Move With Me
Serious Game for Rehabilitation of Children with Disorders of the Upper and Lower Limbs

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To everyone who believed in me...
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Resumo

Os objetivos desta tese eram criar uma ferramenta composta por vários jogos de exercício físico com a presença de um agente virtual destinado a um público infantil e aferir se com a utilização desta solução a motivação e empenho por parte das crianças aumenta. Analisámos o que era feito na área da reabilitação infantil, tanto na fisioterapia como na terapia ocupacional. Em seguida, investigámos algumas soluções existentes na área dos agentes na saúde e vários sistemas que utilizam o sensor Microsoft Kinect e averiguámos a existência de uma lacuna na implementação voltada para a reabilitação infantil. Prosseguimos com a descrição da nossa solução, dividindo esta em 3 partes: módulo dos jogos – onde descrevemos como os jogos funcionam e os seus principais objetivos; módulo do servidor – como os serviços que correm em segundo plano estão estruturados e as suas funções; módulo real-time – descrevemos como a aplicação de suporte ao terapeuta funciona e as suas principais funcionalidades. Descrevemos a implementação no nosso agente virtual, desde a sua arquitetura reativa tal como todo o processo intrínseco de desenvolvimento da personagem. Após a execução de toda a solução, foi iniciado o processo de avaliação da mesma. Esta foi dividida em duas partes: testes preliminares – aqui descrevemos os resultados empíricos dos testes efetuados em 10 crianças e a sua influência na adaptação de cada jogo; avaliação final – avaliamos 13 crianças em ambiente clínico, onde analisámos questionários e resultados do sistema. Os resultados obtidos foram consistentes com a nossa hipótese.

**Palavras-chave:** motivação, reabilitação, jogos sérios, microsoft kinect, agente de conversação personificado, deficiências motoras.
Abstract

The objectives of this thesis were to create a tool consisting of several exercise games with the presence of a virtual agent intended for a young audience and assess whether the use of this solution increases motivation and commitment on the part of them. We looked at what was done in the area of child rehabilitation, both physiotherapy and occupational therapy. Then we investigate some existing solutions in the area of health agents and several systems that use the Microsoft Kinect sensor and ascertained the existence of a gap in the implementation targeting child’s rehabilitation. We proceeded with the description of our solution, dividing it into 3 parts: video game module - which describes how the games work and its main objectives; server module - as the services that run in the background are structured and its main functions; real-time module - describes the application that support therapists’ work and its main features. We described the implementation of our virtual agent, since its reactive architecture as all the intrinsic process of character’s development. After the fulfillment of the entire solution, we started the process of evaluation. This was divided into two parts: preliminary tests - here we described the empirical results of tests conducted on 10 children and their influence on the adaptation of each game; final evaluation - evaluated 13 children in a clinical setting, where we analyzed questionnaires and system results. The results were consistent with our thesis’ hypothesis.

Keywords: motivation, rehabilitation, serious game, microsoft kinect, embodied conversational agent, motor disabilities.
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Chapter 1

Introduction

What drives children with physical problems and cognitive disorders to be cooperative? Is it possible to improve sensorimotor performance using virtual systems? Can motivation on children be achieved by using video games with the companionship of a virtual agent? How to trigger new behaviors on disabled children? It is estimated that 93 million children - or one in twenty children with 14 years or less – is living with some type of moderate or severe disability[1]. In the Cambridge Dictionary the word disability is described as “an illness, injury, or condition that makes it difficult for someone to do the things that other people do”. In the case of children with disabilities, rehabilitation can in most cases, improve their general physical ability and increase their capability in performing activities of daily living (ADL), promoting their autonomy. For the therapy sessions to have a high success rate, children should be engaged in their tasks, however children have a high level of distraction and become annoyed and agitated very quickly, reducing the window of maximum immersion and effectiveness of the rehabilitation session. During therapy sessions, the therapist tries to gain their attention and motivation through games and toys yet those assets are limited and children get disinterested very quickly due to lack of diversity of the previous. Moreover, has been shown that children embrace video games and when playing, they show focus and interest, demonstrating a high degree of dedication and commitment towards the game. Such motivation and engagement to play a game, it’s something that is intended to be captured and used in serious games, more precisely in exergaming and health games. Thanks to advances in technologies either at the software and the hardware level, it is possible to accomplish a new design of games and adapt them to be used in a therapy context, not only adapting the game content but also adapting the input controller method in which children interact with it. In the past, the input controller was limited to game-pads and joysticks, a type of controller that some children with hand disability would not be able to use (this was a severe limitation). Nowadays, it is possible to see other types of controller such as Playstation Eye Camera and Nintendo Wii Remote. But, to increase the immersion and freedom of movement, Microsoft created their controller, Microsoft Kinect. This controller is not limited to any hand-held device nor severe limitation on camera focus (like Sony Playstation Eye Camera). Microsoft Kinect can recognize human figures (bipeds) and translate their body movement and body responses to the game in real-time. This device has a documented limitation on the wearer’s body positioning, in the
sitting position it only tracks the ten upper-body joints (shoulders, elbows, wrists, arms and head). We intend also to affect motivation of users through the use of interesting visual elements, virtual characters, interesting environment and fun levels.

1.1 Motivation

In all rehabilitation sessions, patients need to perform a set of bio-mechanical repetitive exercises. With the progression of sessions, those set of exercises become monotonous and the quality of sessions plunges through time. Both physical and occupational therapists try their best to maintain their rehabilitation sessions attractive and fun, but with the limitation of physical objects the diversity of their creativity is constrained to that reality.

When patients are children, their window of dedication and motivation are more restricted. This kind of patients tend to be more scattered and their energies are spent very quickly on unnecessary activities involving their body movement. Therefore, therapists are confronted with a harder task in each rehabilitation session, they need to redirect this sparse energies to more concise and effective physical exercises and games.

With the limitation of toys and, in last instance, creativity, therapists are always confronted with what they should do in each rehabilitation session. Move With Me emerged trying to answer this question. This project comprises a set of games that try to motivate children by creating an interesting environment to perform physical exercises. This project doesn’t attempt to replace therapists in any way, but wish to be a tool to help them increase motivation and performance in therapeutic sessions.

1.2 Objectives

For this research, the main goal was to create a useful and fun tool that would help therapists achieve better results in children’s rehabilitation. To realize such a task, several challenges needed to be addressed. First, some field work was done, attending therapy sessions to gather and analyze data in order to understand what were the therapists procedures and what type of movements and exercises children (globally) didn’t like to perform. Next, it was important to understand how to synthesize persuasive elements to use in a virtual world (game designing) and embedding those elements in a virtual agent. Subsequently it was necessary to investigate and understand what has been developed thus far in the area of rehabilitation with support of Microsoft Kinect.

In a rapidly evolving world, there are a lot of solutions already made using virtual reality and Microsoft Kinect but they try to aim them to a wider public and these solutions are not designed for a more infant public. Today, children love to play computer and mobile games and their quality standards are high, or even in some cases higher than adult standards. Children became a more aggressive and sincere critics about video games, and so young patients with some physical or cerebral illness are also a critic and have a high standard about the quality of the games. These patients don’t express their opinions
in an open and understandable way, they sometimes expose those feelings and opinions through body language and through the lost/gain of interest and engagement on the action at their hands.

Nowadays, therapists try their best to obtain children's attention, inventing games, stories and by the use of toys. Using these elements to persuade them accomplishing the exercises without noticing it. This premise is the cornerstone of this research, a set of games will be made with an embodied conversational agent (ECA) that will try to build up the children's confidence and motivation to achieve the games goals and indirectly, completing their rehabilitation exercises.

1.3 Outline

This document is organized into major topics, that correspond to 6 chapters in this document:

Chapter 1 (Background) provides an overall analysis of the background theory regarding physical and occupational therapy objectives, the work and efforts of the therapists in the field of pediatrics rehabilitation.

Chapter 2 (Related Work) exposes the definition of serious games and exergaming, an overview of virtual agents used in health and how persuasive techniques can change attitudes and behaviors is reported. Analyzes several solutions implemented and used nowadays that combine rehabilitation with Microsoft Kinect and gaming. Also, a chapter of virtual agents used in health care and how they are useful in certain areas is presented.

Chapter 3 (Initial Studies) in this chapter the preliminary analysis performed regarding physical and occupational therapies sessions with children with health impairments is described.

Chapter 4 (Implementation) explains how the system is structured and implemented: the effectiveness of using Microsoft Kinect controller in real-time environments, how the virtual agent is implemented, which data is captured in real-time by the system and where this data is stored and how it is available to the therapists.

Chapter 5 (Evaluation) the methodology used to evaluate the system is presented and the results gathered are analyzed.

Chapter 6 (Conclusion) from the collected data, some conclusions are drawn concerning this dissertation's problem. Last, a possible path for future work is described.
Chapter 2

Background

In this chapter we present some of the background theories from two therapy areas, that motivated, and supported, many of the research decisions taken in this thesis. Firstly, we review some concepts of physical therapy, its objectives, its main areas of activity and possible inherent limitations of long-term care in children. Then, we depict the field of occupational therapy, its main goals and a small description of its influence in the area of children’s rehabilitation. Finally we describe some health disorders that affected our study demographics.

2.1 Physical Therapy

Physical therapy focuses on the analysis and evaluation of movement and posture, based on the structure and function of the body using specific educational and therapeutic methods. Based essentially on movement and manipulative therapies, with the purpose of promoting health and prevent diseases. Ultimately improving disability, decreasing inadequacy and treat, enabling or rehabilitating individuals with physical, mental or development dysfunction, in order to help them achieve maximum functionality and quality of life[2].

The physical therapist assists in the recovery, increase or maintenance of physical abilities of the disabled, using specific techniques. Assisting in diagnosis by evaluating deficiencies and identifying damaged areas, creating an appropriate treatment programs in order to help the disabled to regain or increase their physical capabilities, using different techniques, such as therapy for movement, manipulative techniques, electrotherapy, including cold or heat, but also more advanced techniques such as neuromuscular facilitation and inhibition. Educates their patients how to proceed more appropriate, depending on their condition. Treats patients with different pathologies, such as orthopedic, respiratory and cardio-respiratory, neurological and rheumatological, individually or in groups[3].

The approach performed by a pediatric physical therapist is individual and personalized, making it a thorough assessment of the child/young person. In earlier ages, the physical therapist intervenes through play and respecting the skills or abilities of the child, recognizing it not as a miniature adult but
as a developing human being. The family and the various contexts in which the child/young person moves are considered as a priority among various factors that contribute to their development.

In all areas of physical therapy, but especially in pediatrics, it is essential to develop a trust with the therapist. Gain the trust of the child is an enabler of intervention further on the affective component is more easily generated. It is a constant challenge for the therapist to act with the child, as this presents different disposals, desires and also limitations on alertness and concentration. Thus, it is important that this health professional adapts and make more suitable his intervention, using his creativity as a tool in order to captivate the interest of the child, which often becomes extremely complicated. Thus, the therapist must explore his inner child and so often uses, as part of his treatment plan, music, cartoons, games and stories in order to motivate children. The children eventually face treatment as something fun and challenging, it is important to recognize the merit that they have, given the success of the intervention. When this happens, e.g., the child cooperates and responds positively to what is requested and in the end of the intervention, eventually, will be given an "award" to him.

However, during the treatments there is a shortage of materials, leading to repetitive items (toys) used throughout the treatments. This generates a lack of interest, figure 2.1, and lack of commitment on the part of the child.

![Figure 2.1: Child unwilling to do the exercise](image)

### 2.2 Occupational Therapy

Occupational therapy aims to promote a satisfactory occupational performance by evaluating and operating with the person in his own occupation and environment. On the person, evaluates the capabilities, limitations and risks, intervening in promoting skills, restoring functions and prevention of disorders; using strategies and/or support technologies. The term occupation refers to everything that
one performs in order to take care of themselves, enjoy life and/or contribute to the development of the community. In the environment where the person is inserted, signals the support and the demands that the spaces and/or equipments that are part of the physical and social environment, attempting to minimize barriers and facilitate participation in occupations. Therefore, the occupational therapist plays an important role in preventing functional impairments, promoting health and well-being of individuals, maximizing the independence and autonomy of patients, keeping in mind the individual possibilities and the available resources[4].

The primary objective of the occupational therapist focuses on maximizing balance and adaptation between what the person wants and needs and make their competence to perform, returning him the possibility of continuing to play an active role in society[5][6].

On the area of pediatrics occupational therapy emphasizes the sensory-motor components, cognitive, psychological and psychosocial, and uses as a tool the recreational activity and playing, acting this way in the rehabilitation, stimulation and development with children and youth. They learn how to communicate and relate to others in an effective way, caring for themselves and learning to use strategies that best fit their needs. The act of playing provides a rich therapeutic environment, creating opportunities for children to develop new skills in activities of daily living, school activities and the coordination and concentration activities[7].

2.3 Health Disorders

Move With Me is a tool whose main task is to assist in children's rehabilitation undergoing a wide variety of health disorders. It is known that exist multiple health problems affecting children which cause severe damage to their health, both physically and mentally. Throughout the entire development of this project, we were confronted with some of those problems. Therefore we emphasize some of these diseases, such as Cerebral Palsy, Brachial Plexus Injury, Rasmussen's Encephalitis, Brain Tumors (sequelae of glioma) and Childhood Stroke. In section 6.2 - Final Evaluation, we will present the assessment performed in children with these disorders.

2.3.1 Cerebral Palsy

Cerebral Palsy (CP) is the term used to describe a heterogeneous group of neurological syndromes derived from injury in the early stages of development of an individual. It should be noted that these difficulties vary according to the nature and extent of the original injury and can thus occur various problems including, motor, sensory problems, or neurological and cognitive deficits[8][9][10][11].

In developed countries there has been an increase in cases of cerebral palsy in the last two decades, with prevalence rates of moderate and severe cases ranging from 1.5 to 2.5 per 1,000 births. These data are the result of an improvement of perinatal medical care, contributing to increased survival of children with gestational age and increasingly extreme low birth weight[12].
Aetiology of Cerebral Palsy

CP motor disorders are usually accompanied by associated problems, including perceptual, sensory deficits (vision and hearing, language/speech) difficulties in cognitive processes and learning, the presence of epilepsy and behavioral changes[13]. CP is often caused by external factors, thereby excludes the possibility of parent to child transmission (inheritance). It is estimated that about 50% of the disturbances are caused by a brain injury before birth (prenatal causes), 3% are due to perinatal (childbirth), 10% are caused by damage to the brain after birth and up to two years and 7% unknown whether the cause[13].

CP causes may be due to several factors, such as maternal prenatal infections during the first and second trimester of pregnancy, such as rubella, cytomegalovirus and toxoplasmosis and postnatal infections (meningitis). As well as the antepartum hypoxia, Von Willebrand disease, specific medications, alcohol and illegal drugs and severe abdominal trauma, as well as birth defects including malformations in cortical development are also associated with the prevalence of CP[14].

Clinical features

In specialty literature we find several proposals for the classification of cerebral palsy. This classification, in general, can be carried out according to the quality of muscle tone and movement of motor impairment pattern, and anatomic location of the lesion topography of the symptom. Little, Winthorop and Phelps were the first to differentiate various types of cerebral palsy: spasticity, dyskinesia, ataxia and hypotonicity as pathological movement patterns[15].

- **Type spastic** - It is associated with a motor cortex lesion or the projection of the substance to/from the sensorimotor cortical areas of the brain. It is the most common form of CP (about 75%), and wherein lack of muscle plasticity (resistance to passive movement speed dependent). There is a limitation in motor control and selective in range of motion, due to the co-activation of muscle groups, with the time of abnormal muscle activation. All these factors contribute to the child present difficulties while eating, walking and other coordinated movements.

- **Type dyskinetic** - It is associated with a lesion of the basal ganglia or connections to the prefrontal area, registering a suppression of complex sequential movements/selective activation, i.e., is characterized by involuntary movements, irregular, continuous, slow and variations in tonicity muscle. Includes athetosis, rigidity and tremor, being athetosis the most common clinical form in dyskinesia.

- **Type ataxic** - It is related to a cerebellar lesion and the least common form of CP. It is characterized by a change or disorder in the balance, timing and/or control in the coordination of movements. The child when trying to reach an object has uncoordinated movements of the upper limbs and moves slowly out of fear that has to lose his balance.

- **Type hypotonic** - It is not linked to a particular brain injury, and sometimes a transitional phase of athetosis or spasticity. It is characterized by a decreased ability to generate force in muscle
contraction, excessive joint flexibility and postural instability.

- **Type mixed** - Some authors also consider the CP mixed type results from lesions in both the pyramidal system, as in extra-pyramidal system. In most cases the symptoms do not appear alone due to multiple lesions, a child can have more than one clinical condition.

In order to better understand the following classifications becomes necessary to explain two types of concept: paresis (plays a minor role because the members are not completely paralyzed) and hemiplegia (severe injury, affecting members deeply, unable to perform global or specific movements of voluntary motor function)[16]. Therefore, we can describe different topographical types, according to the predominance of the motor problem:

- **Diplegia** that registers greater involvement of lower and less involvement of the upper limbs members. The child suffers from a late development in many aspects of the movement and have difficulty learning to walk.

- **Hemiplegia** affects a hemisphere, reaching the upper and lower member of a side of the body. Members of the affected side develop slowly and there may be some loss of sensation in the affected side of the body.

- **Tetraplegia** there is an involvement of four members, with greater incidence in the upper limbs

While some children suffer from slight disturbances, making it clumsy to walk, to speak or use their hands, there are others that are severely affected, unable to walk and talk, being dependent on their daily activities. In this way, we can classify children with CP regarding the level of severity of injury[13]:

- **Mild** - Displays minimum physical limitations, being more evident in more elaborate functional activities. No need for third-party assistance or technical aids, however, requires more time in motor activities.

- **Moderate** - Functional limitations are present throughout the body, with some difficulty walking, acquisition of sitting posture, use of hands and talking. Inability to achieve the stages of development specific to normal ages. With the help of third parties or the use of technical aids, can participate in specified activities for their age.

- **Severe** - Restrictions on the ability to perform normal activities of daily living, such as opening doors, going to the bathroom, in making body transfers. It is dependent on ADL and mobility requiring third-party help. The child shows a deficit in communication, being severely affected quality of life.

- **Profound** - Inability to perform basic motor skills. The accessibility to the Community is compromised and can lead to severe health complications.

In terms of functional capacity, the American Academy of Cerebral Palsy refers to four severity classes[16]:

8
• **Class 1** - Almost no limitations in activities;

• **Class 2** - Mild and moderate limitations in activities;

• **Class 3** - Moderate to major limitations in activities;

• **Class 4** - Total incapacity for any physical activity.

### 2.3.2 Brachial Plexus Injury

In a brachial plexus injury (BPI) there has been a compromise of nerve fibers that compose the plexus in the cervical region, shoulder girdle and shoulder, covering the roots of C5 to T1. It can be due to a pull of the brachial plexus (BP) or direct plexus injury. It is considered neonatal origin, when trauma occurs during childbirth, or traumatic, when an accident occurs at any stage of life. The primary cause of BPI is undeniably a trauma origin[17].

The brachial plexus is responsible for sensory and motor innervation of the upper limb, being formed by the union of the anterior branches of roots C5, C6, C7, C8 and T1 and emerging between the anterior and middle scalene muscles. At this level forms the upper torso resulting from the union of C5 and C6 roots, average root corresponds to C7 trunk and lower trunk originates from C8 and T1 roots. Each trunk divides into an anterior portion and a subsequent[18].

### Aetiology of Brachial Plexus Injury

The BPI is often called Obstetric Paralysis (OP). The brachial plexus palsy (BPP) in the newborn (NB) reflects, as previously stated, a motor and sensory disturbance of the upper limb and at this age group is usually a result from childbirth. The etiology is traumatic, in which during the expulsive phase of delivery, it’s applied an excessive traction of the neck to the departure of the previous shoulder, that when it is “locked” by maternal pubic symphysis, can damage the roots of the brachial plexus. Other pathophysiological mechanisms are described as contractions exerted on the posterior shoulder to “push it” against mother’s promontory. However the primary cause of prenatal BPP is due to miss adaptation intrauterine, as for example in rare cases caesarean section[19]. The risk factors for plexus injury in newborns may be related to childbirth (dystocia shoulder and dystocia childbirth - except caesarean section, extending from the second delivery phase), with the mother (primiparity, diabetes, advanced age, obesity, low height) or the fetus (macrosomia, poor intrauterine adaptation). In about 50% of cases of obstetric paralysis is referred to the shoulder dystocia. Despite these risks factors is not possible to accurately predict the OP in the pre-partum period[17].

The incidence of the OP is between 0.13 and 5.1 per 1,000 live births, and there has been an increasing number of cases in recent years. It affects equally both sexes and the right upper limb is the most affected, about 50%, and 43% the left arm. It is bilateral in 8.3% to 23% of cases according to the series, a situation that occurs almost exclusively in deliveries in breech delivery. They have surgical indication from 5% to 25% of the cases[19].
Clinical features

The recovery occurs in about 75% of cases, although it can extend up to several months or years. The sooner we start the rehabilitation process, the more favorable will be their evolution, decreasing the chances of developing problems in terms of body structure, limitation of movement, atrophy, vasomotor and sensory changes. Nerve grafts are indicated for most severe lesions and when the child reaches 3 months of age. The difficulty in the development of active elbow flexion in the affected limb to 3-6 months of age, may be an indicator element of a poor prognosis of a lesion[18].

2.3.3 Rasmussen's Encephalitis

In 1958, Theodore Rasmussen and co-workers from the Montreal Neurological Institute described a syndrome of focal seizures due to chronic localized encephalitis in three cases[20]. Rasmussen's Encephalitis (RE) also called Rasmussen's syndrome is an infrequent, progressive inflammation of the part of the brain call the cerebral cortex, which is made up of a right and left hemisphere and spreads to adjoining areas on the same side. Which means that does not spread to the other side. The inflammation leads to loss of nerve cells and scar formation and usually results in severe disability. This disease is typically associated with intractable focal epilepsy, cognitive decline and hemiparesis. The age at onset is in childhood, between 6 and 8 years (range between 1–13 years), but it can also start in adolescence and adulthood, affecting children who were previously healthy. Sometimes, an infectious or inflammatory disease has been noted during the 6 months before the first seizure. It is a rare disorder and probably affects one person in every 500,000 to 1,000,000. Both sexes are equally affected. The disease starts with focal seizures and in up to 20% as status epilepticus, for example epilepsy partialis continua (EPC), which is a purely motor status epilepticus. Rasmussen's encephalitis is defined by polymorphous seizures, therefore including somatosensory, motor, visual or psychomotor seizures; so as the disease progresses, the seizures become more frequent, more severe, and more difficult to treat with anti-epileptic drugs[21].

Aetiology of Rasmussen's Encephalitis

Rasmussen's Encephalitis is a rare disease that should be considered as sporadic, since there is no evidence for a genetic component. The aetiology and pathogenesis of Rasmussen's encephalitis still remain unknown. Three hypotheses have been forwarded: (a) a direct viral insult, (b) an autoimmune process triggered through a viral agent, (c) a primary autoimmune process. Today, the autoimmune hypothesis is increasingly, due to the (transient) efficacy of plasmapheresis and other immunomodulatory medications in the treatment of Rasmussen's encephalitis[21].

Clinical features

Three disease stages have recently been proposed. Initially, there may be a rather non-specific “prodromal stage” with a relatively low frequency seizures and moderate hemiparesis, if present with a
median duration of 7.1 months. This stage appears to be briefer in children, compared to what is observed in adults and adolescents. The second phase, called the acute stage (4–8 months, median: 8 months), is characterised by an augmentation in the frequency of seizures, mostly simple partial motor seizures often in the form of epilepsia partialis continua (EPC). The neurological deterioration becomes manifest by progressive hemiparesis, hemianopia, cognitive deterioration and, if the language dominant hemisphere is affected, aphasia.

During the final residual phase the patient presents a permanent and stable neurological deficits and still many seizures, although less frequent than in the acute stage. At this stage, not all the patients are hemiplegic. The large time ranges for the duration of the disease stages indicate the high variability of severity and speed of the destructive process in different patients. For clinical monitoring of the progression, hemiparesis is the most useful marker as this feature is most consistently found, and it allows quantitative evaluation, even in children[20].

Clinical variants

- **Adolescent and Adult cases** - Even though RE has for a long time been considered as a childhood disease, adolescent and adult patients have been described by several groups. The evolution is more variable with a more insidious onset and cerebral hemiatrophy at a later stage. Furthermore, the occipital lobes seem to be more frequently involved during the initial phase[21];

- **Bilateral hemispheric involvement** - The term “bilateral RE” should be reserved for cases with inflammatory lesions in both hemispheres, no more than 12–15 cases have been described up to now, and it may well be that it is a different disease[21];

- **Rasmussen’s encephalitis with basal ganglia involvement** - Unilateral basal ganglia involvement (usually the caudate nucleus or putamen) has been reported to present with features of hemidystonia and hemiathetosis in addition to EPC[20].

2.3.4 Brain Tumors: Sequelae of Glioma

Primary brain tumors are tumors (abnormal growth of cells) that arise from the brain and brain structures. These are not tumors that have spread, or metastasized, to the brain from other parts of the body or from the brain to other parts of the body[22]. There are two types of brain tumors:

- **Gliomas** - is a type of brain tumor that grows from glial cells. Glial cells support and insulate nerve cells with energy and nutrients and help maintain the blood-brain barrier. An astrocyte is a special form of glial cell. Astrocytomas are a type of glioma that forms because of abnormal growth of astrocytes. Ependymomas are another type of brain tumor that comes from abnormal growth of glial cells.

- **Non-Gliomas** - occur in other brain structures. Some of the more common areas involved include the meninges (tissue coverings of the brain) and nerve sheath.
Aetiology of Brain Tumors

There are some syndromes or genetic mutations that can increase a child's risk of developing a glioma such as Li-Fraumeni syndrome, Turcot syndrome, and neurofibromatosis. Children with neurofibromatosis are specifically at higher risk for developing optic pathway gliomas.

Clinical features

The signs and symptoms are related to the location of the brain tumor in the brain. Gliomas can occur in any part of the Central Nervous System. Commonly you cannot tell from the symptoms exactly what type of brain tumor is causing the problems. The most common symptoms are headaches and vomiting. Children with brain tumors may turn into less steady while walking or have difficulty with balance. Other symptoms can be detected in children as clumsiness or having trouble holding objects or writing.

Low-grade and High-grade Tumors

Gliomas represent 40% of primary brain tumors. Of this group, the most generally seen in the clinical setting are astrocytomas, oligodendrogliomas, and oligoastrocytomas. Gliomas can either be low-grade or high-grade. Grading is done based on World Health Organization (WHO) criteria depending on how the tumor cells look under the microscope, their potential for growth, and their potential rate of growth. In most cases, low-grade tumors are tumors that, if removed completely, may not recur, or recur slowly. Grade I or II tumors are the most benign and associated with long-term survival. High-grade (grade III or IV) tumors tend to persist. Any tumor that is not completely removed will recur or continue to grow. If the tumor is high-grade, it has the potential to reappear at a more accelerated rate than a low-grade tumor.

2.3.5 Childhood Stroke

The World Health Organization characterize stroke as “a clinical syndrome typified by rapidly developing signs of focal or global disturbance of cerebral functions, lasting more than 24 hours or leading to death, with no apparent causes other than of vascular origin”[23, 24].

Stroke is a neurological injury produced by the occlusion or rupture of cerebral blood vessels. Stroke can be ischemic, hemorrhagic, or both. In Ischemic strokes brain arteries are blocked by a clot, which will prevent blood and oxygen from nourishing a region of the brain. If an artery is injured or narrowed, or if a problem exists with blood clotting (a so-called hypercoagulable state), a clot may be formed. The clot may travel from a distant site (embolic clot) like the heart and the neck vessels. Hemorrhagic stroke is the result of bleeding from a damaged/traumatized or malformation of the blood vessels ruptured cerebral artery or from bleeding into the site of an acute ischemic stroke (AIS). Blood concentrates inside the brain, gradually increasing pressure that provokes less flow of blood, oxygen and nutrients to those regions, resulting death of the brain cells. The risk of hemorrhage is greater with certain bleeding disorders, such as hemophilia[25].
A stroke or cerebral vascular accident (CVA) in children is considered to be a rare event. However, it is among the ten leading causes of death in childhood, while estimating its incidence between 2.3 to 13 cases per 100,000 children - year, nearly 20 times lower than the incidence in the age group 45 to 54 years[26].

Unlike stroke in adults, there is a significant delay in diagnosis of stroke in childhood, not only due to the rarity of the disease in this period, as well as the distribution of initial clinical manifestations to other more common diseases, including migraine, epilepsy and infections or tumors system central nervous. A previous diagnosis will allow timely treatment, enabling an increase in the prognosis of patients. Children usually recover from stroke better than adults, due mostly to the plasticity of their brains (ability of brain networks to reorganize and recover following injury) and the reality that their brains are still developing.

Stroke appears to be common in boys, even after controlling for differences in frequency of causes such as trauma. There is a preponderance of stroke in black children, this difference remains true even after accounting for sickle cell disease patients with stroke[25].

### Aetiology of Childhood Stroke

About 80% of stroke’s in adults and newborns are ischemic, while the remaining are hemorrhagic. In children nearly 55% of strokes are ischemic's[27]. Wraige[28] suggested the classification of ischemic stroke in eight etiologic subtypes: drepanocitose, cardiogenic embolism, neck-head arterial dissection, Moya-Moya disease, occlusive cerebral artery (like that by infection of the varicella-zoster virus), other undetermined etiology (e.g. bacterial meningitis), multiple etiologies (such as prothrombotic states and metabolic diseases). It is also important to highlight that children with cancer are at increased risk for AIS. In the case of hemorrhagic stroke, venous and arteriovenous malformations coagulopathies are among the leading causes. The most signs and symptoms of stroke are nonspecific which can lead to misdiagnoses. There are various risk factors often present in as many as 25% of children with stroke[27].

### Clinical features

It is estimated that 70 to 80% of children presenting hemiparesis, may be associated facial paralysis or dysphasia. Focal signs and symptoms are normally related to the localization of the ischemic lesion, however one has to be aware that also children with isolated thalamic stroke might present with hemiplegia and/or dysphasia. In opposition, ataxia is a common symptom of an infratentorial stroke, but not limited to cerebellar lesions. Nonfocal symptoms as headache, vomiting, or change of level of consciousness are most commonly in hemorrhagic strokes. Seizures are normal in both ischemic and hemorrhagic strokes[29].

### 2.4 Concluding Remarks

In this chapter we analyzed and reviewed some concepts from physical therapy. Here we depicted its objectives and its approach towards rehabilitation. We unraveled some limitations that physical
therapists have when treating a younger audience. Through the study of this area, it has been possible to perform an initial study to better understand some concepts and techniques used by therapists (section Physical Therapy Sessions - 4.1).

Also in this chapter we characterized the field of occupational therapy. We identified its main areas of expertise and its strong influence on cognitive rehabilitation. Due to this knowledge, we were able to initialize a field study to learn its techniques (section Occupational Therapy Sessions - 4.2).

Finally, we presented several health disorders which affect the children’s audience. By understanding their characteristics, we were able to realize the impact of our solution in children’s rehabilitation sessions with these disorders (section Final Evaluation - 6.2).
Chapter 3

Related Work

In the following chapter we introduce the term Serious Games, here we explain its origins and its objectives. Then we explain a specific classification of serious games named exergaming. We analyze actual virtual agents used in healthcare and how motivation and persuasion allows changes in behavior. Afterwards, we uncover how Microsoft Kinect sensor is a valid system to be used in physical and occupational therapies. Later, we present analogous solutions used nowadays in rehabilitation environment. Last, we compare all presented architectures focusing on the thesis’ problem.

3.1 Serious Games for Health

With the evolution of technology both software and hardware, the area of computer graphics has improved its responses, as to the realism of virtual environments and became increasingly similar with reality. With these improvements, the games have been given a higher importance in the lives of most people. Games are gaining popularity as a tool for health prevention and education. Video games are not just for teenagers or game enthusiasts anymore, they are designed for a wide range of ages. Recent innovations in game controllers and motion sensors are being incorporated into games where body movements are used to control the game. From the area of gaming, a new definition was born, Serious Games.

Serious Games are games that deal with issues that surpass the goal of entertainment itself[30]. This kind of games uses the techniques of the game industry to make the experiences of players, especially in relation to learning more attractive and playful. In game development, multidisciplinary areas must be combined to collaboratively focus on a common goal[31]. This relationship enhances the work, making it more efficient and effective.

Games have missions, goals and rules, which become competitive and complex elements. This competition and adversity can be used as enhancers of motion in the real world, through advanced sensors that allow for real-time capture of changes in body parts for each player. These capabilities allow the current technological world creating games called exergames, trying to promote exercise through virtual gaming, using for example optical sensors type Microsoft Kinect sensors with accelerometers, for
example Wii Remote and other sensors, e.g. Wii Balance and also the use of cameras. The use of this resource has proved quite beneficial for the players, improving their quality of life through interesting activities inserted in a virtual reality.

3.2 Virtual Agents on Health

In this ever changing world the need of creating a system capable of independent actions on behalf of its user or its owner was an imperative urgency. In the past this kind of system was completely unthinkable because there weren’t a true motivation to develop it. In the world today with the increase of distributed computational power, the advance on the connectivity enabling systems to be always connected at all time, the need of solving complex tasks, the urge of delegating critical tasks to automated systems, the necessity of autonomous systems and making them serve humans, propelled the creation and development of virtual agents[32].

Virtual agents are created with two main concerns, agents capable of independent and autonomous actions allowing them to successfully accomplish tasks that are delegated to them and agents capable of interacting with other agents and humans. With the human interaction in mind, Timothy Bickmore¹, a Ph.D. Associate Professor of College of Computer and Information Science Northeastern University which area of interest is development and study of Relational Agents, states that Relational Agents are computer agents designed to produce and maintain long-term, social-emotional relationships with people[33].

Bickmore created an embodied conversational agent named Laura. Laura was designed to help people change health behaviors as in increasing their physical activity[34]. Laura had two versions, a relational one and a non-relational one. Bickmore tried to understand if people would be more compelled to the relational and care giving version of Laura or not. Bickmore learned that a large number of people can be influenced by a synthetic agent, especially if this agent tries to bound in a sentimental level with them (relational agent)[33]. The presence of a embodied agent is very important to improve people’s confidence and increase their motivation.

Lisetti² also designed an empathic embodied virtual agent, ODVIC, the On-Demand VIrtual Counselor, for excessive alcohol consumption behavior change[35]. The results obtain by their control group was clear, the usage of ODVIC was very well accepted having a major impact in user’s motivation.

In the field of agents on health is proven a great improvement and adherence of people when confronted with this new computer-based assistant.

3.2.1 FitTrack - Laura, an exercise advisor agent

In 2003, Bickmore created “FitTrack” an exercise advisor system with single purpose to increase physical activities of free-living individuals[33]. This system was designed to be executed on

¹Timothy Bickmore - http://www.ccs.neu.edu/home/bickmore/
²Christine Lisetti - http://users.cis.fiu.edu/~lisetti/
participants’ computers so they could input their daily activities. “FitTrack” contains an embodied conversational agent (ECA) having text-to-speech technology due to a great number of sentences in the system. In order for users to input data inside the exercise advisor system, Bickmore chose dynamic menus rather than speech recognition, since he believed natural language input leads to high recognition error rates (figure 3.1). The system is divided into two main parts, client and server. Firstly the client is composed by ECA with simple and light weight interface. Lastly the server processes all logic, dialogues and data storage.

To convey the study over FitTrack, Bickmore exposes participants to 3 types of system implementation: relational, non-relational and control. The group assigned to relational condition had contact with all system functionalities including agent with relational strategies. Assigned to another group was non-relational condition which included all system functionalities without all relational strategies from the agent. Finally, to the last group was assigned the control condition which included all system features without interaction of the agent.

Bickmore had in mind the system performance of home computers and used the technique of pre-rendering 2D images in which are synced with speech synthesizer at run time. After applying an inquiry inside Media Lab, it was chosen an ECA with female characteristics of a typical college student with attractive physical features and dressed casually (figure 3.1). Also through the use of survey, were voted two sets of facial and body postures, rated as “warm” to be used in relational interaction and rated as “neutral” for the non-relational. Finally, it was voted the name of ECA as “Laura”.

FitTrack’s server is divided into two main blocks, web server and dialogue server in which interact with each other through database. The main functions of the web server is to provide a correct sequence of panels to the clients’ web browser and store data from any form filled by the him. The dialogue server keeps a connection with clients’ application (if it is running) and records all clients’ actions into database. The dialogue server also maintain control of high-level dialogue events.

In order to build a relationship between the virtual agent and the user, Bickmore believe persistence is a property with major importance in the Exercise Advisor System. This persistence promotes interaction between virtual agent and the user through the memory of past user’s interplay with the system, creating
Bickmore developed 7 hypotheses[33] that he would like to assess, so he conducted an experiment to evaluate these hypotheses and he observed: subjects liked Laura more in the relational condition; subjects would like to continue to work with Laura in the relational condition; subjects feel more a sense of relationship with agent in relational condition; subjects perform more physical activity and participate more in the study with agent in non-relational and relational condition than in the control condition. Subjects engaged better with the relational version of Laura them the non-relational one[34].

3.2.2 ODVIC - On-Demand Virtual Counselor

Christine Lisetti, an Associate Professor from Florida International University and Director of the Affective Social Computing Laboratory, created in 2013 a multimodal Embodied Conversational Agent (ECA) name ODVIC. ODVIC stands for On-Demand Virtual Counselor. Lisetti developed this agent targeting the excessive alcohol consumption and abuse. ODVIC would empathically communicate with the subjects in real-time, verbally and non-verbally way trying to change their behavior[35].

ODVIC is a system that tries to provide access to users to effectively change their behavior, nurturing motivation to change unhealthy behaviors. To accomplish this task, ODVIC features a computacional model of Motivational Interviewing (MI) with a compelling face-to-face patient oriented counseling style, respecting patients’ behavior change rate[35]. The main principles of the model MI are: without discrepancies, motivation cannot be achieved; to engage discrepancy is necessary to become ambivalent; with the increase of discrepancies, ambivalence intensifies; with gradual increase of discrepancy, ambivalence can resolve towards changes[36]. ODVIC uses an adaptation of MI intervention, named Drinker’s Check-Up (DCU)[37] with empathic characteristics.

ODVIC features a 3D ECA named “Amy”, enabling a more realistic facial expressions with text-to-speech and lip synchronization, which Lisetti believes it will increase enjoyment and engagement with the system[35]. Also Lisetti created different avatars representations with different ethnicities in both genders, also helping racial concordance with their subjects (figure 3.2).

Lisetti sectioned ODVIC into 6 main blocks: users’ multi-modal interface; tailored interventions; psychometric analysis; dialogue module; empathy module; ECA’s multi-modal interface. Dialogue Module evaluates users’ inputs and processes statements, it consists in 3 components: Psychometric Instruments; Dialogue Planner; MI-based Dialogue Engine. Psychometric Analysis processes and analyzes data gather by Dialogue Module and features 2 components: Score Evaluator; Psychometric Data. Tailored Interventions adjusts sensitive feedback and plans to change behavior, has 3 components: Behavior Change Planner; User Model; Tailored Feedback Engine. Empathy Module captures users’ facial expressions in real-time and analyze them to appraise users’ most affective state and adapt ECA’s emotion to create a sense of empathy, it is formed by: Facial Expression Recognizer; Verbal, Non-Verbal Model; Facial Expression Generator; HapFACS[35].

Lisetti to evaluate ODVIC, in the same way as Bickmore[33], create 3 versions of OVDIC: empathic counselor - ECA reacts with verbal and non-verbal empathic reactions, expressing different facial
emotions and expressions and reflects on users’ emotions and answers; non-empathic counselor - ECA presents a neutral interaction with user, with neutral facial expressions, ignores users’ changes of emotional states and answers; text-only Drinker's Check-Up (DCU) - is presented a text-only webpage with DCU exact content. To assess these versions, participants were divided into 3 groups (assigned to each version) and through the use of questionnaires, Lisetti was able to verify that: subjects liked the idea using empathic counselor; subjects would like to use the system over a long period of time; subjects enjoyed the company of the empathic counselor; subjects thought empathic counselor was sociable and empathized with them; subjects felt the system was a useful tool; subjects thought empathic counselor was trustworthy; subjects felt comfortable to expose their information to empathic counselor. As for Human-Computer interaction: subjects felt empathic counselor were somewhat human-like with conscious; subjects felt empathic counselor was friendly, kind and likable; subjects thought empathic counselor was alive, organic, interactive and responsive; subjects felt empathic counselor was competent with a good amount of knowledge and responsible; subjects felt comfortable in using this system.

Lisetti achieved the same results as Bickmore. Subjects experienced a significant impact on their motivation when interacting with ODVIC as relational counselor[35].

3.3 Believability

In the field of Arts and Fiction exist a concept of “believable character” which doesn’t try to mimic a real character but tries to present an illusion of life, bringing the spectator a notion of “suspension of disbelief”. In 1817 English poet and aesthetic philosopher Samuel Taylor Coleridge conceived a new term suspension of disbelief[38], this new concept was first introduced into Poetry and Fiction, in which writer infused human interest and a semblance of truth into their narrative to stimulate readers’ imagination to perceive an unrealistic context as real.

This term has evolved and the concept of character was generalized into a fictional area. The art form of Animation brought together by the studios of Walt Disney polished this term creating an illusion of life. In the book The Illusion of Life: Disney Animation[39] the authors (Thomas and Johnston) described
how animated characters can show the illusion of being alive, having motivations, thinking, acting and showing emotions. Placed on the first page of this reference book for all Disney Artists and passionate about realism in animation, it begins with:

“Disney animation makes audiences really believe in (...) characters, whose adventures and misfortunes make people laugh - and even cry. There is a special ingredient in our type of animation that produces drawings that appear to think and make decisions and act of their own volition; it is what creates the illusion of life.”

In 1956 a new field in computer science arose in Dartmouth Conference named artificial intelligence. This term was proposed by John McCarthy which defined it as “the science and engineering of making intelligent machines”[40]. Many investigators dreamed to build robots (agents) that could mimic human behaviours with the ability to think, feel and present a sense of awareness. In 1985 American Association of Artificial Intelligence Presidential Address, Woody Bledsoe expressed his desire to build a computer friend[41]. Bledsoe expressed his excitement to see machines understanding, acting, thinking, learning and expressing emotions by themselves. Researchers inspected artistic views of animated characters that could be used to improve the design of believable agents and in late 20th century, computer scientist Joseph Bates studied those artistic principles used in animated characters to help him and other researchers to craft more believable agents[42]. With the rest of the OZ Group, Bates created the Edge of Intentions which consist in a synthetic world with three self-animated believable agents, named Woggles that can interact with one another[42]. As Bates dissected the work of Thomas and Johnston[39], he understood that to properly portrait the emotional reactions of a character, the animator must keep in mind three key points: “the emotional state of the character must be clearly defined”; “the thought process reveals the feeling”; “accentuate the emotion. Use time wisely to establish the emotion, to convey it to viewers, and to let them savor the situation”.

A. Bryan Loyall, a member of OZ Group, considered personality was one of the most prominent requirement in agent believability[43]. This idea emerge from Loyall analyzing Thomas and Johnston’s work, they explain in order to obtain audience attention and cause the characters to come to life in the audience’s imagination is imperative for the character to have a distinguished personality and preferentially a good one[39]. Loyall epitomized personality as “all the particular details - especially details of behavior, thought and emotion — that together define the individual”. Though Loyall also defined other requirements for a better agent believability implementation: emotion - characters should exhibit their emotions in conformity with their personality; self-motivation - characters must react in accordance with their own desires and objectives regardless of other characters; change - characters must evolve and change due given time depending with their personality; social relationships - characters must engage in interactions with others (also other characters) in consistency with their relations. Eventually these relationships could change depending on character interactions; consistency of expression. Loyall also intensifies the importance described in “The Illusion of Life” of another set of requirements to build a believable agent: appearance of goals; concurrent pursuit of goals and parallel action; reactive and responsive; situated; resource bounded - body and mind; exist in
Believable agents and believable characters are two terms whose definitions go hand in hand since believable characters in game share some aspects with the prior. Believable characters such as main characters inside video game, should be interesting and intriguing, must be enjoyable and lastly must evolve and show a sense of progression, those characteristics are mainly based in characters personality. Game designer David Freeman[44] and Lee Sheldon[45] suggests main characters must produce emotions into players/viewers. Their main goal is to “move the player through an interlocking sequence of emotional experiences” thus creating an empathy bond between players and characters. This empathic response produced by main character should be the same as empathic response between real people[46], meaning players establishes empathic relations with synthetic companions in games.

3.4 Motivation and Persuasion: A way to change attitudes and behaviors

Motivation is often defined as the reason for people’s actions, desires and needs. People to perform an action or task often need motivation. Locke and Latham refer the existence of a relationship between performance of a task (set of actions) and the particularity and difficulty of a goal[47]. Through this assumption, Locke and Latham developed the Goal Setting Theory[47] in which is described how different types of goals triggers different individual responses and how to set those goals to motivate behavior. When people are confronted with difficult goals, they manifest high amount of effort and higher performance towards completing those goals.

Locke and Latham emphasize that goals influence performance when one is committed to them, however not all the goals yield an interest outcome. Goals must be specified by and external entity and its difficulty must be adapted to each case[47]. By introducing goals, tasks become less ambiguous reducing the occurrence of frustration. Locke and Latham believe goals affect performance through four mechanisms: goal direct concentration and effort toward goal relevant activities then goal irrelevant activities; high goals achieve greater effort than lower ones; goals generate persistence; goals influence indirectly actions, since they can lead to arousal, discovery, use of task-relevant knowledge and strategies[47]. To Locke and Latham two factors that contribute to goal commitment are relevance of goal realization to the person, including outcomes he expects to attain and self-efficacy, which is the belief that person can achieve the goal. Finally, Locke and Latham reiterated the major importance of feedback to enable one achieve his goals[47]:

“For goals to be effective, people need summary feedback that reveals progress in relation to their goals. If they do not know how they are doing, it is difficult or impossible for them to adjust the level or direction of their effort or to adjust their performance strategies to match what the goal requires.”

Motivation and persuasion are two definitions that go side-by-side, to Fogg, persuasion is a way to
influence people on changing behaviors or creating new ones[48]. To accomplish a behavior-change, Fogg created a model named Fogg Behavior Model (FBM) in which specifies that to change a behavior or creating a new one, three factors must come in place, trigger, ability and motivation. Fogg believes that if one of those three factors don’t come together at the same time the behavior won’t be achieved[48]. The trigger is the primary action that sparks a responsive action, e.g., a telephone rings. The ability is the feasibility of the action provoked by the trigger, if it’s possible or not to execute the action, e.g., the telephone rings and I was in a meeting so I can’t answer. If the action can be performed, it must have a positive motivation. The motivation is the state of mind where the person wants to do the action. Fogg also says that, even those three factors are interconnected, the ability and the motivation can trade-off[48]. To occur a behavior the following formula must happen at the same moment: BEHAVIOR = MOTIVATION . ABILITY . TRIGGER. This formula can be represented by a graphic, figure 3.3, analyzing this graphic is easy to understand that if the motivation factor is high, the ability to do it can be harder and even so the trigger can be achieved. In reverse, if the motivation is low, the ability must be easier to do to the trigger succeed.

Children with physical and mental disability, their ability to do certain exercises or actions is, sometimes, very low. According to FBM, to be able to change or create a new behavior on those children, their motivation must be high.

Having motivation in mind, Fogg created a framework to better understand the three core motivators [48]. Those motivators are Sensation (pleasure/pain), Anticipation (hope/fear) and Belonging (acceptance/rejection). Developing a game with a virtual agent that acts like a companion, children may bound with him, given the children a sense of pleasure to help the agent in certain occasions, give hope to the children on saving the agent from adversities and at the end be social accepted by the agent (becoming friends).
3.5 Validation of Microsoft Kinect in physical therapy

Microsoft Kinect is a sensor that was created by Microsoft with codename Project Natal in 2010. This sensor has a RGB camera, an infra-red emitting sensor and infra-red depth sensor, together they can recognize gestures and track skeleton. Kinect is used as a controller in Microsoft XBox 360 console. This controller uses body motion to promote interaction inside games. In 2012, a version for Microsoft Windows was released, trying to compete with others motion controllers already released at that time, like Asus Xtion PRO. This version of Microsoft Kinect enabled developers to create Windows-based applications that uses body motion to their behalf. A more immersive set of serious games and exergaming were created.

One major concern on the usage of Microsoft Kinect is its precision and performance on areas of health care. The motion capture performed by Microsoft Kinect is a bit noisy, making posture recognition rough. A major reason of the tracking inconsistency is that body parts are tracked separately and occlusions made by the environment in which the sensor is inserted. Nevertheless, with the application of filters, like Butterworth (maximally flat magnitude filter) and other, data can be smoothed and values transmitted by the sensor could be used inside the game. Further studies describe the results that was obtained, ensuring enough precision for most of the clinical rehabilitation treatments prescribed nowadays to patients[49, 50, 51].

Using Microsoft Kinect as a controller to virtual games, exhibits a more enjoyable experience and increase the patients motivation to participate on physical therapy sessions[52].

Overall by using Microsoft Kinect sensor, a markerless motion capture system, to determine body posture and limbs positioning, compared with systems that use markers, it reveals to be an excellent concurrent[51].

3.6 Rehabilitation Systems

3.6.1 Reflexion Health - VERA

Reflexion Health³ is a San Diego startup with a partnership with West Health Institute that developed a system that uses Microsoft’s Kinect to help physical therapy patients with their rehabilitation. The startup’s first product, is named Virtual Exercise Rehabilitation Assistant (VERA), uses the Kinect motion tracking system and a personal computer, and provides interactive feedback and educational information to patients while they are exercising. Their main premise is instead of giving patients photocopied handouts that illustrate their exercise regime, VERA provides instructional video and full-body video game mechanics to patients in their home (prescription software), using the Microsoft Kinect for Windows. The Web-based system coaches patients through their rehabilitation exercises, monitors their performance, and enables physical therapists and physicians to track a patient’s rehabilitation progress in real-time. VERA targets patients with orthopedic injuries. VERA was

³Reflexion Health - http://reflexionhealth.com
developed to target a wide range of extended demographics, trying this way to respond to a wider audience.

A pilot study was conducted by Komatireddy[53] to assess the level of agreement between physical therapists and VERA in determining the quality and quantity of given exercises. In 426 exercises distributed by 10 healthy subjects, VERA was able to accurately count exercises’ repetition in contrast to therapists and VERA was able to rate the quality of 426 exercises consistently in which only 5 out of 7 physical therapists were able to do the same.

### 3.6.2 SeeMe Rehabilitation

SeeMe Rehabilitation is a solution developed by Brontes Processing in cooperation with specialists (Arie Burstin, Riki Brown) from Beit Rivka Geriatric Rehabilitation Hospital (Israel) which uses Microsoft Kinect in virtual games to promote physical rehabilitation to a more elderly audience[54]. The physical therapists can create a set of exercise plans in which the patients are compelled to perform, at home or at the clinic. This exercises are translated in form of games. All games are designed for a more adult target and with a low degree of complexity and not hard to perform (e.g. cleaning windows, hitting balls, moving blocks out of a maze, go shopping). The major advantage that this system brought was the real-time adaptation on each level by the physical therapist, figure 3.4. This adaptability is crucial in order to not lose the patients motivation and engagement. In the management window, physical therapist can see the data capture by the system and study the evolution of their patients. Also, the physical therapist is a companion to the patients, helping them to get pass all the games. SeeMe Rehabilitation has a web interface making it possible of tele-rehabilitation. Currently, SeeMe has 11 games, targeting from physical exercises to everyday actions.

Sugarman performed a small clinical trial using SeeMe and noticed a good adhesion by her elderly subjects. Every participant showed a great level of motivation, promoting a good quality of normal rehabilitation sessions[54].

![Figure 3.4: SeeMee management window.](http://www.virtual-reality-rehabilitation.com/)
3.6.3 Respondesign - RespondWell Rehab Platform

The RespondWell Rehab Platform\(^5\), developed by Respondesign\(^5\), is a set of services focus in the rehabilitation of adults and older adults. This set of services are divided in modules, those modules are Falls Prevention and Rehab, Pulmonary, Senior Fitness and General Wellness. The Falls Prevention module is an interactive and engaging falls prevention and rehabilitation solution developed to improve patient health and vitality. Designed mainly for older adults, is based on an evidence-based exercise program proven to reduce falls and fall-related injuries in frail older adults. The program increases a patient's level of physical activity, engagement, and adherence to an exercise program over time. This contributes to improvements in patient's lower body strength and balance stability – the two most important factors in falls prevention.

Physical therapists perform an initial evaluation and then prescribe a custom routine comprised of balance, strength, and walking movements. While the patients performs this routine by following an animated virtual therapist, the Microsoft Kinect sensor evaluates the patients form and the Virtual Trainer provides additional encouragement. Performance data is collected and analyzed to help predict future outcomes and improve care for both individual patients and larger populations.

The RespondWell Rehab Platform address a need to accurately collect patient assessment and performance data but also monitor the patient both in the clinic and in the home using medical and consumer devices. Respond Well tools help physical therapists make more effective decisions about their patients care, eventually leading to greater healing and better health.

The RespondWell Rehab Platform features a virtual personal trainer named Maya. She is an animated human-looking character which guides individuals through a personalized sequence of exercises, monitor their evolution and provide them useful feedback.

3.6.4 MIRA

A group of Romanians entrepreneurs created for the IT competition ImagineCup developed MIRA\(^6\). MIRA\(^6\) uses video-games to provide a much more effective way for physical therapists to treat their patients. In order to engage the patient into the recovery process MIRA uses virtual games oriented to physical rehabilitation. Customizable to fit patient needs and cover a large area of pathologies. In order to record the patient's movements, the games make use of Microsoft Kinect, an external camera allowing accurate tracking of the patient's body. The main games that compose the MIRA are BeatBalls, Puzzle, Butterfly, Catch, Airplane, Seasons and Piano. BeatBalls the patient must hit the balls using his hands. Puzzles forces the patient to use his fingers. Butterfly targets hand movements. Catch is focused on shoulder movements. Airplane encourages the patient to do hip and lower back movements. In Seasons, the patient makes shoulder movements. Piano, requires the patient to use also his hands. Each game have three difficult levels: easy, medium and hard, and each game progresses through levels.

\(^5\)RespondWell Rehab Platform - http://respondwell.com/
\(^6\)MIRA - http://www.mirarehab.com/
MIRA keeps track of patient’s progress and statistics making it possible to track the patient’s evolution through rehabilitation sessions. The statistics include both range of motion data, showing the increase of mobility in the patients affected joints, and also game related data, showing the difficulty and certain specific objectives the patient may have reached.

MIRA can also record the patient diagnostics in the initial state by using a goniometer and a somatoscopic filter.

Moldovan[57] conducted an evaluation tests of the MIRA system, trying to assess if this system is a reliable and valid occupational therapy scoring system to evaluate bilateral upper limb functions and performance in children with cerebral palsy. Moldovan performed a clinical trial with 27 participants with average age of 7.4±1.9, in which 16 were healthy children and 11 were diagnosed with cerebral palsy and each participant were subjected to four MIRA games. The evaluation’s tests conducted showed MIRA was a reliable and valid occupational therapy tool.

3.6.5 KineRehab

KineRehab[52] is a Microsoft Kinect-based platform that helps physical therapists to work with students with physical impairments in Taiwan[52]. Uses Microsoft Kinect to track the patient’s movements and uses the data to evaluate whether their condition has enhanced. Depending of the results analysis, the physical therapists determines if they need more therapy sessions or more exercises. The interface of KineRehab was created to be attractive, to enhance students interest and motivation to face physiotherapy sessions, but also useful for the physical therapist as the system records some details regarding students and their progress over time.

This solution was evaluated with two young students with motor impairments and was observed a significant increase on the number of correct movements[52].

3.7 Concluding Remarks

In this chapter we introduced various solutions to physical therapy using Microsoft Kinect. All the solutions are proven to work in their reality and some are already approved by FDA (USA Food and Drug Administration). In general terms, they all use games to motivate patients to perform physical exercises. Nevertheless, there aren’t a solution which target primarily the young population, forgetting that children need a different approach in terms of video games, graphics content and interest, since their motivation are very different from other age groups. Also, some of the above solutions try to offer the possibility to use the system without the supervision of a therapist. The therapists need to supervise at all time the rehabilitation session and their patients’ progress, providing feedback to engage body corrections to better accomplish the goals of the exercises. The absence from the presence of the therapist brings a set of problems that the developers didn’t foresee, which was the risk of falls and eventually body injuries, which could cause a major setback in the rehabilitation process.

Some solution tries to accomplish the motivation and persuasion factor using a virtual character
that will mimic the current exercise whereupon the patient will have to reproduce, but without having a person alongside cheering them and making helpful comments, the patients soon loses interest and engagement. On table 3.1 is presented an overall comparison between solutions.

Further, the existence of a virtual embodied conversational agent (ECA) to bond and help subjects to accomplish and motivate the rehabilitation exercises is proven to be beneficial, showing in the case of Laura and ODVIC a great improvement on people's engagement and motivation toward behavior changing.

<table>
<thead>
<tr>
<th></th>
<th>VERA</th>
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<th>MIRA</th>
<th>KineRehab</th>
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</tr>
</tbody>
</table>

Table 3.1: Comparison features between solutions
Chapter 4

Initial Studies

In March 2014, a preliminary study was initiated in two physical rehabilitation clinics. One clinic is Clínica da Fidalga located in Cacém and another one is Claris Medicina Física e de Reabilitação located in Sintra. The two clinics consists of physical therapists, massage therapists and assistants. Both clinics are well equipped with various equipment designed to help patients improve and getting better. They have a wider target of patients, these patients are from children to the elderly ones.

Overall were monitored 10 children in which 3 cases stood out by their complexity and peculiarity. In this paper, those patients will be referenced as participant 1 (P1), participant 2 (P2) and participant 3 (P3), figure 4.1.

P1 is 6 years old and was born with mild cerebral palsy having hemiparesis of his right side, affecting both right hand, arm and leg. Having this disability, P1 neglects his right side and adapts some of his actions to be done using only his left side. Neglecting one of his sides, his body will be developed in a non-symmetric way, giving him discomfort and loss of quality of life.

P2 is 6 years old and was born with a severe cerebral palsy, in her case she also have hemiparesis of her right side but with a more severe outcome. Her right arm and hand are strongly affected which in her case the negligence is greater, doing all her actions with the left side.

P3 is 12 years old and was born with a severe malformation of both her feet and legs. In her life...
time, she already receive lots of surgeries in order to correct her legs and feet. Nowadays, she is being treated to correct her valgus knee condition. Valgus deformity is a body condition in which a bone or joint is twisted outward from the center of the body.

4.1 Physical Therapy Sessions

At the end of all physical therapy sessions, a reunion was made with the physical therapists in order to better understand the cornerstones of each exercise performed. Every exercise has a specific functionality, always having in mind the promotion of normal motor development of children. For children with cerebral palsy with hemiparesis of one side, the exercises try to transfer weight in a correct and effective way to that specific side and increase movement and action using the neglected side and the physical therapists try to reduce the dependency of the unaffected side.

To enhance and improve the upper limbs, the physical therapists assess which is the deficit of the children and try to promote actions with the affected limb or limbs. Particularly in the previous mentioned cases, P1 and P2 have neglected their right side, so physical therapists try to give them tasks in order to use their right side as shown in the figure 4.2. This task main objective is to reach out as much as they can and also use their hand to grab toys and/or objects, thereby increasing the strength and functionality of the injured side.

![Figure 4.2: P1 and P2 stretching neglected arm](image)

To increase functionality of their lower limbs, such as correct gait and feet placement, physical therapists suggest their patients to walk in straight line, walk sideways and climb a step using as the foot support the affected side. In figure 4.3(a), P1 walks in straight line, trying to maintain his balance. The physical therapist assists P1 making him hold her finger using also the hand that he neglects.

Forcing P1 to walk sideways, figure 4.3(b), the physical therapist tries to increase P1’s coordination using both legs.

With the assistance of the step, P1 needs to climb it using in the first place his injured leg, in order to strengthen the muscles of the affected leg and working the balance in one foot as shown in figure 4.3(c).

At the end of each physical therapy session, if the patient cooperated and demonstrated engagement
towards the rehabilitation exercises, the physical therapists gave them a reward. Typically this reward is a sweet like chocolate or candy. This method motivates children to be more active towards the exercises, because they know that in the end if they had done a good job, they will receive a reward, figure 4.4.

4.2 Occupational Therapy Sessions

In the preliminary study done in the field of physical therapy the reality presented to us at Move With Me was always focused on the area of physical rehabilitation. However as the study progresses another area of interest emerges and present themselves as an area where treatment to develop, recover, or maintain the activities of daily living (ADL) and work skills of people with a physical, mental, or cognitive disorder are imperative, this area is Occupational Therapy. During the preliminary study started in March 2014 we didn’t have access to occupational therapists, since the clinics who agreed to be carried out an initial study of this project had no occupational therapists.

An occupational therapy session, as any rehabilitation therapy, is constructed and executed based
on symptoms, requirements and predisposing of each patient. The primary purpose of occupational rehabilitation is to create autonomy and independence so that they can maximize their potential in activities of daily life.

In the first rehabilitation session, the occupational therapist makes a preliminary assessment identifying the activities that the patient couldn’t perform, for example activities of daily living. At the same time, the therapist assesses structures and functions that limit the patient, through this analysis the therapist sets a suitable treatment plan to the patient’s needs. This intervention consists of use of activities and occupations that are significant to the daily life of the patient. Using this approach the therapist can stimulate and develop skills and, in parallel, to stimulate the patient’s interest to be an active part in his own rehabilitation.

An occupational therapist tries to stimulate strength, mobility, balance and cognitive functions in order to restore the functions and autonomy of the patient, trying to maintain or increase their motivation during that process. Among various techniques, the therapist teaches strategies to handle objects, dress clothes, wear shoes and use electronic devices such as computers. Occupational therapists use as intervention tools the massage and muscle stretching when those muscles presents spastic characteristics. Another widely used technique is the Wilbarger technique[58] and also proprioceptive techniques, including brushing technique to stimulate tissues of the arms, legs and back and later the therapist performs a light pressure on the joints.

The therapist also uses the help of tools such as games and play. According to Bobath[59] and Ferland[60], playing is the main task of children, where they practice skills and abstract roles. Ferland also reports that the action of playing has five main features: the sensory, motor, cognitive, affective and social. Games and playing helps the patient become more comfortable with new sensations and sensory experiences. It is accepted that the act of playing is a unique action, differentiated from other occupations and techniques which has characteristics of fun, imitation, spontaneity, suspension of belief and sequential progression. Ferland noted through the various sessions of occupational therapy that playing was very important for the evolution of the clinical condition of the child, therefore Ferland created a Ludic Model[60] where he grouped concepts in a model in which describes the following: play, ludic attitude, action of the play, interest in the play, pleasure of action, ability to act, autonomy and wellbeing. Ferland describes that the act of playing it’s defined by the interaction of 3 main elements: attitude, action and interest. This interaction generate pleasure and ability to act in which helps the child to develop independence and a notion of wellbeing.

4.3 Concluding Remarks

During initial studies, we found two areas of strong influence in the children’s rehabilitation, physical and occupational therapies. As both names suggest, each therapy acts on different areas. Therefore they strongly complement each other, allowing them to focus more intensely on their areas of expertise.

We have observed that physical therapy’s main objective is the physical rehabilitation. Physical therapists create mechanisms so their patients could perform exercises, such as games and fictional
stories, attempting to never surpass the boundaries of the validated techniques existing in the field. Many exercises observed in this study focus on: contradict body movement of the affected members; creating sequences and rhythms, was found that the same exercises were applied more than once in the same rehabilitation session.

We found that occupational therapy acts at the level of cognition and mental abilities. Occupational therapists use a variety of games, which contain well defined rules and objectives in order to promote the importance of completing a task. Therapists also apply chores of the daily living suited to the corresponding age range. These exercises aim to train the patient and instill a satisfaction in the completion of every exercise.
Chapter 5

Move With Me: Design and Development

In this chapter, we will explain how the system is structured and organized. First we will expose how games are implemented, also, we will describe how agents are developed. Then we will show the functions of real-time module and also how it is designed. Finally, we will expose how game sessions with therapists and children influenced in some adaptations and corrections of the games.

5.1 System Overview

Move With Me is a tool designed to help therapists to perform a better rehabilitation session with children. It consists in 3 main modules: video games module, server module and real-time module (figure 5.1). Video Games module possesses 3 games: Apple Tree Game, Kick The Leaf and Skip The Rope. Apple Tree Game and Skip The Rope have a major influence in the upper limbs and Kick The Leaf on the lower limbs (see section Video Games Module - 5.2). Server module has a major task to manage and share data between the other two modules: video games and real-time (see section Server Module - 5.4). Real-time module is represented by a web interface especially designed to therapists to enable them modify some in-game characteristics in real-time (see section Real-time Module - Therapist Web App - 5.5).

All modules communicate over WiFi LAN. This LAN is private and is only created with the purpose of bilateral communication between all modules, thus allows wiring reduction and assures the therapist a higher mobility in rehabilitation sessions.

In the following sections we will scrutinize in more details all existing modules in the project.
5.2 Video Games Module

Move With Me is composed by 3 games focused on a more childlike target. Each game tries to work a specific area of patient's body. For this project we consider two major body areas, the upper part and the lower part. In the upper part we consider both arms and shoulders and for the lower part both hips and legs. As previously mentioned, these games need to be attractive to children, both visually and in terms of game design. Also these games need to be simple and easy to understand, since the target population of this project holds both several physical and cognitive illnesses. For the development of these games some general considerations had to be taken into consideration as the aspects of the objects that will interact with the patient, they need to be big and with strong colors. The visual feedback (UI) existing inside each game should be as simple and limited as possible avoiding visual clutter. With the objective to increase the motivational factor of patients, a virtual agent is used. This agent is placed inside each game scenario and always requests patient's assistance to accomplish some sort of goal. In order to increase the significance of the patient in the game, the agent should be always with some sort of limitation and request all time the help of the patient to complete the objectives intrinsic to each game.

All games were developed with the help of the game engine Unity3D using the programming language C#. This software was chosen by being an excellent solution in the production of games and virtual environments. Furthermore, the integration of the Microsoft Kinect sensor with the Unity3D is fairly transparent, allowing a greater stability in each game.

5.2.1 Apple Tree Game

Apple Tree Game is a game where the patient must pick apples from the tree and put those same apples inside a basket located on the floor, figure 5.2. This game is designed to motivate patients to exert greater activity and movements with their upper body. This game has a number of visual elements,
though not intrusive that helps therapists to know the current status of the game. In the upper left side is presented a session clock which is the total elapsed time of the current session and underneath is the number of breaks the game already had and what remains to be done. On the upper right side is shown a mean time between goals achieved in this game (time between two consecutive apples dropped in the basket) and below are displayed three apples, one red, one green and another one yellow, those are the counters of how much apples was already captured by the patient and by the agent.

The mechanics of this game are quite simple, patient need to grab red apples with the left hand and green apples with the right hand. In game, each hand is also depicted with same color palettes as their respective apple, so the patient can visually identify which hand he should move to capture a certain apple of the tree.

Apple Tree Game has three game parts, i.e., features three breaks and between each break patient has to grab ten apples from the tree and put them on the basket. When the game starts, the game manager (AppleTreeGM) fetch relevant data about the patient from the database, such data are: which arm the system should apply a higher work load and based on which hip, which way the patient should rotate his torso to position the apple in the basket. With these details, game manager can populate the tree and position the basket in the floor. The progression of levels’ difficulty is due to the increment of variable WorkLoadFactor, with a minimum value of 0.0 and a maximum value 1.0. The ratio between red and green apples is constantly changing as therapy sessions progresses. In order to better define this ratio, game manager uses the following formulas:

\[
WorkLoad_{left} = \text{Clamp}(0.5 + \text{WorkLoadFactor}, 0.0, 1.0)
\]

\[
WorkLoad_{right} = \text{Clamp}(0.5 + (-1.0 \times \text{WorkLoadFactor}), 0.0, 1.0)
\]
If the patient need to exercise more one side than the other, the respective WorkLoad (left of right) is used to calculate randomly the overall apples spawned in the tree (figure 5.3). The formula behind the spawning system is the following:

\[
\text{Spawn}_{\text{RedApple}} : \text{Random}(0.0, 1.0) <= \text{WorkLoad}
\]
\[
\text{Spawn}_{\text{GreenApple}} : \text{Random}(0.0, 1.0) > \text{WorkLoad}
\]

Figure 5.3: Apple Tree Game - Example Work Load Random.

To play this game, preferentially the patient should be in the standing position and located about 1 meter away from the sensor. In a less precise way, patients who are in a wheelchair or with another limitation of the lower limbs in which prevent them from standing up, it is possible to play this game on a sitting position, the sensor tries to ignore the lower bones of the patients’ body, capturing only the upper parts of the body (shoulders, arms and hands).

From physical therapy’s point of view, this game promotes arms movement and body coordination. Also the repetitions of this game propels the patient to exercise their body and therefore reducing their body limitations. From occupational therapy’s standpoint this games stimulate cognitive coordination, foments visual observation of the set and motor coordination.

5.2.2 Kick The Leaf

Kick The Leaf is a game where leaves fall from the tree and the patient need to kick them before they reach the floor (figure 5.4). The game is divided in 3 game parts with 10 leaves to be kicked in each part. There are six columns located on screen, each column is assigned to a type of leaf (yellow or green) and they are interpolated. For each column position represents in real life an orientation of the patient’s legs/feet. Patient must kick a falling leaf with a foot with the same color, i.e., left foot is represented with the color yellow thus this foot only kicks yellow leaves and right foot is depicted by the green color therefore this foot only kicks green leaves. The user interface is similar to Apple Tree Game as explained in subsection 5.2.1, the main difference is the leaf counter on the right side of the screen. For each leaf kicked a value of one is added to their respective leaf color.

In contrast to Apple Tree Game, the mechanics of this game is based on the movement of the lower limbs of the patient. Depending on which columns are activated, a leaf will fall in that line and the patient need to raise his foot and guide it to the position where the leaf is falling in order to kick it. Each column has a system acronym: LL, RL, L, R, LR and RR. These acronyms represents a desired motion of the patient’s leg, LL means bring the left leg out (left leg all to the left), RL is to bring right leg in (right leg all to the left), L and R to raise left leg or right leg in the upright position, LR is to move left leg in (left
leg all to the right) and finally RR is to bring right leg out (right leg all to the right). When this game starts, KickTheLeafGM (game manager) fetch relevant information from database about legs and feet registered in the body chart and it makes use of this information to activate the respective columns. As the sessions progresses, the work load applied to each session increases. This work load affects the speed of each falling leaf, a higher work load index correspond a higher leaf speed. Kick The Leaf can be played with both feet activated simultaneously but this feature increases the difficulty factor of the game, since in this configuration the patient must control both feet at the same time in the standing up position. This feature may lead to equilibrium problems.

To better experience the game, patient needs to be in the upright position, 1 meter from the sensor and with the leg whose foot is not active, he must use that leg and foot as a footrest and with the active foot he must swing it from left to right to capture the falling leaves. Depending on the physical and/or cognitive limitations of the patient, the therapist may suggest to sit on a simple chair. The chair must have thin legs and a small back in order not to confuse Microsoft Kinect sensor.

From physical therapy's standpoint, this game promotes the bending and stretching of the knee, stretch and bend of the hip and applying body load on the supporting leg which tries to promote body balance. As for occupational therapy's viewpoint, foment legs coordination, increases the functional use of the leg and cognitive coordination through the color identification.

5.2.3 Skip The Rope

In Skip The Rope the patient must pick up the arrows located in a circular manner on screen and as these arrows are picked the rope rotates accordingly and so the agent can jump over it (figure 5.5). Skip The Rope has also three game parts and in each part patient must help the agent jump over the rope 5 times. The scene is presented with a rope on the floor and the agent on the middle. The UI is very
similar to the other 2 games explained in subsections 5.2.1 and 5.2.2 with the exception of the jumping counter located on the upper right area of the screen. This counter reports the amount of jumps the agent have already done.

At the time of startup, SkipTheRopeGM (game manager) evaluates which hand should be used in this game based on the data previously given on the body chart. The orientation of the arrows are randomly set and in each game part their orientation changes.

From physical therapy’s perspective, this game stimulates the strengthening of the active arm in the game. As for occupational therapy’s viewpoint, it improves arms and cognitive coordination, through the changes of directions of the arrows and changing of the active hand.

In all tests done, we verified that this game is especially difficult for the majority of the patients due to strong arm coordination component, strong need for visual attention and mental concentration. Also, Skip The Rope promotes an almost continuous arms stretching and strength which causes a great fatigue in the long term which usually reflects in a strong loss of motivation and for that reason Skip The Rope doesn’t take in consideration the evolution of the work load index since this game is very complex since its beginning.

5.2.4 Real-time Goniometer

Goniometric measurements are used by therapists to assess standard limitations of motion. For this measurements is used an instrument which measures ranges of motion (ROM) of body joints named goniometer[61] (figure 5.6). This instrument is a helpful clinical tool that allows for objective measurements in order to accurately track progress in a rehabilitation program over time. These ROM measurements can be taken at any joint of Human body and for each of these joints there are a methodology to acquire these angles. Goniometer frequently is used to measure active range of motion.
(AROM) and passive range of motion (PROM). Active range of motion (AROM) refers to the amount of joint motion attained by a patient during unassisted voluntary joint motion. Having a patient perform active ROM provides the therapist with information about the patient’s willingness to move, coordination, muscle strength, and joint ROM. The structures involved with movement of the bones as well as the skeletal arrangements are factors in limiting motion. Also, pain is a limiting factor. The pain that occurs during motion may be due to contracting or stretching of “contractile” tissues and their attachments to bone, or it may be due to stretching or pinching of noncontractile “inert” tissues. Passive range of motion (PROM) is the amount of motion gained by the therapist without assistance from the patient. PROM is usually slightly greater than AROM because each joint has a small amount of motion available that is not under voluntary control. The additional amount of motion available to joints at the end range helps to protect joint structures by absorbing extrinsic forces. Passive testing provides the therapist with information about the integrity of the articular surfaces and the extensibility of the joint capsule, associated ligaments and muscles.

![Goniometer](image)

**Figure 5.6: Goniometer.**

Move With Me, with the help of Microsoft Kinect sensor, has a goniometer. This goniometer is based on AROM, since patients will be playing the games as goniometer captures ROM (active movement). Depending on the game, a set of joints will be captured by the goniometer. For Apple Tree Game and Skip The Rope the joints to be considered are shoulder and elbow and for Kick The Leaf we have hip and knee. To goniometer calculate ROM on each relevant joint, joints’ position are captured every 2 seconds by Microsoft Kinect and converted to vectors. To create these vectors we grab the common joint (basically the joint to calculate the desired angle) and subtract it with the following joint in both directions of this common joint, as explained by the figure 5.7. After those vectors are built, we calculate the acute angle between those 2 same directional vectors and for that we use $\text{arccos}$ of the DOT Product of these 2 vectors, as shown by the following formula:

$$A, B, C \in \mathbb{R}^3$$

$$V_1 = B - A, V_2 = C - A$$

$$\theta = \text{arccos}(V_1 \cdot V_2)$$

Unity3D engine has a set of Vector3 operations already implemented and ready to use. In this case we use function `Vector3.Angle(Vector3 from, Vector3 to)`. This function replaces the need to do all the
calculation previously exposed, since this function aggregates all these steps internally. As described earlier to calculate an specific angle from a given joint it’s necessary to combine existing joints’ position. The joints used to calculate the desired angles are reference on table 5.1.

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<td>Right Hip</td>
<td>Right Ankle</td>
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</tr>
</tbody>
</table>

Table 5.1: Goniometer - ROM

5.3 Virtual Agents

As previous studies have shown[35][33], an agent must be implemented to increase the motivation and engagement of the patient, with the role of being a companion and a helper to him. This agent is critical to avoid frustration by the patient. In addition it will increase levels of cooperation and/or competition between the patient and the agent. To better connect with them, there will be one virtual agent on scene but it will present itself as equal gender[35]. To achieve this, we will have two avatars, male and female, which will be assigned according to patient’s gender.

5.3.1 Agent Architecture

The main characteristic of this project is its speed. Every game designed for this project is based in real-time features, so the virtual agent must be fairly fast and efficient. Brooks created an architecture named Subsumption[62], it’s a reactive robotic architecture associated with behavior-based robotics. Since its creation, this architecture is used broadly in real-time AI. The Subsumption Architecture is built in layers. Each layer represents a set of predefined behaviors. The higher levels are built upon lower levels to create a more complex behavior. The main features in Subsumption is not using an explicit knowledge representation, all reactive tasks are stacked from bottom-up behaviors and the intelligence factor is in the eye of the observer[63].
Our agent is based on a reactive architecture (figure 5.8), which reacts to the environment modifications and game evolution. Our agents use Subsumption Architecture focusing on reactivity based on behavioral rules. As our agents represent Humanoids, they can see and understand their surroundings (environment). As Brooks states, “the world is its own best model”[63] since the world is always up-to-dated, our agents are presented by sensors to understand their environment. They perceive the environment and react to it.

The agents in this project are built by layers. As Brooks explained, each layer defines an important behavior towards elements in the game set. Every game has its own sets of goals, to agents be able to accomplish does goals each game consists of two distinct types of agents: cooperative and competitive. The cooperative agent always needs the patient help to accomplish his goals and the competitive agent compete for a better result against each patient.

Despite our agents being purely reactive, these agents have a memory module (figure 5.8) that is activated at the beginning of each game. This module allows agent to remember the last session of the patient. The main purpose of this module is to create an emotional attachment to patient and enable a potential long-term relationship between agent and patient[64]. The memory module is responsible for asking the database in which date was patient’s last session and if that session was successfully completed. With this data, agent triggers a memory informing how many days has passed since last therapeutic session and also announce if that session was well done, trying to stimulate the patient to do better than his last session.

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All games are different and for that reason each game has its own implementation of the agent. In Apple Tree Game, agent’s main concern is to grab yellow apples from the tree. In the cooperative version, agent asks for the patient’s help because he can’t reach the higher apples on the tree. In the competitive version, agent challenges the patient to see who can get a larger number of apples. The pseudocode of the algorithm used and implemented on the agent is represented by following:

```
AppleTreeGame
    agent go to initial position
    If agent has Memory
        Then start speech recollection previous session
            start speech game part 1
        Else start intro speech
    EndIf
```
While tree has red or green apples Do
  If current game part not started
    Then start game part
  EndIf
  If player is idle > 8 seconds And Random(0.0, 1.0) < 0.5
    Then Motivate
  EndIf
  If game ended
    Then start speech game ending
    go exit scene
    break while
  EndIf
  If game part ended
    Then start speech break game part
    increase current game part
    next while
  EndIf
  If tree has yellow apples
    Then go to tree
    grab yellow apple
    go to basket
    drop yellow apple inside basket
  EndIf
EndWhile
EndAppleTreeGame

At the beginning, the agent triggers the memory module to see if there’s a last session of the patient registered in the database, if module replies negatively he activate game introduction explaining the game to patient and first game part starts. If the memory module replies affirmatively, agent declare the beginning of the game and the game starts. Every frame agent detects if the tree has more yellow apples and if so, he proceeds to capture them. Also in every frame, agent detects if the game as come to a break or has ended and in that way agent triggers behaviors in compliance to each situation. Simultaneously every 8 seconds agent take a 50% chance to spark a motivational speech, in this way tries to motivate the patient to fulfill the objective of the game (grabbing apples).

In Kick The Leaf agent’s only objective is to kick red leaves that fall from the tree. In cooperation mode agent suggests a game of kicking leaves and asks if patient wants to join him and on the other hand, in competitive mode agent defies the patient to kick more leaves than him. At this game, agent implementation is similar to the previous, the main difference is at the game play. Agent is always looking for falling leaves and determine with which foot he needs to kick the leaf, left foot or right foot, shown by the following:

KickTheLeafGame
  agent go to initial position
  If agent has Memory
    Then start speech recollection previous session
    sit on the bench
    start speech game part 1
  Else sit on the bench
    start intro speech
  EndIf
  While player didn’t kick 10 leaves Do
    If current game part not started
      Then start game part
    EndIf
    If player is idle > 8 seconds And Random(0.0, 1.0) < 0.5

Then Motivate
EndIf
If game ended
Then start speech game ending
    go exit scene
    break while
EndIf
If game part ended
Then start speech break game part
    increase current game part
    next while
EndIf
If agent see falling leaf
    Then If falling leaf is on the left
    Then kick leaf with left foot
    Else kick leaf with right foot
EndIf
EndIf
EndWhile
End KickTheLeafGame

For Skip The Rope, the essence of jumping rope always goes back to a cooperative state, because jumping a rope is necessary two players, one to swing the rope and another one to jump it, that’s why in this game is only available a cooperative version of the agent. Here, the agent asks for the patient’s help to swing the rope for him to jump over it. In this variant, agent is watching the rope and when the rope reaches a certain position, agent triggers the jumping behavior. The agent’s implementation is described in pseudocode below:

SkipTheRopeGame
    agent go to initial position
    If agent has Memory
        Then start speech recollection previous session
            start speech game part 1
        Else start intro speech
    EndIf
    While player didn’t jump the rope 5 times Do
        If current game part not started
            Then start game part
        EndIf
        If player is idle > 8 seconds And Random(0.0, 1.0) < 0.5
            Then Motivate
        EndIf
        If game ended
            Then start speech game ending
                go exit scene
                break while
        EndIf
        If game part ended
            Then start speech break game part
                increase current game part
                next while
        EndIf
        If rope on position to jump
            Then jump rope
        EndIf
    EndWhile
End SkipTheRopeGame
3D Models

Due to the nature of the project, the use of 3D models with a very specific visual design was needed. As previously seen, the target population of this project is a more infant population, for this reason it is imperative that the design of the characters were most cartoon as possible, trying to create a parallelism between video game and TV cartoons. Since we didn’t have at our disposal 3D Modelers (3D Artists), it was necessary to purchase the model of the agents in an international 3D company, with the proper licensing assigned to the chosen 3D models. The character picked to represent the virtual agents inside the game has androgynous qualities (figure 5.9), these characteristic was very important to be possible to adapt the gender of the agent in run-time and reduces the burden of multiply 3D models inside the project. In order to differentiate both genders (male and female), some assets were used to try emphasizing their characteristics. For the male character was used snickers, socks and spiky hair. For the female character was used flip-flops and pony-tail hair, as shown in figure 5.9. So that patients could connect to each character, was given to them names. The male character is named Pedro and the female character is called Margarida.

The models were created to be compatible with the Daz3D Studio system with the main intention of being used as 2D render content, due to this fact these models had a dense 3D mesh (high polygon count). In order to use them in a 3D game engine, in this case Unity3D, their meshes needed to be decimated. This process allows to reduce the vertex/face count of a mesh with minimal shape changes and minimal deformations. In Daz Studio 4 is possible to use a Decimator plugin and get a visual feedback in real-time about the changes that the reduction (decimation) causes to the mesh. After tweaking some values available by the plugin, we were able to simplify the mesh around 50% and finally, we could export the model in FBX format. FBX is a proprietary file format created by Kaydara and owned by Autodesk. This format was created to enable an easiness of sharing 3D content between multiply software, hence it is well accepted by the game engine Unity3D and also by the Motion Capture system. In the moment of exportation, we selected all blend shapes existing in the mesh of the head that can generate the relevant facial animation speech/dialogue, in this specific case all blend shapes which the expression prefix begins by “HEAD”. All blend shapes are well tolerated by the FBX.
After the decimation process, we need to understand how the characters were rigged. The 3D model already contained a rigging system but the naming convention of the skeleton hierarchy were not standardized with the Motion Capture system.

5.3.2 Motion Capture

With the full support of the company 112 Studios, they gave us full access to their motion capture system. Their motion capture system is from NaturalPoint Optitrack\(^1\), it consists of a total of 12 cameras installed in a green chroma room with 34 markers to be positioned over specific areas of the body (figure 5.10). This system runs over 2 major software, Optitrack Arena and Autodesk MotionBuilder, both software owned by the company.

![Figure 5.10: NaturalPoint Optitrack Body Markers.](image)

In the previous subsubsection (3D Models), we verified that skeleton naming convention were not standardized with the motion capture system. The skeleton hierarchy must follow a nomenclature convention as shown in the figure 5.11. To change joints’ names, we used Autodesk MotionBuilder to setup our character. In MotionBuilder we changed all joints to match the naming convention, after this step the character was able to be characterized in MotionBuilder. This characterization allows MotionBuilder to map the motions captured by the actor into the character in real-time.

The motion capture sessions extended for over 3 days, since the actor and the motion capture operator was only one person. During this time we captured more than 75 motions, all of them used inside this project.

After using the system, we observed that NaturalPoint Optitrack motion capture solution has some limitations: it cannot capture fine prehension of hands/fingers and face animation (expressions) in simultaneous with the capture of body movements. Due to the fact characters didn’t have a great level of facial detail, facial motion capture was not relevant to this project.

\(^1\)NaturalPoint Optitrack - www.optitrack.com
5.3.3 Voice Recording

As previously explained, this project has virtual characters. Those characters wanted to create an emotional bond with the patient and motivate them to fulfill each game objective, for that reason those characters needed a voice. This project consists of 2 virtual agents, a male and a female, for each was assigned a specific voice. For the male character was used an actor well known by children through TV and Movie Theater cartoons, his name Tiago Caetano. For the female character we also used a highly experienced actress in the area of Movie Theater cartoon named Sandra de Castro. Both actors recorded all voices for this project in 1 morning using the same script (gender free text). This script was written always based on positive intervention, motivation and interesting phrases (see Appendix A). The script was written with the assistance of both actors, as they have years of experience in representation and interpretation of scripts for children.

The recording sessions were performed on a dubbing company named 112 Studios with the help of an audio technician. After all dialogues were recorded, the technician exported all audio files and saved them in WAV file (Waveform Audio File Format) but this format is an uncompressed audio file which leads to a considerable large file size. To reduce this overhead and without losing too much quality, all WAV files were converted to MP3 (lossy compression format) since Unity3D can interpret and reproduce this type of file format, it can reduce size with the compress ratio of approximately 7:1.

After all dialogues were acquired, was important to develop a way to implement facial animation on virtual agents. As verified earlier, the motion capture system couldn’t capture facial animations, so was
important to find a way to animate the agent in Autodesk MotionBuilder. This software has a Device named Voice which gave us the option to implement lip sync through the usage of an audio file, figure 5.12. This Device is very easy to use, first we must define all the phonemes that will be considered during the processing of the audio file. In this case we consider the following phonemes: AE, AO, B, D, F, FV, G, IY, OW, P, PB, T, TD, UH, UW, Z and Silence. In the initial configuration some phonemes were discarded due to lack of existing blend shapes of the 3D model of the agent. After assigning the phonemes with the corresponding blend shape, we need to adjust the weight of the influence of each phonemes interpreted by Autodesk MotionBuilder to character's blend shapes. After all this settings, it was possible to record the agent's facial animations as he spoke.

![Figure 5.12: Autodesk MotionBuilder - Device Voice.](image)

5.4 Server Module

The Server Module's main functions is to manage and share data between the Video Games Module (section Video Games Module - 5.2) and the Real-time Module (section Real-time Module - Therapist Web App - 5.5). For this data exchange take place, this module is divided into two parts. The first part of this module is accessible via the interface provided by the system’s Web App (Therapist Web App) and the second part of this module is the interface that allows the Unity3D game engine communicate with the database. This last part is transparent to both therapist and patient, making it only accessible by the game engine.

This module consists of a set of software modules that allows it to be a great server system in managing, maintaining, and sharing information. To be able to exchange data with system database a communication software is needed that permits that kind of access. For this function was chosen the web page server Apache 2. Apache 2 makes available to a particular network, in our case WiFi LAN, web pages via the HTTP protocol on port 80. The Apache 2 will serve the Web App system of this project.

For handling database is necessary to use JavaScript and PHP. The JavaScript language is fully interpreted by the Apache 2 server and this is executed on the Web Browser (local side). JavaScript allows asynchronous access to call remote functions in PHP, but for PHP to be recognized and to be able to run those same functions through its language is necessary to install and enable additional module in Apache 2 which enables PHP language. PHP is executed in the server side and its function is to handle
In order to be able to keep the server data in a nonvolatile manner, using a database management system is required (DBMS) in this case we used MySQL system. This DBMS is quite robust, with a great performance and this is available for free. A database was created to address the need to record data from and to the game, as explain in subsection 5.4.1.

5.4.1 Database

The existing database on the server module is composed by 9 tables. Those tables are: Patient, Game, Game_Session, Game_State, Rom, History_Log, AppleTreeGame_Realtime_Settings, KickTheLeaf_Realtime_Settings, SkipTheRope_Realtime_Settings, as shown in figure 5.13.

The Patient table keeps track of patients registered in the system. This table keeps generic information about patient, like his name, gender and age. Also maintain information about which body areas is more affected by the illness where all games must apply a greater work load.

The Game table saves a list of active games available in the project to play with any patient at any time.

The Game_Session table keeps records of therapy sessions details, such as game version used, in this case cooperative or competitive in game_version field. This table still saves the performance of each patient throughout the sessions and their respective session dates. The system records the amount of effort index that was applied in each session in max_work_load_effort field, the time interval between each repetition in mean_interval_between_goals field and if the patient completed the session or not in session_completed field. Also retain how many successful repetitions was made in the duration of each game session in goal_repetition field.

The ROM table holds the active range of motion captured every 2 seconds in-game. Eight ranges are considered: shoulders, elbows, hips and knees for both sides, left and right. All ranges are saved in degrees centigrade. Depending upon each particular game, AppleTreeGame and SkipTheRope captures upper body data (shoulders and elbows) and KickTheLeaf captures lower body data (hips and knees).

The remaining five tables are more relevant to the Real-time Module. The Game_State table saves the system state, the game_state field notifies Unity3D game engine if it should start the game or not with the given game session specifications.

The following three tables AppleTreeGame_Realtime_Settings, KickTheLeaf_Realtime_Settings and SkipTheRope_Realtime_Settings maintain all the real-time gaming settings that are available to the therapist to adjust. The AppleTreeGame_Realtime_Settings retains the information to increase or decrease game parts in game_parts field and to change basket position on screen in basket_position field. All this settings will be explained in subsection 5.2.1. The KickTheLeaf_Realtime_Settings stores the information to increase or decrease game parts in game_parts field, to increase or decrease leaf speed on leaf_speed field. The fields l, rl, l, r, lr, rr and reset_falling_leaf_system are referred to the falling leaf system existing in the KickTheLeaf game. All this settings will be explained in subsection
Figure 5.13: Database diagram
5.2.2. The SkipTheRope_Realtime_Settings owns the information to increase or decrease game parts in game_parts field, which hand to be used, left or right, in hand field and the direction of the arrows in direction field. All this settings will be better explained in subsection 5.2.3.

Finally, the table History_Log keeps a record of all changes made by therapists during game sessions in order to analyze the changes that were made over the rehabilitation sessions.

5.5 Real-time Module - Therapist Web App

Move With Me needs to be dynamic and mobile. To attend this characteristics was necessary to develop a web interface especially for therapists in order to empower them with real-time functionalities. To accomplish this we use a set of free frameworks: jQuery, jQuery Mobile and Highcharts. jQuery is a fast and small JavaScript library. It enables HTML document traversal and manipulation, event handling, animation and Ajax (asynchronous JavaScript and XML) much simpler with an easy-to-use API that works across a diversity of browsers. This library is focused on desktop development, therefore we used an addon for this library to grant a better experience in mobile environment and in this case we use jQuery Mobile. The jQuery Mobile framework allows to design a single highly responsive web application that will work on most smartphone and tablet. The Highcharts is a charting library written in JavaScript, offers an easy way of adding interactive charts to the web application. It’s also highly compatible with most smartphone and tablet browsers.

For this module is imperative working with a mobile device, in this case with a tablet. Through this device therapists can manipulate all game sessions since its start up, to editing some gaming settings that they think fits some situations.

On entering the Therapist Web App, it is shown a front page as presented in figure 5.14. On this page, multiple options are made available to therapists in order to make it easier to browse and access important data relative to their patients. This page is divided in two main parts, the top part of this page is a form to register new patients and the bottom part is a list of all patients already registered in the system (previously inserted by therapists).

In this front page, they can register a new patient through a small simple form located on the top side of this page. This form requires patient's name, gender and date of birth. Also, they need to mark in the body chart, areas of patient's body in which are more important to apply a greater effort in games. After all this elements are correctly filled, therapists need to push Register Patient button.

In addition to patient registration, in the lower part of this page is presented a list of all patients, ordered by patient's name, already registered in the system. In this table is displayed patient's ID, name, gender and date of birth. Further, is possible to Update Information, Start Session, View Progress of a patient and ultimately Delete a patient from the database.

The Update Information, represented by a pencil icon, offers to therapists the option to update any relevant data from any given patient. When the pencil icon is pressed, all data previously added to the

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2jQuery - http://jquery.com/
3jQuery Mobile - http://jquerymobile.com/
4Highcharts - http://www.highcharts.com/
database relevant to the patient is filled on the upper part of the page (form). After some modifications of patient's information, is necessary to push Update Patient button on the upper form in order to make the changes effective.

The Progress option shows a list of all game sessions done by a given patient on a specific game, as depicted in figure 5.15. It's generated a table with the dates of all game sessions, the max work load effort applied in each game session, the mean interval between goals captured during a session, the total number of goals repetition achieved and if the game session reached completion.

The Start Session, expressed by a power icon, when pushed is presented a new page (figure 5.16). This page entitled Choose a Game consists of three buttons, wherein each button represents a game available in the system. When a game is chosen, is prompted what type of game version (cooperative or competitive) therapist want his patient to play, figure 5.17. According to the selection, every game has a unique real-time settings page. Following this selection, one of three pages will be presented depending on which game was chosen. Every game has its own real-time setting page.
When Apple Tree Game starts, a set of parameters are automatically defined by the system, using the information provided by database, such as what type and how many apples to be spawned on the tree and the basket position on the floor. However it's possible to therapist change some of those settings in real-time. If Apple Tree Game is previously selected in the page Choose a Game (figure 5.16), a set of options is presented to the therapist, like in figure 5.18. In this page, therapist can start the game session by toggling the switch of Game State, increase or decrease game parts by pressing the corresponding buttons and change basket position on the floor, to the left or to the right. Finally is possible to see patient's real-time progress by pushing View Progress button.

If Kick The Leaf is selected in the page Choose a Game (figure 5.16), an appropriate set of options are shown (figure 5.18). It's possible to start the game session by sliding the toggle of Game State, increase or decrease game parts, increase or decrease falling leaf speed, override falling leaf system and view patient's real-time progress by pressing View Progress button. The override falling leaf system allows therapist to activated or disable any given leaves’ columns, here each column is referenced by its acronym.

Finally, if Skip The Rope is selected, another set of options are shown (figure 5.18). It's also possible to start a game, increase or decrease game parts, therapist can change the active hand to be used in game, left or right hand, change ring direction (clockwise or counterclockwise) and lastly view patient's progress.

Therapist Web App contains a real-time feedback system enabling therapist to better understand how his patient is doing during that specific game session. This option is available to all games and is accessible through the button View Progress existing in all real-time settings page. By choosing this option, a chart will be drawn in real-time as time progresses (figure 5.19), Y-axis represents ranges of motion (ROM) and the X-axis represents time stamps made in real-time by the patient in the current game session. The amplitudes vary between 0 to 180 degrees and it is captured every 2 seconds (subsection 5.2.4). This option is transverse to all games, the only difference is the set of joints displayed.
5.6 Concluding Remarks

The purpose of this chapter was to describe how we implemented our solution for this project. We described an overview how the system is organized. Then we explained the implementation and the mechanics behind every game existing in this project. In addition, we presented how the integrated goniometer system works. Later we proceeded by explaining the virtual agents and how they were conceived. Finally we described how the server works and how it is integrated with the real-time module.
Chapter 6

Evaluation

In this chapter we will describe how we organized and planned our tests. This project was evaluated in two different times. Firstly we performed a preliminary test with a control group. This first test helped to better understand some limitations of the system. With this feedback some adaptations were made to be used in the final evaluation. We proceed to a final evaluation of the system with a group of children with health problems at a clinical environment. Then we describe how we measure the performance of the sessions and present the results obtained. Last, we express some concluding remarks that include the experiment's main results.

6.1 Preliminary Tests

6.1.1 Motivation

In the initial studies (chapter 4) we began our studies in March 2014 with a total of 10 children with most diverse physical disabilities. At this stage it was only analyzed how physical therapy sessions worked, their major problems, their needs and overall limitations. After we have witnessed all of these sessions it was time to draw and implement the solutions behind this project (chapter 5). Following the first iterations of the development of this project, it was necessary to evaluate each solution made in every game developed at this point in time to better understand all the limitations and the adjustments needed to be done. In order to test the different games available in this project, it was necessary to evaluate this project with subjects from the demographic target. The clinics addressed in the initial studies continued to show a very high availability and professionalism in the face of the intrinsic requirements for the development of this project. Once again they offered their space and made available their patients to evaluate this project.

The motion capture device (Microsoft Kinect sensor) is characterized by some peculiarities and limitations that had to be tested with the target audience and also each game has its own particularities. By evaluating at this point, we could absorb the children's adherence for the games, taking into consideration the difficulty of the levels, the dialogues and interactions of interest that agents must perform during games.
6.1.2 Methodology

In order to get the most out of all test experiments, a set of equipment was needed. In each session we brought 2 cameras, a laptop and a 21’ TFT monitor. One camera was facing the patient and another camera from behind the patient capturing both the patient and TFT monitor. The objective of the first camera was to record patient facial expressions and the second one was to capture the interaction between patient and each game.

For the preliminary test, not all of the 10 patients previously analyzed in the chapter 4 were available for this evaluation. From those 10 patients, only 5 patients tested the games. In order to increase the diversity of test results and to increase the quantity of testers, we requested the assistance of 5 children without any health limitations. For this reason, this preliminary test was divided in two parts, the feedback from healthy children and the feedback from patients. Both players were set with the similar configuration, their only difference was the presence of therapist and the location were the sessions were applied, patients had a therapist present in the room and the healthy children didn’t. Also patients were in a clinical environment and the healthy children were inside a studio. In each game session therapist could interact with their patient in order to correct body movements, body postures or other corrections that they found necessary to do at the time.

From healthy children we want to inspect if they like the visuals of the game, if game play is interesting, if they like agent’s interaction and agent’s animation. From patients we want to understand the same aspects as we addressed in healthy children in addition we want to see if due to some physical and cognitive limitations is necessary to modify some aspects from the game, like mechanics, visual elements and agent’s interaction. Also from therapists who were present in each game session. From them we want all feedback about improvements that could be made to each game.

Despite the image data captured during sessions, we also annotated all the empirical data collected from patients and therapists.

6.1.3 Feedback

Although no statistical tests were performed with the preliminary data gathered, much interesting feedback was collected. We received feedback from three different sources: therapists, patients and healthy children. They appear sparse but as a whole they complement themselves.

Healthy children had a strong feedback towards all games, since they don’t have any health condition, primarily they thought the games were fairly easy. Even so they gave constructive ideas in order to improve the games. They suggested to implement a more competitive version of each game and also suggested to make a more competitive agent in the form of speaking. Also was suggested to use a more energetic music in background.

Patients due to their lack of comprehension and cognitive faculties, providing opinions on their part is always quite complicated, nonetheless some of their feedback was obtained through video analysis and body language. In Apple Tree Game some patients didn’t see the basket in the floor or in some cases didn’t understand the functionality of the basket. In order to overcome this problem we placed inside the
basket some green, yellow and red apples to intensify the function of the basket in the floor. Another problem detected during game play was the shader applied to the hand. The shader was opaque, when patients moved their hands and grabbed an apple, the apple was hiding behind the hand icon creating a confusion if a apple was already captured or not. To correct this, a transparent shader (Fresnel shader) was used to help patients understand when a apple was in their hands.

As some patients had severe body problems, in the game Kick The Leaf they couldn’t raise their foot. This lack of movement limited the sensor responses in which caused a lack of movement by the foot within the game which increased in many cases levels of frustration on the part of some patients. To minimize this situation we adapted the capture of the foot to allow the patient’s foot being placed on the floor and only with the ankle rotation causes the foot within the game to move.

In Skip The Rope, the first iteration of this game was very difficult. This game had a ring with 3 different sizes (large, medium and small). Patients had to maintain their arm raised forward and with clean and precise movement they had to describe a circumference with their arm movement. If the hand inside the game would leave from within the ring a fault action was triggered. This provoked a highly powerful sense of failure, leaving patients in a such emotional state that they didn’t want to finish the game. To correct this major problem, the ring was replaced by arrows displaced in a circular way, in which patients needed only to capture each arrow in order to make the rope to spin.

Finally, therapists were the ones who gave a greater number of feedbacks to improve the system. In all games, therapists would like to have more control over some characteristics of each game. Each game should have the option to increase or decrease game parts, depending of the daily evaluation off their patients. In Apple Tree Game, they suggested the option of relocating the basket in real-time. In Kick The Leaf they suggested to be able to change which leaf column was activated at a given time and consequently which foot to be used. Also they occasionally wanted to change the falling leaf speed. And finally on Skip The Rope they wanted to change the active hand at any time and also the arrow directions. In the first solution, in game modifications were made with the assistance of the keyboard, but since Microsoft Kinect sensor is located in front of the system’s monitor and therapists frequently wanted to make changes in game, they unwittingly blocked the sensor while the game was running thereby damaging the capture done by the sensor. This situation was surpassed by the usage of a mobile interface (tablet).

In the preliminary evaluation done at both clinics, both Apple Tree Game and Kick The Leaf were well accepted by the patients. Skip The Rope proved to be a game of physical coordination and motor resistance far more exhaustive then the other two which sometime created a sense of frustration on the part of some patients depending on their physical and mental limitations.

6.2 Final Evaluation

6.2.1 Objective

With this evaluation we hoped to obtain some insight into our thesis hypothesis:
Is it possible to motivate a patient to perform physical exercises through playing games?
Could a patient momentarily forget or neglect their physical and/or mental limitations through playing games?
Can a game session motivate patient to attend rehabilitation sessions with greater commitment?

This project was developed to help children to increase their motivation towards rehabilitation sessions and ultimately helping them to improve their physical and mental health.

We also developed a virtual companion for the patients. Through this experiment we want to understand if children bonded with the virtual character and if the presence of this character increases the challenge and the interest of patients in each game.

6.2.2 Samples

To test this game utility a collaboration was agreed between Instituto Superior Técnico (IST) and Centro de Medicina e Reabilitação de Alcoitão (CMRA). The study methodology was revised with the director of pediatrics, one physiotherapist and one occupational therapist in order to understand the feasibility of the study and which children diagnose would enable them to play the game, mostly all children chosen had a diagnose of cerebral palsy. In total therapists of CMRA picked 8 children with cerebral palsy, 2 with brachial plexus injury, 1 with Rasmussen's encephalitis, 1 with sequelae of glioma and 1 with sequelae of a tumor in the central nervous system and stroke (see Appendix I). All of these health disorders were presented earlier in the section 2.3 - Health Disorders.

This study was a single subject design, where participants played four sessions with the game. This way 13 participants were able to be part of the study, with ages between 4 and 11 years old (M = 7; SD = 2.08), being 8 males and 5 females (see Appendix I). All participants’ caregivers had to sign a consent form before the beginning of the experiment for their children to be able to participate and also the therapists signed a consent form since they would also be part of the filmed sessions while the children were playing the game (see Appendix G).

6.2.3 Procedure

Prior consent from the parents was asked for their child to be part of the study, so they had to sign a consent form explaining the procedures of the study, which was also given to the therapists that were part of the sessions (see Appendix G). After authorization being given the child participated in 4 sessions of the game in the following manner:

• 1st Session: Parents responded to a brief questionnaire about their child, the therapist answered a first questionnaire about the participant diagnose and evaluated the amplitudes of the members in their active movement. The participant before playing the game answered the question “How much they liked to come to the therapy”. Then the therapist was encouraged to choose which games the participant should play and to control the game tools during it. After the game was
played participants were asked “How much did they enjoyed to play these games” using the Fun Toolkit adapted for children and the question “If they had the opportunity if they would like to play again another day” (for more see subsection Measures - 6.2.4);

• 2nd Session: Upon arrival participants were asked again “How much did they liked to come to the therapy since they started playing the game”. Then the tablet was given to the therapist to choose the games and control them. After playing the game participant answered the question “How much did they enjoyed playing the games today”;

• 3rd Session: Followed the same procedure as in session two;

• 4th Session: Parents responded to a brief questionnaire about their child, the therapist answered again the questionnaire evaluating participants active movement amplitude (which did not changed across the four sessions). The participant answered the question “How much did they liked to come to the therapy since they started playing the game” and they played the game with the therapist controlling it from the tablet. After the game, participants answered “How much did they enjoyed to play these games” and “If they had the opportunity if they would like to play again another day”. Also in this session they answered five brief questions regarding the agent believability. The therapist also completed a brief questionnaire at the end of the session (see subsection Measures - 6.2.4).

All participants questions that were addressed to them were orally asked, participants just had to point in the scale their answer.

At the end of the four sessions participants were thanked by their participation and received a certificate of participation in this Project (see Appendix H).

6.2.4 Measures

In order to understand the utility of this game, different measures were used to try and access its effect as well as its feasibility and use by the therapist as a complementary tool. Being a game to help children with mobility difficulties it was important to access each child amplitudes of movement, in order to build a baseline. This kind of evaluation is normally done with the help of a Goniometer, a tool therapists use to see the members maximum amplitude in certain positions. Due to the lack of time and to the sensitive population we were addressing the active movement amplitude evaluation with the goniometer tool was adapted to a simpler form comparing to the normally used measures for this kind of evaluation (like TMFM[65] and PEDI[66]). This way, together with the therapists a simpler evaluation using the goniometer tool was built in order to get as close as possible to the evaluation amplitudes already done by the system. Of notice, these are still different measures (the therapist method and the system method) so no direct comparison should be made.

Below we describe the questionnaires used in this study:

• Parents questionnaire - this questionnaire comprised a set of questions to understand the
participant level of mobility and possible changes observable by the parents at the end of the four sessions (see Appendix B);

- **Participants demographic questionnaire and active movement evaluation by the therapist**
  – in the beginning this questionnaire served as a baseline of the participant active movement amplitude to be compared to the same measure at the end of the four sessions, but what was observed and noted by the therapists was that these amplitudes did not change so much after just four sessions, so this data was used to compare with some caution (since they are two different types of amplitudes measures) with the amplitudes registered by the system, in order to see the effect of the game in participants mobility. Also a demographic questionnaire was applied to represent our sample (see Appendix C);

- **Participant Questionnaire before playing** ("How much do you like to come to the therapy?") - in order to understand if the inclusion of the game brings changes in the motivation of the participant to come to the therapy session. Using the Smileyometer scale[67] where participants indicated which smile best showed how much they liked to come (see Appendix D);

- **Participant Questionnaire after playing** ("How much did you enjoyed to play these games?") - to understand the level of fun/interest that the game brought or not, using the Smileyometer scale and the Question ("If you had the opportunity would you like to play again another day?"). Also in the last session five additional questions were asked regarding the agent believability adapted from the questionnaires in believability used by Reilly (1996)[68] and Gomes (2010)[69] (e.g. "How much did you liked Pedro?"), using the same scale as before (see Appendix E).

- **Therapists Questionnaire** - consisted of questions regarding the participant evolution and the game usefulness as a work tool (see Appendix F).

### 6.2.5 Results

**Participant 1 (P1)**

- **Parents Assessment**: P1 was a 6 years old boy with a diagnose of Spastic Cerebral Palsy Unilateral Right whose parents considered very motivated each time he came to the therapy which maintained in the fourth session (with a score of 6 in 7-point Likert scale), they reported that his son had a score of 6 in the level of autonomy they saw in him on daily life. Regarding the specific questions of P1 daily life activities: able to put the shoes by himself (score of 6), able to dress by himself (score of 5) and able to go to the bathroom alone (score of 6). The scores tended to maintain in the fourth session, reporting a score of 6 for all. In the last session, his parents noticed an improvement in a better positioning of the upper and lower limbs to dress up his clothes and shoes.

- **Therapist Assessment**: The report given by the therapist showed that P1 amplitude of active movement from the affected members had a considered good amplitude (5 in 7-point Likert scale)
and easiness of movement a little lower (4 in 7-point Likert scale). After four sessions of game P1 score of good amplitude was given a 4 and his easiness of movement maintained the same. After the end of the four sessions the therapist reported no difference on the movement amplitude (score of 1 in 7-point Likert scale), considered the game with a score of 4 as a good tool, felt the child was very involved in the game sessions (score of 5 in 7-point Likert scale) and reported differences in the child motivation towards the sessions compared to the normal sessions without the game (score of 6 in 7-point Likert scale). So overall, the game seemed to help the motivation of the child in the sessions but it is clear that only four sessions of the game were few to see more clear results regarding the child disability.

- **Participant Assessment:** P1 reported a high value on how much he liked to come to the therapy (5 in 5-point Likert scale) and in the subsequent sessions his answers presented a mean of 4.75 still showing a good motivation to come to the therapy (presenting a score of 4 in the second session and of 5 on the subsequent ones). P1 presented a mean of 2.75 of enjoyment in playing the game (score of 5 in the first session and of 1, 4, 1 in the other sessions), representing a low enjoyment. Curiously, every time the participant was asked if he would like to play another day (first session and fourth) the answer was always Yes. So this could suggest that this low enjoyment could be perhaps associated with the difficulty that the game still brings, by stimulating the member with the disability. Regarding agent believability, P1 reported the maximum answer (5) for all questions.

- **System Assessment:** P1 presents a Spastic Cerebral Palsy Unilateral Right, which leads to a strong deficiency on his right side. P1 occupational therapist has acquired passive base readings from goniometer of P1 right side on the first and last sessions. In the first session, it was observed that P1 right shoulder ($\theta = 94^\circ$ in $180^\circ$) and right hip ($\theta = 50^\circ$ in $120^\circ$) had a limitation of joint range of motion[61], other joints had a standard value. P1 therapist decided to assign to his patient 4 times Apple Tree Game, 2 times Kick The Leaf and also 2 times Skip The Rope. P1 completed 50% of all the games applied in his 4 therapy sessions. In the non-completed games, P1 achieved above average scores of goal repetitions, almost completing those sessions (see Appendix I). As shown by box plots on figure 6.1, in the first rehabilitation session P1’s right shoulder and right hip were able to surpass the goniometer passive base readings. P1’s right knee almost reached his base reading, however his right elbow was far below his markings. During subsequent sessions (2nd and 3rd), there was an increase in range of motion performed by the patient. At his last session, P1 therapist had redone passive base readings from goniometer and was reported a slight improvement of right shoulder ($\theta = 100^\circ$ in $180^\circ$) and right hip ($\theta = 60^\circ$ in $120^\circ$) but a decrease in right elbow (from $\theta = 150^\circ$ to $\theta = 135^\circ$ in $150^\circ$) and right knee (from $\theta = 110^\circ$ to $\theta = 95^\circ$ in $135^\circ$). Regarding the right elbow, passive range of motion obtained by goniometer in the last session was lower compared to his first reading, however regarding the amplitudes obtained by the system, this participant set a new maximum value for this same joint. It is also of interest to verify that during the progression of the sessions, the patient gradually increased his range of values, obtaining a
bigger range between the maximum and minimum values. It was observed with the evolution of the sessions, participant was able to learn and control his effort in the game Kick The Leaf which led to a decrease in maximal right hip flexion. Through figure 6.1, we can note a significant increase in the concentration values of the range of motion of the right shoulder and right elbow both Quartile 2 and Quartile 3, which suggests that participant has performed a greater number of high amplitudes of these two joints.

![Figure 6.1: Participant 1 - System goniometer results from first and last session](image)

**Participant 2 (P2)**

- **Parents Assessment:** P2 was a 9 years old boy with Rasmussen’s Encephalitis. During application of the project P2 was always accompanied by his grandparents. They recognize that P2 was always very motivated to come to the therapy throughout all four sessions (score of 7 in 7-point Likert scale). Also, they expressed that their grandson had a score of 6 in the level of autonomy in the activities of daily living. Concerning specific activities, they observed some limitations in putting on his shoes by himself (score 4) and also by dressing himself (score 5). Going to the bathroom and doing his hygiene he is autonomous (score 6). In the fourth session, the scores for autonomy in the activities of daily living (score 2) and putting on his shoes (score 7) have been changed, all others maintained same scores.

- **Therapist Assessment:** Occupational therapist revealed that P2 amplitude of active movement from the affected members had a considered good amplitude (5 in 7-point Likert scale) and also a good easiness of movement (5 in 7-point Likert scale). After four sessions of P2, both scores dropped showing some difficulty on performing exercises with affected members (score 3 in 7-point Likert scale). After the end of the four sessions the therapist noticed and improvement on the active movement amplitude (score of 4 in 7-point Likert scale), considered the game with a score
of 5 as a good tool, felt the child was very involved in the game sessions (score of 7 in 7-point Likert scale) and reported differences in the child motivation towards the sessions compared to the normal sessions without the game (score of 5 in 7-point Likert scale). Therapist reported that at first he was not enjoying playing the games but as the sessions evolved he was much more collaborative, interactive, and endeavored to play the games well.

- **Participant Assessment**: P2 expressed in the questionnaire a high value on his enjoyment into going to the therapy (5 in 5-point Likert scale). In the following rehabilitation sessions his answers granted a mean value of 4.75 which shows a high motivation to go to the therapy (score of 4 in the first session and a score of 5 in all others sessions). On his first session P2 indicated that maybe he would want to play the games on another day, but when one asked him in the last session the same question he affirmed that he would like to play those games in another day. Concerning agent believability, P2 reported the maximum answer (score 5) for all questions.

- **System Assessment**: P2 has a severe limitation on his left side caused by his illness, more pronounced in his left upper arm. P2 occupational therapist acquired passive range of motion from P2’s left side. In the first session, P2 passive range of motion from all joints (left shoulder $\theta = 60^\circ$ in $180^\circ$, left elbow $\theta = 70^\circ$ in $150^\circ$, left hip $\theta = 60^\circ$ in $120^\circ$ and left knee $\theta = 60^\circ$ in $135^\circ$) were severe reduced considering the standard amplitudes[61]. In the course of his four sessions, his therapist selected 4 times Apple Tree Game, 4 times Kick The Leaf and 2 times Skip The Rope. P2 was able to fulfill all game sessions, leading all games to completion (see Appendix I). During first session, P2 was able to surpass all passive ranges of motion from his left side on the exception of his left hip (see figure 6.2), in some cases, like left shoulder and left elbow, P2 was capable to achieve a greater concentration of values that surpassed his own passive goniometer base reading, as shown by the representation of Quartile 3 (Q3) of his first session. In his last session, therapist registered an increase of passive ranges of motion on the exception of his left knee (from $\theta = 60^\circ$ to $\theta = 35^\circ$ in $135^\circ$) in which was noticed a decrease value for this joint. In the fourth session, P2 exceeded his passive ranges of motion maximums on the exception of left elbow and left hip. In this session, P2 significantly increased his ranges of motion values for left hip (75% of values under $\theta = 16^\circ$) and left knee (75% of values under $\theta = 21^\circ$). It’s to be noticed P2 was able to adapt his posture to overcome a greater effort in Kick The Leaf, that is why it’s possible to see a small increase of ranges of motion in left hip and left knee.

**Participant 3 (P3)**

- **Parents Assessment**: P3 was a 6 years old boy diagnosed with Cerebral Palsy Bilateral, more prominent on his left side. In all sessions, P3 was accompanied by his grandparents in which considered him very motivated each time he came to therapy which maintained in the fourth session (with a score of 7 in 7-point Likert scale). They reported that his grandson had a score of 5 in the level of autonomy they saw in him on daily life. Regarding the specific questions of P1 daily life activities: able to put the shoes by himself (score of 6), able to dress by himself (score of
6) and able to go to the bathroom alone (score of 7). All scores maintained in the fourth session. On the fourth session, P3’s grandparents stated that this system increased his grandson motivation towards physical and occupational therapies.

- **Therapist Assessment**: P3 occupational therapist reported that P3 had a good amplitude of active movement from the affected members (6 in 7-point Likert scale) and easiness of movement had the same score (6 in 7-point Likert scale). After four sessions of P3, both scores maintained the same (6 in 7-point Likert scale). After the end of the four sessions the therapist reported a great improvement on the movement amplitude (score of 6 in 7-point Likert scale), considering the game a very useful tool with a score of 7, felt the child was very involved in the game sessions (score of 7 in 7-point Likert scale) and reported differences in the child motivation towards the sessions compared to the normal sessions without the game (score of 6 in 7-point Likert scale). Therapist also stated she observed a major difference in P3 motivation, increase of perseverance, endurance and the ability to neglect the pain. During the 1st, 2nd and 3rd sessions, P3 had a leg cast which hindered the implementation of the game Kick The Leaf. Only on the 4th session this participant played this game. This physical limitation allowed therapist to suggest an adaptation of this game to be used by children in wheelchair.

- **Participant Assessment**: P3 reported the maximum value on how much he liked to come to the therapy (5 in 5-point Likert scale) and in the subsequent sessions his answers presented a mean of 5 still showing a high motivation to come to the therapy. P3 also presented a mean of 5 of enjoyment in playing the game (score of 5 in all sessions), representing the maximum grade of enjoyment on playing the games. After every session, P3 claimed he would like to play another day (first and fourth sessions). As believability factor, P3 didn’t like Pedro (1 in 5-point Likert scale), P3 marked a value of 3 when asked if Pedro caught his attention. P3 reported a score of 5 when
asked if he enjoyed to play with Pedro and he would like to see him again (5 in 5-point Likert scale).
P3 felt that Pedro was not a complete friend to him (2 in 5-point Likert scale).

• **System Assessment**: Due to P3 physical limitations and his temporary physical constraint caused by the use of a cast on his left leg, P3 occupational therapist could not perform the passive base reading of the goniometer on P3's lower limbs, therefore on figure 6.3 are not referenced the values of ranges of motion for his left hip and left knee. P3 passive range of motion from his left shoulder ($\theta = 150^\circ$) almost accomplished the standard maximum value established[61]. Still, his left elbow was far below the standard values ($\theta = 45^\circ$ in $\theta = 150^\circ$). In the course of P3's four sessions, his occupational therapist applied a total of 10 games in which 5 times Apple Tree Game, 1 time Skip The Rope and 4 times Kick The Leaf on the last session where his cast was removed. In figure 6.3 we represent on the first session the only session that he used lower limbs (Kick The Leaf). P3 successfully completed all 10 games (see Appendix I) even Kick The Leaf which used his still recovering leg. On P3's first session, he almost reached the passive range of motion for his left shoulder joint, as for his left elbow he highly exceeded the passive base reading, obtaining a Q3 value of 92° (see figure 6.3). P3's therapist reapplied goniometer on the last session only on the upper limbs, since we hadn't a comparative base for lower limbs from the first session. These new readings showed a reduction in both joints. In his last session, P3 maintained his values of ranges of motion on the upper limbs. To be noted, in the last session P3 surpassed his passive base reading for his left shoulder. By comparing P3's left hip and left knee with standardized values[61], P3 accomplished a maximum value for left hip of $\theta = 90^\circ$ and for his left knee $\theta = 100^\circ$.

![Figure 6.3: Participant 3 - System goniometer results from first and last session](image)

**Participant 4 (P4)**

• **Parents Assessment**: P4 was a 4 years old girl with a glioma's sequelae (brain tumor) whose mother considered very motivated each time she came to the therapy (score of 6 in 7-point Likert
scale), however in her fourth session this motivation dropped (with a score of 4 in 7-point Likert scale), she reported that her daughter had a score of 5 in the level of autonomy in her daily life which decayed in her fourth session (score of 4). Regarding the specific questions of P4 daily life activities: able to put the shoes by herself (score of 5), able to dress by herself (score of 4) and able to go to the bathroom alone (score of 6). The scores tended to maintain in the fourth session, reporting a score of 6 for all questions with the exception of the ability to put the shoes by herself (score of 4). P4 mother stated that despite major limitations of her daughter, she is able to notice a growing autonomy every day that goes by. Also she thinks this kind of games/applications must reach a higher number of children to be able to break routine and by playing they can also work.

- **Therapist Assessment**: P4 physical therapist asserted that participant showed a very good amplitude of active movements from affected members (score 7 in 7-point Likert scale) and a good easiness of movement in performing the exercises (score 5). In the last session P4 maintained the same values from first session. At four session, physical therapist reported a low difference on the movement amplitude (score of 2 in 7-point Likert scale), considered the game with a score of 4 as a useful tool, felt the child was very much involved in the game sessions (score of 7 in 7-point Likert scale) and reported some differences in the child motivation towards the sessions compared to the normal sessions without the game (score of 4 in 7-point Likert scale). P4 therapist noticed that P4 talked about the games in others physical therapists sessions even when the game were not to be applied, showing some motivation towards playing the games.

- **Participant Assessment**: P4 pointed a mean value of 3.25 on how much she liked to go to the therapy (session 1 a score of 2, session 2 a score of 5, session 4 a score of 3). This mean value showed that P4 liked to go to the therapy. P4 presented a mean of 3.25 of enjoyment in playing the game (score of 2 in the first session and of 5, 3, 3 in the other sessions), representing a good enjoyment. On the first session P4 was not very convinced about the game, suggesting that she would not like to play the game again, but in the last session P4 changed her opinion and emphasized that she would like to play the game again. Regarding agent believability, P4 reported an average answer (3) for all questions.

- **System Assessment**: P4 suffers of glioma’s sequelae due to a brain tumor. This illness provoked major limitations on the right and left side of her body, also cognitive, concentration and comprehension was affected. P4’s occupational therapist processed to the passive ranges of motion base readings. In passive stance, all joints ranges of motions were inside normal standards[61]. P4 was subjected to 11 games in which 6 were Apple Tree Game, 3 were Kick The Leaf and 2 were Skip The Rope. In all 11 games, P4 did not completed only 2 games (both Kick The Leaf). On P4 first session, her values of active ranges of motion on left elbow, left hip, left knee, right hip and right knee surpassed the values of base readings of passive goniometer. Her left and right shoulder values were almost the same as passive base reading. P4 right elbow was very inefficient, unable to reach the maximum value of her previous base reading as show in
On P4 last session, therapist did not notice any passive ranges of motion variation from her previous goniometer reading. Inside the games, P4 improved her right elbow range of motion and maintained her maximum value for left elbow. For others joints P4 decreased her maximum values as shown in figure 6.4. Nevertheless it’s to be noted that P4 increased the concentration of values in her left shoulder (Q3 = 54°) and left elbow (Q3 = 55.25°), for right shoulder, P4 incremented the values reached obtaining a higher value of Q3 (Q3 = 78.25°).

Figure 6.4: Participant 4 - System goniometer results from first and last session

Participant 5 (P5)

- **Parents Assessment**: P5 was a 6 year old girl with Spastic Cerebral Palsy Unilateral Right in which father stated she was very motivated every time she went to the therapy (score of 7 in 7-point Likert scale) also he reported P5 was somewhat autonomous with a score of 5 in the level of autonomy which maintained in the fourth session (score 5 in 7-point Likert scale). Concerning the questions of P5 daily life activities: able to put shoes by herself (score 6), able to dress by herself (score 4) and able to go to the bathroom alone (score 4). The score for the ability to put her shoes by herself (score 6) continued in the fourth session however other questions obtained a different score, the ability to dress by herself increased (score 5) but the ability to go to bathroom decreased (score 3).

- **Therapist Assessment**: Occupational therapist received on the first session a questionnaire in which reported that P5 amplitude of active movement from affected members had a somewhat good amplitude (5 in 7-point Likert scale) and easiness of movement received a smaller value (4 in 7-point Likert scale). At the last session both questions obtained the same results. After the end of the last session therapist expressed a low difference on the amplitude of active movement (2 in 7-point Likert scale), considered the game with a score of 4 as a good tool, felt child was very
involved in the game sessions (score of 5 in 7-point Likert scale) and also reported differences in the child motivation towards rehabilitation sessions (score of 4). Therapist noticed that P5 in the first session was afraid but eventually she got involved and enjoyed the game.

- **Participant Assessment**: P5 expressed that she didn’t like to go to the therapy with a mean value of 2.25 (scores of 1, 2, 1 and 5 in each respective session). P5 somewhat liked to play every game with a mean value of 2.5 (scores of 1, 5, 3 and 1 in each respective session). At end of first session P5 was reluctant if she would like to play the game again but in her last session she stated she would like to play every game again. When asked about agent believability, P5 didn’t like very much Margarida (score of 2), thought Margarida didn’t caught her attention (score of 2), she didn’t enjoy playing with Margarida (score of 2), she didn’t like to see Margarida again (score of 2) and ultimately she thought Margarida was her friend (score of 3). All this low scores may be assigned to the lack of language localization of all games, the system were focused in a Portuguese population and P5 is Hungarian with low ability to understand Portuguese which made difficult for the participant to understand what the agent said.

- **System Assessment**: P5 possesses Spastic Cerebral Palsy Unilateral Right, affecting her right side with a high level of tonus. As explained before, P5 is Hungarian whom mildly understands Portuguese and this circumstance did not permitted P5 to have a fully pure experience from the games, since every game implemented in this project utilizes a virtual agents which speaks only Portuguese. P5 occupational therapist took passive goniometer base readings on her right side and reported a severe low ranges of motion on all joints[61] (see figure 6.5). P5 participated in a total of 10 games in which 5 times Apple Tree Game, 2 times Kick The Leaf and 3 times Skip The Rope. In 10 games, P5 did not complete 4 of them (2 Kick The Leaf and 2 Skip The Rope). On P5 first session, she highly surpassed all passive goniometer base readings from all joints, neglecting the pain and muscle atrophy (see figure 6.5), achieving maximum values from almost all joints (right shoulder $\theta = 175^\circ$ in $\theta = 180^\circ$, right elbow $\theta = 150^\circ$ in $\theta = 150^\circ$, right hip $\theta = 90^\circ$ in $\theta = 120^\circ$ and right knee $\theta = 131^\circ$ in $\theta = 135^\circ$). On P5’s last session, therapist repeated passive goniometer reading and reported the same ranges of motions from the first session. In this same session, P5 once again surpassed the maximums values established by the passive goniometer. Important to point out, P5’s right hip and right knee acquired a higher concentration of values comparing with the first session, 50% of the values (Q2 + Q3) acquired by the system are located between $\theta = 51^\circ$ and $\theta = 58^\circ$ for right hip and $\theta = 31.5^\circ$ and $\theta = 59^\circ$ for right knee (see figure 6.5).

**Participant 6 (P6)**

- **Parents Assessment**: P6 was a 7 year old boy with Spastic Cerebral Palsy Bilateral. P6 was accompanied by his grandparents in which they understood his grandson was very motivated towards physical therapy sessions (score of 6 in 7-point Likert scale). They reported an increase of motivation of their grandson on the last session (score of 7). P6 grandparents also affirmed that
Figure 6.5: Participant 5 - System goniometer results from first and last session

their grandson had a normal autonomy on his daily life activities (score of 5 in 7-point Likert scale). For specific activities like putting his shoes (score of 4), getting dress by himself (score of 6) and going by himself to the bathroom (score of 6), he had a good autonomy. On the exception of putting his shoes, they reported an increase of autonomy on all the other activities (score of 7).

**Therapist Assessment**: P6 physical therapist verified that P6 had a normal amplitude of active movement (score 5 in 7-point Likert scale) and the same easiness of movement (score of 5), those scores were kept the same for the last session. In the end of the four session, therapist didn’t notice no improvement on the movement amplitude done by P6 (score 1 in 7-point Likert scale), considered the game a good tool (score of 4), observed the child was very involved in the game sessions (score of 7) and stated no difference in this participant motivation towards rehabilitation sessions (score of 5). Therapist affirmed that maybe he would use this tool in future physical rehabilitation sessions. P6 therapist also observed a more motivated patient wherein verbalized that “he was the best” and “I always win this game”.

**Participant Assessment**: A questionnaire was given to P6 in which he described that he liked very much to go to physical therapy (mean value of 4.75). After playing every game, he continued to like very much to go to therapy (mean value of 4.75). When asked if he would like to play the game again he assertively said yes. Concerning agent believability, P6 answered the maximum values (score of 5) for all question on the exception of the first question (score of 4).

**System Assessment**: P6 carries a Spastic Cerebral Palsy Bilateral affecting mostly his left side. At the beginning of first session, P6’s physical therapist acquired passive ranges of motion from his patient and noted P6’s left shoulder ($\theta = 165^\circ$ in $\theta = 180^\circ$ ) and left elbow ($\theta = 135^\circ$ in $\theta = 150^\circ$ ) reached high values, instead P6’s left hip ($\theta = 90^\circ$ in $\theta = 120^\circ$ ) and left knee ($\theta = 90^\circ$ in $\theta = 135^\circ$ )
have fallen short in terms of their ranges of motion. P6’s therapist assigned to him 13 game sessions, in which 5 were Apple Tree Game, 4 were Kick The Leaf and 4 were Skip The Rope. In all 13 games, P6 didn’t completed only 1 game session (Skip The Rope), presenting a good adhesion to the games. In his first session, his left elbow and left knee beat the passive ranges of motion however his left shoulder and left hip failed to hit passive ranges of motion. In the fourth session, therapist repeated the goniometer on P6 and analysed no changes in him. Inside game session, P6 improved his maximum left hip. To be noted, in the last session P6 left elbow (50% of values between $\theta = 24.75^\circ$ and $\theta = 74.5^\circ$) and left hip (50% of values between $\theta = 6^\circ$ and $\theta = 17^\circ$) increased their values concentration in counterpoint to the first session.

Figure 6.6: Participant 6 - System goniometer results from first and last session

Participant 7 (P7)

- **Parents Assessment**: P7 was a girl with 4 year old which suffer a sequelae of Central Nervous System Tumor and Stroke. Throughout all sessions she was escorted by her grandparents and they reported that P7 was highly motivated to go to the therapy (score of 7 in 7-point Likert scale) in all her sessions. Also they described that their granddaughter had a very autonomy on her daily life activities, at her last session they reported a decrease on her autonomy (score of 5 in 7-point Likert scale). Regarding autonomy in activities such putting her shoes (score of 4), dressing by herself (score of 4) and going to bathroom (score of 5), those scores remained the same on the last session on the exception of putting her shoes by herself which decreased (score of 3).

- **Therapist Assessment**: P7 physical therapist reported a slightly good amplitude of the active movement (score of 5 in 7-point Likert scale) which kept the same in the last session and for easiness of movement is described as slightly good easiness (score of 5 in 7-point Likert scale) this value also remained at the last session. In the last session P7 stated slightly no improvement
in the amplitude of active movement (score of 3 in 7-point Likert scale), also thought this game is a useful tool (score of 4 in 7-point Likert scale), felt his patient were very involved in the session and additionally felt a moderately difference in the child motivation towards rehabilitation session (score of 5 in 7-point Likert scale).

- **Participant Assessment**: When inquired if P7 liked to go to therapy before playing the game P7 answered neutrally (score of 3 in 5-point Likert scale). In later sessions P7 presented a mean of 3.67 showing a slight increase of motivation to go to therapy. P7 expressed she liked to play the game (mean value of 4). In the first session P7 didn’t want to play the game again but at the last session she changed her opinion and she would like to play the game. As for agent believability, P7 liked Margarida (score of 4), taught Margarida caught her attention (score of 4), she liked very much to play with Margarida (score of 5), also expressed that she would like to see Margarida again (score of 5) but she felt that Margarida wasn’t somewhat her friend (score of 2).

- **System Assessment**: P7 suffers sequelae of Central Nervous System Tumor and Stroke which has a greater impact on her left side. P7’s physical therapist applied 11 games during her four rehabilitation sessions. In those 11 games, P7 did not completed 2 games (both Kick The Leaf) (see Appendix I). P7’s therapist proceeded with passive goniometer reading and was noticed a deficit in ranges of motion on both left shoulder ($\theta = 110^\circ$ in $180^\circ$) and left hip ($\theta = 90^\circ$ in $120^\circ$).

In P7’s first session, on the exception of left knee, all joints achieved a high range of motion, surpassing the passive reading. At the beginning of the fourth session, P7’s therapist redone the passive goniometer reading and noticed no evolution in any joint. In game session, P7 consistently maintained the same results including her limitation on her left knee, unable to reach the maximum value of passive base reading.

![Figure 6.7: Participant 7 - System goniometer results from first and last session](image)
Participant 8 (P8)

- **Parents Assessment**: P8 was a boy with 10 years old with Spastic Cerebral Palsy Bilateral whom mother brought him to occupational therapy. She stated P10 was highly motivated to go to therapy (score of 6 in 7-point Likert scale) and P10 had a low autonomy in daily life activities (score of 3 in 7-point Likert scale). P10 mother also referenced that he had absolutely no autonomy in putting on shoes by himself (score of 1 in 7-point Likert scale), as for dressing himself he had somewhat autonomy (score 3 in 7-point Likert scale) and finally P10 wasn’t autonomous to go to bathroom by himself (score of 1 in 7-point Likert scale).

- **Therapist Assessment**: P8’s occupational therapist reported that he had little amplitude in active movement (score of 3 in 7-point Likert scale) and also the same value of easiness of performing exercise (score of 3). No more data were acquired from therapist since P8 didn’t complete all 4 sessions.

- **Participant Assessment**: P8 expressed he liked going to therapy (score of 3 in 5-point Likert scale) and he also liked playing the game (score of 3) affirming that he would like to play the game again.

- **System Assessment**: P8 was a special case presented by occupational therapist to better understand how useful this system was towards a severe physical limitation in a patient. P8 suffered from a highly severe Spastic Cerebral Palsy Bilateral affecting both sides of his body. This illness highly damaged his motor and comprehension skills, also he was unable to focus his attention towards objects and people. P8 was dependent of a wheelchair becoming difficult to the system to interpret lower limbs movements. Nevertheless therapist tried to apply Apple Tree Game to him to better perceive if P8’s motivation to move and cooperate towards therapy sessions could increase since this participant always showed a low interest in rehabilitation sessions. P8 had another problem, P8’s parents neglected his therapy sessions, leaving him with only 1 game session (see Appendix I). However P8 presented a high adhesion towards the game that we felt compelled to present P8 results. P8 passive goniometer reading presented, as expected, a low ranges of motion (see figure 6.8). Inside game session, P8 started the game by directing his eyes towards the monitor and very quickly P8 started to move his arms. In his session, P8 was able to achieve new maximums to all upper joints, surpassing his passive base reading for left shoulder ($\theta = 150^\circ$ in $\theta = 180^\circ$), left elbow ($\theta = 137^\circ$ in $\theta = 150^\circ$), right shoulder ($\theta = 138^\circ$ in $\theta = 180^\circ$) and right elbow ($\theta = 128^\circ$ in $\theta = 150^\circ$). P8 was able to maintain for left and right elbows 50% (Q2 + Q3) of the ranges of motion between $\theta = 38^\circ$ to $\theta = 78^\circ$ and between $\theta = 46^\circ$ to $\theta = 90^\circ$ correspondingly, suggesting that P8 performed more flexions in both joints during game play.

Participant 9 (P9)

- **Parents Assessment**: P9 was a boy with 6 year old with Spastic Cerebral Palsy Unilateral right whose grandfather brought him all sessions. P9’s grandfather reported P9 were highly motivated...
by going to physical therapy (score of 6 in 7-point Likert scale), this score increased in last session (score of 7 in 7-point Likert scale). Also we stated P9 had a moderated autonomy in putting his shoes (score of 5), dressing by himself (score of 5) and going to bathroom by himself (score of 5). During the evolution of occupational therapy session with the game, P9’s grandfather perceived and evolution in his grandson achieving an increment in P9’s autonomy: daily life activities (score of 7), putting his shoes (score of 6), dressing by himself (score of 6) and going to bathroom by himself (score of 7). P9’s grandfather noticed an increase in P9 attention, also suggesting these games should be applied and used in every occupational therapy sessions.

• **Therapist Assessment**: P9 occupational therapist analyzed his movements and stated P9 had a low amplitude of active movement (score 2 of 7-point Likert scale) and a low easiness in performing exercises (score 2 of 7-point Likert scale) which kept the same values in the last session. Therapist indicated the game was a useful tool (score of 4 in 7-point Likert scale), felt P9 were very much involved in the game (score of 7 in 7-point Likert scale) and perceived a moderated difference in child motivation towards therapy sessions (score of 5 in 7-point Likert scale). Therapist also referred P9 had a strong interest in video games, so before the session he was already showing some agitation that reflected the strong motivation towards the experiment.

• **Participant Assessment**: P9 strongly like to go to therapy sessions (mean score of 5 in 5-point Likert scale) and after playing the games P9 maintained the same opinion (mean score of 5 in 5-point Likert scale). P9 also strongly liked the games with a score of 5 and surely P9 would like to play every game again. Regarding agent believability, P9 gave maximum score to all questions (score of 5 in 5-point Likert scale).

• **System Assessment**: P9 possesses Spastic Cerebral Palsy Unilateral right, suggesting a
physical limitation on his right side. P9’s occupational therapist subjected his patient to 12 game sessions in which P9 didn’t complete 3 games (2 Kick The Leaf and 1 Skip The Rope). In the first session therapist read the passive goniometer base readings from P9 and it was notorious a severe limitation on right shoulder ($\theta = 60^\circ$ in $\theta = 180^\circ$), right hip ($\theta = 80^\circ$ in $\theta = 120^\circ$) and right knee ($\theta = 50^\circ$ in $\theta = 135^\circ$). During game play, P9 improved his ranges of motion for right shoulder, right hip and right knee, meanwhile right elbow continued to show some limitations to achieve higher amplitudes. In the last session, P9 therapist had redone goniometer passive readings and was evident an improvement in right shoulder (from $\theta = 60^\circ$ to $\theta = 120^\circ$) and right knee (from $\theta = 50^\circ$ to $\theta = 80^\circ$). When examining figure 6.9, P9’s fourth session revealed that his upper limbs performed a wider ranges of motion and for his lower limbs executed more concentrated ranges of motion with higher values of amplitude.

![Figure 6.9: Participant 9 - System goniometer results from first and last session](image)

**Participant 10 (P10)**

- **Parents Assessment**: P10 is a boy with 9 years old suffers from Brachial Plexus Injury, his mother accompany P10 in all sessions. She reported that he was always very much motivated to go to therapy sessions (score of 7 in 7-point Likert scale), this same motivation maintained in the last session (also score of 7). In daily basis, she felt P10 was very autonomous in all daily life activities (putting shoes by himself with a score of 7, getting dressed with a score of 7 and going to bathroom by himself with a score of 7). In the last session she noticed overall autonomy kept the same (score of 7) but she noticed the activity of putting shoes by himself was a bit difficult, which decreased the score to 6 in 7-point Likert scale.

- **Therapist Assessment**: P10’s therapist analyzed P10 body movements and noticed a low amplitude of active movement (score of 2 in 7-point Likert scale) and a low easiness of movement
by the affected member (score of 2 in 7-point Likert scale), therapist didn’t notice any evident evolution of P10’s movement in which therapist continued to report a score of 2 for both questions. At the last session therapist felt this game were somewhat a good tool (score of 4 in 7-point Likert scale) and the motivation of P10 were good (score of 5) in which therapist understood were the same as a regular therapy session (score of 5 in 7-point Likert scale), nevertheless therapist affirmed that he would use this tool in the future.

- **Participant Assessment**: P10 reported a very high enjoyment into going to therapy sessions (score of 5 in 5-point Likert scale) and in the subsequent sessions using the game tool the enjoyment kept the same (mean score of 5). Throughout sessions, P10 appreciated very much playing the games (score of 5 in 5-point Likert scale) and ultimately he replied that he would like to play the game again in the future. As for believability, P10 liked Pedro (score of 4 in 5-point Likert scale), he taught Pedro took his attention (score of 5), he enjoyed very much playing with Pedro (score of 5), he would like to see Pedro very much (score of 5) and finally taught Pedro was his friend (score of 5).

- **System Assessment**: P10 endure a Brachial Plexus Injury in which damaged his right arm. This severe injury does not allow flexing his right shoulder. P10 occupational therapist applied 12 games wherein 5 were Apple Tree Game, 4 were Kick The Leaf and 3 were Skip The Rope. Therapist chose to apply the game Kick The Leaf on P10 because despite his limitation is in the right arm, sometimes neglecting to use that side causes some imbalance where this game could somehow encourage this type of training. In total of 12 games, P10 failed to complete only 2 of them (Kick The Leaf) (see Appendix I). In P10’s first session, his therapist acquired passive goniometer readings and it has become quite notorious a severe limitation in flexion of the right shoulder ($\theta = 35^\circ$ in $\theta = 180^\circ$), also his right hip and right knee presented a low flexion value[61]. During the game at the first session, P10 attained a maximum of $\theta = 119^\circ$ for his right shoulder largely exceeding the values obtained from his passive goniometer reading. In the last session, therapist verified the same results for P10’s passive goniometer reading. However during the game there were some changes, P10 reduced his maximum flexion value for right shoulder ($\theta = 66^\circ$ in $\theta = 180^\circ$) yet it’s still a higher value than passive goniometer.

Participant 11 (P11)

- **Parents Assessment**: P11 was a girl with 11 years old with Cerebral Palsy whom mother accompanied her every session. Her mother reported that P11 was very motivated to go to therapy (score of 7 in 7-point Likert scale), P11 had a neutral autonomy on daily life activities (score of 4 in 7-point Likert scale), slightly low autonomy to put shoes by herself (score of 2 in 7-point Likert scale), a moderately autonomy on dressing by herself (score of 5) and a very high autonomy to go to bathroom by herself (score of 7).

- **Therapist Assessment**: P11 occupational therapist expressed that P11 amplitude of active movement were slightly low (score of 3 in 7-point Likert scale) and her easiness of execution in
Participant 10 - System goniometer results from first and last session

Performing exercises were even lower (score of 2), in later session she reported the same score for amplitude of active movement (score of 3) but for easiness of execution in performing exercises P11 increased her easiness (score of 3 in 7-point Likert scale). Therapist didn’t notice almost no improvement in the amplitude of active movement (score 2 in 7-point Likert scale), he felt that game tool is somewhat a good tool for rehabilitation sessions (score of 5), felt that P11 were somewhat involved in game sessions (score of 5) and also felt a slightly difference in P11 motivation towards rehabilitation sessions (score of 5). Therapist affirmed that in the beginning P11 was not very pleased in joining the activity but after sometime she strove to improve performance and engaged more in games. Therapist also expressed he would use this game tool in future rehabilitation sessions.

- **Participant Assessment**: P11 also received a questionnaire in which she informed in the first session she liked very much on going to therapy (score of 5 in 5-point Likert scale), in following sessions she continuing expressing she liked very much on going to therapy after playing the games (mean score of 5). P11 enjoyed very much the games presenting a mean score of 5 and she stated in the first session she maybe would like to play the game again in which at the last session she changed her opinion and she would like to play the game in the future. As for agent believability P11 answered she liked Margarida (score of 4), she taught Margarida caught her attention (score of 4), she enjoyed very much playing the games with Margarida (score of 5), she somewhat would like to see Margarida again (score of 4) and finally she taught Margarida were somewhat her friend (score of 4).

- **System Assessment**: P11 suffers from Cerebral Palsy with right hemiparesis. This illness present weakness and clumsiness in her right side. P11 was subjected to 10 games (4 Apple Tree Game, 2 Kick The Leaf and 4 Skip The Rope), completing all games successfully (see Appendix I). While
applying the goniometer in the first session were detected several limitations on her right shoulder ($\theta = 100^\circ$ in $\theta = 180^\circ$), right hip ($\theta = 75^\circ$ in $\theta = 120^\circ$) and right knee ($\theta = 95^\circ$ in $\theta = 135^\circ$) which maintained in the fourth session (see figure 6.11). Inside game, P11 surpassed the maximum values obtained by passive goniometer on right shoulder ($\theta = 100^\circ$), right hip ($\theta = 120^\circ$) and right knee ($\theta = 135^\circ$). In the last session P11 decreased her performance, lowering her maximum values for all joints, nevertheless 50% of her right shoulder ranges of motion increased focused between $\theta = 41^\circ$ and $\theta = 85.75^\circ$.

![Figure 6.11: Participant 11 - System goniometer results from first and last session](image)

**Participant 12 (P12)**

- **Parents Assessment**: P12 were a girl with 6 years old presenting Brachial Plexus Injury. She was escorted by her mother in all sessions. P12's mother observed her daughter were somewhat motivated to go to therapy (score of 5 in 7-point Likert scale) which she understood P12 increased slightly her motivation towards rehabilitation sessions increasing her score (score of 6 in 7-point Likert scale). P12's mother also reported her daughter autonomy in daily life activities were normal (score of 4 in 7-point Likert scale), on specific activities such as putting on her shoes by herself (score of 5 in 7-point Likert scale), dressing by herself (score of 6 in 7-point Likert scale) and going to the bathroom alone (score of 6 in 7-point Likert scale). In the last session, P12's mother felt an improvement in her overall autonomy, giving new scores: autonomy in daily life (score of 6 in 7-point Likert scale), putting her shoes by herself (score of 6 in 7-point Likert scale), dressing by herself (score of 7 in 7-point Likert scale) and also going to bathroom alone (score 7 in in 7-point Likert scale).

- **Therapist Assessment**: P12’s physical therapist reported P12 has a good amplitude of active movement (score of 7 in 7-point Likert scale) and an easiness of performing exercises slightly
good (score of 6 in 7-point Likert scale), both scores maintained in the last session. Therapist stated P12 had a low improvement (score of 2 in 7-point Likert scale), felt this game is a useful tool for therapy sessions (score of 6 in 7-point Likert scale), also felt P12 were much involved in the game sessions (score of 6 in 7-point Likert scale) and as motivation therapist noticed a neutral difference (score of 4 in 7-point Likert scale). Therapist also expressed that novelty game associated with technology has generated an increase of motivation compared to other traditional games which she repeats outside of therapy. He also affirmed that maybe he would use this tool in future rehabilitation sessions.

- **Participant Assessment**: P12 described she liked to go to therapy (score of 4 in 5-point Likert scale), after playing the games she continued to like going to therapy (mean score of 4.33 in 5-point Likert scale). P12 expressed she liked the game with a mean score of 4.25 and also answered she would like to play the game in the future. P12 liked Margarida (score of 5 in 5-point Likert scale), she taught her attention were slightly caught by Margarida (score of 4 in 5-point Likert scale) as for enjoyed playing with Margarida and if she would like to see Margarida again P12 responded neutrally (score of 3 in 5-point Likert scale), nevertheless she somewhat taught Margarida were her friend (score of 4 in 5-point Likert scale).

- **System Assessment**: P12 endure a Brachial Plexus Injury affecting her left side. She was subjected to 10 games (4 Apple Tree Game, 4 Kick The Leaf and 2 Skip The Rope) and successfully completed all of those games (see Appendix I). P12’s passive goniometer revealed normal values[61] (see figure 6.12). During first session P12 it was evident that she performed wide ranges of motion on her left elbow (values between $\theta = 4^\circ$ and $\theta = 148^\circ$ ) and left shoulder (values between $\theta = 5^\circ$ and $\theta = 105^\circ$). Not being a problematic limb, P12’s right elbow also achieved a high wide range of motion (between $\theta = 0^\circ$ and $\theta = 140^\circ$). In the last session the motion spectrum of left elbow has decreased however her left shoulder, left hip and left knee were more prominent. It is also noteworthy the performance of her right elbow in which improved from the first session (see figure 6.12). In both sessions, P12 was unable to surpass any passive goniometer ranges of motion.

**Participant 13 (P13)**

- **Parents Assessment**: P13 is a 6 years old boy with Spastic Cerebral Palsy whom father always brought him to therapy sessions. P13’s father stated his son at first had a somewhat low motivation into going to therapy session (score of 3 in 7-point Likert scale) but after playing the game he noticed an improvement in P13 motivation increasing his score (score of 4 in 7-point Likert scale). P13’s father indicated that his son had a somewhat low autonomy in his daily life activities (score of 3 in 7-point Likert scale), P13 cannot put his shoes by himself (score of 1 in 7-point Likert scale), almost P13 cannot dress by himself (score of 2 in 7-point Likert scale) and P13 had a low autonomy to go to bathroom alone (score of 2 in 7-point Likert scale). In the last session those scores changed slightly, increasing the scores of autonomy (putting shoes a score of 3,
by himself a score of 3 and going to bathroom alone a score of 4 in 7-point Likert scale). Lastly, P13 father understood there should be more sessions with the game.

- **Therapist Assessment**: P13’s occupational therapist reported a slightly good amplitude of active movement (score of 6 in 7-point Likert scale) and somewhat an easiness of performing exercises (score of 5 in 7-point Likert scale), at the last session the amplitude of active movement kept the same (score of 5) but easiness of performing exercises increased (score of 6 in 7-point Likert scale). In the last session, therapist noticed an improvement in P13 active movement (score of 6 in 7-point Likert scale), felt the game was a useful tool (score of 6 in 7-point Likert scale), felt P13 were very much involved in the game session (score of 7 in 7-point Likert scale) and also felt a difference in the P13 motivation towards rehabilitation sessions (score of 6 in 7-point Likert scale). Therapist affirmed that applying this game to P13 increased his motivation towards the rest of the rehabilitation sessions.

- **Participant Assessment**: P13 answered in the questionnaire that he liked very much to go to therapy (score of 5 in 5-point Likert scale) and this enjoyment kept the same after playing the games (mean score of 5 in 5-point Likert scale). After playing every game, P13 stated he enjoyed playing the games very much (mean score of 4.75 in 5-point Likert scale). When P13 was confronted with the question if he would like to play those games again, he replied yes. Concerning agent believability, P13 enjoyed Pedro (score of 4 in 5-point Likert scale), felt Pedro somewhat captured his attention (score of 3 in 5-point Likert scale), P13 enjoyed very much playing with Pedro (score of 5 in 5-point Likert scale) and finally P13 would like to see Pedro very much (score of 5 in 5-point Likert scale).

- **System Assessment**: P13 owns Spastic Cerebral Palsy Unilateral Right which suggests a deficit
in his right side. P13 occupational therapist applied 11 games (4 Apple Tree Game, 4 Kick The Leaf and 3 Skip The Rope). In those 10 games, P13 successfully completed 8 games, unable to achieve completion on 3 games (2 Kick The Leaf and 1 Skip The Rope) (see Appendix I). P13 therapist performed passive goniometer reading on the first session and reported low ranges of motion on all right side joints, being right elbow the worse member (right shoulder $\theta = 125^\circ$ in $\theta = 180^\circ$, right elbow $\theta = 40^\circ$ in $\theta = 150^\circ$, right hip $\theta = 100^\circ$ in $\theta = 120^\circ$ and right knee $\theta = 125^\circ$ in $\theta = 135^\circ$). The same readings remained at the fourth session. During game play at the first session, P13 was able to surpass all passive goniometer readings and in the astonishing case of right elbow 50% of all ranges of motion were made between $\theta = 53.5^\circ$ and $\theta = 118^\circ$. Also on the first session, P13 made a wide range of motion on the joints right shoulder (between $\theta = 3^\circ$ and $\theta = 155^\circ$), right hip (between $\theta = 1^\circ$ and $\theta = 120^\circ$) and right knee (between $\theta = 1^\circ$ and $\theta = 135^\circ$). In his last session, P13 decreased his maximum values for right hip and right knee, nevertheless P13 continues to produce high value ranges of motion in the joints right shoulder and right elbow. P13 right elbow performed 75% of ranges of motion beyond his passive goniometer readings (see figure 6.13).

![Figure 6.13: Participant 13 - System goniometer results from first and last session](image)

### 6.3 Concluding Remarks

In this chapter we sectioned the evaluation process into two distinct parts, the preliminary tests which was conducted in an earlier stage of development of this project and the final evaluation in which we had the opportunity to run the tests in advanced clinical environment. Regardless of the test phase, the clinics that hosted us have provided subjects with health problems which were already performing rehabilitation sessions in these same places.
In preliminary tests we gather opinions and suggestions from patients and physical therapists. Also
during this phase, we applied all games to healthy children whose ages were the same as the project
demography. Even though large parts of the data were obtained empirically, its execution was very
important for the project to move forward and correct some crucial elements in each game. In this
chapter we described the experiment, the tests and all suggestions that were acquired and taken in
consideration.

In final evaluation section we described our main objectives in conducting these tests, we depict all
participants provided by CMRA specifying their illnesses and their main characteristics (e.g. physical
limitations), how therapy sessions were conducted and finally the results acquired during the application
of the tests.

The final evaluation was critical to better understand the impact of these project to improve patients’
motivation and physical abilities. Regardless of the medical condition to be treated and age group, it is
practically impossible to establish a minimum quantity of rehabilitation sessions, however it is easily
understood than just four rehabilitation sessions are fairly low to witness a definitive physiological
change, nevertheless we noticed small subtle changes in some patients. Our demographics was
composed by 61.54% of male subjects and 38.46% female subjects in which 38.46% were affected on
their left side, 46.15% were impaired on their right side and 15.38% were affected on their both sides.
Participants were subjected to a total of 129 game sessions distributed over 4 sessions per participant
and it was observed that 42.64% of them played Apple Tree Game, 32.56% played Kick The Leaf and
24.81% played Skip The Rope. From the total of 129 games played, it was verified 83.72% of them
were successfully concluded and 16.28% were unsuccessful.

Regarding motivation, we presented questionnaires to patients, parents and therapists, through them
we had an overview of the variation in patients’ motivation. In the first session, patients reported a mean
value of 4.17 in 5-point Likert scale on how much they liked to go to therapy, however after they have
been subjected to our tool, they reported a mean value of 4.47 in 5-point Likert scale. We were able to
verify a global change of motivation, parents reported a mean value of 6.17 in 7-Likert scale in the first
session but in the fourth session they reported an increment with a mean value of 6.33 in 7-Likert scale.
Finally, therapists stated a moderated increase of patients’ motivation with a value of 5 in 7-point Likert
scale. Although we have seen a small increase in the overall motivation of patients, in isolated cases we
were able to notice a significant change.

Through the real-time goniometer we were able to study and analyze active flexions and extensions
of all participants’ joints. Due to the objective of the project to manipulate upper and lower limbs, the
system captures only 4 body joints (shoulder, elbow, hip and knee) from both sides. After the acquisition
of the final data from the system goniometer we were able to perceive that 61.54% of the participants
were able to achieve maximum shoulder flexion and 69.23% achieved maximum shoulder extension.
As for the elbow 84.62% were able to reach both maximum elbow flexion and extension. For the hip
joint, 41.67% were capable of achieving maximum hip flexion and 91.67% were able to reach maximum
hip extension and finally 66.67% reached maximum knee flexion and 100% of participants were able to
acquire maximum knee extension.
Additionally, each participant answered a questionnaire about believability and it showed they liked Pedro/Margarida (mean value of 3.83 in 5-point Likert scale), they reported Pedro/Margarida caught their attention (mean value of 4 in 5-point Likert scale), they liked to play with Pedro/Margarida (mean value of 4.33 in 5-point Likert scale) and therefore they would like to see Pedro/Margarida again (mean value of 4.33 in 5-point Likert scale). Finally they believed Pedro/Margarida was their friend (mean value of 4 in 5-point Likert scale).
Chapter 7

Conclusion

In this thesis we focused our attention into understanding how video games would influence the rehabilitation process of a child with disabilities, boosting their motivation and engagement for the remainder of the therapeutic rehabilitation session. In addition, we wanted to comprehend if with the use of embodied conversational agent (ECA) with companionship and friendship characteristics would increase adherence by the children during gameplay.

We researched several exergames and health games in order to better understand the state of the art in this field. We perceived that most of the solutions did not have a main focus in childlike audience, typically using generalist elements intended to comprise a broad range of ages. We also found that some solutions used virtual characters with the main purpose to mime pre-computed motions (playback characteristics).

Literature that targets motivation and persuasion has shown that according to the level of difficulty of an action to be executed, a strong motivation element must exist. To persuade a child to perform a certain action, it was found that three strong elements must be activated at the same time: motivation; ability; trigger. Bearing this in mind and with the development of new technologies and their integration in children's daily life, video games have become a hobby to them, thus we tried to understand if video games became a trigger and a motivator, sparking children's dedication and commitment towards new actions and behaviors.

To better evaluate all the previous premises, we developed a tool which is composed of three games, each with different characteristics: two of them target patients' upper body and one target patients' lower body, aiming exclusively the childlike audience. To appraise the second part of our premise, we implemented an ECA with child's characteristics, using agent's reactive architecture with externalizations of emotions. Knowing this architecture is fairly simplistic, we inserted a memory module to allow the agent's recollection regarding the former game sessions. These features and characteristics were taken into consideration to enhance agent's believability.

The evaluation process of our solution was divided into two crucial moments. At the first evaluation we presented an initial iteration of the tool development to better understand limitations and capture general bugs. Finally, we endured our project into a clinical environment (CMRA), relying the
participation of 13 children with a diversity of illnesses over 4 rehabilitation sessions, where we assessed several crucial components, attempting to answer the questions raised by the thesis. Due to the heavy time constraints imposed by the thesis evaluation process, it is strongly recommended to be applied a new set of tests over a longer period of time, preferably during the complete rehabilitation process of a patient and with a greater number of patients.

Throughout the development and evaluation we verified some system limitations, our system does not support the capture of the patient in the sitting position in a wheel chair, since this object contains many small details which interferes with the capture of the Microsoft Kinect sensor. Another strong constraint is the momentary lost of skeleton tracking when two subjects have their bodies close. When this occurs it causes a discomfort forcing the therapist to leave and reenter the capture area (recalibrating the sensor), which makes it difficult to therapists the occasional body correction. Other possible limitation of our tool lies in the fact that we have pre-computed all speeches and body animations, which makes the diversity of expressions and iterations from the agent more limited.

7.1 Future Work

Although the results obtained during the final evaluation were highly satisfactory, it would be of great interest to expand and reassess the project with a larger audience of patients with a higher range of illnesses.

Throughout the final evaluation, we gathered multiple opinions and suggestions from therapists to improve and expand this project. After analyzing every input from therapists and patients, we find interesting to reference the following for future work:

- Extend the existing games to actuate in more body areas in the same game session, e.g. left arm and right leg at the same time;
- Create more games with simple goals to rehabilitate the hip area, e.g. hula hoop;
- Create more games focusing in another distinct space, since all three games are restricted in coronal space;
- Enabling the goniometer to perform a real-time reading in three distinct spaces: sagittal, coronal and axial for each relevant body joint;
- Create the multiplayer mode, allowing the insertion of two patients simultaneously in the same game session;
- Allow the visual customization of the agents, allowing patients to create their own virtual friend;
- Upgrade the project’s sensor to the newer Microsoft Kinect version 2.
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Appendix A

Agents Speech Script
Apple Tree Game

Cooperative

- Olá! Estás por aqui? Tudo bem? Hoje apetece-me jogar. O que achas? Vá lá, vai ser divertido! Vais ver! Os meus pais pediram-me para apanhar umas maçãs para fazerem guloseimas. Só que apanhar maçãs é aborrecido quando se está sozinho... Mas hoje estás aqui comigo e lanço-te este desafio! Estás a ver esta árvore? Está cheia de maçãs. Podemos apanhar estas maçãs e pôr no cesto que a minha avó fez. Um cesto enorme para guardar várias maçãs. Bolas... Não consigo chegar até aquelas maçãs que estão lá em cima. Estão muito altas... Achas que me podias ajudar? Apanhas as maçãs mais altas e eu apanho estas que estão mais próximas de mim. Com a tua mão esquerda apanhas as maçãs vermelhas e com a mão direita as maçãs verdes. Quando tiveres uma maçã na mão, pões ela no cesto que está no chão. O que achas? Vamos fazer uma boa equipa! Bora lá!
- Boa! Fazemos uma ótima equipa! Apanhamos bastantes maçãs mas o cesto ainda tem muito espaço. Posso continuar a contar com a tua ajuda? Vamos lá!
- Agora estivemos mesmo bem! Estas maçãs não têm a menor hipótese. Pelo menos enquanto nós os dois cá estivermos! Hehe! Olha! Ainda há maçãs na árvore... Vamos apanhar estas últimas e já devo ter suficientes para os meus pais. Vamos lá, últimas maçãs!
- A tua ajuda foi preciosa. Obrigado(a) pela tua amizade, és um grande atleta! Não desistas de fazer exercício! Um abraço e até logo!

Competitive

- Olá! Tudo bem? Hoje apetece-me jogar. O que achas? Vá lá, vai ser divertido! Vais ver! O desafio é o seguinte, vamos apanhar maçãs à vez. Que tal? Eu apanho uma maçã e tu apanhas outra, cada um na sua vez. Com a tua mão esquerda apanhas as maçãs vermelhas e com a mão direita as maçãs verdes. Quando tiveres uma maçã na mão, pões ela no cesto que está no chão. O primeiro a desistir perde! Bora lá?!
- Ena! Apanhamos algumas maçãs. Eu acho que apanhei mais do que tu... Toma, toma! No entanto vamos precisar de mais maçãs... Estas acho que não chegam... Estás preparado? Podemos continuar? Aposto que ainda vou fazer melhor do que tu! Hehehe

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• Uffaaaa! Este foi puxado! Estiveste bem... Não tão bem como eu... mas não estiveste mal! Ora deixa ver quantas maçãs já temos... Hmmmm... Bolas! Acho que faltam um pouco mais e os meus pais vão fazer as melhores guloseimas do mundo! A corrida final! Bora lá!
• Toma! Toma! Ganhei-te ahahah! Mas a tua companhia foi muito boa! Obrigado(a) amiguinho. Na próxima aposto que vais fazer melhor.
• Oh! Mas como?! Ganhaste! Foste melhor! Ena! Nem acredito que perdi ahahha. Vou treinar em casa e da próxima vou fazer melhor! Dá próxima não me ganhas assim tão facilmente!

Reactions
• Olha aquela maçã!
• Vá lá! Apanha mais uma!
• Ajuda-me, apanha aquela ali.
• Oh... Não chego aquela lá de cima, podes apanhar para mim?
• Estas maçãs vão dar um ótimo doce!
• Vou levar estas maçãs para os meus pais para eles fazerem umas guloseimas fenomenais. Depois dou-te algumas! Não te preocupes.

Kick The Leaf

Cooperative
• Olá! Olha! As folhas desta árvore estão prontas para cair! Eu gosto de brincar com elas, que tal brincarem comigo? Vamos chutar as folhas que caem da árvore, com o pé esquerdo chutas as folhas amarelas e com o pé direito chutas as folhas verdes. Preparado? Vamos lá!
• Ahaha! Isto está muito divertido! Vamos continuar!?
• Ufa! Isto cansa! São muitas folhas! Mas contigo isto é bastante divertido!
• Isto foi giro! Adorei! Vamos repetir amanhã? Vou esperar por ti! Até logo!

Competitive
• Olá! Estás por aqui? As folhas desta árvore vão começar a cair, aposto que consigo chutar mais folhas do que tu! Queres ver? Vamos lá!
• Toma, toma! Chutei mais do que tu! Queres ver se fazes melhor? Por mim tudo bem... Vamos lá!
• Oh... Desta vez estiveste melhor... Aposto que foi sem querer! Quero a desforra!
• Ah! Ganhei! Tens de te esforçar mais! Aposto que da próxima vez consegues fazer melhor! Até a próxima.
• Oh! Perdi… Tenho de me esforçar mais! Aposto que da próxima não me ganhas! Vais ver! Até logo!

Skip The Rope

Cooperative
• Olá! Adoro saltar à corda! E tu? Também gostas? Ganhei esta corda e gostava de brincar contigo. Queres fazer me companhia? Com a tua mão vais rodar a corda e eu vou tentar saltar por cima, o que achas? Tens de manter a tua mão dentro do disco que está a tua frente e seguir o sentido das setas. Vamos tentar?! Bora lá!
• Oh… Bolas… Não queres brincar comigo, não é?!” Então está bem… vou-me embora…
• Estava a brincar! Não consigo ficar chateado(a) contigo! Vamos tentar outra vez?
• Ufa! Estivemos mesmo bem! Os saltos foram perfeitos! Podemos continuar? Bora lá!
• Ena! Isto foi muito divertido! Estás-te a divertir?
• Estás a apanhar o jeito! Estou a ver que fazemos uma ótima equipa!
• Ah! Que divertido! Somos imparáveis! Ahahaha! Adorei! Da próxima vez vamos nos divertir ainda mais! Vais ver! Até logo!

Remember patient
• Olá! Já não te via desde…
  o Ontem
  o Anteontem
• Olá! Já não te via há…
  o Um dia
  o Dois dias
  o Três dias
  o Quatro dias
  o Cinco dias
  o Seis dias
  o Sete dias
  o Oito dias
  o Nove dias
  o Uma semana
  o Duas semanas
  o Três semanas
  o Quatro semanas
  o Um mês
  o Dois meses
  o Três meses
  o Quatro meses
  o Cinco meses
  o Seis meses
  o Um ano
  o Dois anos
  o Três anos
  o Quatro anos
  o Cinco anos
• Olá! Já não te via há muito tempo!
Important Events

- Se bem me lembro, da última vez estiveste muito bem!
- Se bem me lembro, da última vez não estiveste a 100%... Aposto que desta vez vais dar o teu melhor!
- Aposto que desta vez vais fazer melhor do que da última vez. Vais ver!

Generic Reactions

- Vá lá! Não desistas! Estamos quase lá!
- Uau! Viste a borboleta?! Neste campo há muitas borboletas com várias cores.
- Já estou a ficar cansado. Bolas! Tu és mesmo resistente!
- Obrigado pela ajuda amiguinho.

Generic Sounds

- Uhh, Ah, Ahh! Uff! Hmm!

Requests

- Vá lá... levanta o pé!
- Então?! Olha o teu pé!
- Não levantas o pé?!
- Levanta o pé.
- Vá lá... estica o braço!
- Então? Olha o teu braço!
- Não esticas o braço?!
- Estica o braço.
- Vá lá, tenta ficar direito...
- Tenta ficar mais direito...
- Então?! Estás todo torto...
- Estás torto... tenta ficar direito...
- Fica direito.

Cheer

- Boa!
- Isso mesmo!
- Excelente!
- Óptimo!
- Bora lá!
- Muito fixe!
Appendix B

Parents Questionnaire
Parents Questionnaire

So that we can understand the usefulness of this game in this context, it is very important for us your feedback, to do so we ask you to answer the following questions. Remember there are no right or wrong answers, we only want to know your opinion.

To mark your answer you can make a circle around the number that best represents your opinion.

Who brought the child to the therapy session:

- [ ] Mother
- [ ] Father
- [ ] Grandfather/Grandmother
- [ ] Brother/Sister

1- Indicate in this scale how motivated your child comes normally for the therapy sessions:

No Motivation 1 2 3 4 5 6 7 Very Motivated

2- Indicate in this scale your child autonomy in daily life:

No Autonomy 1 2 3 4 5 6 7 Very Autonomous

3- Indicate in this scale what is your child autonomy in putting on her/his shoes by herself/himself:

No Autonomy 1 2 3 4 5 6 7 Very Autonomous

4- Indicate in this scale what is your child autonomy in dressing by herself/himself:

No Autonomy 1 2 3 4 5 6 7 Very Autonomous
5- Indicate in this scale what is your child autonomy in going to the bathroom alone:

No Autonomy 1 2 3 4 5 6 7 Very Autonomous

For the 4th Session these two questions were added to the above questionnaire:

6- Since the game has been included in the therapy sessions, are there activities in your child daily life, that you noticed some improvements? Which ones?

_______________________________________________________________________
_______________________________________________________________________

7- Do you have suggestions for the applicability of games in this area of intervention?

_______________________________________________________________________
_______________________________________________________________________
Appendix C

Participants Questionnaire (filled by the therapist)
Participants Questionnaire (filled by the therapist)

Participant Number: ______

Age: ______

Gender: [ ] F  [ ] M

Diagnosis: _____________________________________________________________

Indicate the affected members:
Evaluation of the active movement amplitudes by the goniometer:

<table>
<thead>
<tr>
<th></th>
<th>Shoulder flexion</th>
<th>Elbow flexion</th>
<th>Elbow extension</th>
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<tr>
<td>Left upper limb</td>
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<td>Right upper limb</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Thigh flexion</td>
<td>Knee flexion/ Knee extension</td>
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<td>Left lower limb</td>
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<td></td>
</tr>
<tr>
<td>Right lower limb</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1- Indicate in this scale how is the amplitude of the active movement of the child in its affected member(s):

No Amplitude 1 2 3 4 5 6 7 Good Amplitude

2- Indicate in this scale in general how is the child easiness of execution in performing the exercises with the affected member(s):

Unable to do it 1 2 3 4 5 6 7 Easiness
Appendix D

Participant Questionnaire (before playing)
Participant Questionnaire before playing

1- How much do you like to come to the therapy?

Figure: Smileyometer scale from the Fun Toolkit (Reader, 2008).

Following sessions: “How much do you like to come to the therapy since you play the game?”
Appendix E

Participant Questionnaire (after playing)
Participant Questionnaire after playing

1st Session
1- How much did you enjoyed to play these games?

2- If you had the opportunity would you like to play again another day?

- Yes  - No  - Maybe

2nd and 3rd Session
1- How much did you enjoyed to play these games?

4th Session
1- How much did you enjoyed to play these games?

2- If you had the opportunity would you like to play again another day?

- Yes  - No  - Maybe

3- How much did you liked Pedro/Margarida?
4- How much Pedro/Margarida did catch your attention?

5- How much did you enjoyed playing with Pedro/Margarida?

6- How much would you like to see Pedro/Margarida again?

7- How much do you think Pedro/Margarida was your friend?
Appendix F

Therapist Questionnaire
Therapist Questionnaire
(Fill at the end of the 4th Session)

1- Taking into account that in the game exist two distinct types of game: collaborative and competitive. Indicate in which situations you chose to use a collaborative game and in which you chose a competitive game:
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________

2- In general did you noticed any improvements in the amplitude of the child active movement at the end of these four sessions with the game? Indicate in the scale:

<table>
<thead>
<tr>
<th>No Improvement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Much Improvement</th>
</tr>
</thead>
</table>

3- How useful do you feel this game as a good tool for the therapy sessions? Indicate in the scale:

<table>
<thead>
<tr>
<th>Not Useful</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Very Useful</th>
</tr>
</thead>
</table>

4- How involved in the game sessions did you felt the child to be?

<table>
<thead>
<tr>
<th>Little Involved</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Very much involved</th>
</tr>
</thead>
</table>

5- Did you felt any difference in the child motivation for the session in comparison to a session with the normally used tools?

<table>
<thead>
<tr>
<th>Few differences</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Many differences</th>
</tr>
</thead>
</table>

What did you observed different in the child motivation?
_____________________________________________________________________________
6- Taking into account the challenges you face with children with mobility disabilities, is there something that you would like for the game to help with, that it does not allow yet to do?

7- If you could would you use this game daily for your sessions?

☐ Yes  ☐ No  ☐ Maybe

Thank you so much for your collaboration!
Appendix G

Consent Forms
CONSENT FORM FOR PARENTS

Dear caregiver,

We hereby ask for your collaboration in a project developed by Instituto Superior Técnico University, called “Move With Me”, in collaboration with the Medicine and Rehabilitation Center of Alcoitão (CMRA) belonging to the Santa Casa da Misericórdia (SCML), for a thesis project in the Master of Computer Sciences in Instituto Superior Técnico – Taguspark.

What does this study consist of?

In this study the child will do 4 sessions of therapy playing an interactive game in a 3D environment with movement capture technology in real-time, with the goal of promoting rehabilitation in children with pathology that compromises upper and/or lower limbs movements. By being used an interesting and virtual environment, of a “serious game” kind, the child will do certain movements to try and attain the game objectives. In the game there will also be an animated character that will also help the child in obtaining the objectives.

What do I need to do for my child to participate?

This consent form must be delivered signed by one of the caregivers of the child participating in the study.

What is my child going to do in the game?

In 4 sessions arranged with the therapist, the child will play the game in the therapy session and answer to some brief questions about the activity, so that we can understand the usefulness of this tool in the child perspective. All the sessions will be audio and video recorded for after data analysis, where participant’s anonymity is guaranteed, being the data only available to the Researchers of the Project for purposes of data analysis. In the event of the caregiver authorization the video data could also be used for purposes of dissemination and exposition in Conferences or Scientific Journals of this scientific area (see form below).

The child participation is voluntary and it can give up of the study at any time without any kind of penalty.
We would be happy if your child would like to participate in the study. For that to be possible you will need to sign the form that comes below this consent form.
Consent Form

Considering the “Helsinki Declaration” of the Mundial Medical Association (2000), the International Ethical Guidelines for Biomedical Research Involving Human Subjects (2002) and the Patterns of Physiotherapy Practice of the Portuguese Physiotherapy Association (2003)

- I read and understand what consists this study. I understood the objectives, methods, benefits provided, potential risks or discomfort in the applicability of this study. I had the opportunity to make questions if necessary and to obtain answers.

- I understand that participation in this study is voluntary and that my child can give up of the study at any time without presenting an explanation. If that happens, no penalty will happen and all the data will be removed and destroyed.

- I understand that if I want to give up after starting the study, I should ask explicitly by email to ana.paiva@inesc-id.pt, seven days before the study is complete.

- I authorize video and audio recording during the sessions where my child participates in.

- I authorize video data treatment inside this project for the purposes of analysis by the Researchers belonging to the “Move With Me” project.

- I understood that the data collected in this study will be used as referred above.

- In accordance with what is said above I authorize my child to participate in this study.

In the event of authorizing the use of the video material for dissemination of the Project Results, mark this option:

☐ I authorize the video material to be used in Conferences and/or Scientific Journals of this scientific area.

Caregiver Signature:

............................................................................................................................

Child (First and Last Name):

............................................................................................................................


Diretora do Serviço da Unidade de Pediatria de CMRA

Orientadora do Projeto Move With Me

Instituto Superior Técnico

A copy of the Consent Form is given to the caregiver and the original signed will be kept by the researcher in a secure database.

Dissertation Advisor: Prof.ª Dra. Ana Paiva

Contact: ana.paiva@inesc-id.pt
CONSENT FORM FOR THERAPISTS

Dear Occupational Therapist/Physiotherapist,

We hereby ask for your collaboration in a project developed by Instituto Superior Técnico University, called “Move With Me”, in collaboration with the Medicine and Rehabilitation Center of Alcoitão (CMRA) belonging to the Santa Casa da Misericórdia (SCML), for a thesis project in the Master of Computer Sciences in Instituto Superior Técnico – Taguspark.

What does this study consist of?

In this study the child will do 4 sessions of therapy playing an interactive game in a 3D environment with movement capture technology in real-time, with the goal of promoting rehabilitation in children with pathology that compromises upper and/or lower limbs movements. By being used an interesting and virtual environment, of a “serious game” kind, the child will do certain movements to try and attain the game objectives. In the game there will also be an animated character that will also help the child in obtaining the objectives. This application is a tool that can also be used for the creation and maintenance of the child clinical history records, giving a real time perception for the therapist of the child evolution in the exercises performed.

What will the child do in the study?

In 4 sessions arranged with the therapist the child will play the game (divided into three types of games that independently stimulate activity from the lower and upper members) in his therapy session and will answer some questions about the activity, so that we can understand the usefulness of this tool in the child perspective.

The occupational therapist/physiotherapist will have the control of the game through a tablet, and all the available options in it, being able to adapt the game to the child capabilities and difficulty level. The sessions will be recorded in audio and video for further data analysis, but anonymity of the participants is guaranteed. Being the data only available to the researcher’s part of this project. Yet since the therapist will be part of the session he/she will also appear in the video recording. If you agree, that same video recording data could be used for dissemination in Conferences and/or Scientific Journals of the area.
It will be asked to the therapist to answer a questionnaire in the 1st Session regarding the participant mobility so that we can characterize our sample, and a questionnaire in the 4th Session to evaluate the usefulness of the game as a work tool.

Your participation in this study is voluntary and we would appreciate very much your collaboration. To be part of this study we only ask you to sign the declaration below.
Consent Form

Considering the “Helsinki Declaration” of the Mundial Medical Association (2000), the International Ethical Guidelines for Biomedical Research Involving Human Subjects (2002) and the Patterns of Physiotherapy Practice of the Portuguese Physiotherapy Association (2003)

- I read and understand what consists this study. I understood the objectives, methods, benefits provided, potential risks or discomfort in the applicability of this study. I had the opportunity to make questions if necessary and to obtain answers.

- I understand that participation in this study is voluntary.

- I understand that if I want to give up after starting the study, I should ask explicitly by email to ana.paiva@inesc-id.pt, seven days before the study is complete.

- I authorize video and audio recording during the sessions where I participate in.

- I authorize video data treatment inside this project for the purposes of analysis by the Researchers belonging to the “Move With Me” project.

- I understood that the data collected in this study will be used as referred above.

- In accordance with what is said above I authorize my participation in this study.

In the event of authorizing the use of the video material for dissemination of the Project Results, mark this option:

☐ I authorize the video material to be used in Conferences and/or Scientific Journals of this scientific area.

Therapist Signature:

........................................................................................................................................................................

A copy of the Consent Form is given to the therapist and the original signed will be kept by the researcher in a secure database.

........................................................................................................................................................................

Dissertation Advisor: Prof.ª Dra. Ana Paiva

Contact: ana.paiva@inesc-id.p
Appendix H

Certificate of Participation
Certificado

Completo com sucesso os jogos do Projeto Move With Me

Investigador Gabriel

Investigadora Sofia
Appendix I

Participants sessions
<table>
<thead>
<tr>
<th>Participant ID</th>
<th>Illness</th>
<th>Game</th>
<th>Game Version</th>
<th>Session Date</th>
<th>Repetition</th>
<th>Session Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>13/04/2015</td>
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<td></td>
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<tr>
<td></td>
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<td>04/05/2015</td>
<td>30</td>
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