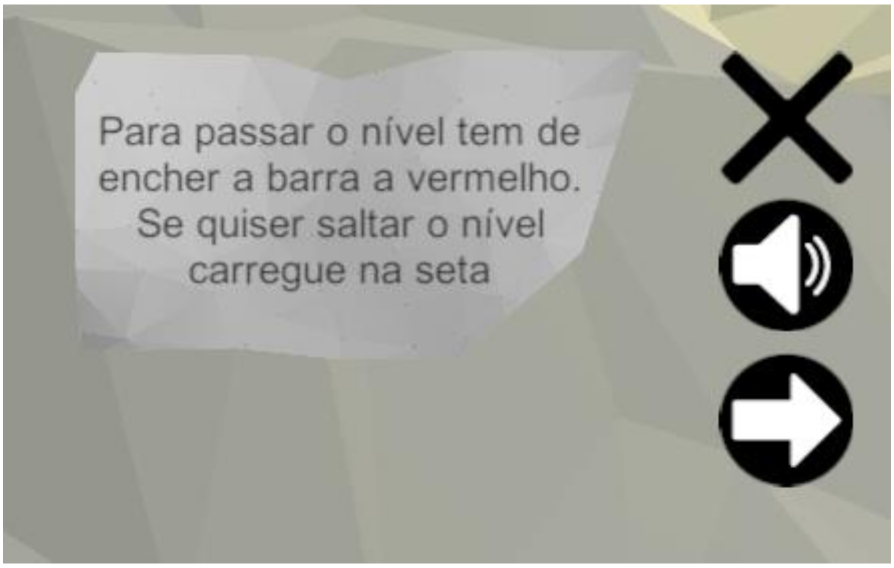


Figure 30 - Help info and icon placement - Game Scene

A logo was digitally drawn for marketing and disclosure as seen in Figure 31. The first iterations had a crucifix, but they were ultimately removed for larger acceptance in other countries with religious differences. The game title font type is named *Vinque* and is the only exception to the Arial typeface. The game title is named *A priest in the Air*, which follows the priest role in showing his discovery to the King. It is assumed that some critics might not like the Portuguese translation because the title might be associated to violence. The name was unchanged to trigger product awareness (Positive effects of Negative Publicity) (Berger et al., 2010).

Figure 31 - Game Logo

Based on the length of the game, there was a limited time for modelling and animating all the scenes of the game. The following text summarizes the modules that were retrieved from assets and the ones that were produced from zero. All 3D models are based on the Low Poly art style as stated in section 5.2 regarding the *Game Art Design* characteristic.

The balloon was fully modelled using cubes and cylinders (Figure 32). In total, there were 226 vertices to form the object. In terms of colours, the red and white in the air bag clearly differentiates itself from the rest of the world environment with enough contrast, which is premeditated since the balloon should be the focus of the player.

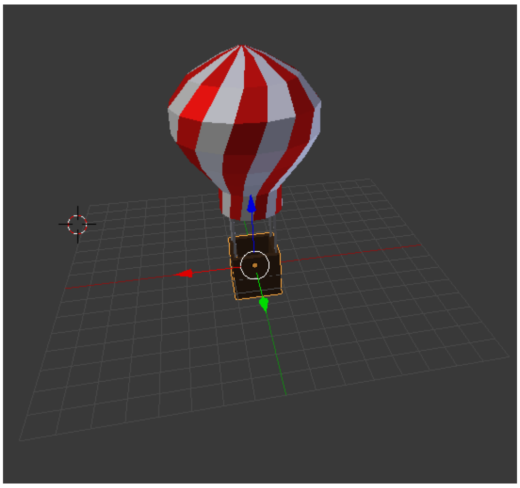


Figure 32 - Balloon

The bird was retrieved from a free 3D modelling library without any skeleton. A rig was added to the body of the bird as depicted in Figure 33. Four body areas were used for the bones, which were the head, claws, tail and wings. After rigging, the file was exported to a compatible *Unity* FBX format and animated using *Unity Animator*.

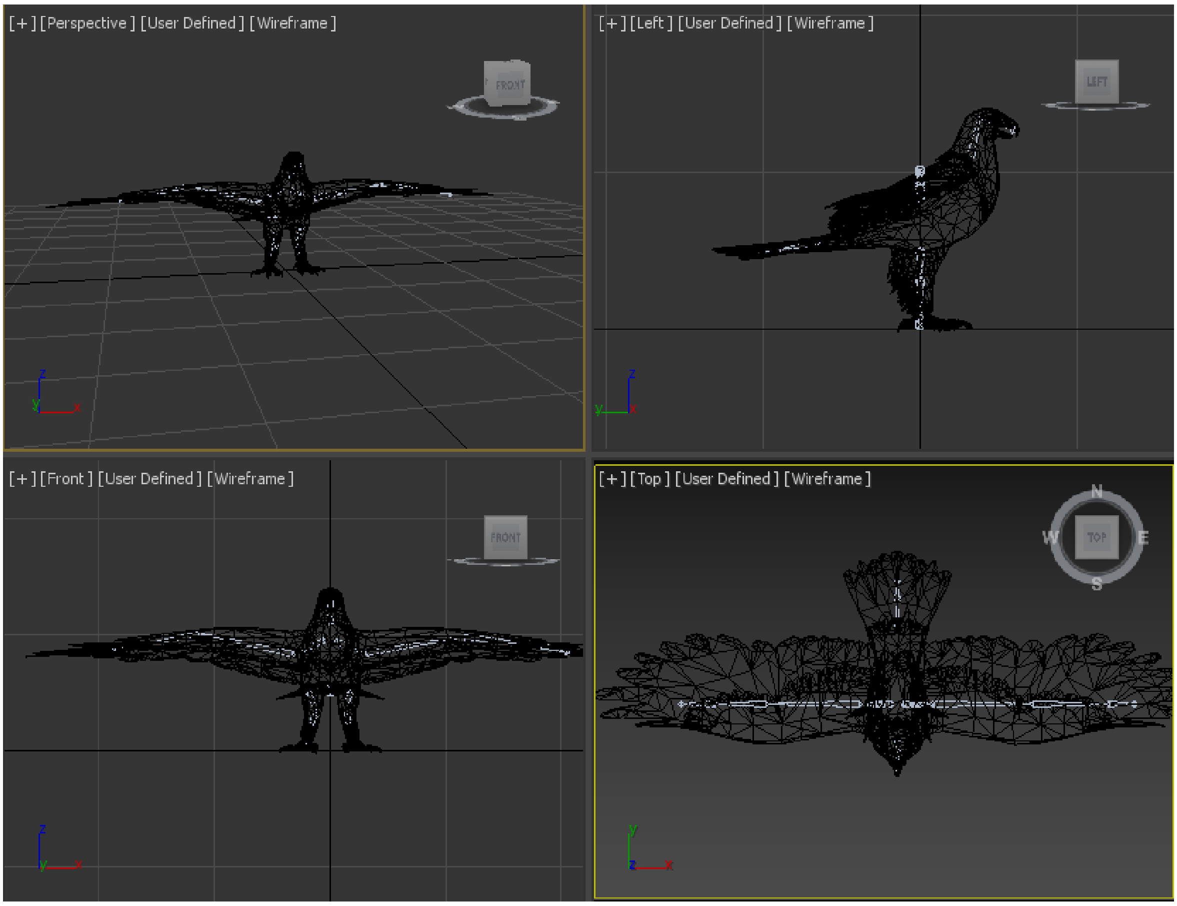


Figure 33 - Basic skeleton Rig for the bird

Terrain elements were retrieved from *Unity* Asset Store (*Low Poly Modular Terrain Pack*)(Justinas, 2018). Its use is justified with the necessity of modelling each terrain part with enough diversity and with three different types of hierarchy LOD levels (Figure 34). *Level of Detail* (LOD) allows reducing the number of triangles rendered for an object as its distance from the camera increases. If objects are not close to the camera, LOD will reduce the load on the hardware and improve rendering performance. Five different biomes were built from scratch using small parts of terrain with different sizes, colours, and positions.

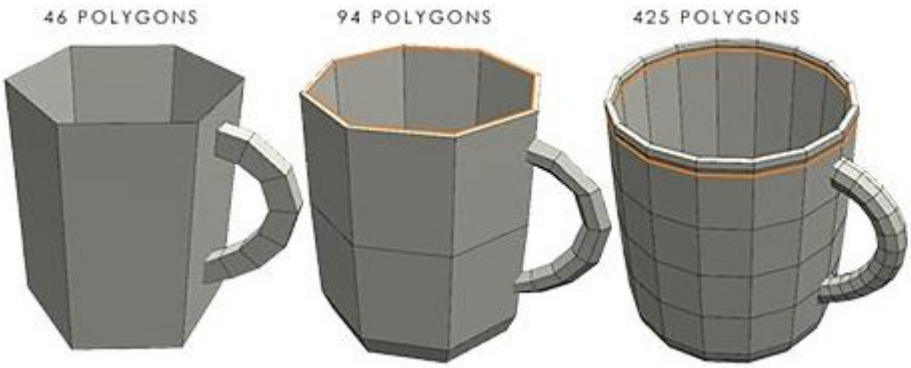


Figure 34 - LOD rendering – Retrieved from https://bit.ly/2AyFgc3

Narrative takes an important part to immerse the player in the game. The story takes place in the priest's cave and the king's room. The scenarios were retrieved from *PolyWorld: Low Poly Fantasy Interiors* asset (Theory, 2018). The character models from the King and Priest were retrieved from Polygon – Fantasy Characters (SyntyStudios, 2018) but were altered to better contextualize the characters.

The graphical interface was drawn using a Low Poly pattern and clipped as depicted in Figure 35. The image was used for the dialogue boxes and the map background.

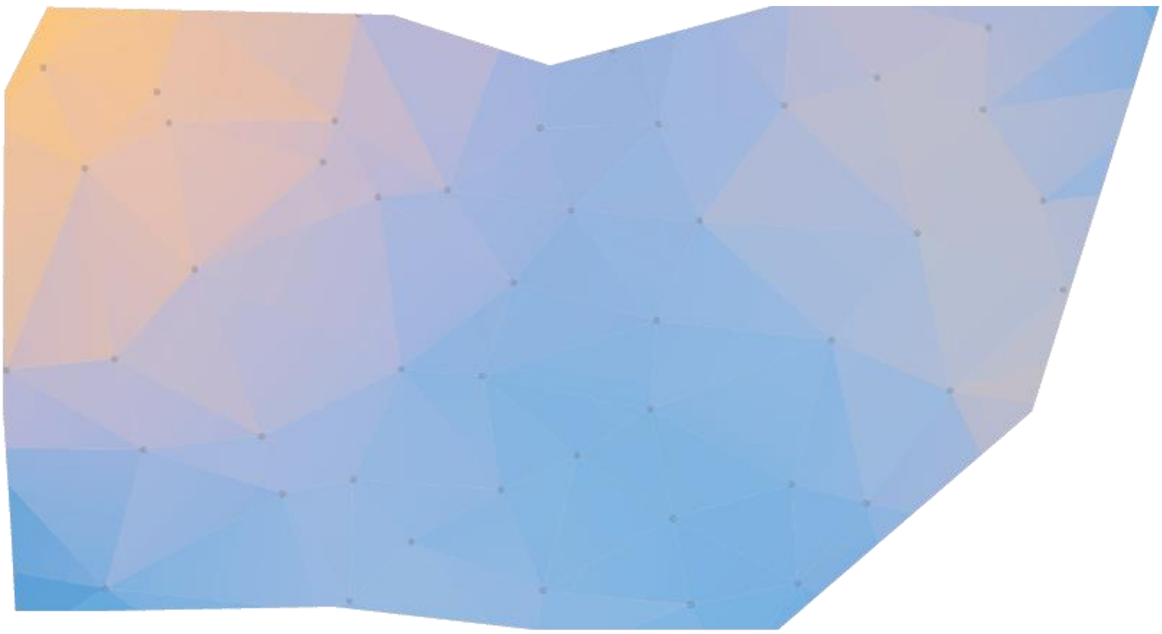


Figure 35 - Low Poly Pattern

Three different avatars were drawn to identify the dialogues as depicted in Figure 36: 1) Priest; 2) Priest's dog; 3) King, respectively.

Figure 36 - Protagonist Avatars

Sliders (Figure 37) have an important role in providing feedback to the user. When the Leap Motion is acquiring a movement, a green slider is to be filled. At 100% the colour changes from green to red. The red slider informs the user that the current movement is correctly executed. There is also another slider variation in white (calibration bar), which calibrates the sensitivity of the *Leap Motion*. Sensitivity control accommodates different types of stroke disabilities.

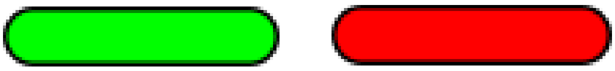


Figure 37 - Sliders

5.3.3 Narrative

The narrative is inspired about a priest called *Bartolomeu de Gusmão*, which was mostly famous for inventing the first balloon. The story takes place in the priest's room, where he is thinking about showing his most recent creation to the king. The priest needs to drive the balloon from his house to the king's castle, thus proving to all the critics that his invention works. However, reaching the king will not be an easy task. The player needs to help the priest in orienting the balloon through its various paths and branches.

The story is settled in three different cut scenes: two in the beginning of the game and a final cut scene after the final score between all levels. All the dialogue in each scene is exemplified according to Table 16 and 17. Each cut scene is composed of a static environment and an animation element, while being textually narrated. A visual guide is inserted on the table to systematize the characters speeches. The text was transcribed from Portuguese to English.

Table 16 - Narrative

Intro scene	
Priest lines	*- I finally built my balloon.* *- I can fly and go to places never imagined.* *- The King must be eager to see such work…* *- But how can i orient myself through air and find the castle?*
Objective	Introduce the story to the player
Visual Guide	
Lifting the balloon	
Priest and Dog lines	*- Go to the basket "Faisca", we are late.* *- Woof, Woof!* *- Good boy, now sit. We are going to see the King.* *- But we need to find the way while we fly…*
Objective	Defining the main objective for the game
Visual Guide	

Table 17 - Narrative

Landing the balloon	
Priest and King lines	- *I have arrived your majesty.* - *I deliver this finding to my king.* - *My faithful Bartholomew, you have been able to prove what nobody ever thought possible.* - *As promised you will be covered with gold and recognized all over the world.* - *I will be eternally grateful, Your Majesty.*
Objective	- Story Conclusion
Visual Guide	

5.3.4 Navigation

Graphical interfaces for gaming are sometimes convoluted and difficult to operate. In order to adapt to the public audience, the interface should be simple, clear, and easy to understand, while avoiding text whenever possible. According to Ijsselsteijn, Nap, Kort, & Poels (2007) interface design for elderly users should minimize the burden of functions that may have suffered a decline, such as demands on spatial memory, working memory, visual functions or motor ability. Interfaces should also be adaptable to compensate for functional limitations.

For the game *A Priest in the Air,* a linear model was chosen, allowing for fewer mistakes while travelling on the interface. Each scene can be skipped by clicking in the arrow on the upper-right corner of the screen, except for the video tutorial that precedes each exercise. Video tutorials will only skip, if the player places the palm of the hand over the *Leap Motion* device.

The scheme in Figure 38, shows the navigation flux for the entire game:

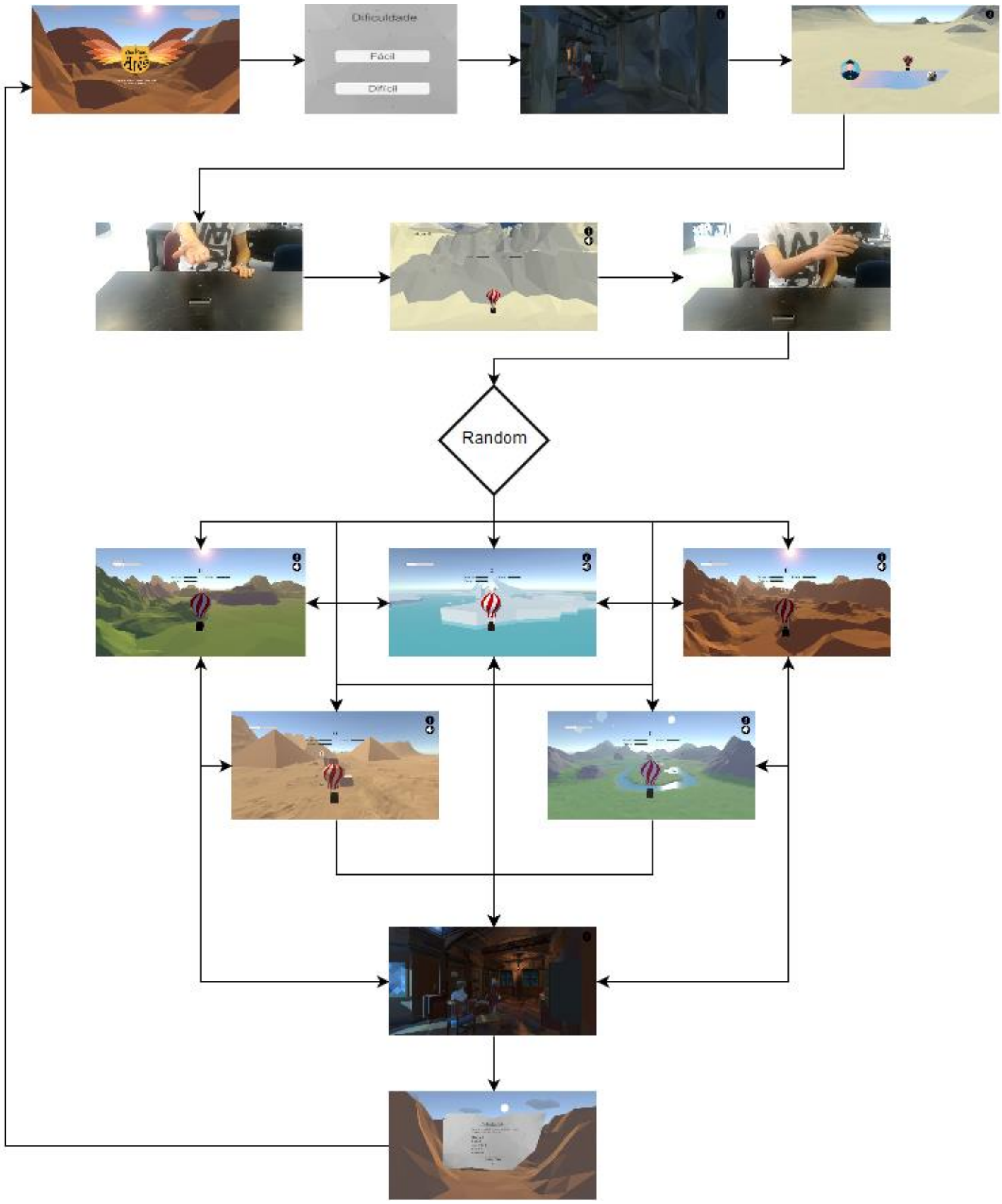


Figure 38 - Game Navigation Scheme

The game contains a sequential navigation scheme until the start of level 2. The random indication selects a random level from five different possibilities. A loaded level is never repeated during the game session. After playing the five selections of level 2, the final cut scene and high score is presented. The properties of each panel are stated in the following text:

Start - where the user can start the game by putting his hand on the sensor radius.

Difficulty Panel – select a slow or fast paced game

First cut scene – Showing the priest's creation

Second cut scene – entering the balloon

Help - Pronation/Supination exemplification movie

Level 1 – Lifting the balloon

Help – Horizontal swipe exemplification movie

Level 2 – Controlling the balloon in five different biomes

Third Cut scene - Arriving to the king's castle and receiving his blessing

Final Score – Show the score for all levels

While the navigational structure is true for a traditional monitor, the HMD functionality does not require navigation, since that module is stripped of all functionalities and navigation except for the existence of one pre-determined level for testing purposes (Antarctica), without map or cross zones. Designing and conceive VR graphical user interfaces for the senior is not included in the development program due to its complexity and time limitations. The absence of UI elements for the HMD, does not allow interacting with the calibration bar of the *Leap Motion*. Instead a default value will be selected. Due to this fact, the evaluation stage will not correlate movement execution between displays.

5.3.5 Feedback

There are several types of feedback between the system and the player for better performance and communication by both parties. Four types of feedback were identified:

Visual:

- Buttons have three types of states: normal, over, and pushed.
- The Sequence system has a counter and fades in/out animations.
- Controlling the balloon occurs in a synchronous way to the user input.
- If a terrain type collides with the balloon, a blinking effect occurs, changing the values in a bracket of 0 to 100 of opacity.
- Clapping hands to open the map is also a type of visual feedback.
- The instructions for the exercises occur in the form of a video.

- Story progression includes text and an avatar for character identification.
- Each movement has a correspondent slider that fills using green (acquiring) and red (acquired).
- A visual representation for each hand is shown. If no virtual hand exists, then the *Leap Motion* is not recording movements.

Sound:

- The three types of objects (bird, stone terrain) produce a penalty sound if a collision is detected.
- Turning the balloon to the left or right generates a sound.
- There are different types of background sound according to the scene.
- Using the Sequence System generates a reward sound.
- Story progression is narrated.

Reaction Feedback:

- The player controls the game objects in real time, and the objects react according to the player gestural input.
- The slider bar at the left upper corner controls the sensitivity of the device for the horizontal swipe motion.

Informative Feedback:

- The score for each level is shown and at the end, all scores are shown and multiplied for a final score result.
- The help button contextualizes allowed operations with the keyboard within the game if selected.
- Selecting the sound button changes the icon to a no sound icon.
- Next to the slide bar exists a text with the explicit movement that is detected within that slider.

5.4 Game Implementation

This section documents the implementation of the prototype. It is expected to use the system at home, or in physiotherapy centres for stroke rehabilitation. Since it is not expected for the final user to purchase high end hardware, such as expensive HMD displays, professional body tracking systems, or high-performance desktops, the systems must be able to run in low-end PC and using smartphones as a substitute for a mainstream HMD.

For this prototype, *Unity Game Engine* was used for its great stability and versatility. It was used the 2017.3.1f1 development environment while using C# scripting. The selected IDE for scripting was *Microsoft Visual Studio* for its improved debugger and editor. Another excluded option was *Amazon Sumerian*, which is a tool to create VR, AR (augmented reality), and 3D experiences in a quick and easy way. It is possible to import 3D models (FBX, OBJ), or to create new models, while using coding scripts to control the behaviour for the specified object. The main interface is simple to use and delivers an easy-to-use design appropriated for new developers. It is possible to build multi-platform experiences that can run on specific hardware, such as the *HTC Vive*, *Oculus Rift, Android*, and *iOS* devices using *WebVR* compatible browsers. Some of the software features are (Walker, 2018):

- Web-based editor for constructing 3D scenes, import, export, scripting, special effects, with cross-platform publishing;
- A library of pre-built objects and templates;
- Asset Import with FBX, OBJ, and in the future *Unity* projects;
- Scripting Library in *Javascript;*
- Hosts: Animated 3D characters that can be customized;
- AWS Service integration baked in integration with *Amazon Polly* and *Amazon Lex* to add speech and natural language into Sumerian Hosts.

Game objects, and 3D models were created using *3ds Max 2017*, and *Blender*. Digital Art was drawn using *Adobe Illustrator* and *Adobe Photoshop*.

During the development process there was a necessity to implement the HMD feature, while using the *Leap Motion*. For that purpose, the *Leap Motion* development team recommends the use of *RiftCat's VRidge* since the *Leap Motion* does not have its own framework for mobile development. *VRidge* is a software that can stream PC VR experiences to the smartphone using WiFi or USB tethering. At the same time, it uses the smartphone internal gyros to provide the head tracking. *Vridge* only streams video and audio data to the smartphone with a maximum of 60Hz, and the overall experience loses some fluency in comparison to a high-end HMD (90Hz), however the PC is responsible for all the physics calculations, and the smartphone processing requirements are very low. Currently, the project supports the latest *Leap Motion* Orion Beta framework. *Vridge* can automatically detect *SteamVR* and emulate tracking devices using the players hands while streaming to the HMD.

5.4.1 Balloon Physics & Movement

The primary goal for the player is to move the balloon in the 3D scenario. Using the Cartesian system, it is necessary to represent the balloon movement for the X, Y and Z axis. The balloon moves forward by adding numerical values in the Z-axis according to a defined speed for the current and next frame. The Y-axis is represented with a sinusoid wave (Figure 39), in order to have different heights between the ground and the maximum height, thus emulating a floating motion. The X-axis has two different motion implementations. **(1)** The first is a pendulum effect in order to give further realism to the floating balloon, by incrementing Euler angles around the X axis. The balloon basket is used as the base, while the fabric that enclosures the hot air waves with a defined angle incrementation of 1 degree per frame until the defined timer arrives at the end, then repeats the effect in reverse. Figure 40 exemplifies the intended motion with an exaggerated representation for better understanding. **(2)** The second intended motion in the X-axis is the movement of the balloon for the left and right. In a first implementation attempt, the X values were simply incremented for the right and decremented for the left. However, the motion of movement was too stiff and unrealistic. The solution was to apply a smooth transition during the motion by using *Mathf.SmoothDamp* from *Unity library*. This specific function needs to receive the actual X position, the target position, the time to apply the smooth effect and a maximum speed. During this motion, any input is locked until the motion ends.

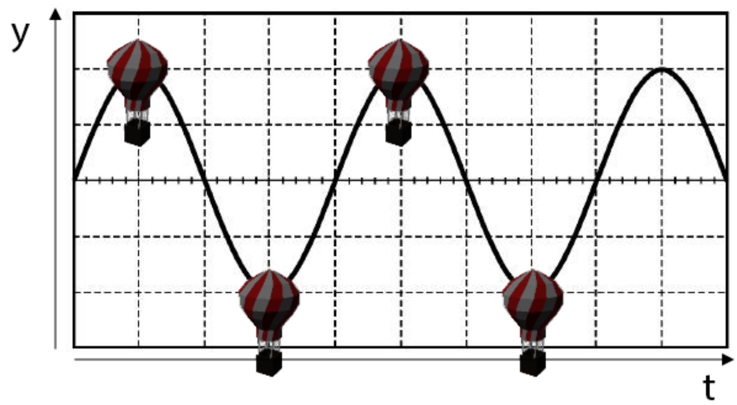


Figure 39 - Balloon movement with a sinusoid wave

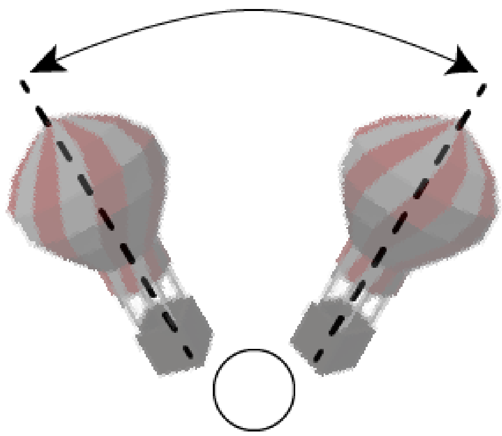


Figure 40 - Pendulum representation

5.4.2 Tracking Device and Gesture Implementation

Tracking devices can digitalize the human body, while making an accurate representation in the virtual world. For this research, two tracking devices were used (*Kinect* and *Leap Motion*).

The *Kinect* was the selected device due to its versatility in tracking "sited" or "standing positions". There was also the possibility to implement upper-limb and lower-limb motions. For the software, *KinectVR* allowed for monitor and HMD displays. However, the system was exclusively compatible with Wi-Fi connection, which increased latency between movements. This statement, plus the end of production of the *Kinect* by Microsoft (Pterneas, 2017), undermined the device future viability. Figure 41 exemplifies this preliminary experiment.

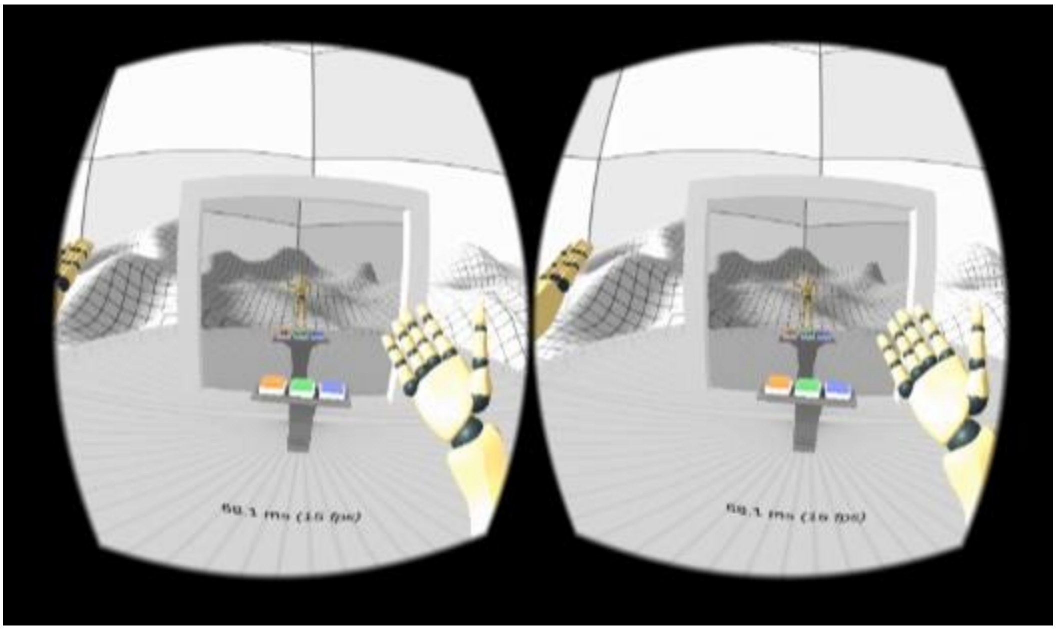


Figure 41 - KinectVR in VR mode

KinectVR (Open-Source, 2018a) is an open-source plugin for Unity, and it contains a main framework to get coordinate data from a *Kinect* (x-y-z axis), while using a normal gaming monitor or an HMD (*smartphone* with *Google cardboard*) with a wireless connection, thus delivering a low-cost motion tracking system. The main advantage for this system is to have greater mobility as long as the *Kinect* can handle the range between the human body and the hardware. The mobility aspect is achieved with a *NodeJs* server that shares data between the computer and the smartphone.

During the use of the Kinect, some other software tools compatible with the device were scouted. The following list consists of software exclusively developed for motion capture with the

Kinect. It is highly possible that some projects will be unavailable to use in a short future, due to the end of production of the device.

- Libfreenect/OpenKinect Project – Retrieved from (Open-Source, 2018b)
- DepthJS - Retrieved from (Zinman, Fritz, Elliot, & Shilkrot, 2010)
- iPi Motion Capture - Retrieved from (IPi, 2018)
- Brekel Kinect Pro Body - Retrieved from (Brekel, 2008)
- Vitruvius – Retrieved from (Pterneas, 2018)

Table 18 resumes all the frameworks which have been identified above.

Table 18 - Software Frameworks

Software	Description	Language	Compatible Devices
Amazon Sumerian	Build VR, AR and 3D environments without specialized programming.	AWS SDK for Javascript	iOS, Android, Oculus Rift, Oculus Go, Htc Vive, HTC Vive Pro, Lenovo Mirage Solo, Samsung Gear VR, Google Daydream
KinectVR	Virtualizes the human body using the Kinect. Ready for 3D environments and VR using mobile phones	C#	Kinect, Android, iOS
OpenKinect	Open Source Libraries to enable the Kinect	Python, ActionScript, C Synchronous, C++, C#, Java JNI, Java JNA, Javascript, Common Lisp, GFreenect	Kinect
DepthJS	Framework that enables Web-based interactions with the Kinect	Javascript	Kinect
iPi	Create asynchronous animations through a GUI		Kinect
Brekel	Real-time body tracking		Kinect
Vitruvius	Real-time body tracking and 3D animation	Undefined	Kinect, Intel Realsense, Orbbec Astra & Astra Pro

The extinction of the *Kinect* dictated the use of another equipment that was inexpensive and available in a nearby store. The Leap Motion was chosen and its software framework from the Orion Library v3.2.1. The main problem that comes with the use of the *Leap Motion* is the fact that the user is limited to an interaction area, while finding a comfortable area to support the elbows. The user is also limited to upper-limb movements (hands). While using an HMD, it is more difficult to determine the interaction area of the device. However, this problem can be minimized with visual feedback of the hands in the interaction area (Figure 42).

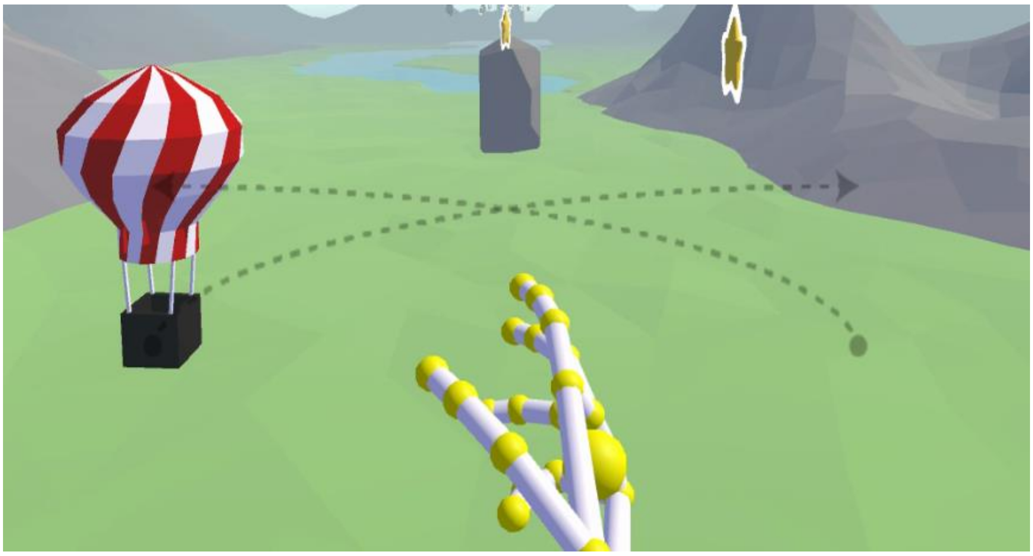


Figure 42 - Right Hand Representation - Game Scene

Section 5.3.1 for the Level Design introduced three different movements for training the upper-limb stroke patient by increasing the difficulty (pronation/supination, horizontal swipe, clap hands respectively). These gestures are adequate for the *Leap Motion* due to the absence of occlusions (grey areas that the device cannot track). In terms of its therapeutic properties, Pronation/Supination and horizontal movement (swipe) was previously validated by Mou-Rehab, PhysioFun and GesAircraft, but the clap does not appear in the theoretical framework. An experienced physiotherapist validates all the appointed movements before the final prototype assessment by senior citizens.

In terms of implementation the *Orion Library* comes with some predefined movements for VR experiences, while connecting the *Leap Motion* to the *Unity* Development environment. None of the examples allowed representing the supination/pronation, horizontal swipe, or clapping exercises, although the horizontal swipe existed within the Orion library predecessors. There were two options presented to the programmer:

(1) Identify each hand bone through the Orion framework and use the Hidden Markov Model (HMM) by following the guidelines from Gesture Recognition with a Wii Controller (Schlömer, Poppinga, Henze, & Boll, 2008);

(2) Find a suitable framework with pronation/supination, horizontal swipe, and clap movements.

The Unity Asset Store has several libraries that are compatible with the *Leap Motion* device, namely, the "Leap Motion Simple Control" (Dttngan91, 2016). After testing the framework, some changes were implemented for the horizontal swipe movement; such has allowing any hand position (open, closed, semi-opened), detection of different speeds and minimum distance between the starting motion and the ending motion. Supination/Pronation exercises were also altered to allow for opened or closed hands although they are easier to execute.

The previous movements can be classified as static and dynamic (Guna et al., 2014). Static movements are defined as an acquisition of a limited number of static points in space. A dynamic movement is defined as variation of form, speed and distance through time. This type of movement is harder to detect and involves more accuracy at the motion in play.

The implemented movement for lifting the balloon in the first level is composed of two static hand positions, which are pronation and supination. The supination movement involves stretching the arm and placing the palm of the hand down. Then, the hand is rotated so that the palm of the hand is facing upwards (Figure 43). Pronation is the reversed operation.

Figure 43 - Supination/Pronation Cycle – Game Movements

Controlling the balloon in the second level requires a different approach since the movement is dynamic and harder to execute. For this case, the horizontal swipe motion uses a horizontal motion from the left to the right, and the right to the left. Swiping in this case is also more contextualized and natural if compared to the supination/pronation exercise, since moving the arm to the left respectively moves the balloon to the left and vice versa. Figure 44 illustrates the horizontal swipe with more detail.

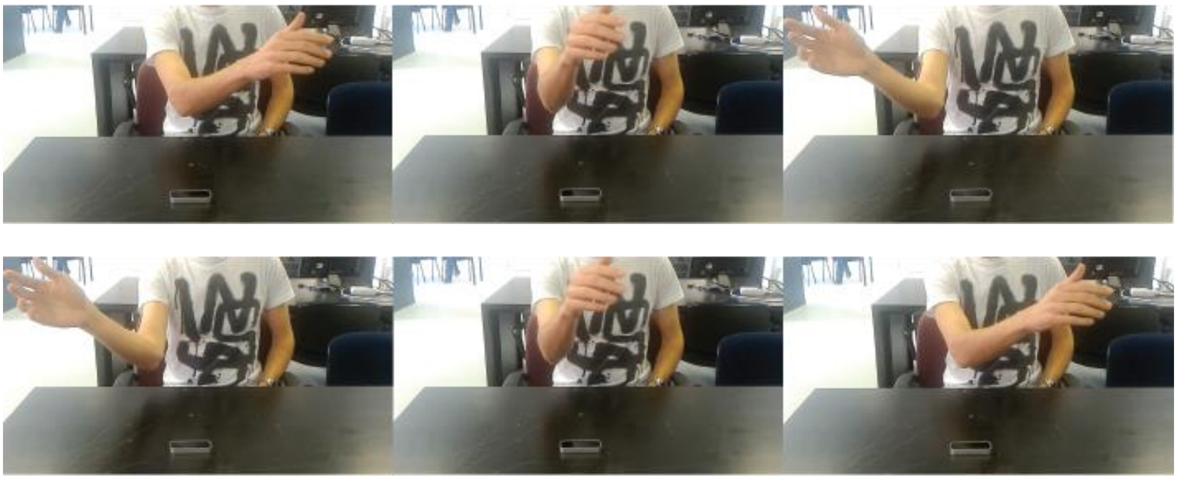


Figure 44 - Swiping Left and Right – Game Movements

To access the map in level 2, the player needs to clap his hands once, and another clap to close the map (Figure 45). Clapping is not supposed to be frequent during the game but can be done whenever the player forgets the correct path in a cross section.

Figure 45 - Clapping - Game Movements

As stated in the *PhysioFun Project* (Ribeiro et al., 2016), the *Leap Motion* was discarded for concerns about user difficulties in keeping the hands inside the interaction area. To better accommodate this concern, a proper chair with height regulation and the use of a pillow to rest the elbow is expected to show good results, if used together with the digitally drawn hands on the screen. The use of a hand support in Figure 46 was discarded since the horizontal swipe and clap movement are not compatible.

Figure 46 - Hand support – Retrieved from: Colgan, 2013

5.4.3 Optimization Techniques

The presented techniques represent an effort to increase and stabilize frame rates. This topic is of high concern especially for the HMD display feature, since higher frame rates directly diminishes the risk of dizziness while also giving a better immersion experience. This aspect allows for longer periods of use with the HMD. The same techniques are reused for the traditional monitor display due to increasing the overall experience and fluidity.

With VR, every frame must be drawn twice, one for each eye. That means that every draw call is issued twice, every mesh is drawn twice, and every texture is called twice. There is also a small amount of overhead (internal processing of the scene) that is required to apply distortion and TimeWarp for the final output frame (approximately 2 ms per frame). TimeWarp is a technique that warps the rendered image before sending it to the display to correct for the head movement after rendering, thus reducing latency and maintaining frame rates. Since most HMD refreshes frames at 90 Hz, it is very challenging to hit a high and constant frame rate.

In order to hit constant and high frame rates, four techniques were applied to the game, according to the *Unity* optimization program for VR (Unity, 2018):

(1) Low Poly models

(2) Baked Lightning

(3) LOD – level of distance

(4) Occlusion Culling

(1) **Low Poly models:** Building a world with a big number of objects can overload the computational resources of the system. The number of polygons can exponentially increase according to increased detail for the appointed object. It is necessary to control and optimize the number of polygons for each object. For that purpose, the game art & design selected for this game is based on the Low Poly Art as stated in section 5.2 and removing high fidelity representation of objects in the scene.

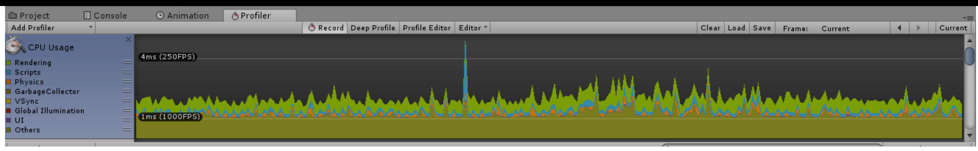
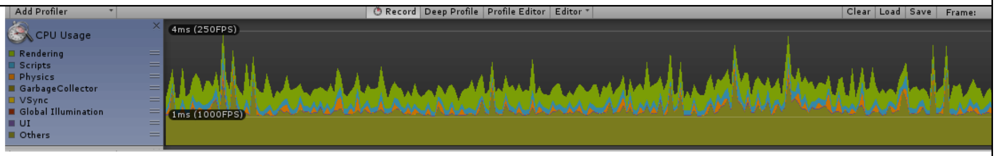
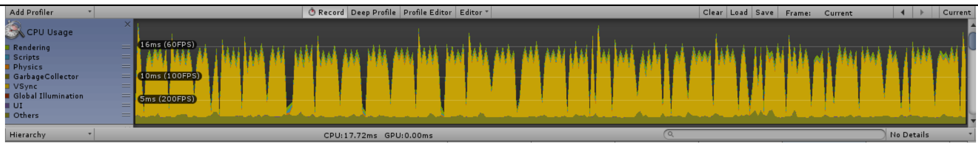
(2) **Baked Lightning:** Eliminates dynamic lightning and real-time shadows. The disadvantages of using real-time lightning are increased memory requirements due to additional sets of light maps used to store real-time indirect bounces computed by the engine lightning system, increased shader calculations, and indirect lightning vectorization over time. The use of baked lighting for the local ambience, means that the engine will pre-calculate the illumination for the lights before run time, and do not include them in any run-time lighting calculations.

(3) **LOD:** LOD rendering is a technique that allows reducing the number of triangles rendered for an object as its distance from the camera increases. In this case, since the terrain is relatively big, it is not necessary to render all the triangles because the increased distance will not allow for the human eye to observe its detail. This approach increases overall performance of the game while providing lower detail meshes for distance groups further from the camera. However, it is necessary to model the object in different detail and hierarchize according to levels of detail.

(4) **Occlusion Culling:** Stops objects from being rendered if they cannot be seen, which increases the number of FPS. This process will go through the scene using a virtual camera and building a hierarchy of potentially visible sets of objects. The data is used at runtime by each camera to identify what is and what is not visible.

To ascertain the amount of frame rate drops for the use of an HMD, *Leap Motion*, and world generation, it was used the *Unity* built-in profiler to capture real-time data and analyse performance. Table 19 compares the actual frame rate for the generated world with simple keyboard inputs, the *Leap Motion*, and finally the VR display. The game was running in a portable computer, with the following specs: i7-4700HQ CPU; 12 GB of RAM, Nvidia 740M graphics card, 256GB SSD and Windows 10 x64 operating system. The computer monitor had 17 inches and was running at 1600*900 resolution.

Table 19 - Comparison between frames per second by inputs

Description	Chart
Keyboard	
Leap Motion	
HMD & Leap Motion	

Keyboard and *Leap motion* interactions had a very similar performance during the game with constant 465 FPS for graphics generation. However, there is a drop of frames when the *Leap Motion* detects an object, which is to be expected, although it is not visible to the human eye. The HMD example was fixed at 70 FPS due to Vertical Synchronization (VSync), which is being forced by *SteamVR*. VSync is a rendering option that prevents the video card from changing the display memory until the monitor is done with its current refresh cycle. This test was executed with a normal mobile phone, which limits the frame rate to the maximum monitor image update. The use of other devices should increase the FPS, although it was not tested. For the reference, VSync was not disabled in order to guarantee constant FPS, even if the frames run at a slower pace.

5.4.4 Camera System

Section 5.2 defined two display characteristics: HMD and monitor. It is required to create two type of perspectives (1st person and 3rd person) for the same scene (Figure 47).

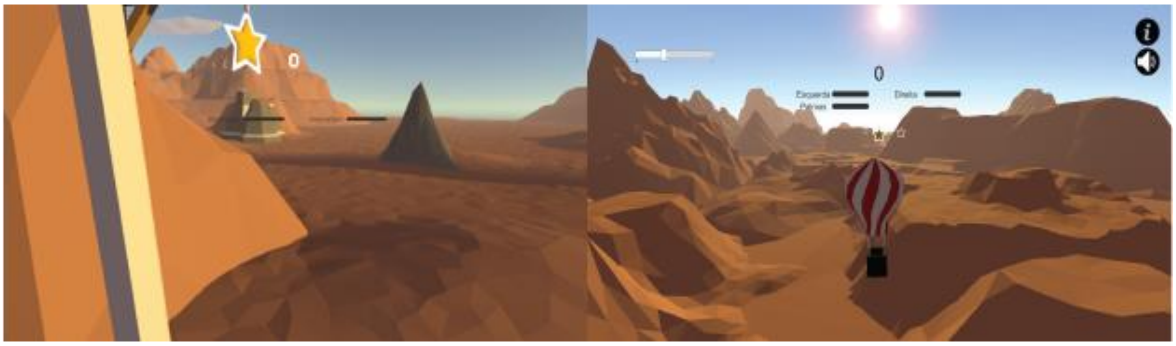


Figure 47 - 1st and 3rd person views – Game Scene

The 1st person perspective for the HMD prototype was implemented using *SteamVR* plugin, which allows developers to target a single interface that will work with all major virtual reality headsets from seated to room scale experiences. Additionally, it provides access to tracked controllers, which in this case was the *Leap Motion*. *SteamVR* compositor allows you to preview content in VR using *Unity* play mode, while the normal game window can be monitored for player support.

The 3rd person perspective has some variations in terms of the implemented camera displays. A global script was developed using Enumerations in C#. The Global Enumerator creates a collection of related constants, named: left, right, forward for the second level and up for the first level. The camera follows the balloon according to the defined targeted axis coordinates and transitions according to the defined state using interpolations between vectors with the "Vector3.Lerp" function. Table 20 depicts the coordinate system for each variable. Each object in a scene has a transform variable that stores and manipulates the position, rotation and scale of the object.

Table 20 – Camera Coordinate System (X, Y, Z) for the Balloon

Type	X	Y	Z
Forward	Static	Static	Variable
Left or Right	Variable	Static	Variable
Up	Static	Variable	Static

Initially, the bottom left corner had a mini-map (Figure 48), before the map functionality was implemented. However, further adjustments for distance rendering allowed for better visibility at cross-zones, with the use of a billboard (Figure 49). The mini-map was discarded for requiring a switch between focus areas of view and being redundant with the billboard. The mini-map implementation was based on a mask with a camera pointing downwards.

Figure 48 – Mini-map – Discarded Game Scene

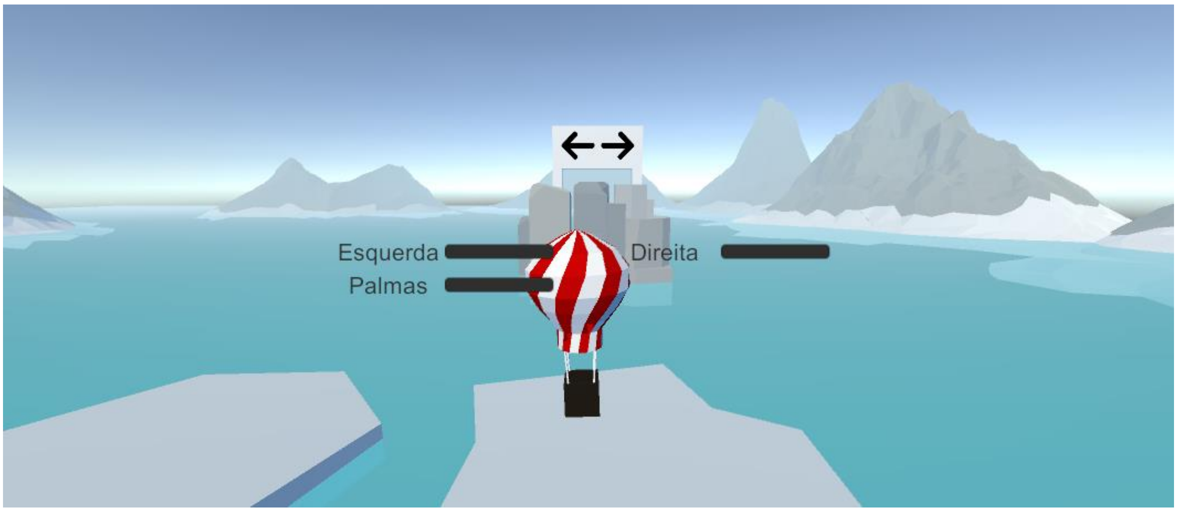


Figure 49 – Billboard – Game Scene

5.5 Prototype Analysis

The most important aspect regarding a digital game for rehabilitation is that its mid/long term use can effectively help the patient to recover. However, this research only allows for preliminary use at the recovery centres by physiotherapists and senior citizens that suffered a stroke. Still, it is possible to find therapeutic game models to ascertain the therapeutic properties of the game.

The model objectives as stated by Mader, Natkin, & Levieux (2012) are to tell game designers which information needs to be gathered, with emphases on medical information. Then, alongside the design and development of a therapeutic game, the model can help to examine the coherency of the game design choices. Table 21 and 22 describes the gameplay model from Mader et al. (2012), and "A Priest in the Air":

Table 21 - Gameplay Analysis following the Therapeutic Game Model. Retrieved from: Mader et al., 2012

Question	Game Analysis
How does the player interact with the game? **(Input System)**	To interact with the system, the user must use the two types of devices: the mouse and the *Leap Motion*.
How does the game convey information? **(Output System)**	The system transmits information through image and sound.
Are there appealing goals? Are they short, mid or long-term goals? **(Goals)**	Short-term objectives are to deviate from obstacles, catch stars for point collection, and use combo system for score multiplier. Mid-term goals are to travel between several worlds, until the king's castle is reached, thus completing a game session. Long-term goals are to improve the overall high score until perfection is reached.
Which means are used to communicate with the player? Are they informative on the player performance or progression? **(Feedback)**	The system sends several types of feedback as depicted in section 5.3.5.
What does the score mean? (e.g. player performance, player progression, health improvement) Is the score informative on the progression towards mid or long-term therapeutic goals? **(Score)**	Score is given based on the performance of the player for each level. A score multiplier is given through the first level, while the second level score is based on the score sum of all five biomes. If the player has a substantially better score, it means that his/her condition improved over time.

Table 22 - Gameplay Analysis following the Therapeutic Game Model. Retrieved from: Mader et al., 2012

Question	Game Analysis
How is the difficulty level chosen? (e.g. adaptive, manually chosen by the player, manually chosen by another person) If adaptive, how does it work? Which parameters of the game are modified by the difficulty level? **(Difficulty)**	The player or physiotherapist manually chooses difficulty. Difficulty directly affects the forward speed of the balloon. Slower speeds allow for more reaction time to change the balloon course, while higher speeds reduce reaction time.
Does the game propose enough variability? (e.g. the player is always doing the same sequence of actions, the player learns regularly to master new patterns, the player can choose his own path within the game, the player must create new strategies to progress) **(Variability)**	There are three types of movements detected by the L*eap Motion*, Levels are loaded randomly from five different maps and random cross-zone direction. Levels have different colours and enemy position.
What are the minimal abilities and knowledge necessary to play the game? Does the game feature tutorials and explanations? **(Usability)**	The game features help videos before the level, while also having help icons at the top right corner. The player needs to have minimum knowledge to setup the hardware and enter the game.
What can the game provide to the player that is not part of the therapy itself? **(Expected Positive Results)**	Partial upper-limb mobility recovery for a stroke patient, with an artefact that provides entertainment. Different results are to be expected depending on the exercises executed in a traditional recovery program.
Have the game or analysed features been used for another serious purpose? **(Reported serious uses)**	The game has not been used for other purposes besides stroke recovery.

5.6 Sample Analysis

To evaluate the game in terms of its inner potentialities for stroke patient rehabilitation and general usability, it is important to gather a convenience sample of physiotherapists to test the interaction during the development and the final prototype. That information will be used to ensure that there are therapeutic properties and to identify positive and negative results in a real-world scenario.

Sample description for the physiotherapists are based on variables such as current profession, experience with stroke patients, and playing habits.

Sample description for the senior citizen are based on:

- Previous rehabilitation sessions that can affect game performance;
- Months of treatment;
- Time of exercising at home;
- Pain management;
- Time spent in the game;
- Level difficulty;

5.7 Data Collection

To ensure that the final prototype may have potential therapeutic properties that can improve a patient condition over time, it is identified two moments of data retrieval. According to the Development Research methodology *(*Van den Akker et al., 1999), the first data retrieval occurs during the second stage of "Theoretical embedding", while the second data retrieval occurs in the third stage of "Empirical Testing".

The first data retrieval refers to a semi-structured interview with an expert physiotherapist, while showing a demo. The pronation/supination, horizontal swipe, and clap were evaluated as capable of improving the condition of the stroke victim, while also defining limits to the use of HMD.

The second data retrieval occurred in a rehabilitation centre for stroke victims and is focused on the evaluation of the final prototype according to: (1) physiotherapists; (2) senior citizens (Figure 50).

(1) Physiotherapists can play the game and identify main problems with UI elements and movement execution. The information is retrieved through semi-structure interviews, and an online questionnaire. After performing the tests, the physiotherapists will identify patients that are eligible for using the prototype and describe the paralysis of each patient.

(2) Senior citizens can play the game while the researcher uses the observation method to fill a performance sheet for the first level and two biomes of the second level. Each display is evaluated though a brief semi-structured interview. During the playing sessions, screen capture is recorded for further analysis.

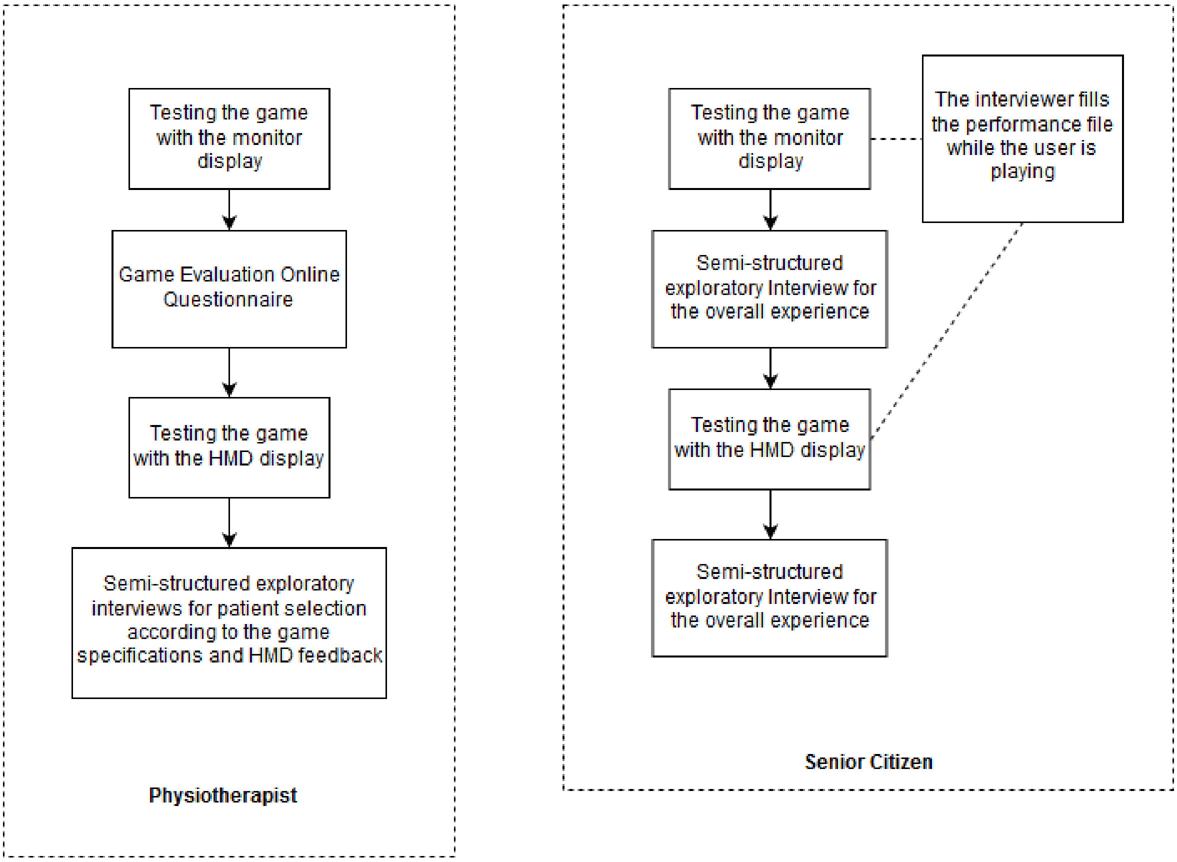


Figure 50 - Evaluation diagram for the game prototype

5.7.1 First Data Retrieval: Expert Evaluation of the Demo

The first data collection occurred after a demo was developed with basic movement interaction and scenario as a proof of concept. The Demo was shown during a meeting with an expert physiotherapist in a format of a semi-structured interview, to guarantee that the proposed movements comply with medical practices and eliminating chances of aggravating damage to the patient limbs and spine during a recovery session. The used demo allowed for the two types of displays (monitor and HMD).

The meeting evaluated the type of eligible movements, and the expected number of movement repetition during a gaming session. The supination/pronation, clap and horizontal swipe movements were validated and identified as recovery exercises for the mid/final phase of a recovery program based on the difficulties that a stroke patient faces in everyday life. It should also be signalized that pronation/supination exercises are not commonly used at stroke recovery facilities, but they effectively stimulate muscles that are not normally explored, which is good for the patient in terms of variety. The final recommendation of use for the game was to use the application two times a day, for an effective recovery program. It was also advised to have some sort of movement pattern and a movement guideline for easier use. An example of movement pattern is positioning stars and obstacles in a way that forces the player to use the turning pattern of "left-right" until the end of the level. Movement guideline can be an assisting UI image in the form of a line, which helps the player to execute the movement correctly.

The meeting was also a clarification session to balance the game in terms of speed, difficulty, and arousal according to the everyday struggles of a stroke patient in terms of cognition, reflexes, reaction time, and motivation. Daily tasks for a stroke victim may consist on picking small balls by colour and sorting them to the appointed box, doing exercises to increase dexterity, or other tasks to stimulate finer motor skills. It was mentioned that it was very hard to motivate a patient to stick to a recovery schedule.

Lastly, the HMD module was analysed as an alternative for the traditional game. Although its use was not forbidden, several questions emerged in terms of its use. To answer them, the manual for the Samsung Gear VR headset (Samsung, n.d.) was analysed and the following rules of use were selected:

- Do not use the device in hospitals, planes, or equipment that can have radiofrequency interference.
- Do not expose the device to tobacco smoke.
- While using hearing devices, contact the HMD supplier for more information about radiofrequencies.
- The device contains magnets. Magnets can affect pacemakers, cardioverters, defibrillators insulin bombs, or other electronic devices. Do not use the device under these conditions.

While these rules remain true for the evaluation phase with the use of the Samsung Gear VR, the use of mobile phones as an alternative at home can rise other unexpected problems which should be discussed with a doctor and phone supplier prior to its use. The use of this system should not exceed more than 10 minutes of use per day as suggested by the physiotherapist. The HMD module is also a problem since a stroke may create eye loss (Teasell & Mbbs, 2013). Users with eye loss should not try the display, while the others can use the display following the user guidelines for the HMD.

The semi-structured interview guidelines and summarized answers are reported on Table 23 and 24.

General objectives of the semi-structured interview:

1. To deepen the perceptions regarding the greatest difficulties experienced by stroke patients in rehabilitation.
2. Collect information about the compatibility of movements belonging to the *Leap Motion* library and its feasibility in the recovery of a member who has undergone partial / total paralysis.
3. Address the use of an HMD in senior patients and care to be taken in the development of a digital game.

Table 23 - Semi-structured interview for the Demo

1st Part: MOVEMENTS

Specific Objectives	General Questions and Answers	Specific Questions and Answers
Know the opinion of the health professional about the main limitations of a stroke patient in their rehabilitation.	What aspects do you highlight as relevant in treating a stroke patient and what are the major limitations of the patient? **The treatment must start right after the stroke for better recovery of the affected limbs.** **The limitations are centred on mobility and execution of everyday tasks.**	What are the relevant differences in the treatment of stroke patients with different clinical condition? **The process is the same for both ischemic and haemorrhagic strokes. The rehabilitation occurs depending on the identification and extension of the injury.** How can we measure the minimum requirements from the point of view of cognition so that the patient can use a digital game in their recovery? **It differs depending on the patient condition before and after the stroke. Literacy and experience with digital tools are also relevant to determine its eligibility.**

Table 23 – Semi-structured interview for the Demo (cont.)

Specific Objectives	General Questions and Answers	Specific Questions and Answers
Perform a screening of existing movements in the *Leap Motion* framework and determine if these movements help in patient recovery in the long run.	Is the horizontal swipe, clap, supination/pronation exercises detected by the *Leap Motion* Framework eligible to be integrated into the rehabilitation of the patient through several repetitions? **Yes, they can be integrated. However, it is advisable that the horizontal swipe has a pattern in terms of obstacles.**	Do arm support devices impair/assist the patient's correct posture when performing the horizontal swipe or the clap? **Depends on the exercise in play and the type of support.** **At an early stage it is advisable to have elbow support, a pillow and an adjustable chair in height.** What is the reaction time in seconds that a patient can hypothetically carry out for each of the illustrated movements? **It varies depending on the condition of the patient. Calibration inside the game can help in that matter.** What is the minimum/maximum number of repetitions in the exercise that can bring benefits to the patient in the long run? **A session should take around 15 and 20 minutes. Doing 30 executions per minute is a recommended goal.**

Table 24 - Semi-structured interview for the HMD Demo

2nd Part: VIRTUAL REALITY INTEGRATION

Specific Objectives	General Questions and Answers	Specific Questions and Answers
Determine the main care to be taken when using HMDs with seniors.	Which type of medical care should be considered in immersive experiences for seniors? **Follow the equipment guidelines and safety concerns for the Samsung Gear VR as an example.**	A sitting position in the physical world, coupled with a fixed reference point (inside the balloon) and with a constant speed in a virtual world could reduce the effect of nausea and anxiety? **Yes, although major audience acceptance may be low.** What diseases can prevent the use of an HMD device? **The diseases identified in Samsung Gear VR guidelines plus schizophrenia and epilepsy can be defined as major obstacles.** Is it necessary to do medical monitoring when using this type of device in a stroke patient? **The game should be used in rehabilitation centers and with proper monitoring (family or physiotherapists) until the person is trained well enough to use the device independently at home.** Can the recovery plan set for a traditional gaming experience (monitor) be articulated with a VR recovery plan from the point of view of the duration of the experience? **Depends on the acceptance of the equipment by the senior, plus limited time of use with the HMD (maximum 10 minutes).**

5.7.2 Second Data Retrieval: Evaluation Materials for the Final Prototype

The proposed evaluation is based on the diagram in Figure 50 for the “data collection” section. To evaluate the chosen characteristics for the game, an online survey was elaborated to ensure that the main game problems are identified. The online survey was inspired on Ribeiro (2016) questionnaire for game evaluation with upper-limb rehabilitation, although some questions were adapted specifically for the proposed game characteristics. Table 25, 26, 27 28 summarizes all the proposed questions:

Table 25 - Profession Analysis - Physiotherapists

Question type	Question	Answers
A. Profession analysis	A1. What is your occupation?	Physiotherapist Occupational therapist Researcher Other
	A2. For how many years have you been working in the health area?	Integer
	A3. Do you have experience in the rehabilitation of stroke patients?	Dichotomous scale (yes/no)
	A4. Do you play digital games?	Dichotomous scale (yes/no)
	A5. Have you recommended digital games to rehabilitate a patient?	Dichotomous scale (yes/no)

Table 26 - General Usability - Physiotherapists

Question type	Question	Answers
B. System Usability	B1. Understanding the game objectives.	Likert Scale (1-5)
	B2. Understanding given tasks.	Likert Scale (1-5)
	B3. Navigation between screens.	Likert Scale (1-5)
	B4. Menu use.	Likert Scale (1-5)
	B5. Evaluate your performance to lift the balloon (level 1).	Likert Scale (1-5)
	B6. Evaluate your performance to control the balloon (level 2).	Likert Scale (1-5)
	B7. Capacity to control the balloon with more experience and game time.	Likert Scale (1-5)

Table 27 - System Relevance - Physiotherapists

Question type	Question	Answers
C. System Relevance	C1. Game contents for the stroke patient are:	Likert Scale (1-5)
	C2. Game involvement is	Likert Scale (1-5)
	C3. Gesture compliance is	Likert Scale (1-5)
	C4. Patient benefits for stroke recovery are:	Likert Scale (1-5)

Table 28 - Global Game Appreciation - Physiotherapists

Question type	Question	Answers
D. Global Game Appreciation	D1. Please write your main prototype criticism.	Long Answer
	D2. State the best features of the game.	Long Answer

After playing the HMD module, a semi-structured interview is to be applied with the following questions (Table 29):

General objectives of the semi-structured interview:

1. To know the everyday struggles of the stroke patient from the physiotherapist perspective.
2. Collect information on the eligibility of users who attend the rehabilitation centre to perform tests with the developed prototype.
3. Introduce VR technology and discuss its strengths and weaknesses.

Table 29 - Semi-structured interview script - Physiotherapists

1st Part: KNOWING THE POPULATION

Specific Objectives	General Questions	Specific Questions
Obtain information regarding the rehabilitation exercises practiced in the recovery of a stroke.	Explain how physiotherapy sessions are executed.	Which exercises are performed by the users in the rehabilitation centres? And at home? Are there many differences in the proposed exercises? How is the rehabilitation schedule spread among the various users? Are there examples of cases where recovery was faster than usual?
Identify individuals at the rehabilitation centre who may be eligible for the tests.	---	Are there many illiterate users? Within the patients that are present in the rehabilitation centre and after having contact with the prototype, can you identify some patients who can integrate this study? (Table 30)

Table 29 – Semi-structured interview script – Physiotherapists (cont.)

2nd Part: VIRTUAL REALITY EVALUATION

Specific Objectives	General Questions	Specific Questions
Discover the inherent weaknesses of this technology	How did you feel when playing with your virtual reality glasses? What did you think of the overall experience?	Did you feel dizzy while playing? Did you ever think you did not know what you were doing? How do you foresee the adherence by the users who carry out treatment in this modality?

Table 30 - User Table - Physiotherapists

Identifier	Degree of Paralysis (%)	Degree of Recovery (%)	Time spent in the rehabilitation centre (days)
To be completed by a physiotherapist			

The following text is dedicated to field interviews with the senior citizen (Table 31).

General objectives for the senior citizen:

1. To deepen the perceptions regarding the greatest difficulties experienced by stroke patients in rehabilitation.
2. Collect information about discomfort felt by the user during the test session.
3. Check if the user felt comfortable with their performance in the game, and if there is a desire to play again at another opportunity.
4. Determine the feasibility of the prototype with an HMD.

Table 31 - Semi-structured interview script - Senior Citizens

1st Part: TRADITIONAL DISPLAY

Specific Objectives	General Questions	Specific Questions
To know the habits of physical exercise in the recovery of the member affected by the stroke, and the profession of the user.	Have you played digital games? Do you speak foreign languages?	Did you have physical therapy before playing the game? For how many months have you had physiotherapy treatment? Do you usually do physical exercise to recover from your injury? If so, how much time do you spend each day doing the exercises? What was/is your profession?
Determine the degree of discomfort felt by the user during the tests and gauge the agreement regarding playing time.	---	Did you feel any pain to lift the balloon? If so, define its location. Did you feel any pain to control the balloon and catch the stars? If so, define its location. How do you consider the playing time in training?
Know the user's opinion regarding their performance and history in the first contact with the game and determine the degree of interest shown by the user during the test session.	---	How do you rate the difficulty of the game? How do you rate this game from the point of view of its story? Refer to the negative aspects of the experiment.

2nd Part: HMD

Specific Objectives	General Questions	Specific Questions
To discover the inherent weaknesses of this technology in the perspective of the target population.	How did you feel when playing with your virtual reality glasses? What did you think of the overall experience?	Did you feel dizzy while playing? Did you ever think you did not know what you were doing?

The performance sheet structure for analysing the stroke victim performance during the game can be found in Appendix A.

CHAPTER 6: EVALUATION AND DATA ANALYSIS

This section is responsible to fully describe the evaluation stage for the final prototype by using the evaluation materials in section 5.7.2 and by the defined order in section 5.7. The main findings are covered in form of quantitative and qualitative data. It is of utmost importance to organize and highlight the results obtained in each phase, to systematize the evaluation of the results to determine some conclusions during this research. Overall, the mixture of different types of data will help on answering the main research question.

Due to time constrains and low availability of personnel, it was not possible to gather physiotherapists to test the final prototype. The evaluation results are focused on a convenience sample of four stroke victims.

Section 6.1 describes the necessity of having a motivated patient after the stroke and defines the conditions needed to be met for optimal recovery during rehab; Section 6.2 states the empirical evaluation and all the details that occurred during the tests. The description will help to emulate the conditions for other experiments; Section 6.3 retrieved data is summarized in Tables while the results are discussed.

6.1 Preliminary Investigation

While identifying the problem based on literature review and the medical evaluation of the demo, physiotherapy sessions by themselves are not enough to activate neural activity, meaning that the patient has a big responsibility regarding self-discipline in order to move the affected limbs as most as possible. Depression and generalized anxiety disorder after the stroke are associated to cerebral atrophy, which substantially interferes with functional recovery and social relationships. The generalized anxiety disorder is very common and long-lasting, which makes heavy demands on early and effective treatment (Aström, 1996).

6.2 Empirical Evaluation

To understand the reality of a senior citizen after a stroke, and to evaluate the game features in a real-world scenario, the prototype was installed at a recovery centre in *Oliveirinha/Aveiro* (*UNIDADE DE MEDICINA FÍSICA E REABILITAÇÃO – Santa Casa da Misericórdia*) the 6 of September of 2018 and the 12 of September of 2018.

At the first observation day, several seniors were scattered around the building, according to their specific situation: nursing, health promotion, disease prevention, physiotherapy centre and other services. The main nurse responsible for the gym had several patients doing several types of exercises for motricity recovery. Two male chronic patients were selected from that room by the main nurse, which implies that their ability to recover is mostly stagnated over time.

All the experiment materials were moved to a meeting room with several chairs, couch, and table. Before starting the tests, the major problem was to find a suitable height and elbow support. To attend the height, it was provided an office chair with adjustable height, and a pillow. For the elbow, a rolled sleeping bag and a pillow were put on top of the legs. It must be highlighted that the table was unusually high (80 cm) and no other furniture was available for the moment. The game was running in a portable computer, with the following specs: i7-4700HQ CPU, 12 GB of RAM, Nvidia 740M graphics card, 256GB SSD, Windows 10 x64 operating system, and a *Leap Motion*. The computer monitor had 17 inches and was running at 1600*900 resolution. For the HMD, it was used an Asus Zenfone 2 5-inch display with a screen protector film, and an HMD plastic support (Figure 51). The protective film was worn, which added a bit of image degradation.

Figure 51 - VRBox

Another aspect of this evaluation was to measure the senior mood and predisposition to play a game for 20 minutes just for the monitor display, since it would be used the easy difficulty and by consequence, the speed of the balloon would be very slow. It must be remembered that the final game compilation had in total 6 different levels, with several panels that contained the main story. At the end, it was selected the level for lifting the balloon (first level), while controlling the balloon was referenced for the Brazil and Antarctica levels (second level). Brazil and Antarctica are short levels, with very little land obstacles and the star disposition is substantially different: Antarctica stars allow for a movement pattern in left and right swipe, while Brazil stars do not have a pattern. Before the evaluation, it would be expected that the Antarctica level would have a better score for the same number of stars. Due to only picking two levels from five random levels, cross zones and maps were not used during the evaluation. For the HMD counterpart, the Antarctica level was selected and isolated from the rest of the game and had an approximate duration of 1 minute and 30 seconds for the overall experience. The screen was recorded using an XBOX application for Windows 10. Headphones were not used during the evaluation phase to guarantee that the patient was able to communicate with the researcher and vice-versa.

Table 32 can resume the evaluation steps for the patients:

Table 32 - Evaluation Steps for each Patient

Session Steps
Place the patient in a comfortable chair and elbow position
Introduce the purpose of the meeting, and explain the game and its movements
Watch the beginning of the story
Play the first level
Play two biomes of the second level
Watch the end of the story
Answer the first part of the semi-structured interview in Table 31
Play Antarctica biome with the HMD
Answer the second part of the semi-structured interview in Table 31
Conclusion of the session

Each patient showed different stroke impairments, age, and time of evaluation. The characterization of each patient is stated in Table 33.

Table 33 – Patient observation grid

Patient File	Age	Gender	Time of evaluation	Paralysis	Description
Patient X	71	M	1 hour	Lower-Body	Right Haemorrhagic stroke, difficulties talking. Only walks with help for short distances
Patient Y	78	M	1 hour	Lower and Upper-Body	Depression, shoulder limitations, general muscle stiffness. Precarious orthostatic balance, and several suffered strokes
Patient W	66	F	45 min.	Left Lower and Upper-Body	Left hemiparesis, epilepsy after stroke, involuntary head drop, alcohol abuse. Difficult walking without help.
Patient Z	82	M	50 min.	Lower-Body	Eye cataracts. Suffered a fall that reduced its mobility and balance. Suffered a stroke without reported spasticity.

Two male patients arrived in wheelchairs for the first day of evaluation. Ethical issues require the anonymity of patients, which will be addressed as patient X and patient Y. The retrieved answers are resumed in the following text and were obtained according to the medical file of each patient, by observation, and according to the semi-structured interview.

Patient X had 71 years, worked in a factory for his whole life, suffered a stroke that affected mostly the legs and was interned for one year. During that time, he was frequenting the rehabilitation facilities to recover his walking abilities. He did not specify how much time he spent at home doing rehabilitation work, but only referenced that he spent very few time doing exercise. It was mentioned that he was executing his normal program at the gym before the prototype testing. The nurse had to assist Patient X while moving him to the chair. Patient Y was present during Patient X session in a seated position and was mostly quiet but observing the room and the prototype setup.

Patient X was introduced to the game with small and improvised talk about his condition, what he did before retirement, and what he was doing at the rehabilitation centre. This aspect is particularly important to gain the patient attention, and to obtain unbiased answers. It was described to patient X why he was present, what the research was about, what he would be doing, and why his answers would be important to improve the prototype for other patients in that same situation. It was also asked if patient X had any contact with digital games, which he politely denied. To see what was happening in the game, the patient asked for his glasses. The researcher pressed the keyboard to skip through the scenes, because the keyboard was too far away from the patient and the elbow support would fall to the floor. The story elements were seen by patient X in a carefully manner during the introduction and the final cutscene.

The first level started, and it was asked the execution of supination/pronation exercise (Figure 52). By observation, there were several difficulties to execute supination. This specific exercise was programmed for an 180º degrees turn of the hand, but the patient only did approximately 120º degrees of turning. It was also explained where the best area for detection existed, but the height of the table did not allow for that specific reach. To increase the rate of success, the researcher secured the patient elbow in a fixed position and moved the right hand for the 180 degrees with success. The sequence animation was never activated during this level. To keep motivation levels high, the game was suspended at 400m of its progression.

In the second level regarding Brazil and Antarctica biomes, Patient X reacted to the objective of retrieving all the stars and tried to control the balloon, by making slow but constant movements to the left or to the right. This fact posed difficulties for the tracking system that was detecting bigger variations of speed and was not activating correctly, even with the maximum sensibility selected. The researcher grabbed patient X hands and accompanied his movement but purposely applied some variation of speed to activate the turning of the balloon, in order to validate a few interactions while the maximum sensitivity was selected.

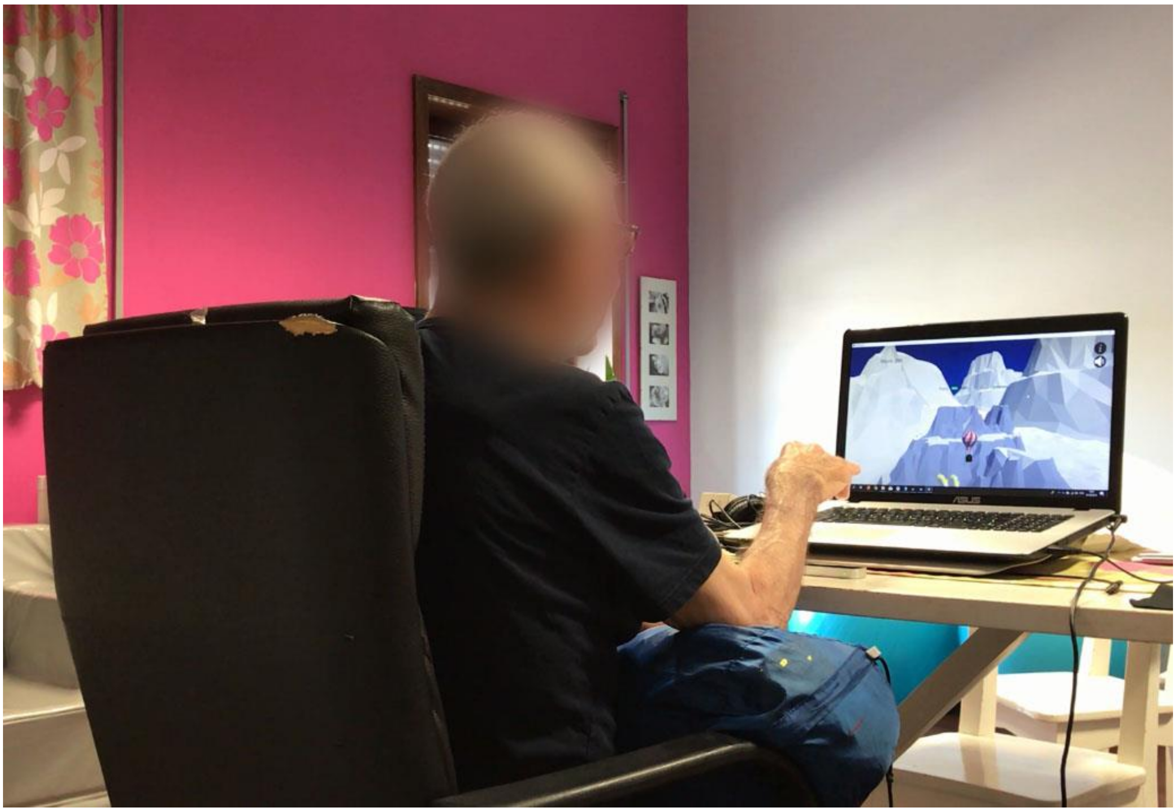


Figure 52 – Supination/Pronation execution by a senior citizen

After completing these levels successfully, some questions were asked to measure his level of pain during the first and second level. It was affirmed that no pain was felt during those 10 minutes of actual exercise and that the time spent was accomplishable. It was asked if the game was difficult, which patient X reported that was a bit harder at the beginning but with time it was becoming a bit easier to do. He also referenced the story elements were funny. At all times the patient was lucid, aware of the demands and tried to execute the exercises by his own will and effort.

The next step was to use the HMD after changing the game configurations for the smartphone. It was signalised to patient X that he would play for 1 minute and that he could quit at any time if he felt discomfort or dizziness. Based on the difficulties of interaction observed prior to the HMD, the researcher asked for the patient to remain his hands in a rested position and to observe the virtual world while the researcher was moving the balloon. After finishing the test successfully, questions regarding discomfort of use were asked. He mentioned that he did not felt any type of dizziness but that he did not like the HMD, the experience was uncomfortable, and that he did not know what he was doing. After leaving the room he mentioned to other people is discomfort about the experience. In total, one hour was spent between all the questions and testing with patient X.

Patient Y started the tests with a similar structure. He had 78 years, suffered in total 7 strokes during his life and had some talking limitations, although it was possible to understand what he was saying. He also had hearing problems, so the researcher needed to shout constantly to establish communication. The office chair was removed, and the wheelchair was used, along with the rolled sleeping bag and pillow. He could not walk, barely moved both his arms, and was using glasses. It was mentioned that he had some pain while moving the arms.

For the introductory questions, patient Y mentioned that he never player a videogame and he had retired after working 18 years for the metalwork industry. He didn't know how to speak foreign languages and was in the recovery facility of *Oliveirinha* for 6 weeks, although he was a chronic patient. It was also known that patient Y didn't perform therapy at home. Since the patient had problems in reaching the keyboard, the researcher progressed through the scenes.

For the first level, the supination/pronation exercises were accomplished, but it was observed that the patient could not rotate the hand, even in small angles. The researcher held patient Y right hand and tried to rotate it but felt muscle atrophy and small splitting sounds from joints. This fact suspended the execution of the first level after two repetitions.

The second level was played firstly with the assistance of the researcher that grabbed patient Y hands and after a while released the hands. In terms of cognition, there was a response to follow the objective of retrieving the stars, but the motion for the hands was mostly incorrect (few centimetres between the *Leap Motion* and the hand, putting the hand on an undetectable area, very slow speed during movement). The Antarctica level was played until the end, and the Brazil level was skipped due to time constraints.

The answers regarding the monitor display revealed that during the tests, he did not feel any pain, and that the time doing it was short. He did reply that he liked what he was seeing but that it was very difficult to do the proposed exercises in those conditions.

For the HMD display, the researcher asked for patient Y to keep his hands still, while the demo was being played. At the end of the demo, it was referenced that he didn't felt dizziness or discomfort, and that he knew what was happening while the researcher moved the balloon. Overall, he enjoyed the experience, and was in a good mood. A more attentive analysis during the recordings show that the head rotated a few times to the side, and that patient Y was trying to discover the virtual world while giving attention to the stars. After finishing the demo, the evaluation of the game was closed. In total, it was established contact with patient Y during approximately one hour.

A second round of tests was scheduled one week later at 12 of September of 2018, with two more patients (one female and one male by this order), patient W and patient Z.

Before starting the session, the researcher asked for patient X and Y feedback regarding their presence on the week after. Patient X refused to participate in any other evaluation due to the

HMD module, but patient Y did enjoy the experience and did reference that some of the pain was alleviated due to the tests. Some hypothesis were lifted due to this statement: a placebo effect since empathy is a crucial element in the healing context (Braga-Simõs, Costa, & Yaphe, 2017), or brain stimulation based on virtual reality images. Literature review show that immersive VR technology is more likely to generate relief from pain, than non-immersive VR technology (Malloy & Milling, 2010). Either the case, it is uncertain the rising of this statement.

Patient W was also a chronic patient with three strokes and had 66 years old. Most of the disability was manifesting itself on the left side of the body. As consequence, she could not walk, showed signs of dementia, drooling, and difficulties to articulate words. From all the patients, patient W was the most affected in terms of cognition according to the medical file.

To guarantee data consistency, the same evaluation steps were followed. For the introductory questions, patient W never played a videogame, was a kindergarten teacher, and only spoke Portuguese. Patient W reported that she did not execute any type of exercises at home and was not performing physiotherapy before the testing session.

During the first level it was observed that sometimes the patient could rotate the hand for the 180-degree rotation, while the researcher supported the hand lightly. For the second level there was a reflexive response for catching the stars, but the hand moved correctly but slowly and in a constant velocity. Both Antarctica and Brazil biomes were played until the end.

Questions regarding patient W performance, reported that no pain was felt during the first or second level, but the subject was getting tired physically after interacting with the game. Overall, she mentioned that the game was not difficult to play but did not answer the questions regarding the narrative or the overall negative aspects of the experience.

After using the HMD, the patient reported a strong sense of dizziness, and eye stress due to changes in lighting. She was mostly looking forward, even when the operator suggested her to look at different angles. In total, evaluating patient W took approximately 45 minutes.

Patient Z was the last person to be evaluated. He had 85 years old, had a stroke many years ago, and suffered a fall that required surgical intervention a few weeks before the testing session, which affected his ability of walking. From all the patients, Z had previous experience with a computer, and he was a retired electronic technician. Communication was also a hard task due to hearing problems.

During the first level, it was observed that the patient could only rotate the hand until 90 degrees, and had difficulties positioning the hands at the optimal height. The second level was the most surprising in terms of results. At the beginning, patient Z suffered from the same problem has the other patients, which was slow velocity during the horizontal swipe. However, after some pressing by the researcher, patient Z managed to execute two horizontal swipe motions without any help. This behaviour was short because after a while the speed decreased consistently until the end of the level.

The performance questions reported that no pain was felt during the levels, the experience was quick in terms of time while operating the balloon, and that the user felt confidence using the device alone. The narrative showed to be neutral in terms of appraisal, and overall, there was nothing to report.

After using the HMD, the patient reported a mild sense of dizziness, but liked the experience. He was mostly looking at the sides and following the movement of the birds. In total, evaluating patient Z took approximately 50 minutes.

6.3 Data discussion

Data discussion is separated in sections for better systematization. There are four main topics: Section 6.3.1 refers to overall player performance for each of the played levels; Section 6.3.2 analyses the *Leap Motion* as a tool to be used as a support in the stroke rehabilitation; Section 6.3.3 discusses UI for the mouse and *Leap Motion* Input; Section 6.3.4 considers the feasibility of the HMD for the stroke citizen.

6.3.1 Player Performance

According to the selection of two levels (Brazil and Antarctica) by the explained points in the previous section, the clap was not used during the evaluation, because the map was rendered useless for playing a portion of the game.

In retrospective, Patient X, Y, W, and Z were totally different patients and were not the most adequate individuals for this game due to extended internment after a stroke. As cited in section 5.7.1 during the interview for the prototype development, the clap, horizontal swipe, and supination/pronation are intended for recovery exercises during the mid/final phase of a recovery program (between three to six months after a stroke).

Table 34 and 35 resumes the empirical evaluation of the *Leap Motion* for the played levels according to the retrieved data from Appendix A template. For ethical concerns, the original sheets cannot be disclosed. Scales from 1 to 5 are organized by ascending order in Table 35.

Table 34 – First Level Performance Sheet

	Level 1			
	Number of sequences	Time	Meters of Height	Pain with Leap Motion
Patient X	1	01:32	398 m	No
Patient Y	1	02:24	0 m	Yes
Patient W	1	02:40	295 m	No
Patient Z	1	03:35	248 m	No

Table 35 – Second Level Performance Sheet

	Level 2			
	Sensitivity in the game (1 to 5)	Time	Degree of control (1 to 5)	Pain with the Leap Motion
Patient X	5	08:08	2	No
Patient Y	5	02:35	1	Yes
Patient W	5	03:44	2	No
Patient Z	5	04:51	3	No

Figure 53 represents the accumulated points for each patient in the Brazil and Antarctica biomes. The most important factor in this evaluation is that the Antarctica level has a star dispersion pattern between left and right, while Brazil does not have a pattern. The values cannot be fully trustable, because the operator helped the patients in some situations and with different times of intervention. Another aspect is the randomness of the selected level by the game. It is expected that the second playable biome will be easier to play, due to previous experience from the first biome. Other factors such has previous exercising before testing the prototype may also have some influence. Based on these statements, it can be observed that the level with patterns (Antarctica) had better performance overall.

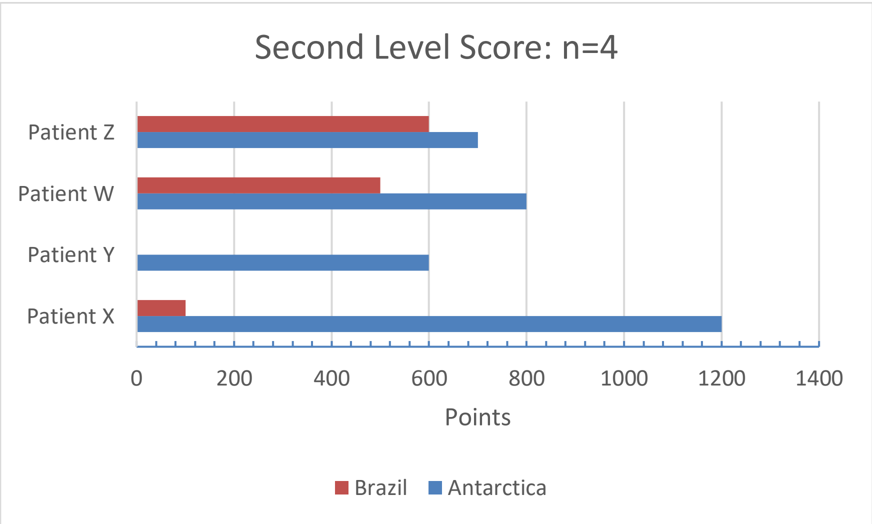


Figure 53 - Patient High scores for the second level

6.3.2 Leap Motion

Using the *Leap Motion* without any type of support besides an improvised elbow support is clearly one identified weakness. This fact allied with a table that was unusually high clearly affected the performance of each patient due to the difficulty in keeping the arm with enough height for optimal detection with the *Leap Motion*. Nevertheless, there are some clues about registering a validated movement that could increase the execution rate of the patients, which are summarized in Table 36.

Table 36 - Leap Motion problems and appointed solutions

Detected problem	Solution
Supination only occurred for the rotation of the hand until 120º degrees.	Validate a wrist rotation starting at 90º degrees or more, instead of 180º degrees.
The horizontal swipe is executed using slow but constant velocity.	Decrease the variable regarding changes in speed for allowing the detection of more constant motions.
Sometimes the horizontal swipe motion directed to the left could be identified as the right direction and vice-versa derived from high sensitivity while putting the hand on the start point.	Restructure the horizontal swipe motion for only validating motions that travel with an increased minimum distance.
It is hard to put the hand with an optimum height for detection.	Change the elbow support and height or change the horizontal swipe for another movement that can be based with the hand fixed in a base and the L*eap Motion* is positioned under it.

The mechanics involved in the game such as understanding the main objective of catching stars while deviating from obstacles seemed well implicit and understood by the patients that reacted by trying to move for the short period of time that the game was running. It is not possible to know if the patients would try to exercise during the full length of the game by their own accord, since the first level was shortly evaluated exclusively for movement execution, and the second level was only played during two biomes (Antarctica and Brazil). Section 1.3 identifies stroke consequences, and it is not possible to know the stamina limit for each patient, based on the identified medical problems of each patient in Table 33 (Section 6.2).

6.3.3 User Interface and Narrative

The graphical user interface cannot be evaluated by two factors: (1) The patients never played a videogame in their life; (2) Muscle spasticity makes the task of pressing a keyboard or pressing a mouse a hard task, and the keyboard was out of reach. The researcher was controlling the interactions of skipping the scenes and the evaluation script does not contemplates user interface evaluation specifically for the senior citizen. User interface for this experiment is to be evaluated with physiotherapists.

The game requires two types of inputs: mouse and Leap Motion. During the development stage, it was considered the development of some UI interactions for picking menus through finger pointing (Figure 54). However, the percentage of muscle spasticity in each patient could potentially make the Leap Motion unusable, and game progression would be impossible. For that reason, the mouse was chosen for UI interaction.

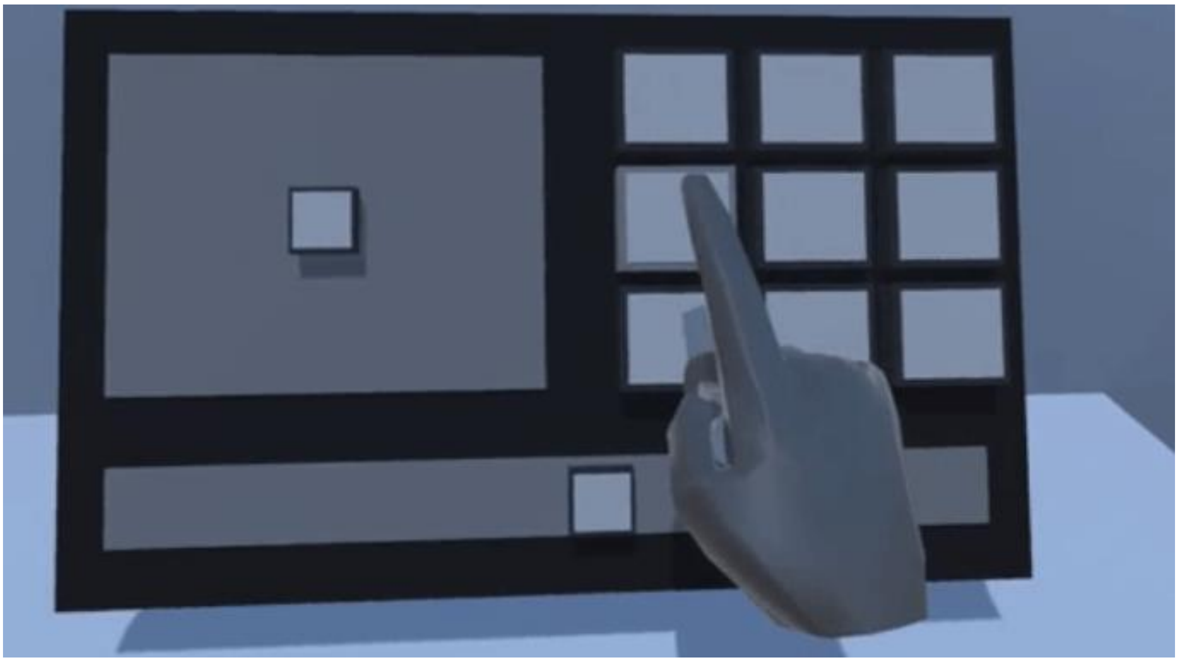


Figure 54 - UI Interaction with Finger Pointing
Retrieved from: https://bit.ly/2qiFoqt

Questions regarding the historical landmark of the priest seemed to be well received and were not criticized during the semi-structured interview. Overall the images for the monitor display seemed to be adequate and were well accepted by the patients.

6.3.4 HMD

HMD acceptance is based on three factors: (1) eye strain complaint; (2) disorientation; (3) consciousness. Table 37 summarizes all three factors for 1 minute and 30 seconds of play. If eye pain and disorientation are negative and consciousness is positive, the patient is eligible for the HMD (Figure 55). Any other values are identified as negative values.

Since the quality of the HMD is low (smartphone screen) it was not expected to have good results overall. The degree of immersion is completely different from a professional HMD in comparison to the smartphone. One patient enjoyed the experience. The data suggests that based on this contained public audience and based on the eye problems that are normal at an advanced age and a stroke condition, there are bigger risks of developing a commercial exergame based on virtual reality if compared to a traditional display.

Table 37 - HMD acceptance sheet

	HMD		
	Eye Pain	Disorientation	Consciousness
Patient X	No	Yes	Yes
Patient Y	No	No	Yes
Patient W	Yes	No	Yes
Patient Z	Yes	Yes	Yes

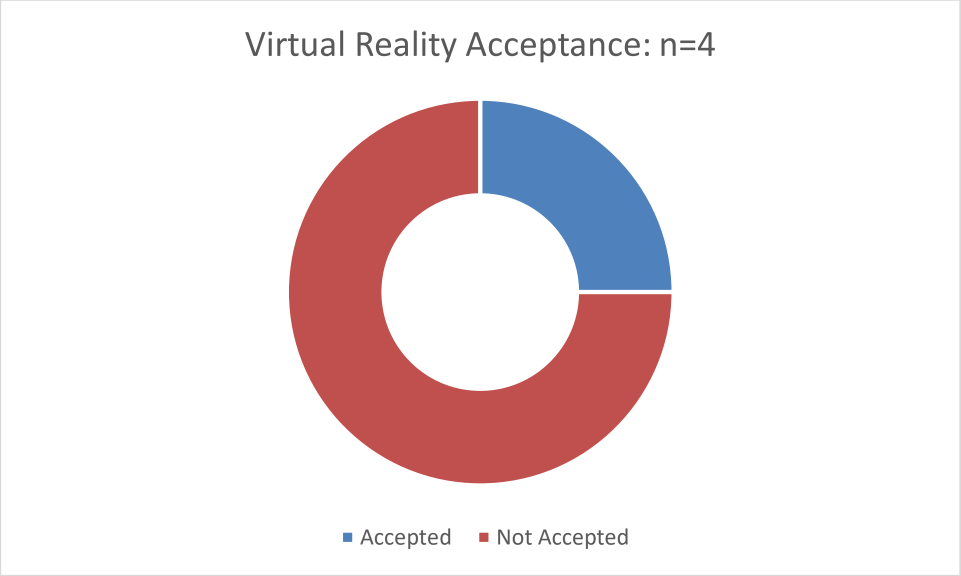


Figure 55 - HMD Acceptance Chart

CONCLUSION

This section presents the main conclusions from the overall research. It will be addressed the research question regarding the selected characteristics and it will be explained how they managed to influence the main game positively or negatively. The sub-questions will also be answered. For the section of Technical limitations, it is highlighted the main detected problems that need to be addressed in other versions of the prototype. The last section explains the main limitations of the research and future work that can contribute for a better rehabilitation tool.

Solving the Research Problem Statement

The stroke is the biggest menace of permanent motor disability, and the number of stroke survivors is expected to increase over time (Putrino et al., 2017). Stroke incidence increases with age, and targets the senior citizen population with higher prevalence (Truelsen et al., 2005). The process of rehabilitation can only recover approximately 50% of upper-limb motricity deficits (Soares et al., 2017). Although the therapy must be early and intensive, most patients carry major trauma from partial body paralysis, depression, and other problems. The rehabilitation program attempts to stimulate the person in a variety of exercises, however it is not uncommon that people develop depression under a stroke condition (Burke et al., 2009). Digital games can be used in the stroke context, due to increasing motivation in rehabilitation sessions (Rego et al., 2010). However, developing a stroke rehabilitation game requires the identification of main characteristics that a game should have, in order to guarantee its therapeutic properties, and focus on the public audience.

To solve the main Research Problem Statement, the main question and sub-questions are described in the following text:

Question: Which recommendations can be included into an immersive game environment, to be played as a support in the rehabilitation of the stroke patient?

Sub-Question1: Which stage of treatment is indicated to prescribe the game?
Sub-Question2: Is it feasible to use low-cost HMD during gaming sessions, as an alternative for the rehabilitation of the stroke patient?
Sub-Question3: Are there alternatives to the identified recommendations?

To answer these questions, the following objectives have been outlined by using the Development Research from Van den Akker et al. (1999), and its identified stages: (1) Preliminary Investigation; (2) Theoretical Embedding; (3) Empirical Testing; (4) Documentation, analysis and reflection on processes and outcomes.

(1) **Preliminary Investigation:** During this stage, the main objective was to analyse state-of-the-art in digital games for the rehabilitation of stroke patients. The theoretical framework was composed of four chapters. The stroke pathology was defined from several themes, and the senior citizen was contextualized under the stroke main consequences, and processes of identifying the impairment during the rehabilitation. In order to understand what a digital game is, and how it is created, the chosen authors from different field areas talk about the intrinsic nature of game and play, definition

of game genres, the globalization culture of digital games, game design considerations from a generalized point of view, and from the senior citizen view. Human Computer Interaction is the field that allows to understand the main concepts of interaction between man and machine, interaction models, definition of immersion by different authors, and types of user interfaces. This stage was essential to understand the software and hardware requirements for a project of this nature. Other games from the same field of research were also important to identify and compare upper-limb movements between digital games for stroke recovery.

(2) **Theoretical Embedding:** The stage was divided in three different moments: (a) conceptualization; (b) game design: (c) development. **(a)** The game conceptualization defined the game characteristics according to the theoretical framework; **(b)** Game design described the main level design, aesthetics and story; **(c)** Justifies the use of the *Leap Motion*, describes each implemented gesture, game optimization techniques, and camera system.

(3) **Empirical Testing:** Validated the proposed movements with a physiotherapist during the development stage, through a semi-structured interview. Results show that each of the selected movements (pronation/supination, horizontal swipe, clap) have therapeutic properties for the stroke patient during the mid/end period of rehabilitation (between 3 to 6 months after a stroke). The final prototype was also evaluated with the senior citizen through a semi-structured interview and the observation method. Results from the evaluation session, show that the *Leap Motion* can incorporate movements with therapeutic properties, but some corrections must be applied (Table 36) to ensure that the patient can have a degree of independence while playing the game. In terms of performance, it was observed that pattern movements are more prone to have a higher success rate. This statement should be interpreted with the necessary cautions due to the researcher intervention during the game, and the effect of previous level experience. Other aspects of the game regarding the story and the visual quality were positive and were not disliked by the senior population. For the Virtual reality module, the success rate was low due to eye stress and dizziness. It is suggested that further tests must be executed with professional HMD such as the *HTC Vive* or the *Oculus Rift*.

(4) **Documentation, analysis and reflection on processes and outcomes:** Considerations regarding the theoretical framework and the evaluation results. The reflection of all the research will suggest future work.

According to the developed investigation and the presentation of results during the Empirical Research, the research question is directly answered through Table 38 and all its identified characteristics, that can be seen as recommendations for future games that might involve seniors under the stroke condition.

Table 38 - Applied characteristics/recommendations for the digital game

Type	Sub-Type
(1) Display	HMD Computer Monitor
(2) Gesture Interface Device	Leap Motion
(3) Genre	Adventure
(4) Game Art Design	Low Poly
(5) Narrative	Historical Approach
(6) Difficulty	Variable
(7) Language	Portuguese

(1) **Display:** This characteristic involves the choice of the display by comparing the HMD to the monitor. According to the results of Figure 55 (HMD Acceptance Chart), the monitor is capable of handling longer sessions of use without straining the eyes if compared to the HMD. Eye problems are a main occurrence after the stroke (Pancioli et al., 1998), and may influence the target audience support. In terms of the monitor, choosing a TN, VA, or IPS screen is expected to have similar effects but the empirical evaluation did not study those differences specifically in terms of eye aggression. Although the use of monitors is suggested instead of the HMD, the literature review from DriVR (L. Liu et al., 1999) gathers a positive review of HMD for a sample of 148 end users with a low cost HMD device for driving simulators in 1999. It is expected that high-end HMD devices from 2018 will be able to better adapt the senior citizen specifications.

(2) **Gesture Interface Device:** Literature review regarding the Gesture Interface Device studied several devices capable of analysing human motion and replicate it in a virtual environment. The *Leap Motion* was selected due to its novelty factor and low-cost but showed its feasibility during the research. Table 36 resumes the main problems and possible solutions for the specific motion of supination/pronation, and horizontal swipe. There are projects that use the device for fine motricity such as *VirtualRehab* (Colgan, 2013), or use the supination/pronation in *GesAircraft* (Putrino et al., 2017). For the specific case of the horizontal swipe, other considerations must be applied such as proper elbow support and further adjustments for the detection algorithm.

(3) **Genre:** *A Priest in the Air* is considered an adventure genre, which is defined as a broad category of games oriented toward action and exploration, mostly in third perspective (Elliott et al., 2012). As stated in Costa & Veloso (2016) there are only a few studies that investigate game preferences for older adults, suggesting that this specific target group is not very attracted to violence in games. Instead, there is room for adventure games with historical settings with PvE

mechanics. Thus, the features for *Genre* and *Narrative* consider the Costa & Veloso statements regarding gaming preferences for seniors. Following the semi-exploratory interview with end-users, the genre and narrative was likeable, and did not receive complaints.

(4) **Game Art Design:** Uses the Low Poly technique for rendering the virtual world while accommodating concerns regarding the limited computational resources that old computers might have. It is difficult to define minimum requirements for the game, but during the evaluation sessions the game run fluently for the monitor and VR headset. Based on the optimization techniques that were used, it is relatively safe to assume that a broad audience can use the game at home if the computer has 10 or less years and is running a Windows x64 operative system for the monitor display. It is excluded the use of mini-computers such as the *Raspberry Pi* or similar products.

(5) **Narrative:** Stated in the genre.

(6) **Difficulty:** The player-centric design (Adams, 2010) requires the designer to place himself into the position of a representative player and to imagine how to play the game. For the stroke citizen, the type of impairment defines the reaction time. The difficulty feature was an option to better accommodate the user performance in a larger spectre. Although all test subjects used the easy difficulty, a longer use of the platform allied with traditional rehabilitation needs to accommodate motor improvements over time.

(7) **Language:** According to Costa (2013) the illiteracy rates of senior citizens is high. The accommodated language for the senior Portuguese audience seems to be well chosen because none of the subjects spoke foreign languages.

Sub-Question 1 asked which stage of treatment is indicated to prescribe the game. According to the developed gestures and following the analysis of a Professional Physiotherapist in Chapter 5.7.1, the game could be used for mid/final phase of a recovery program and should be used as a complementary tool for a traditional treatment. For the cases where the Fugl-Meyer assessment tool for stroke is used, the patient should have a score of 33 or more in order to be eligible for the game.

Sub-Question 2 asked if it is feasible to use low-cost HMD during gaming sessions as an alternative for the rehabilitation of the stroke patient. It was used a Smartphone and VRBox to simulate stereoscopy. Based on the obtained results in Figure 55 regarding the HMD Acceptance Sheet, it is not advisable to use this device, even for a short-use. It is not possible to determine if professional devices such as the *Leap Motion* or *HTC Vive* would have better results, due to better image quality, and higher refresh rates (Hz).

Sub-Question 3 asked if there are alternatives to the identified features. Table 39 systematizes that information based on literature review and the main evaluation results.

Table 39 - Alternative Characteristics

Type	Description
Display	The HMD alternatives for smartphones, are the *HTC Vive* or the *Oculus Rift*.
Gesture Interface	The identified devices on Chapter 3.5 that were not used for the final prototype.
Genre	Traditional and puzzle games (Schutter, 2014), memory games (L. V. Costa & Veloso, 2016).
Game Art Design	Studies from (Pearce, 2008) and (Schutter & Vandenabeele, 2008) are more inclined to a preference in realism between senior casual gamers.
Narrative	*Wii Sports* is a sport simulation game without story but is popular along the senior population (Rego et al., 2010) (used in the recovery centre of *Oliveirinha*).
Difficulty	Instead of selecting the difficulty, the software can change it according to previous use.
Language	Translate the game for other languages.

Final comments

This research was based on the *PhysioFun* Project (Ribeiro et al., 2016), but it is not a direct sequel to the project. Instead, it was possible to use an exploratory methodology with a high level of freedom regarding the features that would build the foundations of the game. Ribeiro (2016) evaluates the main characteristics that a digital game must have, to support the stroke patient during rehabilitation, which are synthetized in Table 40 and compared to the "*A Priest in the Air*" prototype.

Table 40 - Comparison between game characteristics conclusion from PhysioFun and A Priest in the Air

General Game Characteristics	"A Priest in the Air" characteristics
Low Cost System due to the patient social reality	The *Leap Motion* costs 70€ in the *Leap Motion* official store (20/09/2018). The computer used for playing does not need to be high-end, due to low poly count.
The system should be tailored to the intended audience and consider the physical and cognitive aspects of it: vision, hearing, physical difficulties and the decline of episodic memory.	Narrative, genre, language, and difficulty were tailored specifically for the target audience. The HMD is the most intrusive device that needs to have a different approach.
Navigation should be simple with buttons with clear and unambiguous functions.	Scenes and menus are shown in a linear fashion, buttons have a big clickable area, and the type font (Arial) has good legibility.
The system should have sound and visual feedback.	Catching stars or hitting objects have sound feedback and collisions with terrain active a specific animation.
Objectives should have short, medium, and long term to keep the player motivated.	Short and midterm objectives are focused on the balloon mobility. Long-term objectives are related to improving the overall score.
Elements of the game should have high contrast, specifically objects that need to have decision making.	The balloon has high contrast relatively to the world environment, and the stars have a white shader for better identification.
The game should have variability.	Levels are presented randomly, and cross-zones change depending on the generated map.
The system should provide accurate visual information regarding the movement to be performed to avoid injury.	The *Leap Motion* provides visual feedback regarding the position of the hands, and the execution bars show if the movement was executed correctly.

Technical limitations

During the prototype development, some bugs and limitations were found due to the inclusion of features that were not initially expected and were not fully compatible with the structured code. This topic resumes all the identified limitations.

Pausing the game blocks any interaction with the *Leap Motion*. If clapping is used to open the map, the game continues and is not paused.

Horizontal swipe movement implementation does not identify some slow movements, which means that more logic layers need to be created to accommodate more variations, namely distance, velocity, and acceleration.

The software was not tested for *Apple* OS, and there is no guarantee that will work correctly.

Changing between the traditional monitor and the HMD has proven to be a challenge and was very time consuming during the evaluation sessions because *SteamVR* would constantly detect the monitor and retrieve an error when the smartphone was being connected to the computer. It would be frequent to reset the computer, redo the phone configurations, and open a new session for *Vridge*. The *XBOX* application that recorded the screen sometimes crashed because of *SteamVR* during the HMD evaluation.

Hitting a terrain obstacle sometimes repositions the balloon in a situation where you need to hit the obstacle again to continue the progress in the game. Coding was done to detect all the identified obstacles and always use the same repositioning distance. For those cases, the gaming objects must be repositioned, or the repositioning distance needs to be customized for those situations.

Sometimes, due to the balloon height variation, it is possible to hit some obstacles that were not expected to hit.

Debugging was very time consuming due to the size of the virtual environment. The world size was defined in order to allow for 20 to 30 minutes of play in total for the easy mode and approximately 15 minutes of play for the hard mode. The building process was mostly manual, except for the star generation that was executed with an algorithm. The advantages of building a world manually is having more realism and the dispersion of objects through space is believable and without patterns. However, having a world that is built based on procedural coding allows for an easier debugging and the virtual world can be adjusted in the future without much trouble. The disadvantages of this approach are less believable worlds and it is common to have patterns for object positioning, which may or may not affect the overall experience.

The sensitivity scroll bar loses its last value, and always starts with the predefined value while changing levels. This bug was detected after delivering the final prototype but is easy to correct.

Study limitations

The studied features that show promising results are not intended to be the only answer to solve the main problematic but can be referenced as an option for complementing a traditional recovery program. The scope of this research does not involve motivation and overall health benefits of using the prototype, given the short-term evaluation phase.

First, it should be mentioned that the number of evaluations is reduced for an accurate statistical extrapolation, and the space used for testing was not the most adequate for the use of the *Leap Motion*. The graphical user interface was not evaluated, because the researcher decided that the minimal conditions of use were not reached. Using the *Leap Motion* showed some limitations of the developed gestures for chronic patients but based on the empirical evaluation it is believed that with a more refined development, the *Leap Motion* is still a capable candidate for the stroke recovery treatment.

There is not a direct comparison between the HMD and the monitor due to different testing conditions. The retrieved data for the HMD is only focused on the acceptance of the senior citizen based on eye pain, disorientation, and consciousness.

In total, it was necessary 10 months to conceive, develop and write this research. Several ideas and devices were abandoned due to not meeting the minimum requirements or the unavailability of better equipment.

Future Work

To improve the current project, several improvements are displayed in Table 41 and are identified as priorities for further development based on the monitor display. Future work based on the HMD can be based on the game, but it should have an intuitive structure for interaction according to the *Leap Motion* potential and adapted to the reality of the patients, while avoiding the use of peripherals such as the keyboard or the mouse.

Table 41 - Future Work

Improvement Nature	Description	Proposal
Technical	Improve the movement detection.	Check Table 36.
	Monitor user performance.	Create a platform for uploading patients' scores, time of use and other values that can be shown in chronograms and charts. The physiotherapists can analyse the data and can watch the progress of the patient through time.
	Create a scene were the values for each movement can be calibrated before entering the game	Depending on the improvement of the patient through time, the physiotherapist can calibrate the values for easier or harder sessions.
Physical	Build an adequate hand support	Design and build a support for all the current gestures, based on recyclable materials.
Conceptual	Expand the narrative.	Have more animations, movement from characters, and enhance character development.
	Create new gestures.	Other types of levels can be created with different gestures with a more diversified choice.
Art & Design	Improve the GUI.	Improve all the graphical drawings for better visuals.
Evaluation	Further development will need more evaluation with end users and physiotherapists.	Periodic evaluations that confront patients and health providers with the progress of the system.
	Evaluate the same patients over time with regular use of the game.	Determine the therapeutic properties of the game and motivational values of the players.

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APPENDIX A – User Performance Sheet

Game operator guide

General requirements:

Monitor video capture.

Filled by the operator during the game and after consulting the videos:

1. ID: ___
2. Age: ___
3. Sex: ___
4. Side of the paralysis: (left or right) ___________________
5. Level difficulty _________________

---------------------------------- **TRADITIONAL MONITOR** ---------------------------------

Exercise 1

6. Describe/ illustrate the exercise performed by the patient. What are his main difficulties in executing the movement?

7. What is the maximum value reached in the sequence animation?

   ____

8. How much time until finishing the level?

   ____

9. The player concluded the level?

   ☐ Yes ☐ No

Exercise 2

10. What is the sensitivity value most used by the user?

    - ☐ ☐ ☐ ☐ ☐ +

    1 2 3 4 5

Scale description: Less sensitivity implies more speed and greater distance in the movement and more sensitivity implies short movements and reduced speed.

11. How many times was the sensitivity adjusted?

    ____

12. The player finished the level?

    ☐ Yes ☐ No

13. Describe/ illustrate the exercise performed by the patient. What are his main difficulties in executing the movement?

14. Final Points for each level:

    Mexico: ______

    Antarctica: ______

    Egypt: ______

    Brazil: ______

    Canada: ______

15. How much time until finishing the levels?

    ____

16. Did he/she managed to finish all levels? If not, which levels were not completed?

    ____

17. How many times the map was opened?

    ____

18. How many times the wrong path was taken?

    ____

19. Fill the players control over the balloon

    - ☐ ☐ ☐ ☐ ☐ +

    1 2 3 4 5

--------------------------------- **VIRTUAL REALITY** -----------------------------------

20. The player finished the level?

☐ Yes ☐ No

21. Were there any complaints of eye pain?

☐ Yes ☐ No

22. The user felt difficulties in positioning himself in space?

☐ Yes ☐ No

-------------------------------------- **General** ---------------------------------------

23. The user was aware of his actions:

☐ Yes ☐ No

24.1) If not, describe his condition

____

____

____

24. The user had eyesight problems?

☐ Yes ☐ No

25. Write the difficulties in dealing with the game interface.

____

____

____

26. Complete the ICF Core SET information of the user or use another existing scale used by the physiotherapist if possible.

____

____

____

APPENDIX B – Contents of Enclosed CD-ROM

The enclosed CD-ROM consists of eight different directories:

- Playable Game
- Video playing the full game and showing the GUI
- Excel Charts
- Questionnaires
- Monitor captures during the evaluation
- Leap Motion SDK installer
- Dissertation PDF
- Curriculum Vitae

The game is playable without the leap motion or the HMD display by using the arrow keys for the balloon movement. However, it is required to install the provided *Leap Motion SDK. Press "S" to skip between scenes.*