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Development and Test of a Serious Game for Dorsiflexion and Plantarflexion Exercises of the Feet

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Abstract

Congenital clubfoot is the most common disease of the musculoskeletal system, causing deformities in the musculature of the foot and requiring long-term motor rehabilitation. This article shows the design and development of a serious game to support the process of motor rehabilitation of clubfoot through dorsiflexion and plantarflexion exercises. The game is controlled by a wearable device (Papete shoes), where the accelerometers are responsible for detecting the movement of the foot. A pilot test was carried out with two children with and without clubfoot (Congenital Talipes Equi-novarus-CTE) to examine the feasibility of the game as a therapy instrument. Usability and applicability questionnaires were applied after using the game. The results show that both children reacted in the same way to the proposals, performing the necessary movements for the motor recruitment of the muscles related to the leg and foot and maintaining the range of motion of the ankle joint.

Keywords: *congenital clubfoot, dorsiflexion and plantarflexion, motor rehabilitation, game therapy, wearable technology.*

1 Introduction

The use of video games as a support tool in the rehabilitation process has gained strength in recent years by emerging a new research area called gametherapy. The literature shows evidence that games can improve people's physical and cognitive abilities (Morri et al. 2019; Hee et al., 2017; Sato et al., 2015; Lv et al., 2014; Gil-Goméz et al., 2011). Among them is the study reported by (Gil-Goméz et al., 2011) who used the Nintendo® Wii Balance Board® to improve the balance of patients with brain injury through motivational and adaptive exercises. The experimental results showed that, after 20 rehabilitation sessions, patients who used the game had a significant improvement in static balance compared to patients undergoing traditional therapy. Sato et al. (2015) related that the Xbox 360 Kinect® video game improved muscle strength and balance in healthy seniors. This study indicated that, after 24 rehabilitation sessions, gait, muscle strength, and motor function improved in the intervention group participants compared to the control group. The Nintendo® Wii Balance Board® was used by Morri et al. (2019) to improve the balance and performance of walking in patients undergoing resection and reconstruction of the knee caused by a primary bone tumor. The game's rehabilitation sessions were held twice a day, during 25 minutes of postural and proprioceptive control training. The authors concluded that there was an improvement in walking speed and postural control in the standing position in the experimental group compared to the control group.

The commercial video games most commonly used in gametherapy sessions are Nintendo® Wii, Kinect 360 and Playstation. However, these technologies still do not selectively and specifically stimulate dorsiflexion and plantarflexion of the feet. It is known that the feet constitute a base for the human body and have the function of promoting stability, transmission of forces and locomotion, among others (Hamill; Knutzen, 2006). Therefore, a congenital injury or malformation in any of the structures of this area of the body, as in the case of Congenital Clubfoot (CTE), can compromise the mechanical relationship and body balance and significantly impair the performance, causing early fatigue, pain, an overload of other segments, in addition to compromising gait and other motor functions related to the individual's daily life (Hamill; Knutzen, 2006; Soares et al., 2016). To prevent this, the treatment of the lower limbs must start as early as possible (Corbu et al., 2020). It is usually intense and repetitive, especially in the first months, and must be carried out by a qualified professional team, with a physiotherapist and medical monitoring, through daily sessions, with fifty minutes or weekly, depending mainly on the severity of the feet. With the corrections obtained, visits to the physiotherapy sector become biweekly, monthly, and half-yearly. However, it is necessary that the monitoring happens for four to eight years, in some cases reaching up to ten years, to avoid recurrences of CTE (Ferreira 2018; Dimeglio; Canavese, 2012). The possibility of incorporating Serious Games in this process can bring significant benefits,

Some technologies can be applied in the rehabilitation of the feet. The Dance Dance Revolution (DDR) (Kloos et al., 2013), for example, uses techniques to receive signals from the user's foot movement, but it is limited concerning the shape and position in which the feet touch the ground and would not serve to stimulate specific dorsiflexion and plantarflexion exercises. The PONG game (Hee et al., 2017), with two surface electromyography sensors (EMG) for dorsiflexion and plantarflexion exercises of the feet, has been adapted and associated with electromyography (EMG) sensors, used to acquire muscle activity in the anterior tibial and gastrocnemius muscles. However, EMG equipment is not affordable for rehabilitation clinics or the general public due to its high acquisition cost.

Despite the proposed solutions, there is a special need to create a direct way of commanding the game, in close synchrony with the movements generated by the foot, without depending on an interface that reads and interprets the electromyographic signal of each muscle to produce control of the moving element on the screen. Also, the movements depend on an intricate neuromotor relationship between agonist, antagonist, and synergist muscles of the generated movement, making it impossible to access all the motor points of each unit. It is also necessary to consider the deepest, slender, and extremely juxtaposed muscles, whose access is only possible through thin needles that should be inserted through the belly of the superficial muscles, which would make it challenging to collect data in the segment, mainly due to pain or discomfort caused in children.

In this project, an serious game called "Acelera" was developed, where the user (children) with CTE has to control a car to avoid cones and holes in the road. The car is controlled through movements with the feet, actively taking them up and down. Such movements being called dorsiflexion and plantarflexion, respectively. To capture the foot's movement, a wearable device (papete) was developed, analogous to a joystick for the game, where sensors integrated into the papete transmit, to a computer, information on the user's foot movement. Foot movements are used to modify a graphic representation in the game, allowing the user to obtain a high degree of control. The obstacle game was selected because it is a simple game that can be easily understood and played by children from 4 years old. The sequencing of obstacles and the dorsiflexion and plantarflexion activities proposed by the game were structured with physiotherapists' support around a simulation of tasks usually performed in rehabilitation sessions for children with CTE. We tested a game in a pilot study with two children, one with CTE and the other with typical development. The pilot study results with these two children and the game development are covered in this article.

2 Related Concepts and Works

This section presents some important concepts for understanding this study. We started by introducing the CTE and presented the description of the plantarflexion and dorsiflexion exercises normally performed in CTE motor rehabilitation sessions. Then, we present concepts about wearable technologies and some increase sensors used to develop these types of systems. In the sequence, we present concepts of game therapy where we approach the importance of video games for rehabilitation, followed by the presentation of some works related to this study.

2.1 Congenital Clubfoot (CTE)

Congenital clubfoot (CTE) is the term used to describe the complex deformity that includes changes in all distal musculoskeletal tissues to the knee (Campos, 2019; Maranho; Volpon, 2011). It is a congenital dysplasia of musculoskeletal, tendon, ligament, osteoarticular and neurovascular structures. It is of multifactorial origin and idiopathic cause (Santin; Hungria Filho, 1977). CTE deformity results from the bones' malalignment, alteration of bone conformation and retraction of the involved soft parts. The talus is the bone with the most significant deformity, its neck is shortened, and its medial surface is reduced (Campos, 2019).

According to Maranho and Volpon (2011), idiopathic CTE has an unknown origin. It may be related to several causes, from the fetus's intrauterine position to genetic defects not being identified on ultrasound before the 12th week of pregnancy. Regarding the treatment that best responds to the therapeutic objective, there are still controversies. The objective is to obtain plantigrade feet, painless, with good mobility and do not require special shoes (Lara 2013).

It is believed that conservative methods can produce plastic deformation and stretching of contractured structures progressively through the connective tissue's viscoelastic properties. Tissue mobilizations, followed by immobilization of the segment, or part of it, must be done in a serial form and always be the initial treatment (Santin; Hungria Filho, 1977). Among the different conservative treatment modalities, physiotherapeutic joint mobilization is included, followed by the use of elastic bandage and/or orthosis; continuous mobilizations, made by a small Continuous Passive Motion (CPM) machine, under the supervision of a physiotherapist who also makes corrective manipulations, followed by immobilization. Alternatively, manipulations, followed by orthopedic plaster (Campos, 2019; Dimeglio; Canavese, 2012).

Surgical treatment consists of posteromedial release with ligaments and joint capsules section, positioning to reduce cartilage structures and fixation. The extensive release of soft tissues frequently generates failures and complications, culminating in one or more revision surgeries. The aesthetic appearance of the foot improves, but this foot is weak, rigid and often painful. When the relapses feet are reopened, it is possible to notice intense fibrosis in the foot and joint stiffness with deformities (Santin; Hungria Filho, 1977).

Many parents consider that, after the child receives one or more extensive surgeries, he will not need any follow-up, medical and/or physiotherapeutic treatment, considering that the child is already wholly cured. However, many children who receive such procedures need postoperative follow-up and often support, physiotherapeutic and physical activities guidance to avoid tissue adhesions and relapses in the medium and long term. Therefore, when observing all the risks of extensive surgical approaches, it is concluded that, currently, these are not the best forms of treatment for CTE (Santin; Hungria Filho, 1977).

2.2 Dorsiflexion and Plantarflexion

The human ability to walk is possible through a synergy between the lower limbs' muscles and the foot's joints, knee and hip (Dimeglio; Canavese 2012). The foot is considered one of the most important joints in the body. Besides having essential functions in supporting weight and walking, it is the cause of several pathologies, instabilities, or imbalances in the entire musculoskeletal system (Ferreira 2018; Dimeglio; Canavese 2012).

There are six types of basic foot movements (Caetano 2020): abduction and adduction, inversion and eversion, dorsiflexion and plantarflexion. This study will be limited to the study of plantarflexion and dorsiflexion movements. It is necessary to define the following foot reference planes to analyze these movements (**Figure 1**):

- Frontal plane: The plane separates the anterior part of the foot from the posterior part. This plane passes sensibly through the ankle.
- Sagittal plane: The plane divides the medial part (internal part of the foot) from the lateral part (the foot's outer part). This plane passes through the axis of the foot.
- Transverse plane: The plane divides the upper part from the lower part of the foot.

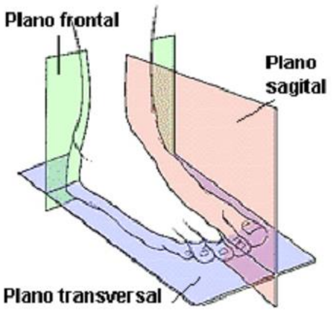

Figure 1. Foot reference planes (Caetano 2020)

The dorsiflexion movement is performed in the sagittal plane when the foot moves upwards (towards the tibia). The rotation axes are located in the frontal and transverse planes (**Figure 2**). In plantarflexion, the movement of the sagittal plane happens when the foot moves to the ground. The axes of rotation are located in the frontal and transverse planes.

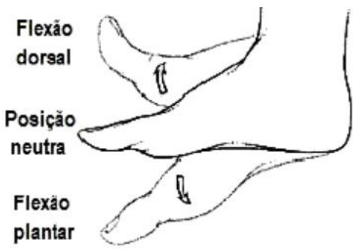

Figure 2. Dorsal Flexion and Plantar Flexion (Caetano 2020)

2.3 Smart Wearable Devices

A wearable device is defined as an accessory used by the user, with integrated electronic and computing technologies, capturing or reporting user information in real time (Yoon et al., 2016). The data obtained using wearable technology vary from physical activity (walking, running, et so on.), limb movement, heart rate, temperatures, among others, which can be used later for analysis and reference (Dimeglio; Canavese 2012). Although the shape adopted by the device can vary from a wristwatch to a bright shirt or sneaker, its functionalities are often similar.

Wearable sensors can collect physiological and movement data, thus monitoring the individual/patient's status (Ianculescu et al., 2019; Kaewkannate; Kim, 2016; Toma et al., 2018; Bonato et al., 2003). The sensors are implanted according to the clinical application of interest. For example, the so-called fitness trackers or activity trackers present in bracelets, watches and smartphones allow monitoring information about sleep quality, the number of steps taken, distance covered and heart rate (Kaewkannate; Kim, 2016). In addition to applications aimed at fitness activities, the use of wearable devices allows monitoring vital signs such as heart rate and respiratory rate in patients with heart failure or lung disease in real time (Toma et al., 2018), as well as objectively monitoring and quantifying the severity of symptoms presented in individuals affected by Parkinson's disease (Daneault et al., 2021). This real-time monitoring allows the recording of individuals' quantitative data throughout the day and developing their daily functions (Daneault et al., 2021) (Bonato et al., 2003).

The use of wearable technologies can be perfectly adapted to assist in motor rehabilitation interventions (Ianculescu et al., 2019; Bonato et al., 2003) both of upper limbs where Cifuentes (Cifuentes et al., 2012) uses wearable devices to assist in the rehabilitation of individuals after stroke, as well as in the rehabilitation of lower limbs where electromyography sensors (EMG), inertial measurement unit (IMUs) and pressure sensors can assist in the evaluation and rehabilitation of knee osteoarthritis (Chen et al., 2017) and the evaluation of gait biomechanics (Faragó et al.,2021; Gouwanda et al., 2016).

2.4 Game Therapy

Gameterapy is conceptually defined as a rehabilitation technique for patients who uses video games (Mader et al., 2012). This type of therapy is being increasingly used in physiotherapy sessions in order to offer more dynamics and fun for the patient, providing them with greater engagement in the treatment offered (Corrêa et al., 2019). This technique increases the possibility for patients to recover in a shorter time, since it motivates them to remain engaged in exercises that are sometimes repetitive and painful (Alcover et al., 2018).

In addition to stimulating brain activity, gametherapy also facilitates the adaptation of patients, especially children and young people in physiotherapy treatments. Games can be adapted to the needs of each patient in terms of cognitive load (memories, attention, perception, knowledge representation, reasoning and creativity in solving problems) and motor (number and frequency of repetitions) (Alcover et al., 2018). Although it does not replace other practices, the technique is well accepted by doctors and patients.

The interactivity provided by the games offers several types of motor rehabilitation exercises, each with different goals, simulating real movements that patients would do in a conventional therapy session. In the most common model of treatment, the patient is accommodated in front of video game consoles and / or sensors that capture their body movements. In this way, it is possible to interact with the elements of the game, for example, guide characters, capture and move objects, among others. In addition, this entire process can be controlled by the therapist.

Most works in the literature report the positive effects of game therapy for the rehabilitation of upper limbs, balance and posture. For lower limbs, work is scarce, but it is promise as shown section 2.7.

2.5 Game Design for Motor Rehabilitation

Game designer experts want to maximize the likelihood of success for their products by creating the best experience for players. To achieve this good usage experience that motivates people to remain interested and engaged in the tasks provided by the game, it is necessary to understand the principles that guide the development of the game as well as its mechanism of interaction (Cataldi; Silva, 2017).

Burke et al. (2009), identifies three principles of game design considered of particular importance for rehabilitation: a) the game must be significant; b) it must provide fault handling; c) favor an appropriate level of challenge.

According to (Burke et al., 2009), the significant game for rehabilitation arises from a game in the relationship between the actions of a player and the response of the system. The main thing for creating and maintaining a meaningful game is the concept of feedback, the methods by which the game responds to changes or choices made by the player. Feedback can be auditory (sound effects, verbal dialogue), visual (text, images, punctuation indicators) and tactile (vibration). It is important that a user of motor rehabilitation games know their progress towards the goals (short and long term), in order to achieve a more effective involvement.

Fault handling corresponds to the management of movements poorly executed by the player. In motor function rehabilitation games, in which the affected limbs are being stimulated at all times, there is a risk that, if the player suffers failure during the initial game, he may attribute that failure to the poor motor function and this could result in a poor engagement in the game. The level of challenge that a game offers is an influence on the degree of involvement of the player. The range of motor function varies widely from person to person, and what may be easy for one person may be impossible for another. As the game progresses, the game must adapt to the challenge dynamically, changing the pace and the positions and the size of the elements of the game. Thus, for players with more severe motor impairments, the pace of the game must slow down and the elements of the game can become larger and easier to reach.

2.6 Flow Theory and Serious Game

It is hoped that a serious game for rehabilitation will cause great engagement in the patient so that he can overcome the difficulties of therapies that require constant repetition. Thus, it is very important to check if the recommendation to focus on gameplay will be more motivating for the player than the focus on movement required by the activity in a serious game for motor rehabilitation. When experience provides a very high state of engagement, this state is called the Flow state (Nakamura, J. & Csikszentmihalyi, 2009).

Flow Theory predicts that an individual needs to remain challenged as he uses his maximum skills to achieve greater performance in a given activity. According to Nakamura, J. & Csikszentmihalyi (2009), the Flow is a state in which the individual feels with a complete and energized focus on the activity and with a high level of satisfaction and fulfillment. To keep the individual in the Flow, the activity must strike a balance between the individual's challenge and skill. If the challenge is too great for the skill, the anxiety generated by the activity challenge will cause the individual to give up. And if the challenge is too low for the skill, the activity will cause boredom.

According to (Csikszentmihalyi, 1990; 1996; 1998), the flow occurs due to the following aspects of gameplay:

- Existence of clear goals: it makes the individual pay attention to those goals, and she does what she can to achieve them, this increases her concentration (therefore, the chance of reaching the flow).
- Concentration and focus: you should avoid many graphic and sound effects that can distract the player.
- Immersion: when there is a loss of the sense of self-awareness, that is, when the individual loses a sense of himself, he becomes one with the game.
- Feeling of distorted time: when the individual is so interested in the tasks proposed by the game that he forgets the tasks of daily life.
- Feedback: the game must clearly indicate to the player that he has done something wrong or something correct, from simple things like decreasing the life bar, or flashing the screen red when the player's character suffers damage.
- Balancing between difficulty and ability: a very easy game usually takes the player out of the flow state and into the boredom state; the same happens when the game is very difficult, the player feels frustrated, incapable, and then the same stops playing. A recommendation in this case is to allow the player to set the game's difficulty levels.
- feeling of control of the situation: the individual must feel in control of the game, that is, he must not feel “caught up” by the rules of the game; this provides the player with a better gaming experience.

- Reward: the player must be rewarded when reaching an objective or goal within the game; for example, receiving a bonus that can be a lifetime or more playing time; earn points that can be exchanged for "things" like equipping the character.

- fusion between action and attention: it is related to immersion and distortion of time, that is, when the person becomes so attentive in what he is doing that he loses his attention in other things.

Measuring the Flow is a practical method to know which form of interaction and rule is reaching its motivation objective, because the Flow represents a high degree of engagement in the activity. Souza Neto (2015), in his master's dissertation, sought to verify whether games with a focus on gameplay would present greater Flow than games with a focus on movement. The method of interaction with the game environment was the Microsoft Kinect for Xbox 360 sensor. A prototype was adapted in order to change the focus of the gameplay to the required movement. The study involved the participation of 60 individuals, half of whom interacted with the prototype of the game focused on gameplay and the other half with the second prototype, focused on movement. There was no significant difference in the Flow between the two groups, that is, the hypothesis that games with a focus on gameplay provoke greater engagement in players than games with a focus on movement has not been confirmed. It is therefore necessary to review the instrument to measure the flow.

2.7 Related works

The research and development of portable devices have gained more attention and efforts recently. Attempts have been made to develop smart portable devices that capture human movement (Ianculescu et al., 2019; Alexandre et al., 2018; Bonato et al., 2003). Improvements in balance and gait control have been achieved with these devices (Ianculescu et al., 2019; Ma et al., 2019; Domingues et al., 2019). One such device consisted of an ultrasound probe, two sets of surface EMG electrodes, three force sensors, a two-axis goniometer, a wireless Wi-Fi transmitter module and two rechargeable batteries (Mar t al., 2019). The system provided a real-time ultrasound image of the muscles and measured muscle activation, muscle vibration, plantar foot strength, and joint angle simultaneously. Another study used two motion sensors IMUs (accelerometers and three-axis gyroscopes) that collect data related to movement metrics (orientation, speed and gravitational forces) to analyze the patient's knee movements (Bonato et al., 2009). The motion sensors are mounted above and below the knee joint and connect with a mobile application that receives real-time data from the sensor on the patient's activity. In another study, Fiber Brag Grating (FBG) sensors were used to monitor the ankle's angular movements for physical rehabilitation (Domingues et al., 2019).

Concerning games developed for foot rehabilitation, most employ manually operated devices, such as a gamepad, joystick, mouse and keyboard. Generally, these conventional games are limited in the complexity of the measured data signals and the methods in which these data signals are processed. For example, game consoles, such as Dance Dance Revolution (DDR) (Kloos et al., 2013), use specific techniques to interactively receive signals from the user's foot movement during the game. Although the DDR can detect these movements and process the location and time to interact with the rhythm or beat of a song, the dance pad limits the processed data signals to the shape and position that the feet touch the ground, essential to treat CTE. Besides, the DDR platforms are large, heavy and relatively expensive.

Another study presented the PONG game based on interactive electromyography (EMG) for dorsiflexion and plantarflexion of the feet (Hee et al., 2017). The PONG game is a classic game that can be easily understood and played by young and old. Two EMG surface sensors were used to acquire muscle activity in the anterior tibial and gastrocnemius muscles.

In another study by Pichierri et al (2012), the result of a cognitive-motor intervention using a dance video game was presented to improve the accuracy of foot placement and gait in dual-task conditions in older adults. Feet games have been developed to demonstrate an innovative interface based on the smartphone's foot motion detection approach (Lev et al., 2014). The computer-based hybrid detection and tracking method provide essential support for the foot interaction interface, accurately tracking the user's shoes.

The patent of the Picunko (2010) consists of a system and a method that obtains data of movement and position of sensors of a user's footwear and transmits corresponding data signals to a receiver via wireless communication. The receiver, in turn, inserts these signals as data into a processor configured to run a computer program.

All of these works show that the purpose of this research is viable.

3 Development of Acelera Game

The design of the Acelera game came from a demand for practices of care for children with CTE. Conventional treatment is usually repetitive, tiring and boring for children because, in addition to passive manual maneuvers applied by the physiotherapist, which are indicated for stretching biological tissues, such as tendons, ligaments and capsules to allow physiological joint adjustment, exercises that stimulate muscle activation and strengthening are also necessary. Physiotherapists believe that the insertion of a serious game in this process can increase these children's engagement in therapy and provide important information of the feet during the practice with the game, such as position, speed and heel elevation time (from the ground).

From specifying requirements to pilot testing with the target audience, the entire development process involved two specialists in the field of physiotherapy, one of whom specialized in the care of children with CTE. This user-centered development process made it possible to ensure that the game was designed appropriately for the target audience and had clinical utility for the professionals who use it.

The Acelera game consists of three modules: a) serious game with dorsiflexion and plantarflexion exercises; b) wearable device for controlling the game called "Smart Papete"; c) communication and data storage module. Below, each of these modules is detailed with a greater focus on the description and specification of the game module that is the objective of this work.

3.1 Game Module

The Acelera game consists of a track with cars and obstacles such as cones and holes (**Figure 3**). The player's goal is to control a car and dodge obstacles to score points. The obstacles were carefully positioned on the road to allow the player to remain as long as necessary with the foot flexed in the plantar or dorsal position and also at rest. For example, due to the presented images, it is necessary to perform a plantarflexion movement for 4 seconds (to overcome obstacles on the track).

Table I presents the 6 phases of the game with proposals for dorsiflexion and plantarflexion exercises. The phases were designed to support specialists in rehabilitating children with CTE and organized in increasing difficulty (challenges), considering a 20-second rest between phases. Each phase of the game was designed to provide 12 repetitions of the movements specified in Table I, with a minimum of 70% correctness being considered to move from one phase to another automatically. If the player has not completed the minimum 70% of points in the phase, a screen with buttons (Redo and Continue) is presented. The therapist can judge the need to redo the phase or to continue to the next phase.

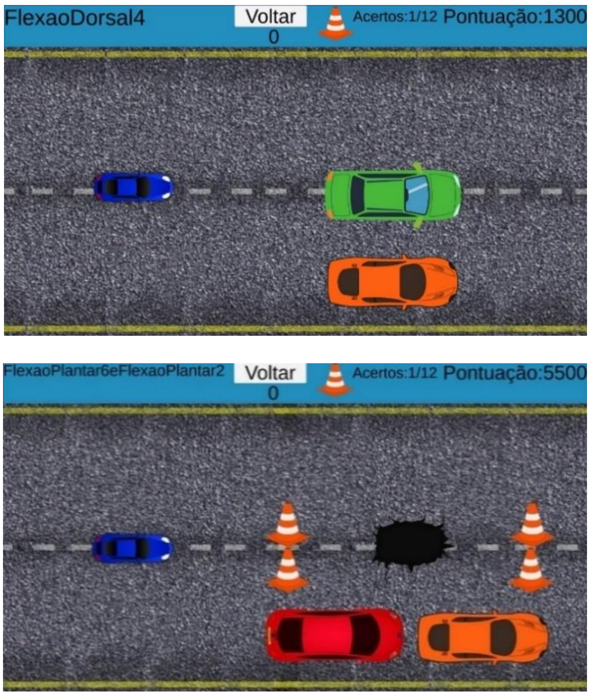

Figure 3. Acelera Game scenario

Table 1. Challenge levels of plantarflexion and dorsiflexion exercises. DF = Dorsal Flexion, PF = Plantar Flexion

Stage	*Description*	*Movement Duration*
FD2	Dorsal Flexion (2 sec)	2 seconds with foot flexed in the dorsal position; 2 seconds with foot at rest.
FD4	Dorsal Flexion (4 sec)	4 seconds with foot flexed in the dorsal position; 2 seconds with foot at rest.
FD2 + FP2	Dorsal Flexion (2 sec) + Plantar Flexion (2 sec) alternatively	2 seconds with foot flexed in the dorsal position; 2 seconds with foot at rest; 2 seconds with foot flexed in the plantar position.
FD4 + FP2	Dorsal Flexion (4 sec) + Plantar Flexion (2 sec) alternatively	4 seconds with foot flexed in the dorsal position; 2 seconds with foot at rest; 2 seconds with foot flexed in the plantar position.
FD2 + FP4	Dorsal Flexion (2 sec) + Plantar Flexion (4 sec) alternatively	2 seconds with foot flexed in the dorsal position; 2 seconds with foot at rest; 4 seconds with foot flexed in the plantar position.
FD6 + FP2	Dorsal Flexion (6 sec) + Plantar Flexion (2 sec) alternatively	6 seconds with foot flexed in the dorsal position; 2 seconds with foot at rest; 2 seconds with foot flexed in the plantar position.

At the end of the game, that is, after playing the six game phases, a report containing the player's performance is presented (**Figure 4**) containing the following data for each phase performed: score; longer time in Dorsal Flexion; longer time in Plantar Flexion. This data is also saved in a .csv file on the computer for future analysis.

The principles of game design for motor rehabilitation, suggested by Burke et al. (2009), were incorporated as follows: a) significant game (feedback) when the player makes a dorsiflexion or plantarflexion with the foot, then the car moves from side to side on the screen; sound effects have been incorporated and favor game feedback; b) failure handling is related to poorly executed movements (they are treated through pilot tests with healthy children and children with CTE); c) challenge level was proposed with the support of physiotherapists specialized in the treatment of children with CTE.

The game was developed using the Unity 3D game engine. The scenes were created in the following sequence: a start scene for game and player settings, a scene where the game is played and records the results and the final results scene. The scripts were created with C# language and allow the game to be integrated with Arduino. The game has soundtrack and sound effects to provide greater engagement. The audios, in MP3 format, were selected from the free database available on the Internet.

Figure 4. Game general score screen

The criterion of progress in the game, through minimum score, is usually a strategy for player engagement. Conversely, it can also discourage the child who fails to reach the goal. According to the Flow Theory proposed by (Csíkszentmihályi, 1990; 1996; 1998), if the challenge of the game is too great for the skill, the anxiety generated by the challenge of the activity will cause the individual to give up playing. And if the challenge is too low for the skill, the activity will cause boredom. In this way we have developed some strategies that can be used to configure the level of engagement of the player in the game. Into de configuration screen of the game, the therapyst can:

1. choose the elevation angle of the dorsiflexion and plantar flexion movements that will make the cart move around the screen. The angles vary between 5 and 30 degrees.

2. choose the amount of obstacles in the game. This implies difficulty setting as it impacts game time.

3. the animation speed of the game. This implies increasing or decreasing the difficulty in executing the movements

At this time, the physiotherapist needs to use a goniometer to measure the angle of elevation of the ankle, responsible for the movements of dorsiflexion and plantar flexion. This measure is obtained for each patient individually and then the physiotherapist configures the game according to these measures. But we are designing a module to measure these movements in an automated way by the system, that is, the system itself will be able to measure the angles through a calibration mechanism.

3.2 Smart Papete

A Papete type shoe was equipped with an Arduino prototyping board based on the ATmega328P microcontroller and an accelerometer (**Figure 5**). The accelerometer was positioned on the papete between the second and third metatarsals to capture foot movement parameters in dorsiflexion and plantarflexion.

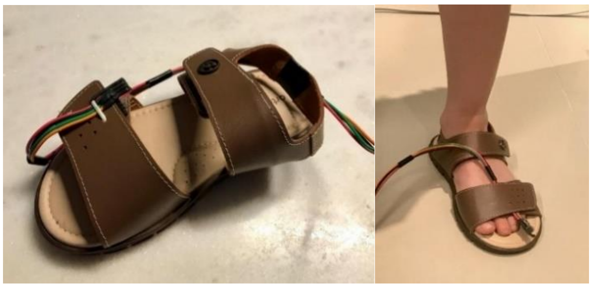

Figure 5. Smart papete

3.3 Communication Module and Data Storage

The communication between Papete and the game (Unity 3D) is done via UART serial *(Universal Asynchronous Receiver/Transmitte)*, where the transmission rates between Papete and Unity are previously set at 115200 bps (bits per second). The player's performance data is being provisionally saved in a .csv file. In the future, the data will be stored in a cloud database so that the patient and therapist can have remote access through an application.

3.4. System Environment

As for the usage environment, the system currently requires a computer (desktop or notebook) with Windows 10 or higher operating system, USB port (to connect the paper) and Core i5 processor and 4GB or higher memory.

4 Pilot Test

The pilot test aimed to verify the usability of the game "Acelera" in two children, male, aged four and six years. The youngest has idiopathic CTE on the right and receives physiotherapeutic treatment since he was born. The six-year-old has a typical development. The children and their respective parents gave a favorable opinion and signed the Completing the Informed Consent Form approved by the Human Research Ethics Committee (CAAE: 87369418.3.0000.0084).

The tests were done individually and the procedures applied in the same way for both children. Initially, the physiotherapist performed an anamnesis with the children and their parents to find any impediment to carrying out the activity. It was asked whether the child had suffered any recent injuries and/or trauma or had complained of pain in the lower limbs. A physical protocol examination was carried out based on parents' and children's denial regarding the above questions. The professional verified that the infants were fit for the procedure. With comfortable and proper clothing (shorts and t-shirt) and barefoot, the children were invited to sit on a stable stool, with four supports and non-slip material on the distal ends of this bench, which does not have wheels,

The Papete was placed on the right foot of the participants, and the center of the computer screen was positioned in the line of their eyes. After a countdown, the game started. The participant verified that when moving the foot upwards (dorsiflexion) and downwards (plantarflexion), the car shown on the screen moved at a constant speed to the left and the right of the road. With this, the child intuitively controlled the vehicle in order to avoid it crashing into obstacles or other cars that appeared on the screen. According to Table I, the six phases were performed, and at the end, a score was assigned. After the end of the session, the physiotherapist removed the Papete and performed a clinical reassessment, checking if there was any point of hyperemia, edema or excoriation, in addition to palpation on the structures of the foot and leg, inquiring about pain or discomfort, as the use of the equipment could have caused. The children reported feeling well and had no pain or changes in the limbs involved in the tests.

A semi-structured interview was applied with some questions about the impression they had with the game, which was answered as follows (consider that participant 1 (P1) has a typical development and participant 2 (P2) has CTE):

1- What did you think of the game?

P1: "I really enjoyed it. Can I play again?"

P2: "I liked it. Will I be able to play at home too?"

2- What did you like most about the game?

P1: "It looks like I'm in a race and I got many points."

P2: "I liked the challenge of having to dodge the lava (volcanic activity). I liked being able to control the car with my foot, and I did better than with my hand" (at the end of the test, this participant asked to restart with the papete in his right hand).

3- Did anything bother you during the game?

P1: "No, nothing bothered me."

P2: "No."

4- Were you tired?

P1- "No. I'm ready to play again."

P2- "The foot got a little tired." (Father speaking: "due to the recess due to COVID-19, he had not been doing physical therapy on his feet for months").

5-Did you miss any explanation about the movements before starting the game?

P1: "No, I realized that when the foot was moved, the car moved."

P2: "No."

6- Is there anything you don't understand about the game?

P1: "Ahh, I didn't understand my score very well. I know I won many points".

P2: "I understood the game."

7- Is there anything you would like to improve in the game?

P1: "I wanted to see, on the road, some trucks for me to be able to dodge too."

P2: "It's cool like that, but the car could run faster, too."

8- If you were invited to join a team that invents games, would you have any suggestions for this game?

P1: "I would put a steering wheel, like steering, with some controls to have some control of the car, in this part too. I also wanted some coins on the road to earn some money and a gas station to fill up and drink water. I wanted more vehicle options, like motorbikes and other car models."

P2: "I wanted to play with other runners too. As if more people were running on the road."

An interview was also conducted with those responsible. Here are the questions:

1- What was your impression of the game?

A1: "I really liked it because this game is in the generation of games that require movement and stimulate exercises with other parts of the body, besides the hands."

R2: "The idea is excellent. The game is clear and visually easy for the child to understand."

2-Would you like your child to play more often? Why?

A1: "I would like to because, as I mentioned, this game requires other parts of the body. Moreover, it is not a complex or difficult game for us to follow and encourage them to move on."

R2: "Yes, because playfully he could do some of the exercises necessary for physical therapy."

3- Do you think your child enjoyed the experience with the game? Why?

A1: "Yes, I am sure he liked it. Both for his insistence on continuing to play and for his excitement and surprise while playing."

R2: "Yes, he came home talking about the game."

4- How do you think your child's interaction was with the game? Do you think it can improve? Do you have any suggestions?

A1: "I think it was great. I suggest that more items catch the eye, like coins and other types of obstacles."

R2: "The interaction was very good, as the stroller moves in sync with the movement of the foot, something that seems to be essential for the child to understand and play. The visual part is also obvious and understandable."

5- How do you think your child's motivation was with the game? Can you make any suggestions?

A1: "He was very motivated with the game, both because it was something new and because it challenged him to use the foot control."

R2: "At first, he was surprised by the game (as unlikely the iPad, it has the sandal that controls the movement of the car), but he soon understood the dynamics."

6- How do you consider the game feedback concerning the interlocutors (you and your child)? Do you have any suggestions?

A1: "It would be perfect if there were a sound showing whether the maneuver was right or wrong and at the beginning and end of each stage."

R2: "It was good. I believe that new contacts with the game will allow him to get used to the dynamics of the game even more, in therapy."

7- Would you like to make any suggestions?

A1: "The suggestions he made, for me, are sufficient. If it were possible to generate a report, it would be good."

R2: "I believe that the movements of the game will be according to the need for physiotherapy. Anyway, my suggestion is that the game is really dynamic, with challenges that keep the child entertained."

8- Do you consider that technology and specifically serious games can contribute to the treatment of your child and children with CTE? In what way?

A1: "I believe that yes. Technology has increasingly participated in our lives and even more in the lives of our children. Games of this type can help a lot in the treatment and be another good tool for their recovery."

R2: "The game can certainly contribute. The long time of treatment makes the child tired of the therapeutic routine, and the game inserts a playful element that for children is a great motivational factor."

In this first experiment with the game, children's feedback was paramount for collecting usability requirements that need to be improved: adding audios and sound effects, make it more explicit when the user scores in the game, and increase the animation speed of the car.

5 Conclusions and Future Work

CTE disease is the most common of the orthopedic diseases that humans can present at birth, requiring early interventions, with weekly frequency and professional monitoring throughout childhood. Such interventions require specialized knowledge about the anatomy and physiology of the newborn and child's body, in addition to in-depth studies on musculoskeletal, neuromotor development and the skills inherent to each stage of development.

Currently, there is a consensus that the approach, whenever possible, should avoid surgeries, and the treatment should maintain the structures of the child's limbs, seeking conservative and minimally invasive therapies to reduce the changes in the least aggressive and possible impactful way. Such approaches have promoted very satisfactory corrections. However, health professionals' biggest problem has been in maintaining the corrections initially obtained over the years. Many resources have been used, such as fixed orthoses for the lower limbs, elastic adhesive bandages, muscle, and connective tissue stretching and targeted therapeutic exercises. Even so, part of the deformities can return, even though they have been corrected, mainly between 4 and 10 years of age.

This game's proposal can be an essential ally to stimulate and favor the performance of controlled and repetitive movements through a playful interface. This involves the child's interest in having fun and the therapeutic need to perform exercises in a playful and controlled manner. The recruitment of the muscles related to the ankle joint, inserting themselves in the leg and the different bones of the foot, is essential for the lower limbs' coordinated actions and the various functions of displacement locomotion of the human being. The establishment of a routine that can digitally provide a series of active movements with distracting and involving elements, consistent with the therapeutic need to maintain the stretching of the connective tissues of the region.

The game showed applicability to support the rehabilitation of children with PTC. However, the system is still at the prototype level and should be used by patients individually, with support from the therapist, that is, in face-to-face clinics. This is because it is necessary to enter various game configuration information such as maximum angle of dorsiflexion and plantar flexion movements, number of obstacles (playing time in each stage), speed of animation, among others, which impact the level of difficulty of the game. Therefore, for its use today to be effective, the physiotherapist always needs to adjust these settings and keep track of the evolution of each patient, through the performance reports generated by the game.

In the future, we intend to create a communication module via bluethoot from papete with the game and port it to mobile devices (tablets). We also intend to port our database, which currently data locally (on the computer), to a cloud architecture. That way the patient will be able to use the system at home and the therapist will be able to configure the game, monitor the treatment and provide support to the patient remotely. But that is still a challenge to be achieved.

As future work, we intend to add new features to the game, such as inversion and eversion and abduction and adduction movements. This pilot study's continuity provides for a controlled clinical trial with a more significant number of participants. So that, some scientific evidence of this intervention model for CTE treatment can be obtained. From the evidence generated, it becomes safer to apply a protocol based on serious games. The treatment may be extended to children with other diseases that also involve changes in the lower limbs, such as arthrogryposis, myelomeningocele, and cerebral palsy.

A future work that is already being developed in this same research line is on applying this same game in children with neurological diseases, such as myelomeningocele with lesions considered to be high, for presenting functional viability of the lower limbs.

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