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

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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.

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 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. 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 capture and use in serious games, more precisely in exergaming and health games. With the assistance of Microsoft Kinect, the main goal was to create a useful and fun tool that would help therapists achieve better results in children's rehabilitation, through a set of games with an embodied conversational agent (ECA) that will try to increase children's confidence and motivation to achieve the games goals and indirectly, completing their rehabilitation exercises.

2. Background

Physical and Occupational therapies are the two main health areas aimed at the rehabilitation of several diseases of various age groups. Through the study and analysis of these fields we perceived what was behind them, their goals, their motivation and

their influence in children's rehabilitation.

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 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.

2.2. Occupational Therapy

Occupational therapy aims to promote a satisfactory occupational performance. In its approach evaluates and operates with the person, the occupation and the 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. 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[3].

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[4].

3. Related Work

3.1. Serious Games for Health

Serious Games are games that deal with issues that surpass the goal of entertainment itself[5]. 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.

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 (e.g. Microsoft Kinect). These capabilities allow the current technological world creating games called exergames, trying to promote exercise through virtual gaming.

3.2. Virtual Agents on Health

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[6]. With the human interaction in mind, Timothy Bickmore states that Relational Agents are computer agents designed to produce and maintain long-term, social-emotional relationships with people[7]. Bickmore created an embodied conversational agent named Laura. Laura was designed to help people change health behaviors as in increasing their physical activity[8]. 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)[7]. The presence of a embodied agent is very important to improve people's confidence and increase their motivation.

Christine Lisetti also designed an empathic em-

bodied virtual agent, ODVIC, the On-Demand VIrtual Counselor, for excessive alcohol consumption behavior change[9]. 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 and behavior change.

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 Samuel Taylor Coleridge conceived a new term suspension of disbelief[10], 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. 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[11] the authors (Thomas and Johnston) described how animated characters can show the illusion of being alive, having motivations, thinking, acting and showing emotions.

Researchers inspected artistic views of animated characters that could be used to improve the design of believable agents and in late 20^{th} century, computer scientist Joseph Bates studied those artistic principles used in animated characters to help him and other researchers to craft more believable agents[12]. 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[12]. As Bates dissected the work of Thomas and Johnston[11], 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 considered personality was one of the most prominent requirement in agent believability[13]. This idea emerge from Loyall analyzing Thomas and Johnston's work[11], 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[11]. Loyall epitomized personality as "all the particular details - especially details of behavior, thought and emotion — that together define the individual".

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[14] and Lee Sheldon[15] 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[16], 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[17]. Through this assumption, Locke and Latham developed the Goal Setting Theory[17] in which is described how different types of goals triggers different individual responses and how to set those goals to motivate behavior. 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[17]. 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.

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[18]. 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[18]. The trigger is the primary action that sparks a responsive action, the ability is the feasibility of the action provoked by the trigger, if it's possible or not to execute the action and the moti-

vation 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[18]. To occur a behavior the following formula must happen at the same moment: BEHAVIOR = MOTIVATION . ABILITY . TRIGGER.

3.5. Validation of Microsoft Kinect in physical therapy

Microsoft Kinect is a sensor that was created by Microsoft, it has a RGB camera, an infra-red emitting sensor and infra-red depth sensor, together they can recognize gestures and track skeleton. One major concern on the usage of Microsoft Kinect is its precision and performance on areas of health care. Further studies, describes the results that was obtained guaranties enough precision for most of the clinical rehabilitation treatments prescribed nowadays for patients[19, 20, 21]. 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[22]. 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[21].

3.6. Rehabilitation Systems

Reflexion Health developed a system named Virtual Exercise Rehabilitation Assistant (VERA). VERA's provides interactive feedback and educational information to patients while they are exercising. A pilot study was conducted by Komatireddy[23] 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.

SeeMe Rehabilitation uses Microsoft Kinect in virtual games to promote physical rehabilitation to a more elderly audience[24]. Sugarman performed a small clinical trial using SeeMe Rehabilitation 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[24].

The RespondWell Rehab Platform[25] is a set of services focus in the rehabilitation of adults and older adults. 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.

MIRA uses virtual games oriented to physical rehabilitation in order to engage the patient into the recovery process. Moldovan[26] 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.

KineRehab is a Microsoft Kinect-based platform that helps physical therapists to work with students with physical impairments in Taiwan[22]. This solution was evaluated with two young students with motor impairments and was observed a significant increase on the number of correct movements[22].

4. Initial Studies

In the preliminary study we monitored 10 children though we focus our attention in 3 cases, two cerebral palsies and one severe malformation of both feet and legs (Valgus deformity). 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.

Physical therapists try to give them tasks in order to use their neglected limbs. Usually the main objective is to reach out as much as they can and also use their hand to grab toys or objects, thereby increasing the strength and functionality of the injured side. 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 the first rehabilitation session, the occupational therapist makes a preliminary assessment identifying activities that 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 on activities that are significant to the patient. Using this approach the therapist can stimulate and develop skills and, in parallel, stimulate the patient's interest to be an active part in his own rehabilitation. The occupational therapist uses the help of tools such as games

and play. According to Bobath[27] and Ferland[28], 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 the Ludic Model[28]. 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.

5. Move With Me: Design and Development

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. To exercise the upper body we created Apple Tree Game and Skip The Rope and for the lower body we created Kick The Leaf.

5.1. Video Game Module

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. This game is designed to motivate patients to exert greater activity and movements with their upper body. 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 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 information, game manager can populate the tree and position the basket in the floor. As the levels progresses, the tree will be more populated with apples with the color of the affected arm and less with the other one.

Kick The Leaf is a game where leaves fall from the tree and the patient need to kick them before they reach the floor. 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. In contrast to Apple Tree Game, the mechanics of this game is based on the movement of the lower limbs of the patient. Depending 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. When this game starts, 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.

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. 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. At the time of startup, 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.

In order to observe the progress of the patient during the rehabilitation sessions, we used a technique employed by therapists named goniometric measurements. For this measurements is used an instrument which measures ranges of motion (ROM) of body joints named goniometer[29]. 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. Passive range of motion (PROM) is the amount of motion gained by the therapist without assistance from the patient.

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 and subtract it with the following joint in both directions of this common joint. After those vectors are built, we calculate the acute angle between those 2 same directional vectors and for that we use arccos of the DOT Product of these 2 vectors, as shown by the following formula:

$$A, B, C \in \Re^3$$
$$V_1 = B - A, V_2 = C - A$$
$$\theta = \arccos(V_1 \cdot V_2)$$

5.2. Virtual Agents

Our agent is based on a reactive architecture, which reacts to the environment modifications and game evolution. Our agents uses 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"[30] 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 define 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 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[31]. 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.

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.

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.

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 character picked to represent the virtual agents inside the game has androgynous qualities (figure 1), 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 1. 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.

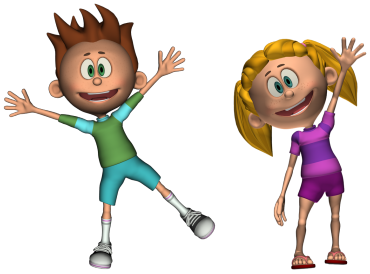

Figura 1: Virtual Agents - Pedro and Margarida.

To animate each character we used motion capture. The motion capture sessions extended for over 3 days, since the actor and the motion capture operator was only one person. During this time was capture more than 75 motions, all of them used in-

side this project. To enhance believability, we dubbed each character with well known voices used in TV and Movie Cartoons, Tiago Caetano and Sandra de Castro. The script was written with the assistance of both actors, as they have years of experience in representation and interpretation of scripts for children. After all dialogues were acquired, was important to develop a way to implement facial animation on virtual agents, for this we used Autodesk MotionBuilder to lip sync all audio files to blend shape animations.

5.3. Server Module

The Server Module's main functions is to manage and share data between the Video Games Module (Subsection 5.1) and the Real-time Module (Subsection 5.4). 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.

5.4. 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. For this module was 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. Therapist Web App contains a real-time feedback system enabling therapist to better understand how his patient is doing during that specific game session. A chart will be drawn in real-time as time progresses, 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 5.1). This option is transverse to all games, the only difference is the set of joints displayed in each chart. In upper body games is shown shoulders and elbows values for both sides and in the lower body games is shown hips and knees values also for both sides.

6. Evaluation

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.

6.1. Preliminary Tests

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 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.

For the preliminary test, therapists from *Clínica da Fidalga* and *Claris Medicina Física e de Reabilitação* selected 5 children with physical disabilities and to increase the diversity of test results, we requested the assistance of 5 children without any health limitations, making a total of 10 subjects. 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. 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.

Healthy children 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.

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 cor-

rect this, a transparent shader (Fresnel) was used to help patients understand when a apple was in their hands. In 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, 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.

In all games, therapists would like to have more control over some characteristics of each game. Each game should have multiple settings to be adjusted in real-time, depending of the daily evaluation off their patients.

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.

6.2. Final Evaluation

In the final 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?

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.

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. 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.

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).

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.

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.

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.

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. This project has enough room for further improvements: 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.

References

[1] World Health Organization. Better health for all people with disability. *WHO global disability action plan 2014–2021*, 2014.

[2] Decreto-lei n. 261/93 de 24 de Julho. Diário da República n. 172 - I Série-A. Ministério da Saúde. 1993.

[3] Helene Polatajko and Elizabeth Townsend. *Enabling Occupation II: Advancing an occupational therapy vision for health, well-being & justice through occupation.* Canadian Association of Occupational Therapists, 2007.

[4] Erik H Erikson. *Childhood and society.* WW Norton & Company, 1993.

[5] Michael Zyda. From visual simulation to virtual reality to games. *Computer 38(9)*, (September):25–32, 2005.

[6] Michael Wooldridge and NR Jennings. Intelligent agents: Theory and practice. *Knowledge Engineering Review*, (January):1–62, 1995.

[7] TW Bickmore. Relational agents: Effecting change through human-computer relationships. *Technical report, PhD Thesis*, 2003.

[8] TW Bickmore and RW Picard. Towards caring machines. *Proceedings of Conference on Human Factors in Computing Systems (CHI)*, 2004.

[9] Christine Lisetti, Reza Amini, Ugan Yasavur, and Naphtali Rishe. I Can Help You Change! An Empathic Virtual Agent Delivers Behavior Change Health Interventions. *ACM Transactions on Management Information Systems*, 4(4), 2013.

[10] Samuel Taylor Coleridge. *Biographiae litteraria of biographical sketches of my literary life and opinions*. Rest Fenner, 23 Patermaster Row, 1817.

[11] Frank Thomas and Ollie Johnston. *Disney animation: The illusion of life*. Abbeville Press, 1981.

[12] Joseph Bates et al. The role of emotion in believable agents. *Communications of the ACM*, 37(7):122–125, 1994.

[13] A Bryan Loyall. *Believable agents: building interactive personalities*. PhD thesis, Mitsubishi Electric Research Laboratories, 1997.

[14] David Freeman. Creating emotion in games: The craft and art of emotioneering^{TM}. *Computers in Entertainment (CIE)*, 2(3):15–15, 2004.

[15] Lee Sheldon. *Character development and storytelling for games*. Cengage Learning, 2014.

[16] Petri Lankoski. Goals, affects, and empathy in games. *Philosophy of Computer Games*, 2007.

[17] Edwin A Locke and Gary P Latham. Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American psychologist*, 57(9):705, 2002.

[18] BJ Fogg. A behavior model for persuasive design. *4th International Conference on Persuasive Technology*, 2009.

[19] Adso Fern'ndez-Baena, Antonio Susin, and Xavier Lligadas. Biomechanical Validation of Upper-Body and Lower-Body Joint Movements of Kinect Motion Capture Data for Rehabilitation Treatments. *2012 Fourth International Conference on Intelligent Networking and Collaborative Systems*, pages 656–661, September 2012.

[20] BF Mentiplay and RA Clark. Reliability and validity of the Microsoft Kinect for evaluating static foot posture. *Journal of Foot and Ankle Research*, 6(1):1, 2013.

[21] RA Clark, YH Pua, Karine Fortin, and Callan Ritchie. Validity of the Microsoft Kinect for assessment of postural control. *Gait & posture*, 36(3):372–377, 2012.

[22] YJ Chang, SF Chen, and JD Huang. A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. *Research in developmental disabilities*, 32(6):2566–2570, 2011.

[23] R Komatireddy, A Chokshi, J Basnett, M Casale, D Goble, et al. Quality and quantity of rehabilitation exercises delivered by a 3-d motion controlled camera: A pilot study. *International Journal of Physical Medicine and Rehabilitation*, 2(214):2, 2014.

[24] Heidi Sugarman, Aviva Weisel-Eichler, Arie Burstin, and Riki Brown. Use of novel virtual reality system for the assessment and treatment of unilateral spatial neglect: A feasibility study. In *Virtual Rehabilitation (ICVR), 2011 International Conference on*, pages 1–2. IEEE, 2011.

[25] Phineas Barnes, Ted Spooner, Jade Dhabolt, and Jason Leighton. Instructional gaming methods and apparatus, January 18 2005. US Patent App. 11/038,892.

[26] IM Moldovan, AD Călin, AC Cantea, LA Dascălu, CA Mihaiu, O Ghircău, S Onac, O Rîză, RA Moldovan, and LV Pop. Development of a new scoring system for bilateral upper limb function and performance in children with cerebral palsy using the mira interactive video games and the kinect sensor. 2014.

[27] Berta Bobath and Karel Bobath. *Desenvolvimento motor nos diferentes tipos de paralisia cerebral*. Manole, 1989.

[28] Francine Ferland. *Play, children with physical disabilities, and occupational therapy: The ludic model*. Paul & Co Pub Consortium, 1997.

[29] Cynthia C Norkin and D Joyce White. *Measurement of joint motion: a guide to goniometry*. FA Davis, 2009.

[30] Rodney A. Brooks. Intelligence without reason. In *Proceedings of the 12th International Joint Conference on Artificial Intelligence - Volume 1*, IJCAI'91, pages 569–595, San Francisco, CA, USA, 1991. Morgan Kaufmann Publishers Inc.

[31] Timothy W Bickmore. Establishing and Maintaining Long-Term Human-Computer Relationships. 12(2):293–327, 2005.