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Rehabilitation Games for Juvenile Rheumatic Disease to Knees and Ankles

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Abstract

The scope of physical rehabilitation process related to the cure of a chronic illness is to make the patient perform repetitive and tedious exercises. The result is often the loss of interest of the patient, and this causes a loss in the regularity and quality of the rehabilitation process itself, especially if the patient is a child.

Our goal was the design and the development of a system, composed of a set of rehabilitation games for the patients affected by Juvenile Idiopathic Arthritis to the lower limbs (specifically the knees and/or the ankles) and a management tool for the therapists to help them during the preparation and control of the therapy. We applied the “serious games” principles to design games that are medically relevant and fun to play, realized as smartphone’s applications in order to reduce the cost of the required equipment.

Our system was developed in collaboration with the Clinica Pediatrica G. e D. De Marchi where we performed several therapeutic sessions in order to test our games. During these sessions we have tested the reaction of the patients, their level of engagement. Data collected while the patients were performing the exercise have been used by the therapists to understand the behaviour of the patients in order to evaluate the rehabilitation process. The feedbacks we received from the patients were very good; also the feedback we received from the therapists was positive, since they appreciated the possibility to monitor the patient even in remote and also exercise the patients did while paying was greater than that they did without playing.

Sommario

Scopo del processo riabilitativo per la cura di una malattia cronica consiste nel far eseguire al/alla paziente una serie di esercizi ripetitivi e tediosi. Il risultato è spesso la perdita di interesse da parte dei pazienti, che provoca la non regolarità nell'esecuzione della terapia e la scarsa qualità con cui questa viene eseguita, soprattutto se i pazienti sono bambini.

Il nostro scopo è stato la progettazione e lo sviluppo di un sistema composto di un set di giochi progettati per la riabilitazione fisica di pazienti affetti da Artrite Idiopatica Giovanile agli arti inferiori (alle caviglie e/o alle ginocchia) e di un programma di gestione per i terapisti per aiutarli a preparare e controllare la terapia dei pazienti. Abbiamo applicato i principi dei "serious games" per sviluppare giochi con rilevanza medica e che siano divertenti da giocare, realizzati come applicazioni per smartphone in modo da ridurre il costo dell'equipaggiamento.

Lo sviluppo del nostro sistema è stato fatto in collaborazione con la Clinica Pediatrica G. e D. De Marchi, dove abbiamo svolto alcune sessioni terapeutiche per provare il nostro sistema durante le quali abbiamo testato la reazione dei pazienti e il loro divertimento. Le informazioni raccolte durante lo svolgimento dell'esercizio sono state usate dai terapisti per valutare il processo riabilitativo. I riscontri che abbiamo ricevuto dai pazienti sono stati molto positivi; i riscontri da parte dei terapisti sono stati molto buoni: hanno molto apprezzato la possibilità di monitorare il paziente anche da remoto tramite il nostro sistema e hanno notato che i pazienti mentre giocavano ottenevano risultati migliori nei movimenti rispetto a ciò che avveniva senza giocare.

Chapter 1

Introduction

1.1. General introduction to rehabilitation

In recent years a new frontier in the design and development of videogames has started to be explored: the games for rehabilitation. In order to understand what is the core for this kind of games we first of all need to understand what is rehabilitation: rehabilitation is the process by which, after a serious injury, illness or surgery, a patient is able to regains strength, relearns skills or finds new ways of doing things that he/she was able to do before [27]. However there are many different possible aspects that are linked to the rehabilitation and many fields in which this is used with completely different characteristics. Our effort has been directed to a special type of rehabilitation, which is the physical rehabilitation after the insurgence of an illness or after a surgery: this type of rehabilitation is of particular importance when the pathology affecting the patient is a disabling one.

This kind of rehabilitation process is developed through a series of simple exercises that must be performed frequently by the patients and generally for a long amount of time, eventually for all their lives. Another characteristic of this exercises is the repetitiveness and the main issue that is caused by this is that the patient lose interest in the therapy, get bored of the exercise and stop performing them before the results have been correctly accomplished [7]; this may cause problems in the future life of the patient by compromising the effectiveness of the therapy. For this reason it is of the utmost importance to find a new way to make the therapy more enjoyable, especially for children, who has a very limited amount of patience.

Taking in consideration this very important aspect one of the most important solution that has been tested is the use of the serious games, a special subset of the videogame development research field that is dedicated to specific usage different from simple amusement, while keeping the entertaining factor of classic videogames.

In particular we focused on a specific type of serous games that are the rehabilitation games, videogames dedicated to help the patient with their physical therapy to lower their physical impairments.

The development of this research field has been limited by external factors, mostly related to the cost, the technical limitations and the technical expertise needed to use the products and the sensors that were needed: for a lot of time the effort was centred on the development of specialized hardware, dedicated to the measurement of the patient's performance; however this choice present high cost of realization, high cost of maintenance and also require high technical skills to install and also in some cases use them.

The development of commercial input devices, such as the Nintendo's Wii Remote™and Balance Board™, Microsoft Kinect V2™, Sony PlayStation Eye™, the new gadgets for fitness linked to smartphones and other similar devices have opened new possibilities: movement oriented control devices present on the general market can be used for physical rehabilitation at a limited cost with respect to the specialized hardware sensors. There have been also studies in order to validate these technologies as useful tools for rehabilitation.

The problem is still, however, in the designing of effective software that is suitable for the patients of physical rehabilitation activities: the patients who suffers of a certain illness and are required to perform physical rehabilitation hardly presents the reactivity and the movement possibilities of normal men, which are the target of the development of the global market of videogames. This may lead to the unfeasibility of the usage of the general purpose market games, even if the input devices are working correctly. There is the need of specially designed games that could adapt to the patient necessity, while keeping the effectiveness of the therapy and the amusement of the game.

We focused our attention particularly on the physical rehabilitation that is assigned to patient affected by Juvenile Idiopathic Arthritis. This illness is composed of a set of different rheumatoid diseases for which there is still not a clear definition of the cause. The main common symptoms are the swelling and the feeling of pain in the affected joints, uveitis and skin rash, always accompanied by joint inflammation. The illnesses generally begins before the age of sixteen years old and can last years or in some cases for the entire life of that patient, affecting generally more than one joint simultaneously, limiting the movements that the patient's joints can afford and lowering the quality of life of the patient and of the people around him/her. Unfortunately this illness is not uncommon, since we know that about once child every thousand develop some form of juvenile arthritis.

We are focusing our attention on the design of videogames for rehabilitation of the lower limbs and in particular we are focussing our attention on the rehabilitation exercises performed for the mobility of the knee and of the ankles. We applied the specific rehabilitation principles to the ones of the common game design, to obtain games both medical relevant and fun to play. We applied the iterative design approach, a methodology based on a cyclic process of prototyping, testing, analysing, and refining of the games.

Our aim was to design a set of games that would be considered amusing by children while helping them in performing their rehabilitation exercises. We have decided to adopt simple and intuitive gameplay, so that children can learn easily how to play without the need of long training session. We designed a reward system based on a scoring system, dependent on the game; this system promote the correct exercises but does not punish the patient for possible errors. We have designed and realized four different games, one for the ankle, three for the knee, in order to fulfil the needs of the largest possible part of patients. The exercises, that inspired the gameplay we propose, were presented us at Clinica G. e D. De Marchi and we adapt them to games to make them fun to perform.

The first game is Gyroscope, a race game: in this game the patient has to complete a track, constituted by different obstacles, in the shortest possible amount of time. The exercise prescribes the use of the wobble board, a board mainly used to perform equilibrium exercises. During the exercise the patient have to tilt on all four different directions the board by performing the deflection of the extension of the ankles, if the patient is seated on a chair, or by changing the position of the whole body; this movements have been mapped as the different movements of a ball over the track in the game Gyroscope.

The second game is Break Out, a reinterpretation of the classical Altari arcade game. The third and fourth games are a reinterpretation of Puzzle Bobble by Taito, but they have been redesigned to perform two types of exercises. All these last three games have to be played by the patient performing different exercises for the knee's tilting.

The first exercise prescribes to perform the extension-deflection movement of the knee while the patient is seated from the rest position to the maximum angle reachable by the patient. This movement has been used in both Break Out and Puzzle Bubble version 1 in order to control the character's avatar (the paddle and the cannon), even if in the two games there is a difference in the focus: the frequency of the movement in Break Out and the resistance in keeping the position in Puzzle Bubble. The second exercise prescribes the patient to perform the complete movement of deflection of the patient from the minimum reachable angle to the maximum reachable position in a repetitive way.

For each of these games the therapist can completely personalize the parameters of the game in order to personalize the experience of the patient and make it suitable for his/her clinical condition.

The system is also recording two types of information for each performance that the player has made: the first data is a set of game information, useful to understand if the parameters of the exercise are adequate for the patient's ability and possibilities. The second is the recording of the values registered by the accelerometer of the device on which the game has being played. This information is helpful to reconstruct the movement of the patient and to detect eventual errors in his/her movements. All this information can be showed in a delayed time through the dedicated management software for the therapists.

Finally at Clinica G. e D. De Marchi we performed a set of experimental sessions to validate the result of our system. We have been helped by a team of therapist and a group of patients. We inserted our gamed in their normal rehabilitation session, substituting their normal exercises with the exercises performed with our games. We tested the interaction of the patient with the games, and verified how they react to the different type of experience. We have also verified through the data analysis the results of the patients by a point of view more interested on the observation of the movements.

With the tuning session, we wanted to obtain a first feedback to validate our work, both from a rehabilitation point of view and with respect to the subjects engagement. In the following therapeutic sessions, we focused more on the user experience. Feedbacks were good from both the subjects, who appreciated the games, and the therapists, who were satisfied with our designed features for the analysis and with the patients reactions to the games.

1.2. Thesis organization

This work is organized as it follows.

In chapter 2 we analyse the state of the art about serious games for the lower limbs; we start from the description of what is a serious game, than we analyse the different aspects that in the literature are considered important in the designing phase of a videogame for rehabilitation and then we present some products that have already been realized for the rehabilitation of the lower limbs.

In chapter 3 we present the illness that affects our target patient, which is called Juvenile Idiopathic Arthritis, and in particular we present who this illness affect the patient and what is the appropriate therapy.

In chapter 4 we present the designing principles that we have considered in the development of the system we are proposing. We present the specific requirement we have received from the therapists of Clinica G. e D. De Marchi.

In chapter 5 we describe the system we have designed and realized, giving an overview of the architecture of our system. We present how the system is composed of sub-systems, how these sub-systems interact and what is the hardware required to use our system.

In chapter 6 we describe the serious games we designed and developed; for each of them we present the exercise that our patient are supposed to perform while plying; then we present the game mechanic that is used in our game to mime the exercise; finally we describe the game, showing the aspect of the game, how the mechanic is used and what parameter can be modified by the therapist to customize the exercise for each patient.

In chapter 7 we present the results we have collected during the therapeutic session we have held to validate our designing process. We describe the patients' conditions, how each session has been conducted and the plots, relative to the patient's data, the significant game data and also the feedbacks we received from patients, families and therapists.

In chapter 8 we present a detailed description of the auxiliary sub-systems we realized to manage the data and help the therapists in controlling the patient and managing the exercises: the database and the therapists tool. For the first one we describe the data stored in it and the security measures we adopted, for the second we describe the different functionalities that are available and how the therapists can use them.

Finally in chapter 9, we draw our conclusions about the results we have obtained in the development of our system and present some possible future development of our system.

Chapter 2

Serious Games for Rehabilitation

In this chapter we focus on serious games, in particular on the sub-genre specific for medical physical rehabilitation. We give a definition of serious game and we also provide a brief history of the development of serious games and the process that led to the use of videogames for rehabilitation. Then we present some specific features and game design rules found in the literature about the design of rehabilitation games. Finally we give a brief overview of the state of the art for rehabilitation games, ending with the specific solutions for the lower limbs.

2.1. Definition and History of Serious Games

The definition of the term "serious games" is not related to the introduction of electronic devices for entertainment, but has been used long before that moment. The first time that the term "serious game" has been used in the modern significance it was in 1970 by Clark C. Abt, who gave a useful general definition which is still considered applicable in our computer age:

> «*We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement*» [2]

This definition has been deeply affected by the concept of education games and simulation games that were the object of Abt's research at that time, but in this definition there are all the key concept that are still considered discriminator for the classification of a game as a serious game.

This definition is also in contrast with the conventional wisdom, as Sawyer [32] has said, that consider videogames and unhealthy and a waste of time.

A more recent definition has been given by Rego *et al.* [30] as they had defined serious games as

> «*games that allow the player to achieve a specific purpose using the entertainment and engagement component provided by the experience of the game* »

Historically the evolution of serious games start from the war simulation games, but from that time the number of sub-genres of serious games has grown, and now there are several possible application; the most important are education, advertising, military, ecology, culture, religion, scientific research purpose, politics, crisis management and healthcare.

According to Wilkinson [37] the first serious game has been America's Army, a war simulation game used by the U.S.'s army for military training. In the mid of 20th century there has been a great development of serious games for military training, but they were mainly analogue games: form 70's there has been the development of digital serious games, such as Oregons Trail in 1974 that has been one of the first educational serious games and is still used nowadays. Other special mentions between the serious games of that period must be done for Battlezone by Altari in 1980, which is considered one of the most important games in videogame history, that has been adapted by Altari for the US Army to mime real tanks and planes, and for Pepsi Invaders, which has been developed by Coca Cola in 1983 to promote their product and is considered the first advertising game. Djaouti *et al.* [16] also state that serious games has also been used in scientific research, especially in the computer science and artificial intelligence field. Between 1980 and 2010 there has been a great increase in the number of serious games, especially the ones related to education and healthcare and we can notice that in 2004 there have been two very important conferences on the development of serious games: the Games for Change conference and Games for Health conference.

Among the fields in which serious games have been used, we are interested in the healthcare field. In this case serious games have been developed both for healthcare and health professions, and are present in a variety of application area, as Ricciardi and De Paolis [31] have classified. In their work they have identified serious games to train the medical staff during the surgery, for example in the replacement of knees or the blood management during orthopaedic surgeons, and many other examples of training serious games; another possible application that have been identified is odontology to train students in the absence of a real patient; another field has been identified in teaching the nursing staff to manage different possibly critical situation; However the most of the games that Ricciardi and De Paolis have identified are related to first aid training and crisis management for the medical staff. Examples of serious games designed for patients, instead, can be found in the cardiology field where there are examples of games both for training doctors and games for patients, or in the management of diabetes and in the cure of some psychological conditions.

However we are interested in a different subset of the healthcare problem that is related to the rehabilitation of patients. Rehabilitation is the process by which, after a serious injury, illness of surgery, someone regains strength, relearns skills or find new ways of doing things done before [27]. There could be different types of rehabilitation, according to the nature of the disease of the patient, however we focus our attention on a particular type of rehabilitation that is the physical rehabilitation. The physical therapy is essential for the rehabilitation process of disabling pathologies, and it usually consists of a series of repetitive exercises that most of the times must be repeated for an important amount of time and that, since are performed on the injured part of the body can be also painful for the patient. These exercises have also different possible goals, since they can affect the strength or the functionality of an injured part of the body, the ability to speak, the ability to perform normal daily activities or the pain management.

All of these types of rehabilitation processes have interesting and unique features, but we focused only on the physical rehabilitation of patients to increase the strength and the functionality of the patient's injured art. The aim of this process is not always the complete recovery of the functionality, that unfortunately sometimes cannot be achieved, but rather the improvement of the life quality of the patient. In order to achieve this effect, generally, the therapy must be performed frequently and for a long period of time. This type of rehabilitation is generally divided in different phases, form the hospital where the patient is daily followed by therapists, to a phase in which the patient is seldom visited at hospital or in specialized clinic and the most of the therapy is held at home.

This two are the most important issues in the physical rehabilitation process: as Rego *et al.* [30] has mentioned the repetitiveness of the exercises is the main cause for the patient to lose motivation and interest in performing the rehabilitation compromising the effectiveness of the therapy; Burke *et al.* [7], instead, noticed that there are numerous elements that a therapist want to monitor and that it is impossible to properly measure with standard rehabilitation, for example the patient movements measurements are imprecise, the effort and the frequency of performing the exercise are impossible to monitor; both these two issues worsen when the exercises have to be performed at home and if the patient is a child.

With the increase of the popularity and availability of videogames, researchers had increased the attention in the use of videogames as a possible solution to these problems. The ability to entertain and engage the player is the most important ability of a videogame and it also motivate the players to keep playing even after long periods of time. Researchers wanted to use this kind of engagement to boost the patients to keep performing their therapy.

Burke *et al.* [7] also noticed that there are some solutions that could be found in the interactive technology, but this solution presents some important defects that Borghese *et al.* [5] [6] have identified. The most important problem they have found is related to the devices used to let the patient interact with the game: specifically designed devices that can be used are generally expensive and they require special technical abilities to use them, especially at home; a partial solution to this problem has been found in the development of new input devices for the general purpose market, such as the Wii™Remote, the Wii Balance Board, the Microsoft™Kinect™or the Sony™PlayStation™Eye: differently from common use controller this devices have been designed to recognize the motion of the body, or part of it, in order to play. Unfortunately even if this devices are very powerful, but they may not be sufficient for the special needs of the patients: one issue is that none of them is able to measure some of the important biological markers that are important to measure according to the analysis cited by Sawyer [32]. Some studies were conducted for example on Kinect™[11] [12], to validate these instruments as suitable rehabilitation tools, testing them on some general market games, resulting in the acknowledgment that general market games are not practical in general since they require speed and range of motion that are impossible for most of the patient who needs physical rehabilitation.

Many studies have been conducted in the development of serious games for healthcare and a significant number of results have been acquired in the recent past. Now we propose some of the most interesting solutions that have been found for generic rehabilitation problem using serious games.

Borghese *et al.* [6] worked on the Intelligent Game Engine for Rehabilitation, a complex system composed of a set of different games to be played at home. The system is integrated into a multi-level platform that provides continuous monitoring by the hospital. As input device they have integrated different user interfaces like Wii Balance Board™and Microsoft Kinect™sensor.

Gil *et al.* [20] designed a low-cost framework that has the aim to perform different customized standing exercises. The system is able to provide objective measures and the evolution of the exercises automatically, allowing less dependence of patient in relation to the specialist. It is based on catadioptric velcro strips placed on the feet of the patient and some signals projected on the floor.

Zhang *et al.* [39] created a system for post-stroke hand rehabilitation: this system has integrated videogames technology, augmented reality and an instrumented glove able to detect the movement of the fingers. Goal of the game was to play the piano with the fingers: the game present different level of complexity to increase the challenge and to take into account the different physical condition of the patient. The game also provides the therapist a qualitative feedback.

Friedman at al. [18] developed a game called MusicGlove, a specially designed glove that requires the user to practice gripping-like movements and thumb-finger opposition to play. The game they proposed is a customized version of Frets on Fire, a game inspired by Guitar hero. Results of the experimentation of this game have supported the hypothesis that hand therapy in post-stroke rehabilitation, if it is engaging and incorporate a sufficiently high number of repetition is a promising approach to improve an individual ability to manipulate small objects.

Chiuri *et al.* [10] have developed a suite of games for the training of the wrists of patients affected by Juvenile Idiopathic Arthritis: the system was composed of four different games that were controlled through the movement of one or both wrists. As a controlling device it has been used a Leap Motion sensor. The system also provides the therapist a feedback and the possibility to see the replay of the patient's performance.

Lately a new result have also been very important and it is the work of Donati *et al.* [17] that have created a brain machine interface and through long term training with this machinery were able to induce a partial neurological recovery in paraplegic patients and the results are incredible and brings hope to the future of medical application for informatics.

2.2. Serious Games for the Rehabilitation of the Lower Limbs

When we focus on the rehabilitation for the lower limbs we have to remember that it is a research field less explored with respect to the research on the upper limbs, and this is probably due to the fact that until recent past the development of suitable input devices was not as easy as to create devices for the upper limbs, especially the hands. Nowadays, however, with the use of new technologies like optic input devices like Kinect™from Microsoft™, PlayStation™Eye produced by Sony™and similar technologies, or with the spread of new types of smartphone and technologies for the fitness that uses accelerometers and GPS components in their hardware, it is possible to develop new systems that would not constrain the patient and are easily accessible.

We can cite also particularly the work of De Vita *et al.* [14] as a demonstration of the applicability of the use of Kinect technology to the rehabilitation of the lower limbs: the system they propose uses the Microsoft Kinect device to map the position of the player on a grid of pillows over which the patient had to move according to the game requests and the obstacles the therapist had put over some of the pillows.

The other important aspect to take into account is that most of the research about videogames for physical rehabilitation has been held for post-stroke rehabilitation. In this perspective the work of Luque-Moreno *et al.* [25], who has developed a systematic review of the literature to describe the different virtual reality and interactive videogames solution applied to the patient's lower limbs is interesting, since many of the challenges that have to be faced in post-stroke rehabilitation are in common with the ones we have to face while considering arthritis patients.

Gil-Gomez *et al.* [21], instead, decided to compare an intervention program with the use of the Nintendo Wii™Balance Board with eBaViR to a conventional physiotherapy treatment in patients with brain damage. During this experiment a software for Wii™has been specifically designed and has been used by some patients, while other patients had been used as a control group. According to the results the patient who has used this software showed improvements in the static balance, if compared to patient who has gone through the normal therapy, even if some of them (six over seventeen) had hemiplegia not secondary to stroke.

Jaffe *et al.* [22] decided to compare the results of the virtual approach and the real approach in the training to overcome obstacles. They used two groups of patients: for one group there were used real obstacles, while for the other group the patient were equipped with a VR head mount that used virtual stationary images of obstacles and get the patient feedback. As a result of the comparison it has been noticed that the virtual obstacle training had generated greater improvements on both the fast walking test and the self-selected walk test in the gait velocity, the stride length, the walking endurance and obstacle clearing capacity.

Chen *et al.* [9] developed a system called LLPR that was a human-computer interactive videogame to train the muscles of the lower limbs of elderly people. The experiment consists in the analysis of 40 participants. The system permitted to perform sit-to-stand movement on fast or low speed; in the experiment half of the participant were asked to perform 30 minutes training twice a week using the system with the fast speed, and also twenty age-matched participants in the control group were asked to perform the slow speed exercise as well as the strengthening and balance exercise. The results showed a significant improvement of all the mechanical and time parameters have improved in the group who had taken the exercise with LLPR, while in the control group only the maximal vertical ground reaction force improved. Finally as for the clinical assessments (balance, mobility and self- confidence) the group equipped with LLPR has demonstrated significantly better scores.

Chapter 3

Juvenile Idiopathic Arthritis

In this chapter we describe illness that is affecting our target patient known as Juvenile Idiopathic Arthritis, or in short JIA, firstly describing the causes of the disease, the its progress, the different types of illnesses that are contained in what is globally called JIA and the suggested therapy. Finally we present a set of rehabilitation exercises for the lower limbs that were presented us at Clinica Pediatrica G. e D. De Marchi on which our work has been based.

3.1. Description of the Illness

Juvenile Idiopathic Arthritis is the most important disease we are studying and is the most common illnesses between our target patients and for this reason is the first one we present. Whenever we talk about arthritis we have to remember that it is an inflammation of the joints that is characterized by swelling, heat and pain. Arthritis can be of different nature, but we focused just on Juvenile Idiopathic Arthritis (normally abbreviated with the term JIA), however it can also be called Juvenile Rheumatoid Arthritis (normally abbreviated with JRA).

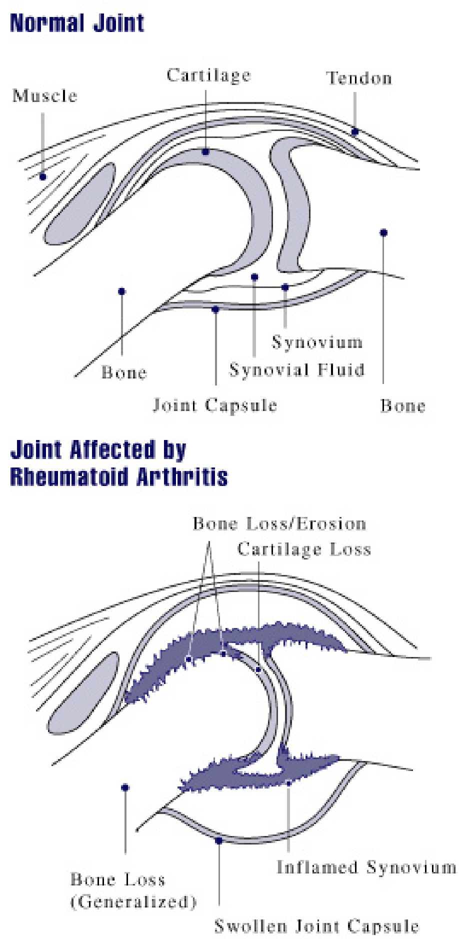


Figure 3.1: Difference between a normal joint and a joint affected by rheumatoid arthritis [13]

When we talk about JIA we have also to remember that it is not a specific illness, but it is a broad term used to describe a clinically heterogeneous group of arthritis of unknown cause and that generally occurs in the patient before the age of 16 years of age [1](and generally even in pre-scholar age). The condition can be temporary but if it persists for more than six weeks it is considered chronic arthritis.

Even if this illness is not very known to the general public, about one child in every one thousand develops some form of juvenile arthritis, as shown Arthritis in Children by Abransom.

Each of the different categories of arthritis that are considered possible manifestation of JIA, in reality, presents differently both in the clinical signs and symptoms, and in some cases can be influenced by the genetic background of the patient.

We still do not completely understand the cause of the disease, but it seems that to be related to both genetic and environmental factors and this complexity of causes is the reason for the heterogeneity of the illness [29]. Research also indicate that this is probably an autoimmune disease, a disease in which the white blood cells and the immune system of the body is not able to identify the difference between the body's cells and extraneous cells or virus, and for this reason it attack also the body's cells as potential threats to the patient health, causing inflammation and pain.[13]

Figure 3.2: The effects of Juvenile Idiopathic Arthritis on legs [38]

Arthritis Research UK [34] defines five different major onset types for JIA. We are reporting them in inverse order of rarity:

Oligoarthritis: It is the most common type, since it affects about two thirds of the young people affected by arthritis. Generally it affects one or both the knees and wrist, and generally not more than four joints, and also affect eyes, in particular causing chronic anterior uveitis, a form of eye inflammation. Fortunately this type of disease is also likely to vanish with time leaving little or no joint damage in the patient. However if the problems affect five or more joints for more than six months, it transforms in extended oligoarthritis, that can cause joint damages, and should be threaded with drugs to reduce the damage at the minimum.

Polyarthrithis: It is the second most common type of JIA. It may steadily involve more joints over months or it can manifests suddenly in the patient. It affects principally fingers, toes, wrists, ankles, hips, knees, the neck and the jaw causing painful swelling.

It can also present a sense of disorder and tiredness and occasionally present slight fever. This form can last also in the adulthood f the patient, but may also go into remission, where all the symptoms disappear. It can be detected by a blood test searching for a marker called rheumatoid factor is present in the blood.

Enthesitis-related JIA: this type of JIA affects the places where tendons attach to the bones, called enthuses from which derives h name of the type of JIA, causing inflammation of this part. It often affects the joints of the leg and the spine and is also generally associated with acute uveitis, a red painful eye condition. It generally present with stiffness in the neck and the lower back, especially during patients teens. This form of JIA is probably linked to genetic background of the patient, since it is more probable to affect people within their family history cases of ankylosing spondylitis or inflammatory bowel disease.

Psoriatic arthritis: It is a form of arthritis associated also with psoriasis: psoriasis is a form of skin rash and when it is combined with joint pain, this condition is called psoriatic arthritis. It usually affects fingers and toes, but can affect also other joints. Joints can be affected also before the appearance of psoriasis. This form can be also associated with uveitis, but in this case they are the painless type of uveitis and do not present the traditional red colour in the eye. In this type of JIA it is difficult to predict the outlook of the disease, but between 30-40% of the patients suffer of this disease even in their adulthood. It can be anticipated by the analysis of the fingernails and toenails that might be affected.

Systemic-onset JIA: in this particular type of JIA the joint pain in possibly he whole body is a part of a general illness that is involving also high fever, tiredness, rash, loss of weight and appetite. It can present the enlargement of glands, especially in the neck and under arms or around the groin. It can also present enlarged spleen and liver, and in very rare situation also the covering of the heart present inflammation, called pericarditis. These symptoms however may stand silent for few weeks at the beginning, so it is difficult to diagnostic. Also predict the outlook of the illness is complex, but usually the fever and the rash settle, although the arthritis may continue for several years before settling.

3.2. Treatments for Patients Affected by JIA

Unfortunately a cure to chronic arthritis has not yet been found, but there are many cases of spontaneous remission that represent the hope for most of the patients. However while the disease is affecting the patient life it can affect deeply the life of the patient how may be limited in some actions or can feel high pain, or can avoid some actions just for the fear of the pain that may feels. For this reasons the therapy goal is to induce the remission while controlling pain and preserving range of motion, muscle strength, physical and psychological development [8].

Most of the times children affected by chronic arthritis require a combination of pharmaceutical, physical and psychological treatments. One of the most important aspects of the treatments is to encourage a normal social growth, both on a physical aspect by overcoming the pain and the limitations of the illness but also on a psychological level to avoid the children to feel excluded by the society due to their limits.

For this reason associated with specific therapy ,children affected by JIA should be involved in the same activities performed by the healthy children, even if taking in consideration their own level, especially activities like playing games, walking, and more in general every activity that involve social interconnection between children. It is also very important to make affected children interact with other patient affected of arthritis, so that the children may understand that they are not lonely in the world but that other people have their problem and maybe have overcome their limits, becoming a icon or a idol for the patient, so that they become more motivated in their effort to regain health.

There are four different aspects that are more important than the others in the disease treatment:

Pharmacological management: drugs are generally the first element to be considered every time someone refers to an illness treatment. In this case, unfortunately, there is no drug to cure the disease, but some drugs are very important, in particular no steroidal anti-inflammatory drugs are likely to be used to reduce inflammation of the joints and the consequent pain[19]. It is of the utmost importance that this pharmaceutical treatment begins as soon as possible, as soon as the disease is discovered, in this way the possibility of permanent consequences is diminished.

Nutrition: this is an often underestimated aspect, but nutritional and vitamins supplementation are often indicated as part of long term management of the therapy.

Physical therapy: the objective is o minimize the pain and maintain or restore where it has been lost the functionality of the injured joint, so that the patient can live his/her life at the best he/she can and also it is useful to prevent deformities and disabilities and also correct wrong compensatory movement that are even unconsciously assumed by patient that try to avoid the use of the injured joint by performing movements that on long term could damage the rest of the body.

Orthopaedic surgery: it has a limited role in management of chronic arthritis in young children, but for older children it could be useful in the treatment of contractures, dislocation or joint replacement in the worst cases.

3.3. Physical Therapy for Patients Affected by JIA

As discussed in the previous section, one of the main symptoms of the juvenile idiopathic arthritis (JIA) is joint inflammation. If this crucial aspect of the symptomatology of every type of JIA is not carefully treated, it can result in the loss of articular functionality and in the consequential worsening of the patients quality of life.

Moreover, the child is prone to actuate incorrect compensatory postures or movements that persist even after a full recovery to ease the pain caused by the use of the injured joints. These compensations in particular increase the burden on muscles and other joints, leading to new possible physical problems.

For these reasons, the main goal of physical therapy is not the healing of the inflammation that is generally treated through the use of pharmaceutical therapy, but to help the patient managing the symptoms and improving his/her self-sufficiency. In particular the therapist guides the child in the process of understanding which is his/her moving capabilities, both in natural and in sport activities. He/she also helps reducing the patients fear of pain and the familys propensity to overprotect their child.

An important aspect we have to keep in mind is that the physical therapy should be customized for each patient and should take place both at the medical structure and at home. This is not always easy to accomplish and require important effort form all the parties, the physicians, the parents and the patient in a cumulative effort to reach the common goal. In combination with this monitored process, therapists recommend also to play some sports. Indeed, a main aspect of physical therapy is allowing the child to live a life as normal as possible, and sports can help him/her not feeling different.

For what regards the personal therapy the patient are subject there are exercises for both large joints, such as the knees or the shoulders, and small joints, such as those of the hand. In this work we focused on the exercises for lower limbs rehabilitation, and special importance is given to the exercises involving the mobility of the knee and the ankles and in particular the exercises that are preformed at Clinica Pediatrica G. e D. De Marchi and that guided us in the design phase. There are innumerable possible types of exercises: we can cite Chiuri *et al.*[10] that has been interested in the development of games devoted to perform exercises for the upper limbs and in particular the wrists, and De Vita *et al.*[14] that have been interested in the development of games devoted to perform exercises for the lower limbs.

A first category of exercises we are presented is related to the flexion-extension of the knee. This exercise can be performed in different ways; all of the exercises are performed by the patient seated on a chair.

The first way is to perform the rotation of the knee until the maximum that is allowed by the limited mobility of the patient, keep the position for few seconds, and reposition the knee in the rest position and to repeat this process for a long period of time. This exercise is very helpful to increase the muscular mass of the knee and the reactivity of the knee joints. It can be performed one leg at the time or both legs together, but in this second case the amount of time for the repetition is reduced due to the increase of effort required to the patient.

A second type of exercises requires the player to perform the extension to the maximum angle that he/she is able to reach in front of him/her and to reach the minimum angle reachable, the maximum flexion of the knee with the feet beside the knee and repeating this process multiple times over a certain amount of time. This exercise is useful to increase or maintain the mobility of the knee. It can be performed one leg at the time or both legs together, but in this second case the amount of time for the repetition is reduced due to the increase of effort required to the patient.

The first category of exercises we are presenting is an exercise performed over a platform and is used to stimulate both the sense of equilibrium and to increase the muscular mass of the ankles. There are many different types of this table but the two most important are the squared balance board, that is simpler to use since it allows only rotation around one axis, and the round balance board, that is more difficult to use since involve rotation about two different axis independently.

Figure 3.3: A round wobble board

Figure 3.4: A squared wobble board

The exercise can be performed in different modalities, but we can broadly classify them in two cases: the weight free version and the exercise with load.

In the first case the patient is seated over a chair and perform the exercise by tilting the board; in this case the exercise is performed mainly through the use of the ankles and is focused on reaching the maximum flexion-extension of the ankle both frontally, backside and laterally (the exercise is performed simultaneously with the round board, while if the patient is using the squared board the exercise affect only one movement, laterally or frontally and backside, and it must be performed two times, changing the orientation of the board to reach the goal). This exercise is dedicated to the acquirement of mobility of the ankles.

In the second case the patient tries to stand in equilibrium above the stable, in the best case without the need to use any support. The exercise in this case involve not only the ankles but all the lower limbs (hips, knee ankles and all the muscles) and partially also the rest of the body to maintain the equilibrium. Obviously the exercise is more difficult in this second scenario than in the first one, but this can be used as the final step of the therapy, when the patient has confidentiality with his/her condition. This exercise is typically a proprioception type of exercise, meaning that the exercise is useful to take confidence with the movements and the response of the patient's body.

Figure 3.5: A wobble cuishon

A third category of exercises involve the use of the Wobble Cushion, an object equipped with smooth spikes on one side. The patient has to keep the equilibrium above it while performing some movements. The cushion is deformable and the difficulty is to keep adapting the position according to the modification of the cushion.

We have decided to focus our attention on the exercises for the knee due to the repetitiveness of the exercise and the round wobble board for the complexity of the exercise.

Chapter 4

Designing Rehabilitation Games for JIA

In this chapter we discuss the design process that we have followed in the designing process of our system, form the principles we have adopted in designing our system in accordance to gather the requirements that were requested during the preliminary meeting hold at Clinica Pediatrica G. e D. De Marchi.

4.1. Designing for Rehabilitation

Designing a game is not an easy task, because it is difficult to properly address the tastes of the players, which could vary for each individual player. Designing games for rehabilitation is even more complex because there is the need to provide a suitable solution that is able to satisfy the needs of the therapist, the therapy and the tastes of the patients.

In our care we needed to design a product that able to correctly implement a physical exercise, which means that the exercise is performed with the correct motions and with the correct speed, for the patient who is also the player of our game.

The system has also to provide suitable tools, inside the game and/or in a separated application, for the therapists both to control the exercises, or more specifically to personalize the therapy for each patient, and to verify the patient's improvements on the long period of time.

4.1.1. Games Not Just Medical Tools

To design a system for healthcare, generally, the design process is focalized on four main entities: the patient, his/her illnesses, the therapist and the therapy that has been prescribed to the patient by the therapist.

This is, of course, of the utmost importance since these are the main actors of a healthcare system. However if this approach is applied to the design of games for rehabilitation is not sufficient to obtain a good rehabilitation game: a game must be fun, involving and the less the impact of the illness is evident the better it is. This is important in every type of rehabilitation, but it is fundamental when we are facing physical rehabilitation, since, as Bianchi *et al.* [4] has identified, the movement can raise the engagement of the patient, while simultaneously the videogame increase the engagement for the exercise, producing a virtuous circle as Lohse *et al.* [24] has demonstrated.

We note that not considering this aspect during this phase in the design of the solution can bring to the underestimations of the potential of this tools and more importantly may lead to a non enjoyable solution that on the long time period will bore the patient as much as the normal therapy.

The development for the general public of new types of games more oriented on the movement (especially thanks to the spread between the public of games for Wii™from Nintendo™, Kinect™form Microsoft™and PlayStation™Eye form Sony™that uses movements of the player's body instead of a classical controller composed of buttons and levers) it was possible for the medical community to test the benefits of games for rehabilitation even on tools not specifically designed for rehabilitation rising interest for this type of tool to provide a differentiate and funnier therapy with hopefully equal or better results.

This interest has also increased recently with the introduction of new affordable technologies for virtual reality, like Lange *et al.* [23] and Stone [33] had shown.

Another important aspect that has to be considered in the design of rehabilitation games, especially for children, is related to the relationship between the games and the patient: a patient that has to use a special medical tool will feel always to be somehow "different" from the other people around him/her, increasing a feeling of exclusion from the society that can have deep effects in a ill child mind; however if the game uses devices that everybody can use (for example the friend who may want to play together with the patient and compete with him) and the game can be played by both children as it is, without the need of penalizations for the normal user, it may lower this sense of exclusion from the society of the patients stimulating him/her in keeping the therapy to get better health condition in an unitary effort of relatives, friends and therapists.

Games that are intrinsically engaging have the power of attracting the players with a challenge and to delay the advent of boredom for the therapy, and this is important to ensure that the patient will perform his/her rehabilitation therapy for a longer period of time. However to obtain a game that is engaging, during the design phase there is the need to consider also the good game design principles that has to be followed during the design of every normal game.

However this is not an easy task since the amusement is linked to gameplay, difficulty of the game, and rewards to success; in this case of rehabilitation game every element of the gameplay have to be designed in accordance to the limitations of the patient and the prescribed therapy that the designer has decided to mime with his/her product.

4.1.2. Medical Tools Not Mere Games

In the previous section we have argued that in designing rehabilitation games we would consider them as games, even if there are some special meaning and constraints below it. However it is equally dangerous to think that a game for rehabilitation is a simple game. A simple game is a means to spend time feeling fun and amusement so it can be played whenever the player feels to be in the right mood to play. But this can be dangerous if we are considering the effect of this assumption on a game that has been designed for a precise scope that is rehabilitation that requires concentration on the movement, a constant cognition of the situation of the body and particularly certain constancy in performing the exercise.

It is also important to notice that one of the factors that make a game engaging on long period of time is the challenge presented to the player: push the player to his/her limits and then we he/she get confidence with the game mechanics push him/her a little further to keep the player feeling he/she needs to play more to get better, and this limits can be both psychological in having to face complex solution to complex problems, physical with the increase of the difficulty or of the speed of the movement that are required to reach a certain state, or more frequently both factors simultaneously.

However even if this can be a perfect solution for a normal purpose game, when we are considering a game for rehabilitation we have to remember that we cannot really push the patient over his/her limits without the assurance to not cause serious consequences to the patient, and this apply both for physical rehabilitation, that is the goal of this work, but assumes an even more important role when we are considering mental rehabilitation or games for the treatments of mental illnesses.

For this reason the gameplay and the controls must adapt to the player and the difficulty of the game cannot grow unlimitedly, as for what happens in general purpose games, but a rigid control must be exercised by the physicians on the elements that are going to make the game too difficult for the player.

Regarding this last element we have also to notice that an healthcare system must respect some rules that are fundamental for the effectiveness of the rehabilitation game, not only as a game, but also as a medical tool: this implies that the division of the competencies between the physician and the patient is respected, a certain supremacy of the therapist over the patient in the decision of the exercises is granted, a special lookup to the patient conditions in the design of the gameplay elements is needed as wonderfully expressed by Ball *et al.* [3], even if they were more focused on general healthcare system, and not on games for rehabilitation.

As for the first point in the design of a rehabilitation game there must be a clear differentiation between what has been approved by the physician and what is a decision of the player, or to be clearer, what part of the system are in control of the physician and are linked to the exercises that the physician has authorized and considers adequate and what can be modified by the patient in order to experiment or to customize the game. This keep completely separate the roles and let the therapist feel the control over the treatment, while letting a certain degree of freedom to the patient that has the desire to experiment the extends of his/her capacity and maybe can be used also by "non-patients" such as friends or relatives, in order to fulfil the social inclusion of the patient.

As for the second point it is obvious that the therapy must be a decision of the physician, and this means that the exercise must be decided by the physician in its details; however a certain degree of freedom can help the patient to feel more like a player and to experiment and test his/her limits increasing the general engagement of the game. Unfortunately there is another problem we have to face: our is a society where the diffusion of computer material is a delicate and very complex theme, the uncontrolled diffusion of programs and games has been a problem for many years up to now, but this assume a completely different importance when we are considering programs, such as serious games for rehabilitation, that may affect the health of the user. As for every medical tool an incorrect use can not only be useless and a waste of time that can be used for better therapy by the patient, but can also lead to damages to the patient body due to wrong settings that push the body of the patient out of the limits, where a therapist knows this elements and can set up the game such as to avoid this negative conclusions.

This has been proved especially in the videogame area, where form the beginning of its history hacking has been a plague. It is very difficult to ensure that our game is being used only by the patients that needed it and under control of the therapists.

As for the third point we can never forget that the patients that will have to use our software are not healthy people, and that our design choices can highly affect the clinical development of the patient: we have to identify possible dangers, limitations and pain provoked that may transform a fun game for normal player into a painful or inadequate experience for a patient.

For all this reasons we want to point out that in the designing phase of our system we were deeply concerned about this elements and have identified some solutions with the aim to let all this elements coexisting ensuring above all the other principles the design principles for amusing good game design for the gameplay, while for the generation of the exercises we have decided to give more importance to the physicians' decisions, ensuring their supremacy.

4.2. Design Principles for Rehabilitation Games in Literature

Researchers have been interested in defining specific game design rules that would guide developers in designing therapeutic games. Here we want to present some of the most interesting models that have been proposed in literature

Burke *et al.* [7] had discussed on some features that a rehabilitation game should provide to be effective as a medical purpose serious game. This features are relative both to the functionalities offered to the actors (patient and therapist) and the gameplay applied in the game; they suggest that the game should provide data recording of the patient performance, so that the therapist is able to evaluate the exercise execution and eventual improvement or errors, correlated also with a feedback for the therapist relative to the level of the exercise to be put in relation with the patient condition; a game should also provide feedback to the patient, so that he/she is able to measure the progress in his/her performances: to do so it is proposed to handle both rewards, an advantage in the game to award a success in the task, and a failure system, so that the patient is able to identify when he/she has made a mistake, in order to keep the patient effectively engaged. A game should also be challenging for the patient in order to increase the engagement: this can be achieved by a level structure of the game or dynamically adapting the difficulty of the game in accordance to the patient's performance and ability.

Borghese *et al.* [6] have identified three elements that are important for the effectiveness of the game as a medical tool for rehabilitation: adaptation, monitoring and real-time evaluation of the movements. The adaptability of the game is a feature that is related to the modification of the difficulty of the game in order to avoid the frustration of the player caused by his/her condition or to bore the player due to the simplicity of completing the task; secondly the patient's movement should be constantly monitored in order to enforce a correct execution of the exercise: this monitoring is both useful in the rewarding system, used by the game to engage the player, and in the control tool. Borghese *et al.* also remark that the design of a rehabilitation game should also follow the principles of good game design, in order to keep the player engaged, which is the main reason to use serious game. They state that the patient, while exercising, should feel like a player, focused on having fun while playing the game.

Nixon and Howard [28] have defined five game design principles specifically to create engaging rehabilitation games: in-game story, easy-to-use interface, interactive feedback, encouragement in the exploration and the sense of achievement. As Borghese and Burke they remark the importance of the continuous feedback provided to the player and the importance of a rewarding mechanism to keep the player engaged and encouraging his/her in continuing the rehabilitation process, but Nixon and Howard also present three new concepts: the first is referred to the fact that an engaging story is essential to try to lure the attention of the patient away from his/her condition in the game; the second is relative to the fact that the game must be easily understandable: this is important because the player should focalize on performing the exercise, not to learn the interface; the third instead is related to the fact that the game should let the player able to explore different solutions to complete the task in order to acquire confidence in his/her abilities.

Mader *et al.* [26] assert the importance of two fundamental elements that are related to the motivation of the player on short and long term; these two principles are the challenge and the variability. Adapting the challenge to the player's ability prevents the player to feel anxious or bored while playing the game, letting him/her concentrating on the exercise and on the game increasing the motivation to complete the level or to win a match: this is an example of short term motivation, since it is affecting the patient only as long as the current game is running. To keep the player engaged for longer period of time, instead, it is not sufficient: there is the need to add variability to the game, so that the player can learn different patterns, gather new information or explore the consequences of making different choices.

Mader *et al.* also propose a model to evaluate a therapeutic game. This model is based on three entities, namely the game, the patient and the therapy, and also the relations between them. The model classify the three entities according to some parameters: for the patient the parameters are the age, the gender, the condition of the player and the abilities that he/she has, while for the therapy instead they are effects that are desired to be reached and the counter effects. As for the game the parameters that have to be taken into account are relative to the gameplay (input and output devices, how feedback is communicated to the player and the scoring system), the variability and the minimum requirement for the patient. In the therapy-player relationship it is important to detect if the therapy that a game is proposing can improve the patient condition, than it is also important to consider the context in which the game would be used, which features present in the game are therapeutic and which are motivational. Finally there is also the need to verify that the player is able to play the game, the game is enjoyable and if it is safe for the patient's health.

4.3. Preliminary meeting and requirement

When have started our project we knew that there was the necessity to have competencies of experts in the field of rehabilitation both to guide us in the definition of the needs of the patients and physicians, and to organize the experimentation of our product to test the potentiality of it.

For this reasons we have asked the collaboration of Dr. Ft. Amalia Lopopolo and her colleagues of the physiotherapy ward at the Clinica Pediatrica G. e D. De Marchi in Milan.

The first meeting has been held in Clinica Pediatrica G. e D. De Marchi, at the presence of therapists and physicians. During this meeting they have presented us briefly the illness that our future players will suffer and its effects on their normal life.

This has obviously leaded us to the analysis of the therapy our future players have to take and the frequency of these treatments. It has been immediately clear why it was interesting the use of games in this treatments: the patients are required to perform tedious and repetitive exercises for a discrete amount of time daily, and continue to perform such therapy for long period of times from the arise of the illness in order to keep a lifestyle that resemble the lifestyle of a normal children. The main problem in the therapy is precisely that patients get bored very easily and tend to skip the rehabilitation if are not forced or worse can quit the rehabilitation due to boredom.

The exercises that were presented to us are basically of two kinds: in the first exercise the patient has to perform repeatedly the deflection of the knee while sitting with the feet not touching the ground, while in the second the patient, with the eventual help of another person, moves on a wobble board or alternatively try to stay in equilibrium over the same board.

A more detailed explanation of the exercises is presented in the next chapters when we describe the game that has been realised to perform each particular movement.

We were also presented the requirements that our system had to match.

First of all we were presented the request to let the patient perform correctly the exercises, meaning that not only the movement is correct but that the patient will have to force the movement as far as the physician believe appropriate for the patient condition and that if he does not put effort to reach it the patient feel that he has to put more effort in it.

Secondly the developed software should be amusing for children. In consideration of this fact we had to consider that we have to identify games suitable for both female and male, from ages of 6-7 years old to preadolescents and everyone should feel fun while playing with our product.

Thirdly that the therapy can be performed also at home, independently of the presence of the therapist, but the physician must be able to control that the patient is not doing wrong or that is not skipping the therapy just because none is watching.

Last requirement was that the system we would develop should have the lower cost possible. In order to match these requirements we have developed a complex system that is completely described in the next chapter. However the fulcrum of our system is in the use of a smartphone or tablet as principal device so that every patient (or at least a parent or someone close to him/her) will be able to install the applications and perform the therapy completely independently from the therapist reducing the number of visits to checking session. Moreover a smartphone is generally commonly present for each family, so has not extra costs and since most of the smartphones are connected to internet network the patient can be kept controlled in its performance by the therapists and also we can use the effect of social gaming to augment the engagement.

We have noticed that the other devices that were present on the market (for example we tried Intel RealSense™3DTM and Kinect™V2) were not appropriated: Intel RealSense™3dTM camera has a too short range of sensibility and is not able to detect joints different from the hands making it impracticable to use it for lower limb rehabilitation, while Kinect™V2 has problems in the recognition of the joints when the player is moving simultaneously the legs and when the feet occlude the knee due to the complete deflection of the knee and this result in an imprecise and inappropriate detection of the motion and in conclusion to an inadequate performance of the device.

However Kinect™V2 sensor has been used in our project to keep track of the motion of the body of the patient in the exercise that uses the wobble board because is sufficiently precise to give the therapist a control of the whole body position and in particular of the other joints not directly linked to the exercise and that may behave wrongly and unnoticed.

Chapter 5

Description of the System

In this chapter we describe the system we have designed and realized. In particular we analyze the subdivision of the system in the different sub-systems that compose it, the hardware requirements that are needed to use the system and how the patient and the therapist can interact with it.

5.1. System and Sub-Systems Overview

Our goal is to design a system that let the patient perform rehabilitation exercises while playing a game, simultaneously let the therapist control the game and verify the performance of the patient. The system has to be fully operative both at hospital with the presence of the therapist and at home without therapist. The system can be used to let the therapist monitor the patient even when not present and also to ensure that the patients have been actually doing the therapy. The system we are proposing is composed of four elements, called sub-system, that need to interact in the simplest possible way. The first subsystem is responsible for the management of the data collected by the system and consist of a online database placed on a server; the second is a management tool dedicated to the therapists from which the specialists are able to monitor the patients, even by remote, and to simply manage the settings for the exercises that the patient have to perform; this application is called Meditool. The third and fourth subsystems are serious games, core of the system and are the elements that the patient is interacting with to perform their exercises: one game is dedicated to the use of the wobble board and the exercises for the ankle, and it is called Gyroscope, while the second is dedicated to the knee exercises and is called Puzzle Bubble and Break Out.

The interaction between the sub-systems division need to be transparent to the players and the therapist, to let them concentrate only on the elements of their interests and not focussing on the technical details of the realisation.

For this reason we have decided that the elements of the system has to communicate through network.

The system also has to guarantee the privacy of the users and the security of the patient's data, and this is of utmost importance since we are dealing with personal data of users that are under medical treatment. For this reason security and privacy measures have been implemented.

The system has also to provide answers to all the requirements that were presented in the presented in the preliminary meeting with the therapists.

5.2. Hardware Requirement

To let the system behave correctly there has the need of a server active online able to store a SQL database and containing a PHP interpreter, a computer able to connect to internet, and, to use the fullest potential of our system, it must be equipped of a USB 3.0 port and should have mounted Windows 10 operative system (this two requirement are needed in order to be able to use Microsoft Kinect™on a computer), a smartphone able to connect to internet, possessing the an accelerometer and with a recent operative system (Android 4.4 KitKat or superior, iOS 8 or superior), a casting device Google Chromecast™connected to a suitable television or screen (to be suitable it just need to possess an HDMI port) and an internet connection.

It is also needed a platform, called wobble board and a fit band or any other element to store a smartphone in a place that can be attached to the body and in particular legs.

The server is needed only once for every user and is used to interconnect and exchange information between the different applications; the computer is needed only for the physicians and the doctors and is meant to run the application that we called Meditool; in order to reduce at minimum the costs of the materials, the patients have only to get a suitable smartphone (that most commonly is already in the possession of one member of the family), the Google Chromecast™device (commonly sold in the stores), a wobble board and a fit band. In total the expected cost for the patient is around 50-60 Euros, making our system easily accessible for everyone, and can be eventually afforded by hospitals that, in agreement with the families of the patient, can stock and loaned to the patients.

The other important advantage of our system is the modularity: each application is constituted by modules that can be used to increase the offer of games usable through this system, given that this games use a continuous input on one direction or two direction.

We are considering smartphones due to the commodity of using them in particular when the device has to be placed over the legs with the fit band; however the applications for the patient can also be played on a tablet and solutions alternative to fit band can be found in homemade elements.

As for what concerns the software part of the system, we consider that the amount of information to be given in order to make clear the scope and the effects of each part is too large to be fully contained in a single chapter.

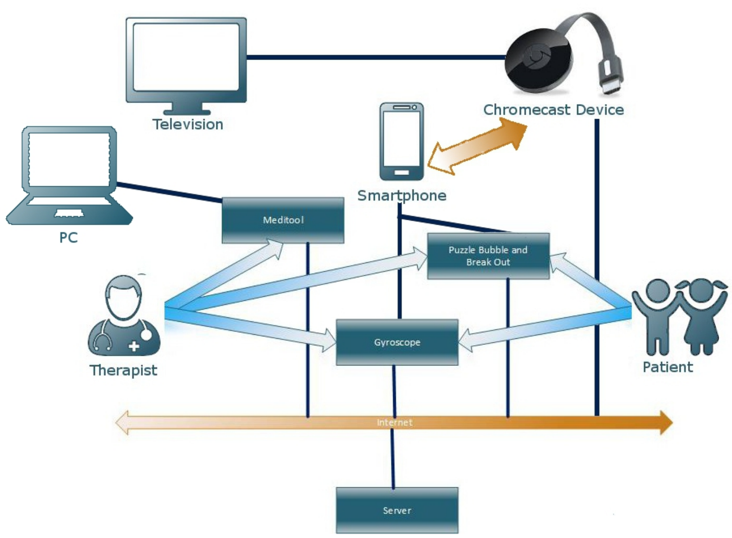


Figure 5.1: Schema describing the system and the interactions of different users with it

5.3. Interaction Description

We describe how different users interact with our system. The first passage that must be done is the preparation of the devices that are required to perform the therapy, while the second passage is related on the actions the patient and the therapist have to follow to use our system.

The procedure start with the preparation of the Google Chromecast™: the device must be connected to a suitable television through its HDMI port and plugged to a power source. Once this has been done the user can switch on the television and following the procedure guided by the official application developed by Google™the device must be connected to a wireless network.

Then it is needed to prepare the smartphone, o an analogous device; this depend on the exercise that is required to be performed: if the patient is required to perform exercises with the wobble board the mobile device must be attached to the board's surface through the use of tape or velcro strips, placing it in the centre of the board; if the patient need to perform exercises for the knee, instead, it is sufficient to place the fit band around the patients ankle. The mobile device must also be connected to the same wireless network at which has been connected the Google Chromecast™device and the mirroring functionality must be activate.

Now the application can be started and the second part of the interaction between the users and our system start. If the patient has to use the wobble board the system ask each time the game is started to calibrate it: this procedure is needed by the game in order to adapt the controls of the game to the maximum deflection that the player can reach and to interpret correctly the orientation of the phone; this procedure is guided by the game on the screen and require the patient to perform one tilting movement in every of the four main direction: frontally, backside, on the right and on the left.

Then the patient is asked to log in the system, independently on the game that he/she is using, by providing a valid couple of username and password; if the rehabilitative session is held at the hospital the physician can also log in the system through the Meditool application. If the patient has not been registered to the system, this operation can be done either by the therapist or directly from the games.

The therapist can also decide to prescribe new exercises and/or to modify the actual parameters of the exercises from his/her dedicated application Meditool accessing to the appropriate menu of the tool.

If the patient has been prescribed to perform exercises for the knee with the application Puzzle Bubble and Break Out and it is the first time that he/she use it or the therapist have identified a significant modification of the mobility range of the patient, the patient can calibrate the game: this procedure is completely guided by the game and require the user to place the smartphone inside the fit band previously placed on the ankle, he/she is asked to perform one time a complete deflection of the knee up to the angle that the patient can reach by bringing the foot in front of the knee, a position that we call maximum angle reached by the patient, and one time a deflection rising the foot beside the knee; to be more precise in the measurement the game ask the patient to keep the position for few seconds.

At this point the patient can perform his/her exercises: if the patient has to use the wobble board he/she is required to place the feet one per side of the smartphone attached to the board, load an exercise from the game menu and then controlling the game by tilting the board on the different directions according to the needs of the game, keeping the feet adherent to the bard's surface; if the patient, instead, has to perform the exercises with the knee, he/she can load his/her exercises, place the phone in the fit band previously positioned and according to the game needs performing deflection movements of the knee.

At the end of the exercise, or at the end of the session or whenever there is the necessity the therapist can access through Meditool application to the records of the exercises afforded by any patient and to the data collected by the game during the execution, in order to discover the behaviour of the patient, especially if the patient is performing his/her rehabilitation mostly at home. While the patient is at the hospital, through Meditool application, it is also possible for the physician to record the movement of the patient registered thanks to the use of Microsoft Kinect™V2 sensor: this functionality has limited capacity due to some limitations of the device, but is able to register the approximate position of the joints of the skeleton and show them to the therapist both online and in a successive time if saved on a file; this is useful to control, for example, compensation movements performed by the patient that have gone unnoticed during the session.

Chapter 6

Description of the Serious Games

In this chapter we analyze the serious games that are part of our system. These games are called Gyroscope, Puzzle Bubble and Break Out. For each of these games we describe the exercises that are meant to be performed while playing the game, how the exercise has been mapped on a game mechanics and how the game has been designed around it.

6.1. Gyroscope Description

6.1.1. Description of the Exercise

The first exercise we have analysed is focused on the training of the patient's ankles: this is achieved by forcing the patient to tilt his/her ankles in order to increase the mobility range of the joins that are compromised by JIA. To perform this exercise there is the need of a suitable device: the equilibrium board, a device used both for recreational activities such as circus skills or athletic training but is mainly used in a series of rehabilitative therapy, especially to help the patient regain sense of equilibrium, and brain leg coordination. However in our case we are more interested in a specific therapeutic use of this device since by tilting repeatedly the board on the different directions or keeping the equilibrium over it; it is possible to exercise all the muscles that are controlling the ankles, achieving an increase of muscular mass around the joints: this help the patient to lower the effort of the damaged joints through the work of the muscles.

However there are several possibilities to perform this exercise. We explain only the two we have tester or that have been taken into account in the designing phase.

The distinction we would like to make is between the exercise performed with load and the exercise performed without load.

Figure 6.1: A patient while playing gyroscope with load

Figure 6.2: A patient while playing gyroscope without load seated on a wheelchair

When we use the term load we mean that over the ankle it is present a certain amount of weight. This weight is the body of the patient him/herself while standing over the table. This position put under stress not only the ankles, but also knees are used to control the board. To keep the body in equilibrium over the table is not easy and the patent could fall, this mode is taken into account only for some patients whose needs are special or that are close to full recovery of the mobility of the joints. The use of this mode in the game increases radically the complexity of the game.

The exercise require the patient to alternatively tilt the board on one of the cardinal directions, then he/she is asked to perform gradually the tilting of the board from right to left passing for the frontal tilting or the backside one; finally the patient is asked to keep the equilibrium position over the board for some seconds. All this procedure must be repeated several times.

When we consider the exercise performed without load we intend that the body of the patient does not exercise his weight over the ankles and knees, but it is supported by another element, as a chair or a wheelchair. Using this mode of execution the patient has less complexity in the movements and can focus more on the exercise, but also has the ability to familiarize with the board and this is very important because can establish a guideline for the therapist in the preparation of the exercises with less variables. It also allows the game to be used also by patients who are not able to stand on the board. In this case the exercise proposed is the same without the part that ask the patient to stay in the equilibrium position.

6.1.2. Description of the Game Mechanic

The game is performed by attaching the mobile device over the top of the wobble board, possible parallel to the feet position and as cantered as possible on the board. The phone connected to the Wi-Fi network show the game on the television through the mirroring device, so that the patient is not required to face down during the exercise.

In order to let the patient perform the exercise there was the need to have a game which can be controlled by the recognition of three different commands: frontal/backside tilting, left/right tilting and equilibrium position.

The solution we have designed is a game that registers the orientation of the board through an accelerometer placed on top of the board: in this way the game is able to detect all the commands required by the exercise.

The most intuitive way to use such commands is to transform them into directions of movement: the direction of the tilting is the direction in which the player moves his/her avatar in the game, while the equilibrium position is a stop position.

No other command are available, since the player cannot interact safely with the device in any other way; for this reason it was important that the game take into account only this three movements.

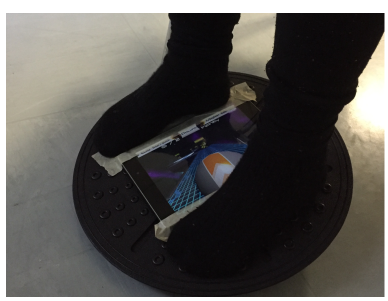


Figure 6.3: A patient while playing Gyroscope while tilting the controller

In order to adapt to the different abilities of the patient the player is asked to calibrate the game: in this initial phase the player is required to perform the basic four tilting of the board (front, back, left and right) in order to let the game identify the orientation of the mobile device and the maximum angle that can be reached by the player in tilting the board.

However the relative orientation of the axis with respect to the board can vary and we have used this to generate a different option for playing: on normal condition the most intuitive way to perform a movement onward using the table is to perform the flexion and extension of the ankle tilting the board in front of the user. We have tried also to let skilled patient to perform the exercise with opposite command. In this mode the controller register that the board is tilted backward and consider it as a movement onward of the ball. This does not affect the rotation of the ball that is still oriented as normal (tilting the board on the right cause the ball to turn right and vice versa for the left side).

This mode is useful because racing games are structure such that so the patient tends to perform the titling onward more frequently that the tilting backward and only careful consideration about the tracks can be used to establish certain equilibrium. Alternating the two modes, instead the patient is forced to perform the exercise in both ways and while once one direction is predominant the second time the other direction will be dominant. The only inconvenience of this mode is that it is required to perform two times the calibration of the device.

6.1.3. Description of Gyroscope

Gyroscope is a race game designed to let the patient perform his/her exercises on the wobble board in an amusing way.

The aim is to let the player perform his/her rehabilitation not focusing on the painful movement but to reach the end of the track in the smallest possible amount of time.

The player can accelerate until a certain speed has been reached, decelerate and rotate on right or on left using the orientation of the board. The deceleration presents two different modes: a simplified mode called "modalit freno" where it is impossible to move backward on the track; the other mode permits movements backward by performing the deceleration movement. The simplified mode is helpful at the beginning to learn the basics of the game. The normal mode instead is more complex but permits a larger control over the ball and can results in faster corrections of the directions.

The player has to control the ball from a starting point to an ending point on a track avoiding to fall from it: in order to avoid penalizations that may demotivate the patient there are no penalties when the player fall from the track, but the player is repositioned in the last save point that he/she has activated. Save points are automatically placed on the track so that the frustration of the patient if he/she is not able to perform a certain task, due to the medical condition he/she is, is reduced. This is very important because frustration is one of the main causes why a player lose interest in a game and this is even more problematic in medical rehabilitation where losing interest leads frequently to stop taking the therapy.

Figure 6.4: A save point in Gyroscope

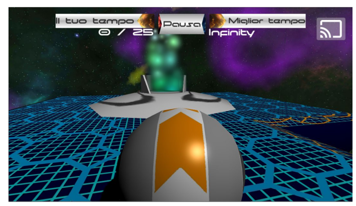


Figure 6.5: The element at the end of each track in Gyroscope

For the same reason there is no "Game over" state. This has been decided to keep the patient motivated in playing and avoiding frustration of having lost. The feeling of falling and to have to start again from the last save point is a good compromise between giving sensation of having faced the obstacle badly and the feeling of having missed the win of just a bit, increasing the engagement and the desire to keep trying till success; a game over would have conceived the idea of total defeat and this is a negative experience that we want to avoid.

There is also no concept of level passage: this is because the completion of a level consists of reaching the end point of the track: this means that at the end of the "level" the player can replay it or simply go back to the menu. Consequence of this is that there is no ordering in the tracks, except for the temporal ordering of creations of the exercise.

The main component of the game is the track. Each track is a composition of 6 base types of connectors that comprehend a straight platform, a curve to move right, a curve to move left, a ramp up, a ramp down and an obstacle block.

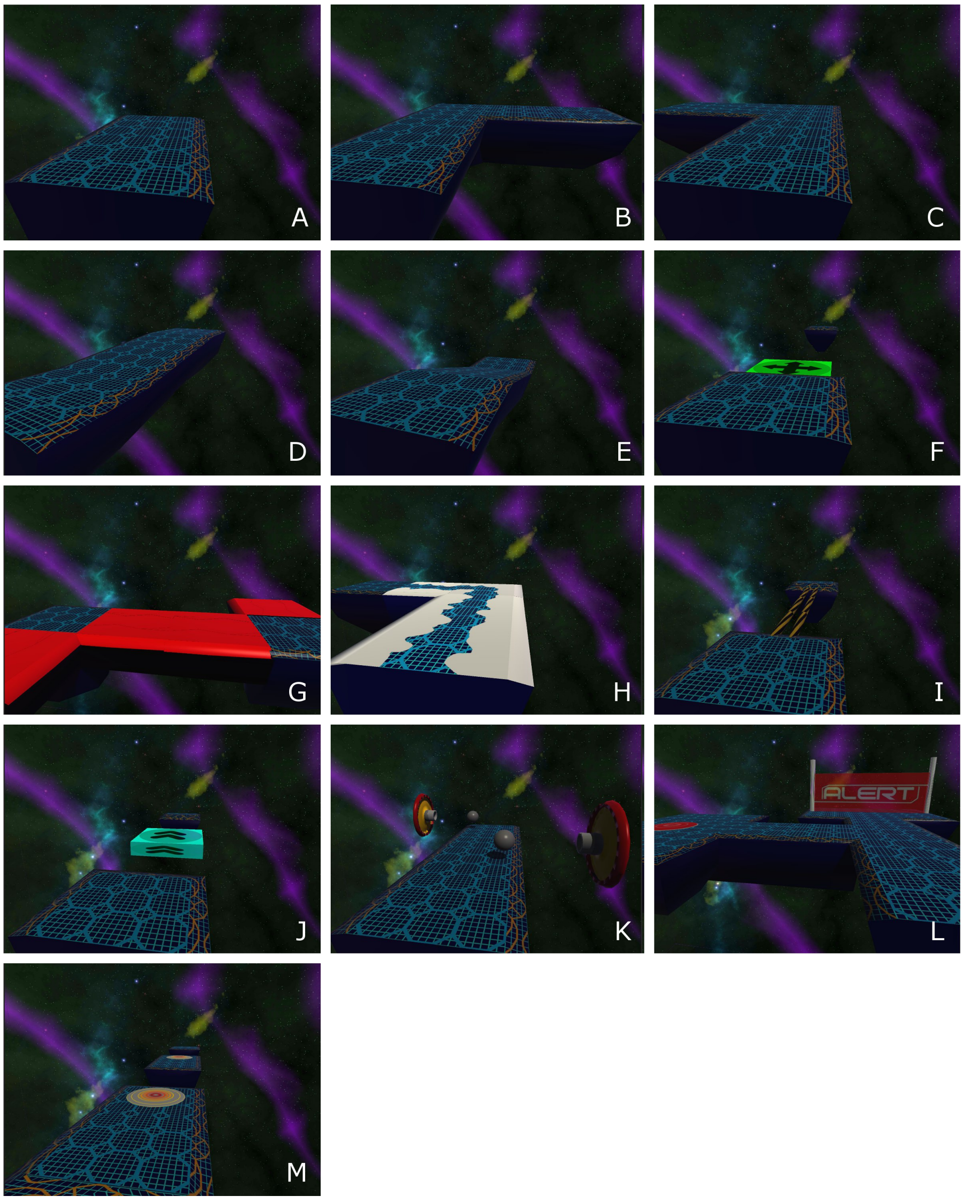


Figure 6.6: The different components of Gyroscope tracks: in order the straight connector ("A"), the curve to right("B") and left("C"), the ramps up("D") and down ("E"), the equilibrium platform ("F"), the breaking ground("G"),the ice ground ("H"), the tubes("I"), the moving platform ("J"), the cannon path ("K"), the closed door ("L") and the jumping path ("M")

The first component is a very basic element that has no particular therapeutic importance but is just a connector between two blocks and can be used to relax the player .

The two curve elements are simple connector that has the goal to force the patient to deflect the ankles perpendicularly to the feet in the direction of the curve. This is a movement that most patients feel difficult, so these elements have an importance in the therapy.

The ramp up component is used to force the patient to push the frontal deflection of the ankle in order to reach the maximum speed of the ball. This is a difficult position to reach for most of the patients so it could be useful to add these elements in the track.

The ramp down component instead is not related to a particular exercise but has a function of engagement: this happens because the presence of this element hides some part of the track and this element per se is sufficient to increase the expectation and thrill of the player.

The elements are characterized by a certain level of friction that help the player by limiting the inertia of the ball and the initial movement, otherwise the control of the ball would be really hard and the player gets bored due to continuous fall and correction of direction.

Last element of connectors is the obstacle block. These elements are the ones that have the largest impact on the players because they can give a challenge to the player, but must be also carefully balanced in order to avoid to push the player too close to his/her limits. In order to specifically address the needs of the patient the obstacle's presence, type and difficulty is delegated to the therapists while designing the track.

Obstacles are pieces of the track that tests the ability of the player with timing, control and easy puzzle solving abilities. These obstacles are designed to be easy to overcome increasing the challenge of the track and the variability of the game.

Once the player has gained more experience the complexity of the track can be increased by incrementing the number of obstacles (and the length of the track) or changing the level of difficulty of the obstacle. Each obstacle has 5 level of complexity (from 1 to 5) that are related to the number of movement, precision, timing and control that has to be mastered by the player in order to overcome it in the track.

The designed obstacles are:

Jump track: The track presents holes and isolated platforms. On each platform there is a "jump platform", a zone that gives a push to the ball on the vertical axis. The player has to calibrate the run-up phase in order to have the appropriate speed to jump over the hole.

The player has also the carefully decide the direction of the run-up since it is more difficult to correct the trajectory in middle air. This exercise is simple and is meant to train the player in precision of the movement. The different difficulties augment the number of jumps and the complexity of the direction of the run-up phase.

Blocking door: The track is blocked by a barrier, which is controlled by a series of switches. To pass the barrier the player has to find and activate the switches by passing over them. This obstacle is not meant to train a specific movement, but is more a puzzle solving task; the goal is to add variety to the possible tracks. The different levels increase the number of switches to lift the barrier form one to five.

Breaking ground: The track presents a zone where the single elements composing the passage are fragile and break if the player passes over (in red to clearly identify them). Each piece breaks in three pieces that falls one at the time reducing the dimension of the passage. The obstacle is meant to train the patient on timing and to reach the maximum frontal deflection of the ankles in smallest time possible, since it require the maximum speed and to stop in short time. The increase in the difficulties comes from the increase of the number of elements that broke down and the complexity of the passage, which may include ramps or stairs.

Ice ground: The track presents a zone where the track is covered of ice (with white borders to clearly identify them) where the friction is highly reduced. In this case the maximum speed can be obtained in a very short time, but is more difficult to control the ball. The track presents curves and the number of curves increases with the difficulty of the track. The goal of this obstacle is to teach the patient to control the movement on the board and to add challenges to a movement that has been already learnt.

Moving platforms: The track presents a single large hole and in the middle there are a sequence of moving platforms and the player has to pass over all of them to reach the other side. This platform has a straight movement and a constant speed. The player has to choose the right moment to go over one platform and to regulate the speed of the movement in order to stay on top of it. This obstacle is meant to train the patient on timing and control. The number of platform to be crossed increase with the difficulty of the track.

Equilibrium platform: The track presents a single large hole and in the middle there is a single platform that is waiting the player. When the player reaches the platform, it moves to reach the other side of the hole, while he/she has to keep the equilibrium over the board. The difficulty of the track influence the length of the route covered by the platform and consequently the length of the exercise.

Pipe passage: The track presents a hole where the two sides are connected by two small tubes nearby placed. The player has to reach the zone between these two tubes and to pass it in order to reach the other side. The goal of this obstacle is a preliminary obstacle to start learning how to behave on movable and equilibrium platforms. The difficulty of the track increase the number of passages that has to be faced.

Shooter: The track is surrounded by elements that shot at constant pace balls crossing the lane, while the player has to avoid them. The player has to choose the correct timing to accelerate and to stop to avoid the different shooting lanes. The number of shooting elements increases with the increase of the difficulty of the track.

At the beginning of each execution of the game the player is asked to log in or to register with a valid couple of username and password.

To make the access faster and easier and facilitate the users there is also an icon system login, similar to the modern console login. It stores in an inaccessible file the credential of the players that would like to be registered on the device.

Figure 6.7: Login using icon identification system. Names are of dummy user, not real patient

The exercise proposed by the therapist is loaded from the database, after the patient has decided which track he/she wants to load form a menu, and at the end of the performance the game save the results of the game on the database; this results include the time needed to complete the track, the number of times the player has fallen, the date in which the exercise has been taken and the tracking, which is an information that the Meditool can use to reproduce the movements of the board and detect wrong behaviours of the patient. The game also present the possibility to generate a pseudo-random exercise by setting the length, the difficulty and the number of obstacles present in this track; the results obtained through this exercises would not be saved in the database. It can be used to let the patient explore or to let the patient play with other players not patients, increasing the social inclusion of the patient.

Figure 6.8: Menu to input the parameter on a random game on Gyroscope

The game also presents a tutorial in which the player can play different minimal tracks in order to understand how to handle completely the commands and how to overcome the obstacles. Helps for the patient are shown in both textual and graphical form.

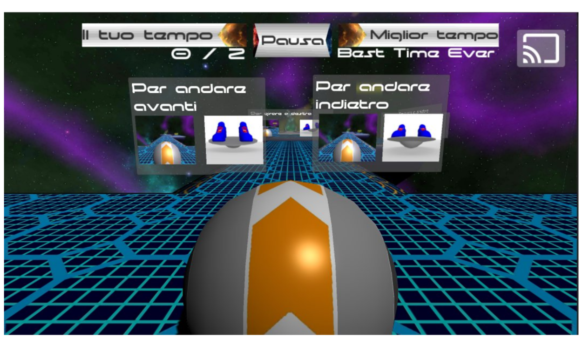


Figure 6.9: A footage recorded during the tutorial of Gyroscope

6.2. Puzzle Bubble and Break Out Description

6.2.1. Description of the Exercise

We have identified three different types of exercises, one for Break Out and two for Puzzle Bubble (one for each version weave developed of the game) that are focused on different aspects of the movement even if the movement of the knee is almost the same.

All the exercises require the patient to be seated on a chair or on the border of a table.

A first exercise is related to the strengthening of the muscles of the leg and thigh. In order to do this the game has to force the patient to keep the position once he has reached a desired position for few seconds. The patient decides an inclination of the leg and have to keep it for few seconds according to the decisions of the therapist. This exercise is useful for patients who has to regain muscular mass on the knee or has to regain strength after the medical treatment because the fact of keeping the position is intense and permit a greater empowerment of the muscular tone, especially of the quadriceps that is the main muscle involved in the movement. However this type of exercise present some inconvenience: first of all this kind of exercises weary the patient in a limited amount of time. Second problem is that the performance of the player on long term drops due to the fatigue, so that a game that is set to be long make the player wear before it is able to end the game. Last but not least this kind of exercise could be boring after a while, and it is not sufficient a game to make the player distress.

A second type of exercise is related to the speed of the movement of flexion-extension of the knee. This type of exercise is focalized on making the patient perform the flexion-extension of the injured joint in the smallest possible amount of time until a certain position is reached. The patient is asked to perform the flexion-extension movement as fast as he/she could in order to place the paddle under the ball before it falls. This exercise put under stresses the muscles and joints of the knee because it asks the player to perform rapidly and constantly. In order to let the player relax the game has to be designed so that it alternate moment of intense speed and moment of relaxation.

The third and last type of exercise is related to the increase of the maximum and minimum angle reached during the flexion-extension movement of the patient. This exercise if oriented to increase the general movement allowed by the injured joints and also to strengthening all the muscles of the knee. In this type of exercise the patient is asked to repeatedly perform the complete movement form the maximum deflection to the minimum deflection. After the calibration of the game the system knows the angle that the patient can reach when he/she is lifting the feet in from of him/her and the angle that he/she can reach when he/she is bending the knee besides. The patient has to switch between these two positions continuously in order to play the game while the game has been adapted to the patient condition. This mode is the one which consumes faster the energy of the patient, but it is also one of the most difficult exercises for the patient to perform.

In particular the goal is to train the movement of the quadriceps of the patient and to extend the general mobility of the knee by augmenting the maximum deflection of the knee both frontally and behind. To strengthen the quadriceps the idea is to force the patient to deflect the knee as much as possible and to reposition it in the normal position repeatedly; as for increasing the general movement of the knee the exercise consists in frequent complete movement from the minimum deflection (where the feet is behind the knee) to the maximum deflection (where the feet is in front of the knee) possible.

However the game cannot be completely independent form the therapy, since each patient has an unique capability of motion due to the physical limitation caused by JIA.

In order to do so it has to be calibrated by the patient: the player is required to perform the exercise one time and this means to perform one complete deflection with the maximum angle and one deflection with the minimum angle, in order to let the game identify the extreme positions reachable by the player. These calibration values are stored in the database and reused until a new calibration. In order to be sure that the exercise is being correctly executed this calibration phase require to be verified by the therapist by inserting his/her credentials to save the result on the database.

6.2.2. Game Mechanics Description and General Settings

In order to detect the movements previously described the game must be able to detect the inclination of the knee. For this reason the games are performed by placing the phone in a fit band attached to the ankle of the patient in order to be able to use the accelerometer to detect the deflection of the phone. The phone connected to the Wi-Fi network shows the game on the television through the mirroring device.

Figure 6.10: A patient while playing Break Out

The reason why we can use the orientation of the phone instead of the deflection of the leg is that the two are jointly liable so the angle is the same.

However it is impossible to interact effectively on the screen of the mobile, so the game can use only the orientation of the phone as input The game control is highly intuitive. In particular Puzzle Bubble version 1 require to orient the pointer by deflecting the knee, while Break Out require to control the position of the paddle by deflecting the knee; in Puzzle Bubble version 2 instead the maximum deflection correspond to shot, while the minimum deflection correspond to reload the pointer. Considering that these games have similar mechanics and that are generally useful together, the three games have been grouped into a single application.

At the beginning the player is asked to log in to the system through a valid couple of username and password. The credentials are stored on the remote database previously described. It is possible to use also the same login system through icon present in Gyroscope. This is required in order to access to the prescribed exercises for the patient in each of the games.

To execute the prescribed exercise the game loads from the database an exercise that has been decided by the therapist and saves the results of the game on the database. This results include the time the player has passed till game over or win, the date in which the exercise has been taken, the number of bubbles or bricks that have been destroyed, the score to create a scoreboard the number of repetition of the exercise and the tracking, which is an information that the Meditool can use to reproduce the movements of the leg and detect wrong behaviours of the patient.

6.2.3. Description of Puzzle Bubble Version 1

The reason why Puzzle Bubble had been chosen are basically three: this two game are very simple to understand, secondly they are so famous that have been found amusing by a huge amount of users and thirdly because they have simple mechanics that can be easily reduced to a one lever game, which is a simple approximation to the exercise they are meant for the patient to perform.

It is a version of the famous Puzzle Bobble by Taito in 1994, but this version has been designed to be played with a single command.

At the start of each game, the rectangular game arena contains a prearranged pattern of coloured bubbles grouped in a matrix form. Each ball presents a randomly chosen colour from a palette of 5 colours.

In our version the playable area, called arena, contains a number of bubbles organized in a matrix of 7 columns and the number of rows according to the parameter that has been set by the player or the physician. At each bubble is assigned a colour between 5 possibilities: green blue, yellow, red and purple. These bubbles are attached to the top element of the arena.

At the bottom of the screen, the player controls a device called a pointer which aims and fires bubbles up the screen. The colour of bubbles fired is randomly chosen from the colours of bubbles still left on the grid.

In our version the shot frequency of the bubbles, instead is controlled by a countdown; this countdown is representing a constant time decided in the parameters of the exercise. When a ball is shot it proceeds in a straight line (eventually bouncing on the left or right element of the borders of the arena) with an initial inclination that is the inclination of the pointer in the moment it shot. The bubble stops when it encounter another bubble or the top element of the arena borders.

If a bubble touches identically-coloured bubbles, forming a group of three or more, those bubbles explodes and points are awarded. Also if a group of ball is no longer attached to any bubble they fall and extra points are scored. After some time, the "ceiling" of the playing arena drops downwards slightly, along with all the bubbles. If the bubbles reach the bottom of the arena then the game is over. In our version this event is temporized according to the therapy and has constant speed in order to simplify the game.

Figure 6.11: Original version of Puzzle Bobble of Taito [36]

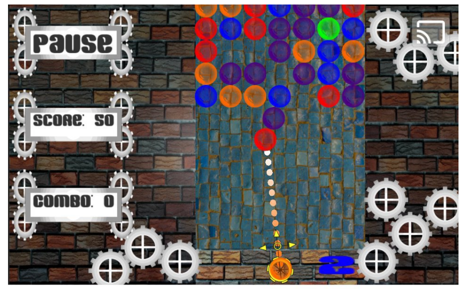


Figure 6.12: Our version of Puzzle Bubble

In this version the player has the control of the pointer orientation by means of the inclination of the legs; in particular when the player leave the legs down the angle between the thigh and the leg is almost 90 the pointer points to the left side of the arena, while when the patient has reached the maximum deflection of the knee that his/her condition permits him/her(the value stored during the calibration as maximum deflection) and the pointer points at the right side of the arena. When three or more bubbles with the same colour are near they are removed from the game and the player receive points according to their number.

The game can concludes in two different ways: the first is the win of the player, when there are no more bubbles in the arena; the second is when the bubble in the arena reaches the bottom element of the arena.

Considering that one of our main goal is to avoid to frustrate the players in case of failures for their mistakes caused by their physical condition, a game over state could be identified as a defeat and could be frustrating for the patient; however in order to reach the game over state a lot of mistakes have to be committed by the player: what we consider a mistake of the player is to be not able to position a bubble in the desired position because the timeout reaches zero before the patient reach the desired deflection; the player have high probability to solve that error in few steps and eventually to get a bonus (the mistaken bubble can fall creating a combo and getting higher score) to have been able to solve the error.

Differently from the original game, in our version there is no concept of level, since each time the player plays one round of the game he/she is in the same "level" but it is completely different game due to the randomness of the process of colour assignment.

In order to give a help to the player we have also added a straight dotted line, passing for the centre of the pointer and oriented ad the orientation of the pointer: the player can use it to foresee where the bubble hits. It is also coloured with the colour of the loaded bubble so that the player can concentrate only on the direction of the pointer. The therapist and the player can decide a certain number of parameters in order to adapt the game to the abilities of the player and the therapeutic needs (if the parameters are chosen by the patient the results would not be saved in the database). All the parameters are set in the setup menu.

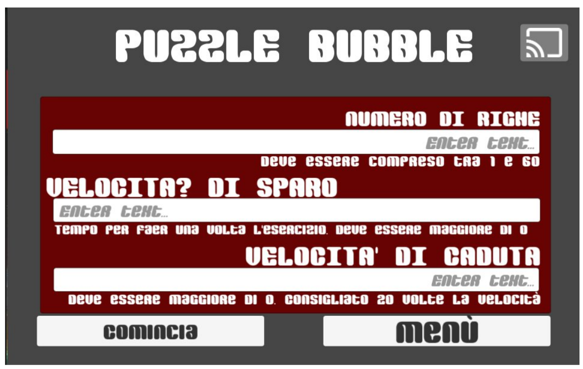


Figure 6.13: Menu to input the parameter of Puzzle Bubble

This set of parameters contains:

Length:this parameter is an indirect indicator of the length of the exercise, since it is referred to the number of rows in the grid of bubbles of Puzzle Bubble (both versions). The greater the number of bubbles, the more difficult is to win the game.

Descent speed: this parameter in Puzzle Bubble (both versions) indicates the amount of time before the bubbles fall. It is a measure of the ability of the player, since the fastest the ball falls, the less possibilities are given to the player to make wrong moves.

Shot Speed: this parameter has two different meaning considering Puzzle Bubble version 1 and Puzzle Bubble version 2. In particular in Version 1 this parameter indicate the amount of time after which the pointer shots a new bubble. In Version 2 instead it indicates the rotation speed of the pointer. However in both cases it is a measure of how much time it is being given to the player to perform one repetition of the exercise.

6.2.4. Description of Puzzle Bubble Version 2

In this version we have decided to keep the same game principles, ending condition and states of Puzzle Bubble version 1 and for this reason we describe only the differences from what has been described in the previous paragraph.

The most important difference is the type of movement the player has to do. In this version of the game the goal exercise is the third exercise that we have resented for the knee, the one focused on increasing the mobility range of the joints. When the deflection of the leg has been close to the maximum deflection that the patient condition permit the pointer shots the bubble that has been loaded, while to load a bubble the player has to reach the minimum deflection.

The other difference is in the motion of the pointer, since the movement that was used in Puzzle Bubble version 1 to control the pointer overlaps with the movement the player use to shot in this version; to solve this issue we have chosen to let the pointer in this version move continuously: in particular we have chosen to let the pointer rotate where the angle is regulated by a sinusoidal function that can give a smooth movement and can be easily foreseen by the player.

6.2.5. Description of Break Out

The game has been designed t perform the second exercise we have presented for the knee and it is a version of the famous Break Out game by Altari from 1976.

The reasons why Break Out have been chosen are basically three: this game is very simple to understand, secondly it is so famous that have been found amusing by a huge amount of users and thirdly because it has simple mechanics that can be easily reduced to a one lever game, which is a simple approximation to the exercise it is meant to be performed.

The original version of Breakout begins with eight rows of bricks, each two rows a different colour. Using a single ball, the player must destroy as many bricks as possible by using the walls and/or the paddle below to ricochet the ball against the bricks and eliminate them. If the player's paddle misses the ball's rebound, he/she loses a turn. The player has three turns to try to break two screens of bricks. For each colour a different amount of points is scored when the brick is broken. The paddle shrinks to one-half its size after the ball has broken through the red row and hit the upper wall. Ball speed increases at specific intervals.

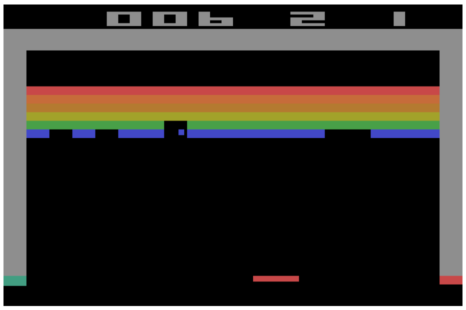


Figure 6.14: Original version of Break Out of Altari [35]

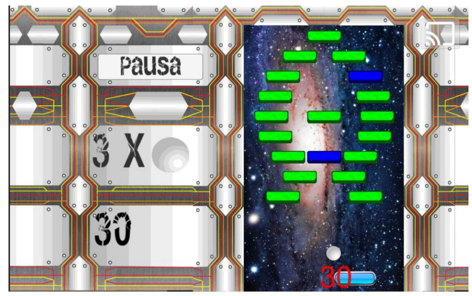


Figure 6.15: Our version of BreakOut

In this game the player has the control of the paddle position by means of the inclination of the legs; in particular when the player leave the legs down in the rest position the paddle is positioned to the left side of the arena, while when the patient has reached the maximum deflection of the knee that his/her condition permits him/her the paddle is positioned on the right side of the arena. The paddle can move only horizontally in the lower area of the arena. Goal of the game is to get the highest score before the number of lives reaches zero.

The ball moves in the arena bouncing on the arena borders, the paddle and the bricks. Each time the ball hit a brick the player scores some points, while every time the ball reach the zone below the paddle the player loose one live. We choose to keep the ball's speed content, because it is also affecting the amount of time the player has to identify the correct position at which the paddle has to be positioned to avoid losing lives; the increase of the speed may lead to frustration of the patient due to his/her physical limitations or it can force the patient o compensatory movements or to damage his/her joints in the effort.

The player cannot interact with the device running the game in any other way except the movement already used to control the paddle movement, the ball start moving at the beginning of the game and after each time the player loose a life after an automatic countdown of five seconds. During this countdown the ball moves slowly on the two border of the paddle and at the end of the countdown it is launched by the position it has reached.

We have also decided that to increase the challenge there are different rooms where the disposition of the bricks is different and that every time the player break all the bricks present in one room a level completed state to praise the player is shown and then a new room is instantiate for the player to be able to continue to play. In this way the game results simpler than the original, but keep the amusement of the match while can be performed for theoretically infinite time without having to restart it.

In order to lower the frustration of the moment when very few bricks are left and are difficult to hit there is the possibility to force the game to start a new room: in this way the patient can continue to perform the game avoiding to get stuck in difficult points, but is not praised by the game, with the hope of spur him/her to improve their skills, but not penalising them for not having them.

The therapist and the player can decide a certain number of parameters in order to adapt the game to the abilities of the player and the therapeutic needs (if the parameters are chosen by the patient the results would not be saved in the database). All the parameters are set in the appropriate setup menu.

Figure 6.16: Menu to input the parameter of Break Out

This set of parameters contains:

Initial number of lives: this parameter is important in Break Out since it indicates the number of times the player can lose before ending the game: a low number of lives means a greater challenge for the player.

Ball Speed: this parameter in Break Out is a measure of the speed at which the ball moves in the field. For this reason this parameter is an indicator of how much time the patient has to perform one repetition of the exercise.

Chapter 7

Testing and Data Analysis

In this chapter we analyze the results we have obtained through the experiments performed to validate our system. We performed several rehabilitation sessions with the help of real patients during their rehabilitation sessions in the hospital environment. We started with an initial tuning session used to tune the games, collect the patient and physician feedback and to verify the usability of the system in all its components. Then we performed a series of therapy sessions in which we focused more on personalizing the therapy for the patients.

7.1. Experimental Setup and General Notes

Three therapeutic sessions has been held at the Clinica Pediatrica G. e D. De Marchi, with the collaboration of two therapists. We used the same devices for the three sessions and in particular we used the round wobble board produced by Tiger, diameter 36 cm, a tablet Asus Zenpad S8.0, a smartphone Cubot S222, both mounted with Android 4.4, a Google Chromecast device and a notebook with Intel Core i7-2620M, Processor 2.7GHz, 6 GB RAM, Nvidia GEFORCE GT 520M and Windows 10 64 bit OS. The games were developed in Unity 5.1.0f3, a cross-platform game engine and using the public preview of GoogleCastRemoteDisplay, released on April 2016. To develop Meditool instead it was used Unity 5.3.4f1 and the public preview of Kinect™'s plugin released on September 2014.

We performed the therapeutic sessions in the gym of the Clinica Pediatrica G. e D. De Marchi. We connected the Chromecast device to the television already present in the gym, used the tablet attached to the wobble board through some tape to use the game for the ankles; Instead, for the knee therapy we used the smartphone and a fit band to use the games for the knees.

The system required that all the devices were connected to the same network, in particular to permit Google Chromecast™device to perform screen mirroring. Thus we used a computer to generate a hosted network connected to the hospital network as a repeater for all our devices.

We have tested all of our games, but due to the predominance of patients with diseases to the ankles we have collected more data on Gyroscope that the other games.

Before entering in the specific analysis on the patient performances we want to make some general annotation that are valid on all the therapeutic sessions we present.

For each session we collected the accelerometer data and all the available information about the state of the game. The values of the accelerometer have been sampled at frequency of 4 Hertz while the patient was playing. This sampling has been decided to balance between the need of precise and punctual references of the behaviour of the patient and the technical needs of preserving memory, reduction of corruption risks and memory saturation, communication and memory required on the database to store data.

7.2. Initial Tuning Test

We performed two tuning session that has been held under the supervision of Dr. Ft. Lopopolo, with the presence of a student of physiotherapy and the parents of the patients.

7.2.1. Patient F1

The first patient, who we call F1, was a 15 years old girl affected by JIA. She was affected since 4 years old and the disease is affecting specifically the ankles, causing pain and selling. Main goal of the treatment of the patient was to recover the lost mobility of the ankles: to reach this goal the use of the wobble board is important because it is able to stimulate the correct movement of the ankles in a controlled form. Due to the presence of some necrosis in the milk vetch the patient could not perform the exercise with load over the ankles, so the exercise has been performed with the patient seated on a chair. The patient has been prescribed to perform these exercises at home before the visit, but according to the patient herself and her mother it has not been performed regularly.

Before performing the personalized exercises with the game gyroscope F1 had been visited and had familiarized with the game using the tutorial available in the game.

The feedbacks we have received from F1 were really encouraging since the patient was very happy after the treatment, even if generally does not like to perform rehabilitation. Even the mother who has participated to the session as a spectator was very enthusiastic of the game. The therapists were surprised; instead, of the efficacy of the game since it let patient play and performing a very good and intense exercise in a small amount of time.

7.2.2. Patient F2

The second patient who participated in the tuning session, who we call F2, was a 12 years old girl affected by JIA. Her disease, like the one of F1, was acquired at young age, but for F2 it was more widespread since it affected both ankles and knees, and predominantly the right side of the body. Her movements results greatly limited, swelling and pain can be registered in all four joints and bad compensation movements are clearly visible from her walking. Main goal of her treatment was to increase the muscular mass around the knee so that it can sustain the movement in aid of the joint and to correct the compensation movement. For this reason she was prescribed to perform exercise of frequent flexion-extension of the knee and some exercises with the wobble board to increase the muscular mass around the ankles and correct the deviation of the right foot. All exercises are not to be performed with load. The patient was prescribed to perform the exercises at home, but they were not performed due to the dullness of the therapy that demotivates F2.

The feedback we received from the patient was extremely positive, with a maximum degree of satisfaction from both the patient and her father, very surprised by the effort the daughter has used in the exercise. The therapists have expressed interest even for the other games that were not seen the first time, since the patient, while playing with the game, was able to perform movements not registered in previous rehabilitation session.

7.2.3. Analysis of Tuning Data of Patient F1

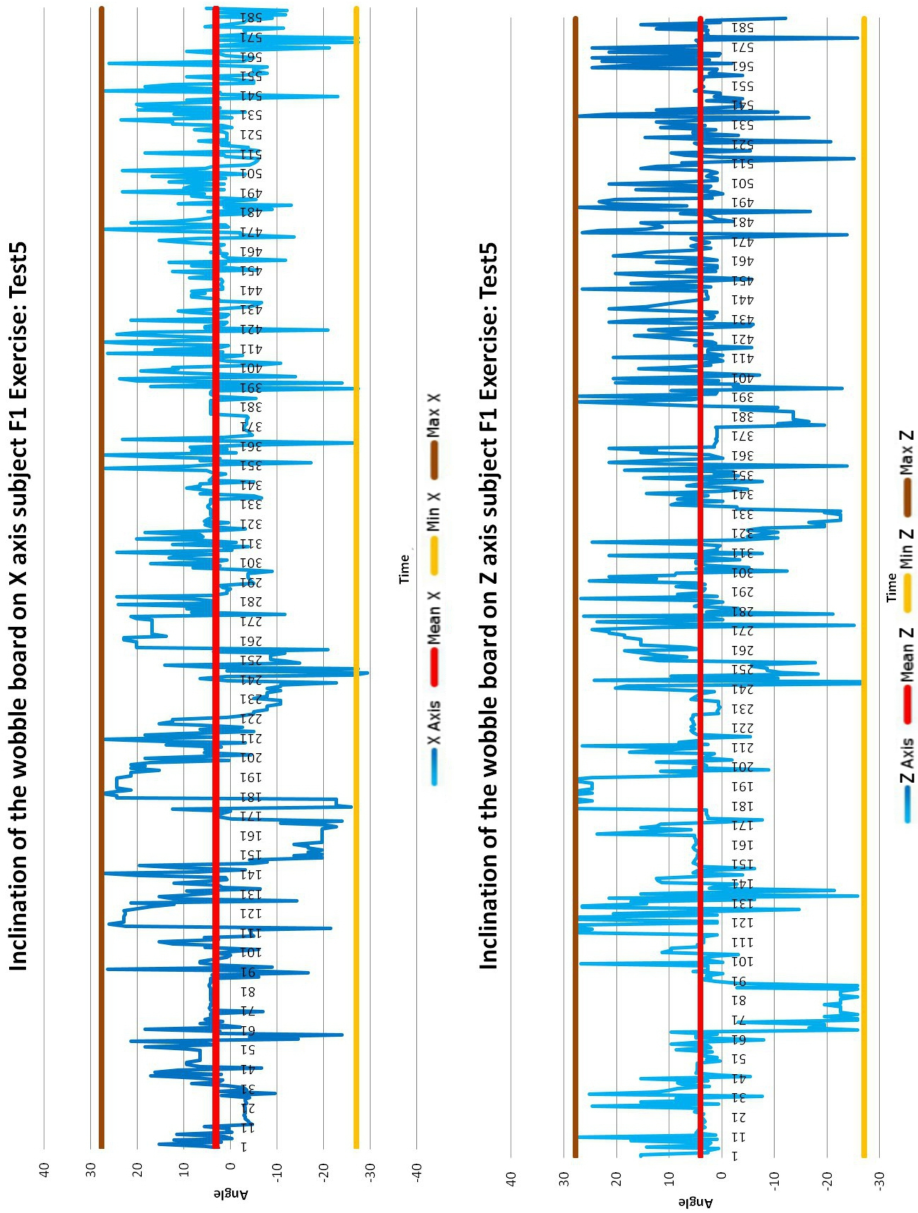


Figure 7.1: The performance of F1 while playing Gyroscope, track Test 5 during the tuning session.

For this first test we have asked patient F1 to play with the game Gyroscope, performing a short training with the tutorial of the game in order to familiarize with the controls and let us understand how patients would react to the controls we have designed. The game has been played on a tablet attached over the wobble board with some tape. The session has lasted completely about 25 minutes.

We want to point out that the measures produced by the accelerometer, as every experimental measure, are affected by some experimental random errors, due to the irregularities on the floor, the surface of the wobble board and the tablet, the positioning of the device on the table, *etc*, and especially because each patient had a different behaviour, pain resistance, he/she react differently to fatigue or pain and had different learning rates. When we are analyzing the results of Gyroscope we present two plots. We assert that the values obtained through accelerometer represent the movement of the patient's joints. When we are considering the values obtained through the use of the board we are enforcing the patient to keep the feet attached to the board, and since the only cause of tilting of the board is associated to a pressure employed by the patient feet; the feet, in turn, are moved only by the ankles, permits us to analyze the movement of the articulation, which is difficult to measure, in a simple way using the inclination of the tablet.

The accelerometer record the values along all three Cartesian axis, but thanks to the fact that it is attached to the board the Y axis is restricted and in not interesting for us. We only show the values registered along the X axis, associated to frontal deflection, called plantarflection, (positive values) of the ankle and backward deflection, called dorsiflection, (negative values) of the ankle, and along the Z axis, associated to lateral tilting through right (positive values), composed of left ankle's inversion and right ankle's eversion, or to the left (negative values), composed of left ankle's eversione and right ankle's inversion.

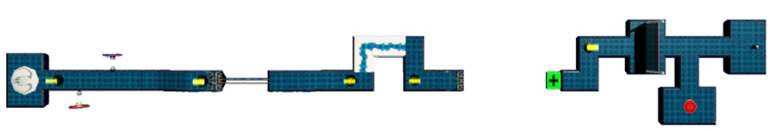


Figure 7.2: Top view of Test 5 track

Figure 7.1 shown the modification of the angle of the wobble board when F1 has tested the exercise called Test 5. The track, shown in Figure 7.2 is composed of a linear connector, a closed door obstacle, a turn to the left, an equilibrium platform obstacle, a turn to the right, an ice ground obstacle ramp up, a tube obstacle a ramp down, and finally a passage between cannons obstacle. This is a fairly balanced in the number of turn on the right and on the left and also in the typologies of obstacles that require reaching the maximum flexion-extension movement and the ones that require precise and small control adjustment.

We can notice that the mean value of the plots relative to the X axis is positive, as we could have expected from the nature of the game: this means that to reach the end of the track the patient has exercised more the plantarflexion movement than the dorsiflection movement. The mean X value is quite low, meaning that the track was effectively fairly balanced with respect to the needs to brake. We notice also that the movement does not follow one direction, but it is continuously alternating between positive values and negative values, an index that the track does not permit the patient to simply push the ankle in a single posture for a discrete amount of time, but it forces the patient to alternate frequently the movement, causing a more intense exercise.

From the plots we also notice that that the patient was able to reach the maximum position permitted by the board (the ones when the border of the board touch the floor) and surprisingly also on the frontal axis, that was the most problematic movement.

We can also notice that the oscillation of the plot increase at the end of the track, once she has obtained a certain confidence with the game and the device, and she tried to perform sharper and faster movements, overcoming the obstacles faster than before; at the contrary, in the beginning, the movements were sensible, with less intensity and kept for a bit longer time.

As for what concern the movements on Z axis we may notice that there is a clear predominance of the movements to the right, probably caused by premature overheating of the right ankle that affected the patient during the session, caused by a worsening of her clinical condition. However the patient at the beginning has concentrated on the two movements separately, so when she was accelerating and braking she was not curving, while at the end the movements are simultaneously present on the plot. It is interesting to notice that nevertheless her condition, the patient was able to reach the maximum extension of the ankle permitted by the board.

Finally the analysis of the game data shows that F1 completed the track in just 2 minutes and 54 seconds, which is a very small time and just fell 3 times in different part of the track. These results suggest that the track was adequate to the necessity of the patient and maybe even a bit too simple for her, but thanks to this she has been able to concentrate also to perform well the exercise.

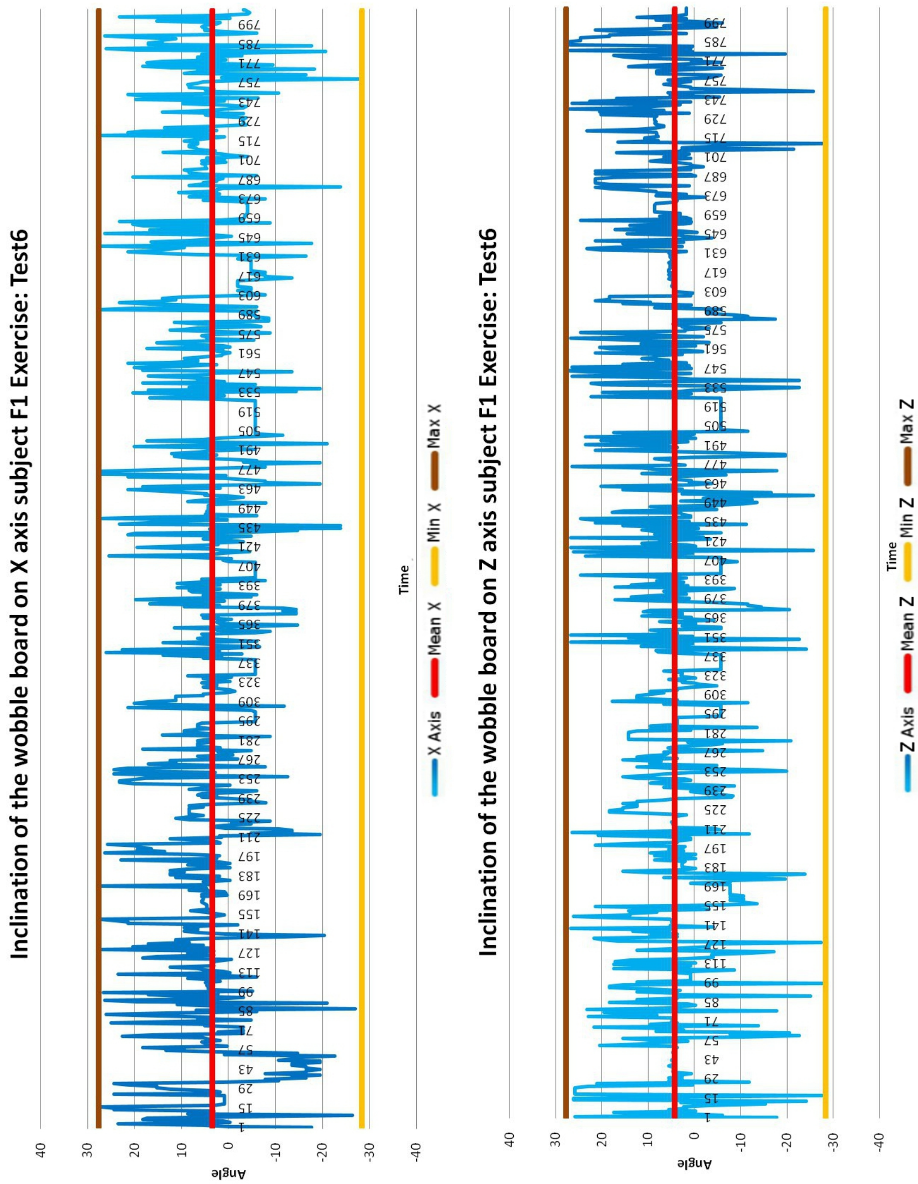


Figure 7.3: The performance of F1 while playing Gyroscope, track Test 6 during the tuning session.

Figure 7.3 shows the behaviour of F1 while performing the second exercise, called Test 6.

This track presents a turn to the left, a jumping path obstacle, a ramp down, a mobile platform obstacle, a linear connector, a ramp up, an equilibrium platform obstacle, a turn to the right, a path between the tubes, a linear connector, a ramp down, a closed door obstacle and finally a linear connector. This track is more complex than the previous one because the obstacles are more challenging, and for the patient it is more complex since it puts more effort in the control of the frontal movement that in the lateral one. This is visible from the number of falls and the time to complete this track that is higher than the previous exercise.

We may notice that, as we expected, the mean X value is positive, and this means that the frontal movement has been used much more than the backside movement, exercising the plantarflection of the ankle more intensely than the dorsiflection. We can notice how the patient has used also the command to execute a reverse course, by keeping the board tilted backside even after the ball has stopped.

The patient during this second exercise has reached the maximum deflection of the ankle (both upward and downward) more frequently than in the previous test, demonstrating more effort in completing the track.

As for the values of the angle around Z axis, instead, we can notice that the values are much more equally distributed between positive and negative values with respect to the previous exercise, even if it is still present certain predominance on the right side. We can also notice that this time the lateral inclination of the ankle has been kept for more time, resulting in a more intense exercise on the lateral deflection movement of the ankle.

The game data are worse, since the patient needed 4 minutes and 24 seconds to complete the track and fell 8 times, especially on the mobile platform obstacles and the jump obstacles, as could be expected since this are two of the three most difficult obstacles present in the game.

Nevertheless F1 has found much more stimulating and amusement to perform this second track instead of the previous one.

7.2.4. Analysis of Tuning Data of Patient F2

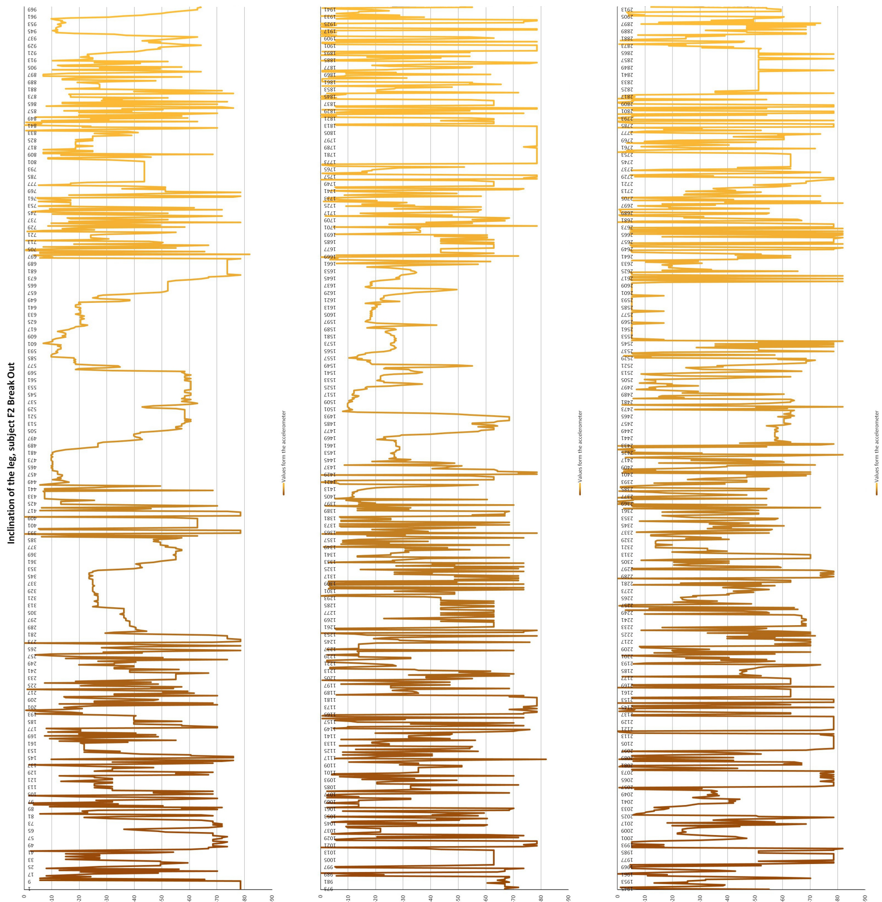


Figure 7.4: The performance of F2 while playing Break Out during the tuning session.

Figure 7.4 shows the movement of the leg registered while F2 was playing Break Out. To record this data we have put a smartphone inside a fit band and attach it to the ankle of the patient, while the patient was seated on a chair. The session has lasted for approximately half an hour. We have decided to split the plot into smaller consecutive fragments in some cases because of the complexity of visualization and analysis.

When the patient is playing Break Out the device is, differently from what we have shown for Gyroscope, directly linked to the leg of the patient and this has an effect on the measures registered by the accelerometer: the fatigue the patient have to bear makes the patients leg shake faster than the leg of a normal person would do: the recordings obtained in this way have intrinsically more noise than the ones registered over the board. We are assuming that the inclination of the device is directly linked to the inclination of the knee: this is based on the observation that if the device is positioned correctly above the ankle the patients leg can be simplified as a simple lever and the movement is caused only by the knee.

We have to notice that the accelerometer read the data about all the three axis: the X axis is used to measure the inclination of the patient's leg, while Y axis has been fixed since the fit band that contains the phone is attached to the leg and Z axis is used to understand if the foot is in front or behind the knee, defining univocally the position of the lever in the space. We also want to notice that the registered values are mostly negative angles and the values are clamped between -90 degrees and 60 degrees because of the physiognomic of the knee; assuming that we are placing the relative reference system in the knee and the angles are identified by the segment placed between the origin and the position of the ankle, we consider the initial position (rest position) where the patient's feet are at the minimum distance from the floor as the angle with value 0 degrees, while when the knee is extended at the maximum position we can detect an angle negative so that the position with the knee and the ankle parallel to the floor correspond to value of -90 degrees; positive values, instead, are relative to angles that are registered when the foot of the patient is placed beside the knee.

It is important firstly to notice that the parameter set associated to this exercise was not correctly tuned for the abilities of the patient, but due to the absence of reference data for patients, so we have decided for a conservative approach: we have decided to tune a simple exercise because it is preferable not forcing fast and dangerous movements in order to reduce the risks of damaging the joint. The results have been however satisfying from the point of view of the patient and from our point of view we have identified a base line for future exercises parameters.

The patient has completed the exercises breaking all the bricks in two rooms and almost every bricks in the third one, for a total count of 58 bricks and a score of 1740 points; the exercise has been particularly long, since it is ended after 12 minutes and 34 seconds and this is the cause the fatigue that can be seen from the plots in the different type of movement at the beginning and at the end of the exercise.

During the exercise the patient is alternating two kinds of moments: moments of peace and moments of rush. The rush phase coincide with the creation of a new room, where the presence of bricks in the lower part of the playable area make the ball bounce back to the player in a short amount of time while when few bricks remains in the room they are generally in the upper part of the screen and this means that the ball needs more time to traverse the playable area and go back to the patient, permitting moment of rest to the player. This process repeats periodically every time a new room is started by the patient and this make the exercise fairly balanced regarding the total effort of the patient that can alternate between rush and rest.

We can also notice that the movement is well distributed, sign that the patient has been forced by the game to perform the complete flexion-extension of the knee multiple times, leading to a correct execution of the therapy.

We can notice that the real problems in the execution of F2 are the two zones where the movement is interrupted or better when the angle remain stable: that problem is caused by the bad choice of the speed of the ball we have made at the beginning. The second time the impasse is smaller because the patient has acquired ability, precision and control with the game controls.

The last part is richer of fast movements and no impasse: this is due to external factors since F2 was distracted by listening to the conversation between the therapist and her father: this lack of attention made her lose the time to prepare herself and this required fast and unexpected movements to catch the ball.

7.3. First Therapeutic Session

The first therapeutic session has been held under the supervision of Dr. Ft. Lopopolo, with the presence of the parents of the patients.

During this first therapeutic session we had the participation of four patients, three females and one male. Between the participants there was also F2, already present during the second part of the tuning session.

7.3.1. Patient F3

The first patient who we call F3 is a girl of 7 years old hospitalized after a complex heart surgery. In her case there is no evidence of JIA, but the patient present a dramatic reduction of the muscular mass over the complete body: during this session she was not able to walk or even stand, does not communicate verbally with anyone except the parents and is not able to perform arts lifting. Her therapy is focussed on trying to make her happy and making her performs small tasks by herself so to let her regain her muscular mass. This rehabilitation is done every day, since the patient is resting in the wards of Clinica G. e D. De Marchi.

It was impossible to obtain a specific feedback from the patient, however we think she was satisfied since, according to her father, she kept smiling during almost all the time of the game, and it was the first time from her surgery.

7.3.2. Patient F4

The second patient, that we call F4, was a girl of 15 years old that was affected by JIA from young age. She has been getting better, but a new incident caused a worsening in her condition, especially in the trust in herself, to the point she was prescribed to walk in the garden of her house, but she refuses to do it for the fear to fall and damage the joints. Her JIA is affecting the ankles, but fortunately not the knees.

After the session the feedback we received was really positive from both the patient, who has got amusement, and the mother of the patient who was very interested in the application since her daughter, that has always demonstrate a certain impatience for the rehabilitation, seemed to have take it more seriously through the game.

7.3.3. Patient M1

The third patient, who we call M1, is a boy of just 6 years, affected by Ehlers-Danlos syndrome to the ankles and knees. This pathology provoke articular hypermobility due to hyperlaxity of joints and muscles: this provoke problems in the patient since the joints cannot sustain completely the weight and need to improve the muscular mass and to train it to sustain the joints. The typology of exercises normally proposed to patients affected by Ehlers-Danlos syndrome is the same of patients affected by JIA, even if the aim is different. His therapy had just begun, so the patient was completely inexperienced with the exercises that were familiar for the other patients, who had been under treatment for a longer period of time.

He has participated to our session while patient F2 has been occupied in a check up in the middle of her rehabilitation session, and for this reason he was just able to perform one short exercise.

However the feedback we have received from him has been very positive since M1 had fun playing and he would have performed for a longer amount of time, if possible, or a new therapeutic session. His parents were very pleased by the fact that their child was enjoying himself, even if in this situation. We received also compliments from the therapist who was following M1 and that was not involved in the designing phase of our system.

7.3.4. Patient F2

Last patient we have seen is F2, the same patient who has taken part in the tuning phase. Her clinical situation has not really changed in the time between the tuning phase and this first session, but this was to be expected since her situation is chronic. This time we have prepared more suitable levels of difficulties for her. Her feedback was also good and better than the previous time because, according to her, this time she had to put effort to win.

7.3.5. Analysis of First Therapeutic Session Data of Patient F3

The first patient we have met during this session if F3. Her pathology is not JIA, but her conditions require some exercises to increase the muscular mass. Her condition was slowly improving, but the patient gets tired very fast and is not able to sustain a long exercise. For this reason the patient was able to overcome only 20 minutes of rehabilitative exercises before being tired. We have decided to focalize our attention on the ankles of the patients since she was not able to move properly the knees, so we have decided to let her play with the game Gyroscope. We have performed with her the basic tutorial to let her understand the commands of the game and then created two dedicated levels. Her performance has been made with the patient seated over her wheelchair, and in this condition she was not able to reach the table on the floor: we had to place a wooden step under the table so that she was able to reach it.

We were much concerned with the fact of creating simple levels, not only to avoid to tire her, but also we had in mind the purpose of avoiding her to demoralize if she has encountered difficulties; however we were completely surprised by the ability and dedication the patient had devoted in the game, surprising both the physicians, who were enraptured by the amount of exercise she was performing, and her father for the amusement seen in her face.

The goal of her exercises was to improve the movement of the ankles on all the four possible directions in the most balanced possible way, remembering that the game does privilege specifically the front movement and that we would like to avoid, initially, the obstacles that could complicate the track, even if they are useful to force the patient to brake more frequently.

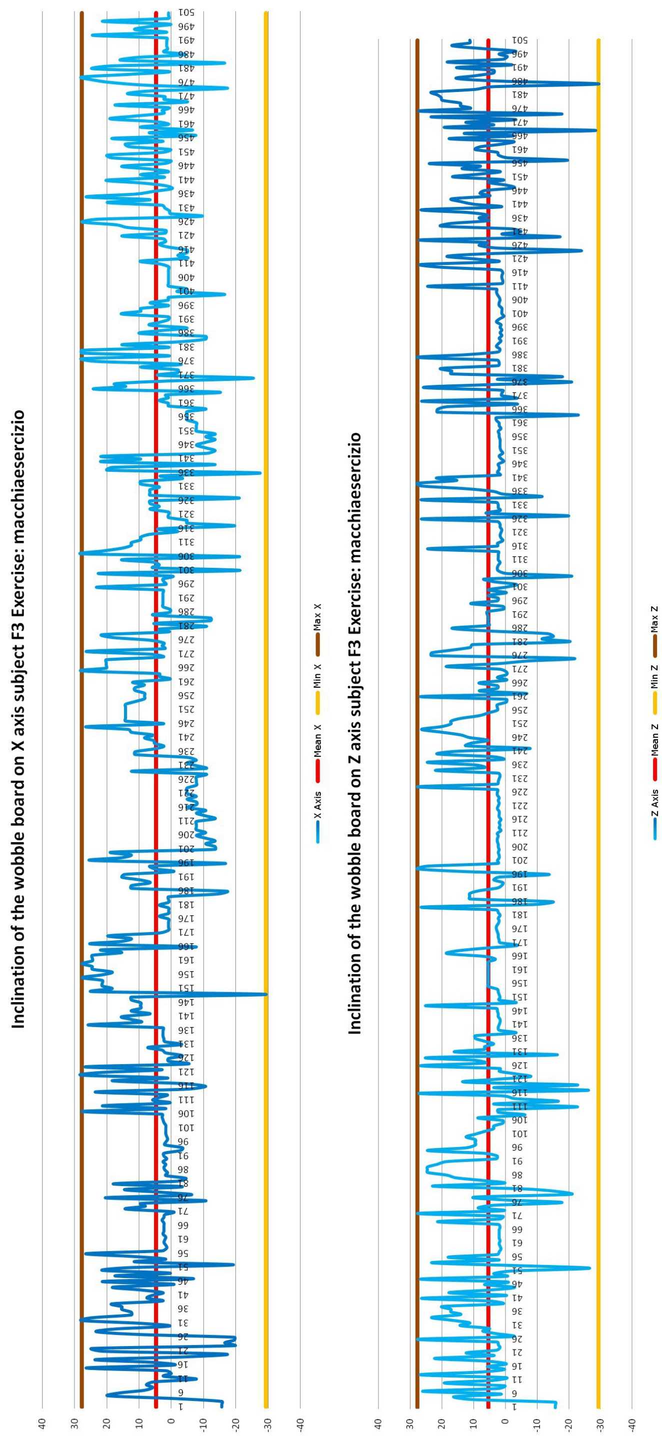


Figure 7.5: The performance of F3 while playing Gyroscope, track eserciziomacchia during the first therapeutic session.

In particular in the first exercise we have proposed her the track, called eserciziomacchia, was simply composed of a linear connector, a turn to the left, a linear connector, a turn to the right, a turn to the left, a turn t the right and finally a linear connector, so that the track is very easy and more focalized on the lateral deflection that the dorsiflection and plantarflection, relegated more to the need of finishing the track and to stop to avoid falling from the track. Accelerations registered during this performance are shown in Figure 7.6

We can notice that the number of peaks in the negative part of the values read on X axis are limited and this is a consequence of the fact that the braking movements was needed only when the patient was facing a turn. This also explains the reason why mean value on X axis is so high. Moreover having seen the precision demonstrated by the patient there was no need at all to perform strong braking. We can also notice that the patient had some problems in reaching the maximum inclination permitted by the table, especially with the backside movement, but has been able to train well the muscles around the ankles.

As for what we can derive from the second plot in Figure 7.5 of the values around Z axis, we can notice that the movement is symmetric, as we would have expected in consideration that the track has an even number of turns on the right and on the left. What we are surprised is the limited number of peaks and this is the demonstration of the ability of the patient. In the plot we can also see there is a highly oscillating behaviour at the beginning, expected because there is low confidence with the game, but also at the end; it is caused by a difficult position in the game in which the patient has found herself, forcing her to perform a sequence of corrective rotation. We can also notice that the plot does not show very large oscillation and that these are not sudden, differently from the other patients: this is caused by the difficulties of the patient to perform the movement.

From the game data we can confirm most of our deduction, since F3 has completed this exercise in only 2 minutes and 31 seconds, a very short time, and moreover she never fall, a result over the expectations, both for her situation and because it was the first time she try both the game and the wobble board; this results have convinced us to test on her a slightly more complex exercise.

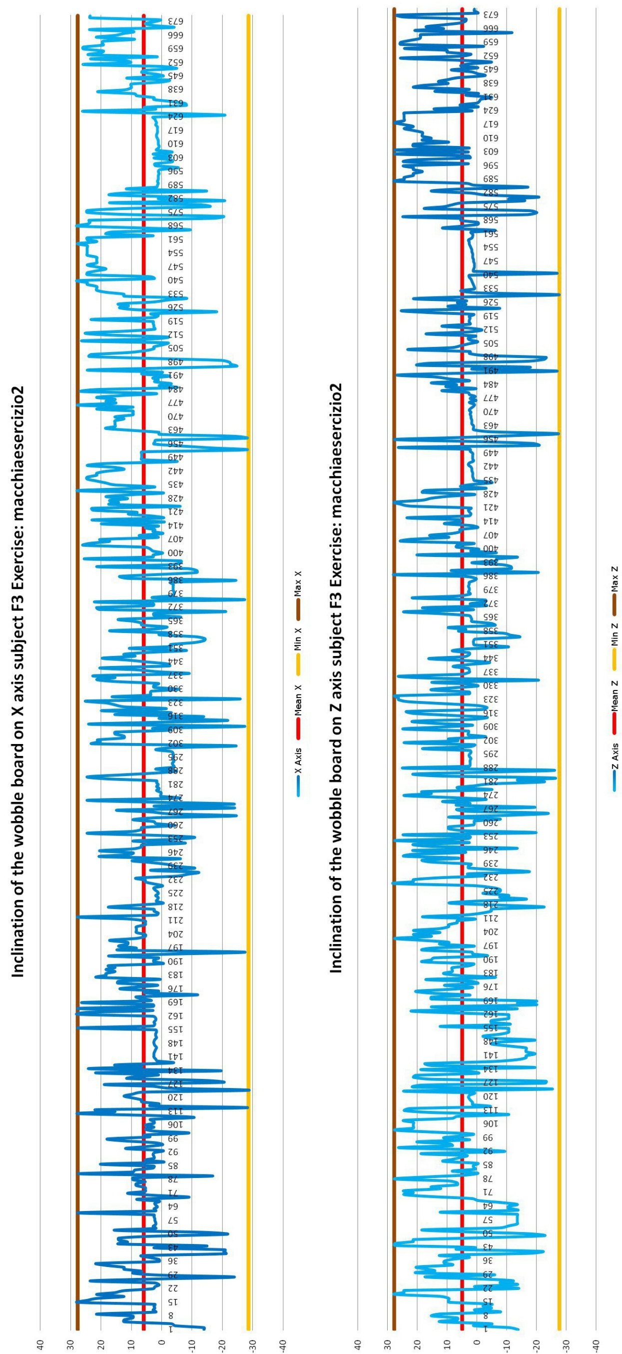


Figure 7.6: The performance of F3 while playing Gyroscope, track eserciziomacchia2 during the first therapeutic session.

Figure 7.6 presents the performance of the patient while testing the exercise eserciziomacchia2, a lightly more complex track that is obtained by the previous exercise adding in the middle an ice path exercise, represented in Figure 7.7. We have decided to use this obstacle because it is not particularly difficult, but it forces the patient to experiment some needs of controlling of the movements and some more brake movements. The result of this modification has been positive since the patient had more fun in facing a new challenge and responded to it with a great effort.

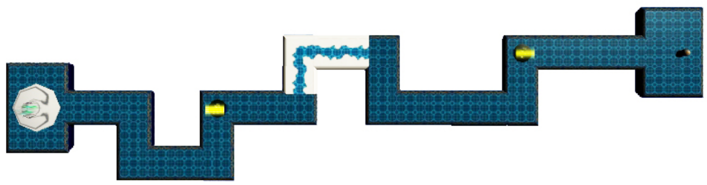


Figure 7.7: Top view of eserciziomacchia2 track

We can immediately notice that the patient has used more the backside deflection of the ankle, resulting in more negative peaks than before and there are also fewer pauses between the movements, index that the patient has acquired self-confidence with the wobble board and the game and that she does not need to pause the exercise to get rest, however it was not sufficient to significantly reduce the mean value on X axis. We can also notice that the absolute values of this plots are higher than the previous one, so we can notice that the patient has reached the maximum deflection (frontally or backside) with less difficulty.

We notice that the patient has also reached faster movements on the board, that are more important in her training since it stimulate more the muscles and is also a good index of the reactivity of the muscular mass.

In the second part of Figure 7.6 we can notice how the result is a bit more balanced between the right and the left deflection of the ankles, even if it a bit more intense the tilting motion toward the right. The results present less pause zones and this means that the patients ankles have worked more than in the previous exercise, causing probably the tiredness that reached the patient at the end of the exercise. We notice also that in the central part of the game, where the patient had to face with the obstacle the tilting of the board becomes more frenetic , while after the obstacle the plots is less oscillating.

From the game data we can confirm that the addition of a single obstacle has deeply changed the behaviour of the patient, condition that was expected, but not with this significance. The patient was, however, able to have fun with our game even with the fatigue and she was able to have a moment of fun in her hospital experience.

7.3.6. Analysis of First Therapeutic Session Data of Patient F4

Patient F4 suffered from JIA, but her conditions have limited more her dorsiflection and plantarflection functionality of the ankles with respect to the lateral functionality; for this reason we proposed her two exercises more concentrated on the plantarflection and dorsiflection performed on the game Gyroscope. The session has lasted for about 30 minutes.

The patient was terrified by the thought of getting injured, a fear that has been causing new voluntary social exclusion, so part of her treatment has been devoted also to build some self-confidence and being able to overcome also difficulties in a game can be helpful.

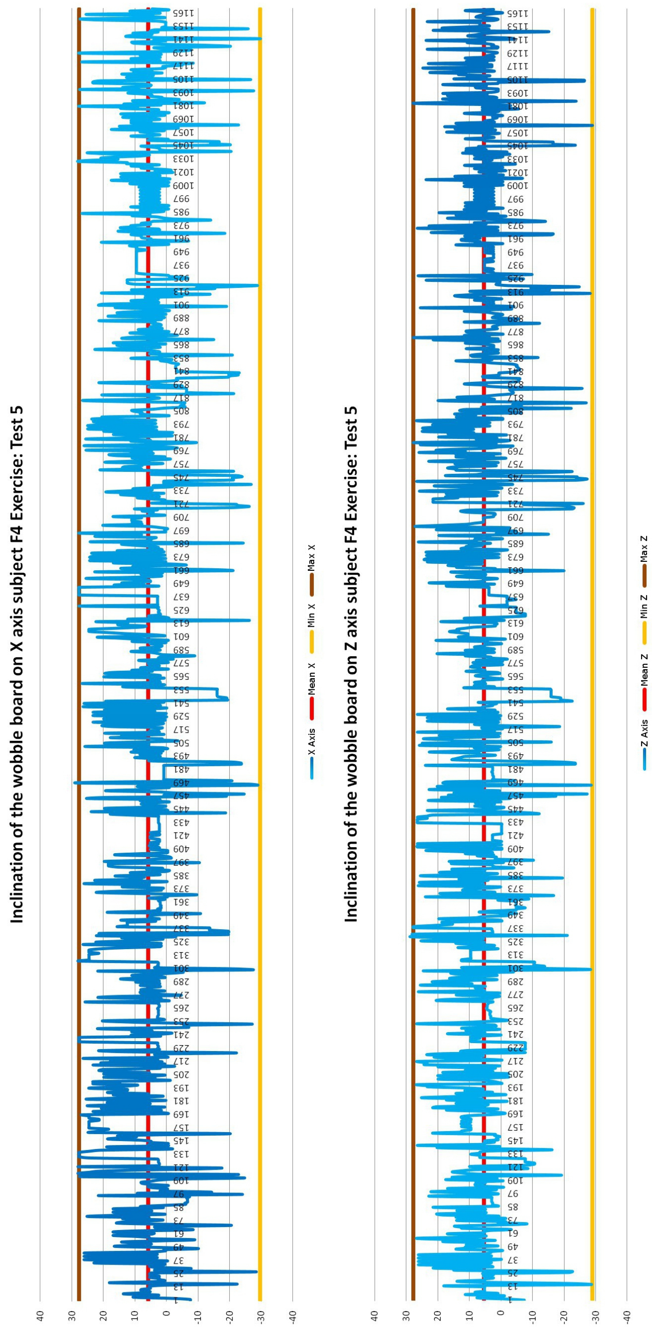


Figure 7.8: The performance of F4 while playing Gyroscope, track Test 5 during the first therapeutic session.

We have started with a pre-prepared level, Test 5 already used during the tuning session to understand better the response of the patient to the game and to build up her confidence on a track we know perfectly so that we can help her. This first track contains a linear connector, a closed door obstacle, a turn to the left, an equilibrium platform obstacle, a turn to the right, an ice ground obstacle ramp up, a tube obstacle a ramp down, and finally a passage between cannons obstacle. The complexity in this exercise for the patient was not in the obstacles complexity, but mainly in the control and the speed required to the player to complete them, and also by being able to complete the obstacles we hope that the patient acquire self-confidence.

We can notice that the patient has performed very well the exercise: the movement that we registered in figure 7.8 has been very highly oscillating and it vary for most of the time of the exercise between the extreme values and the rest position; the patient has oscillated between the maximum plantarflection and the maximum dorsiflection in a limited amount of time, a situation that has surprised the therapists that were impressed by the effort the patient was putting in the game, since this kind of movement was not commonly seen in her behaviour. We can also notice that even if the nature of the game is putting more effort on the frontal deflection the patient has performed a discrete number of backside movement to affirm that the exercise has been well balanced. We notice however that this type of movements is diminished in the final part of the game, and this is a consequence of the fact that the patient has discovered how to use the friction present in the game to help inexperienced players by performing a sort of engine brake: F4 has discovered that if she kept the speed sufficiently low she can brake without the need to perform the movement that was painful for her.

As for what we can derive from the plot about the inclinations around the Z axis we can notice that the movement is extremely reactive: the patient can oscillate between the right and left side of the table in a small amount of time and she is continuously correcting her movements. We can notice, however that there is a clear predominance of the right side. This behaviour is probably caused by the decision of the patient to perform some turns to the left by turning towards the right for a longer period of time instead of performing a more natural tilting to the left. However this decision seems to be not related to pain or the medical condition of the patient.

We can notice, at the end that form the game data we can also understand that the patient is lacking a bit of skill, especially on the turning precision, but that she is facing the game with dedication, and so we can see that the time needed to complete the exercise is of 6 minutes and 34 seconds, that is not small, but that the patient has fallen only 3 times nevertheless of the number of obstacles.

After this exercise we have decided that we would have tried a track more focused on the frontal tilting and to perform this exercise two times: the first time with the natural orientation of the axis, while the second time Dr. Ft. Lopopolo has asked to try the version with X axis inverted to stimulate more the two movements frontal and backside.

The track that has been tested is called esercizio9 and it consist of a linear connector, a turn to the left, the obstacle with moving platform, a linear connector, a turn to the right, the obstacle with the breaking ground, a linear connector, a passage between the tubes and a turn to the left, as shown in Figure 7.9.

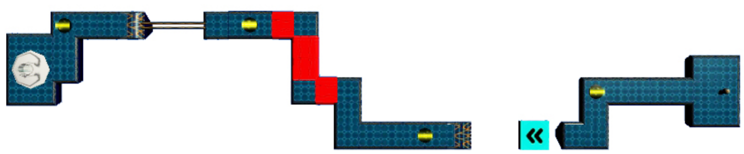


Figure 7.9: Top view of esercizio9 track

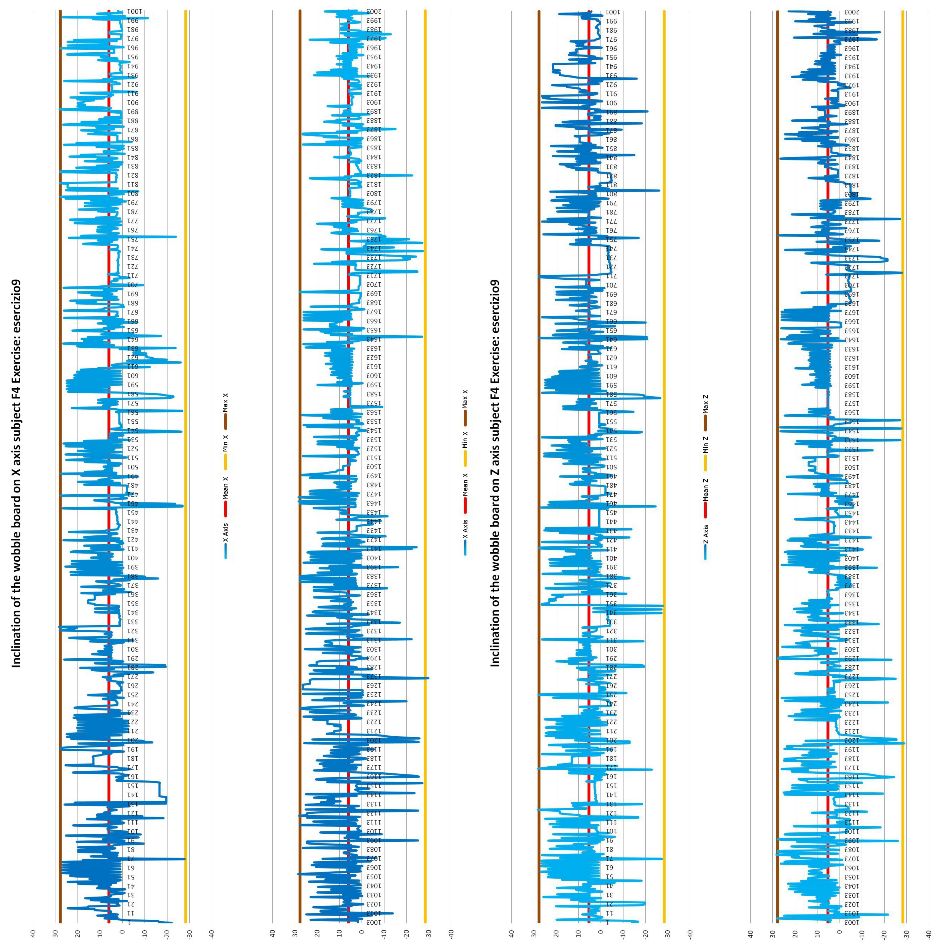


Figure 7.10: The performance of F4 while playing Gyroscope, track esercizio9 during the first therapeutic session.

Figure 7.10 shows that the results over the frontal extension has been fully reached, as we can see from the positive value of the mean value on X axis, meaning that the patient has performed for most of the time of the execution of the track a movement that implied the plantarflection of the ankles. We can also notice that most of this tilting have a value considerably positive and close to the maximum permitted by the table and there is absence of flat areas near the maximum: this means that the patient has performed frequently the movement of flexion-extension of the ankles frontally, performing a good exercise for them.

As for what we can derive from the plot about the Z axis' accelerations we can notice that there is no substantial change from what we have noticed in the previous exercise, just a partial balancing between the movement towards right and left in the second half of the game.

From the game data we notice that the patient has faced a more difficult exercise, but that her spirit has not waver: the track has been completed in 10 minutes and 51 seconds, a very long time that could cause fatigue, the complexity of the obstacles has increased dramatically, since the moving platform and the breaking ground are two of the most complex obstacles present in the game, but the number of fall is just 9, and mainly concentrated in the moving platform. Nevertheless of these difficulties the patient had fun and was very happy of being able to solve such difficult exercise, a good result also for her spirit.

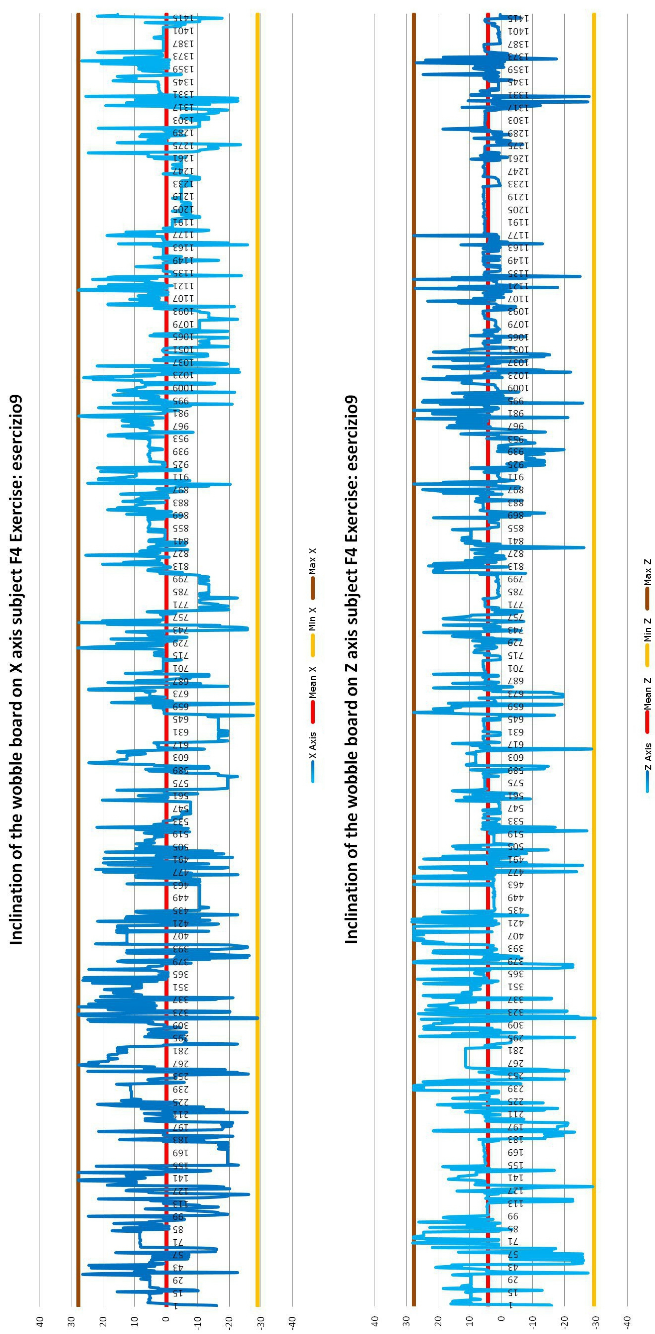


Figure 7.11: The performance of F4 while playing Gyroscope, track esercizio9 during the first therapeutic session with inverted X axis.

We would have expected that Figure 7.11 would have shown a behaviour mainly symmetrical to the one presented in Figure 7.10, where the patient has performed again the exercise with the X axis inverted, so that the patient needs to perform a dorsiflection of the ankles to move forward in the game and vice versa perform a plantarflection of the ankles to brake. But this has not been registered by the game, especially because we have underestimate the mechanical memory already acquired by the patient, that have repeatedly performed the natural movement instead of the inverted one before realizing her mistake and performing a brute movement to avoid the ball to fall from the track.

We can notice, however that the fact that the track was known and also how to overcome the obstacles, has weakened the threat of the obstacles by themselves, but has permitted the patient to focus more on the different mode of the controller.

We can notice that the movement has been effectively more intense in the lower half of the plot, meaning that the patient has used more effort in the dorsiflection than in the plantarflection, exactly the results we wanted to reach. The presence of significant flat area in the middle of the plot, area where the patient had stopped to think. We can notice also that the maximum backside deflection has been reached only at the beginning, but the magnitude of the backside inclination is dropping during the exercise, probably due to the fatigue and the pain felt by the patient in performing a movement particularly challenging for her condition.

In the plot expressing the inclination of the board on the Z axis, instead, we can notice that the situation has finally fairly balanced, and we can see that this time the patient has performed much less rotation, just the required ones limiting the number of corrections. We can detect that the last part of the game is characterized by a certain minimal effort quest.

From the game data we can also see that the complexity of the inversion of the control has affected the number of falls, that has highly increased from 9 to 28 and are mostly concentrated at the beginning of the exercise, while the total amount of time to complete the track has been of only 6 minutes and 53 seconds, highly reduced from the previous performance.

7.3.7. Analysis of First Therapeutic Session Data of Patient M1

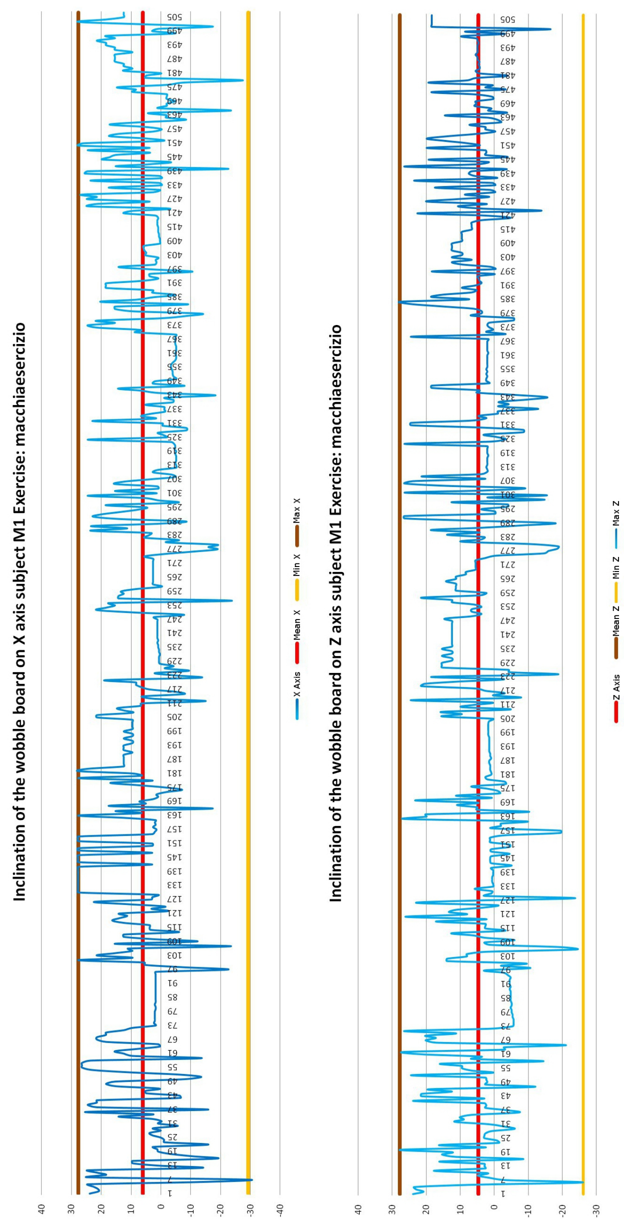


Figure 7.12: The performance of M1 while playing Gyroscope, track serciziomacchia2 during the first therapeutic session.

Patient M1 was affected by Ehlers-Danlos syndrome, so we have decided to use the game Gyroscope to let him perform an exercise for the ankles. Figure 7.12 shows the performance of patient M1 while performing the exercise macchiaesercizio2, the same exercise that was performed by F3 as her second test, even if the motivations were deeply different.

He was not prescribed any particular constraints on the exercise, but for the limited amount of time he has and in consideration of the young age we present him a really simple exercise and also there was no time to make him play the tutorial to familiarize with the game, even if he had participated to part of patient F2s tests as a spectator.

We can notice form the plots obtained by M1s performance that the patient has responded excellently to the game, demonstrating much more exuberance than all the other patients, but also more control that what we would have expected. We can see in the plot that the movement is fairly distributed on all the four components of the movement, except the backside movement, that as we would have expected from the track that was not designed for this purpose. In the plot of the lateral inclination, instead, we can notice immediately that the result is normally balanced, as we would have expected form a symmetric track in the number of components that require turns. We can also notice that the patient has demonstrated to be able to reach the maximum deflection movement on all four directions and also has demonstrated rapidity in the change of the inclination of the ankles, both sign of a good mobility.

The patient has completed the exercise in just 2 minutes and 39 seconds and just 4 falls, mainly on the ice ground obstacle and at the beginning when the patient was trying to get confidence with the game commands, remembering that he has not performed the tutorial, differently from the other patients. This is an excellent result and is also very encouraging about the patients attitude towards the therapy.

We can also say that the feedback we received from this test is not limited only to the boy, who has expressed a very positive impression, but also by the parents of the boy and another therapist that was following the boy and that was not involved in the development of our system, who has expressed a very positive feedback.

7.3.8. Analysis of First Therapeutic Session Data of Patient F2

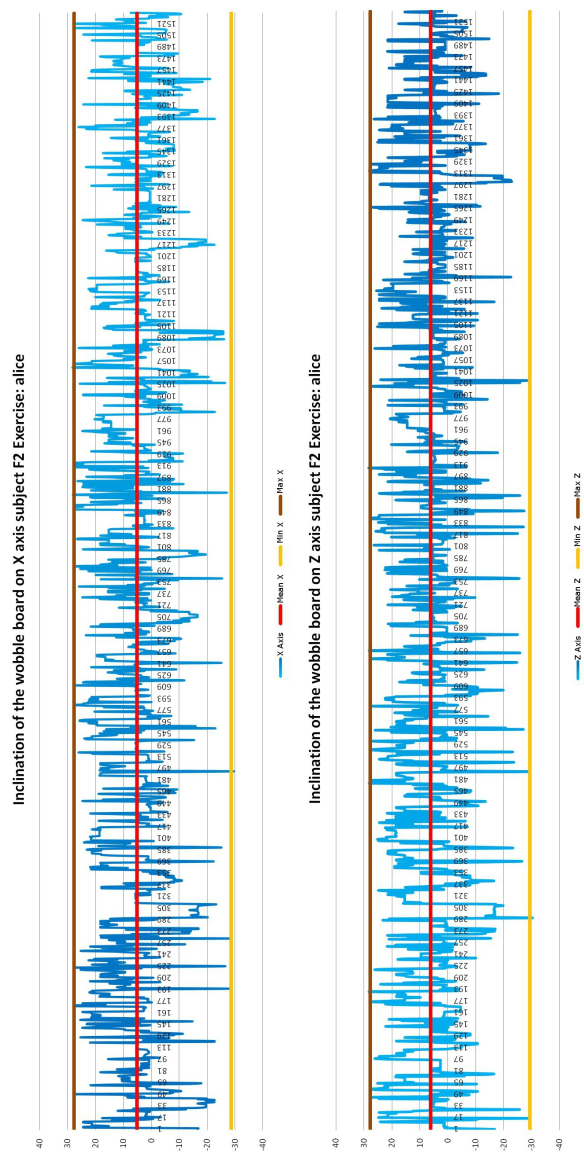


Figure 7.13: The performance of F2 while playing Gyroscope, track alice during the first therapeutic session.

Patient F2 had already participated in the tuning session. She was asked to perform two tests on Gyroscope, than she was visited while M1 has played and then she was asked to perform again two tests with Break Out, the game she had already tested but with a new set of parameters for her exercise.

To this session have participated as spectator M1 with his parents and his therapist, but also another patient affected by JIA and her father that were interested in performing their exercises in this way, but not yet ready to play.

Before the beginning of the personalized exercises the patient has asked to perform again the basic tutorial in order to regain the familiarity with the device, obtaining a good result, nevertheless form the conditions of her right ankle and leg that limited greatly her movements.

The first track, called alice, is composed of a linear connector, a turn to the left, a passage between cannons, a rump up, a passage between the tubes, a linear connector, a platform for the equilibrium, a linear connector, the movable platform, a linear connector, the passage with the jumps a turn to the left, another movable platform obstacle and a linear connector, as shown in Figure 7.14.

Figure 7.14: Top view of alice track

As for what we can deduce from Figure 7.13 we can see that the patient has used a strategy that is constituted of small but frequent impulses performed form frontal deflection with a small amount of braking positions; F2 is able to reach the maximum deflection permitted by the wobble board, a good sign for her highly damaged ankles.

We have to say, however, that the wobble board has the defect of permitting to the user to compensate the weak ankle with the stronger one, so especially in this case we noticed that the mobility of the right ankle is not complete: the compensation is being reduced through the repetition of the movement but this does not forbid her to have fun and to use our game for her therapy.

As for the other plot about the inclination along Z axis, we can see that the movement of the right ankle is highly preponderant, that is a very good news for the patient, since at least in one of the two direction the movement of her ankle is good, even if we have to say that he lateral movement is much more easy to compensate than the frontal one with the use of the other ankle and of the knees.

The patient has some difficulties in facing this track, but also thanks to her competitive spirit she was able to have fun even if the number of falls has been 24 and the time needed to complete the track was of 8 minutes and 22 seconds, F2 appreciated particularly the possibility of facing such a challenge in our game; we can notice that the execution of such a long exercise had not affected painfully her ankles, a sign that the exercise has been performed correctly.

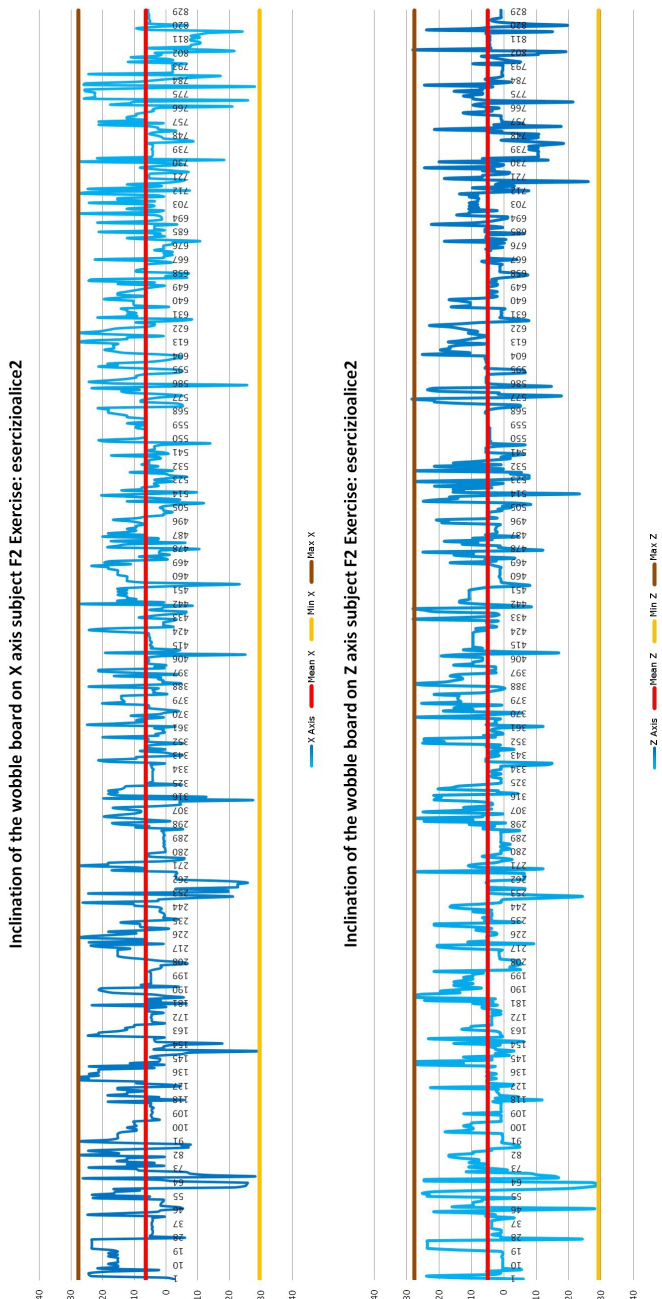


Figure 7.15: The performance of F2 while playing Gyroscope, track esercizioalice2 during the first therapeutic session.

The second track, called esercizioalice2, contains a linear connector, a turn to the left, an ice path obstacle, a turn to the right, a jump path obstacle, a turn to the left, a rump up, a linear connector, a passage between tubes, a turn to the right a breakable ground obstacle and finally a linear connector.

We want to highlight that even if it is probably simpler than the previous one, the results suggest that the training, repetition and the acquisition of confidence with the game permit the patient to increase rapidly their ability in the game.

This second track has been designed, just like for patient F4, in order to train largely the frontal movement of the board in prevision of letting the patient perform the exercise a second time with the X axis control inverted. Unfortunately F2 had shown us that she was not ready yet for this more conceptually complex mode.

We can notice from the plots in Figure 7.15 that our goal has been achieved, since we were able to create a track in which the maximum flexion is reached frequently and rapidly, while the plot is oscillating so we can see that it is not kept for long period of time, but the patient has been forced to perform repeatedly the movement and this is very important. We can also notice that the repetition of the movable platform two times in the same track has been useful to exercise this frequent movement form rest to acceleration.

We can also highlight that the movement around the Z axis, instead, has become more balanced, even if the predominance is still in the right movement, that is mainly associated with corrections of the direction of the ball, while the turns has been correctly faced this time by the patient.

After all these exercises, F2 felt fatigue and pain in her ankle and this is probably the cause of a certain difficulty she showed in the end. As a matter of facts the exercise ha last for 4 minutes and 25 seconds, that should be added to the 8 of the previous exercise and the 3 of the tutorial, leading to an exercises' durations of 15 minutes, almost without stops. We can also notice that also the number of falls has dropped drastically to just 4 episodes, mainly focused in the first movable platform obstacle, when the patient was experimenting, while the second time she passed the obstacle without falling. This means that the patient has acquired a good ability and intuition about the game, but exactly this was the problem with the test with the inverted X axis, in which the patient has fallen a huge amount of time in few seconds because her movements were mechanically performed as if the commands were normal.

We have continued for few minutes this test, but we stopped when her ankle has begun to be clearly painful.

After this exercises for the ankles, and after few minutes of rest, the patient has been asked to perform some exercises with her right knee, to reinforce the muscular mass of the knee affected by JIA to support the damaged joint.

With respect to the tuning session we had noticed that the parameter set we had used was underestimating the capacities of the patient, so we have decided to increase the speed of the ball: in this way we are reducing the time that the patient has to decide the position to assign to the paddle and complete the movement.

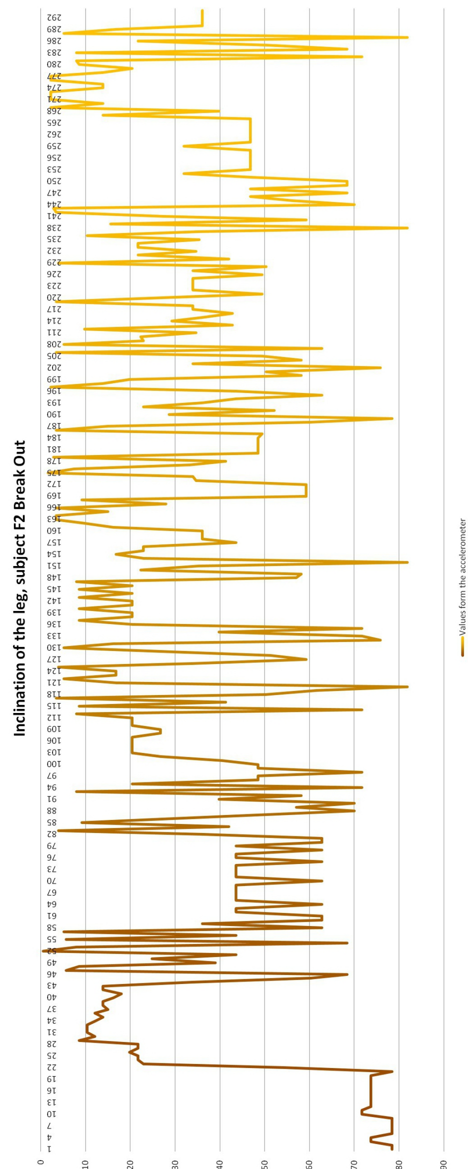


Figure 7.16: The performance of F2 while playing Break Out during the first therapeutic session.

We can highlight from the game data of the first trial that the patient do not expect such a difference: if the first time the patient had difficulties in losing the game this time the match has lasted for just 1 minute and 19 seconds instead of 12 minutes and half and consequently the score that has dropped to just 540 points, before the game over. This time, instead of losing lives for distraction, the patient had a difficult time in reaching the correct position in time. We can however say immediately that the patient has appreciate more this parameter set, instead of the previous one even if she had a harder time in playing. Probably in this session we had overestimated the capacity of the patient: the correct parameters set is probably in the middle between the ones we had used during the tuning test and the ones we had used in this session.

We can see form the plot in Figure 7.16, however, that the exercise has been done correctly, in a way that left the leg in the rest position for very short amount of time, while the knee has been performing rapidly the exercise for almost all the time of the performance, so we can say that the muscles had performed a huge amount of exercise and the t the patient has put a lot of effort in the exercise. We can also notice that the oscillatory movement of the knee if quite frequent and this means that the number of repetition of the exercise is high in a small amount of time, a good index that could be used by the therapist to see the health of a joint.

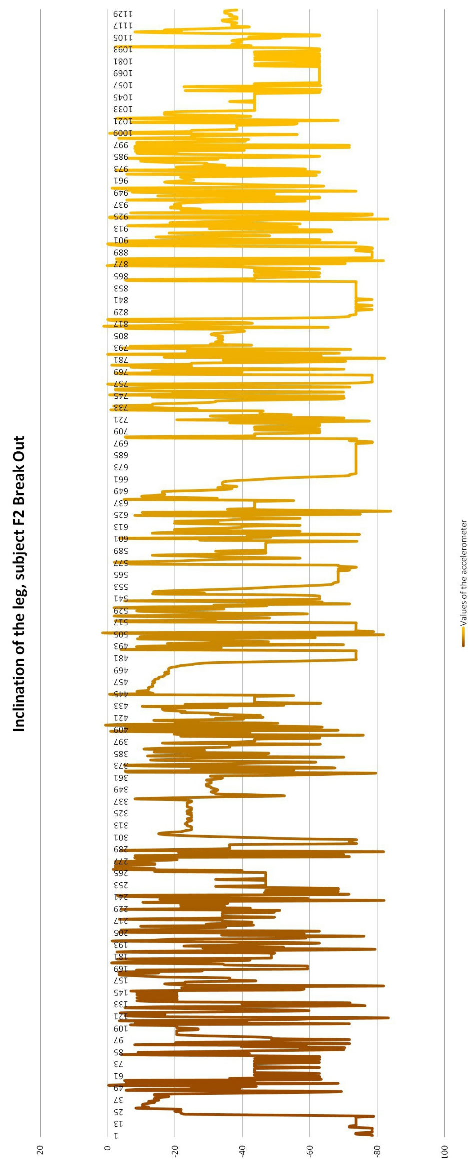


Figure 7.17: The performance of F2 while playing Break Out the second time during the first therapeutic session.

The second repetition of the game, represented in Figure 7.17 has been a confirmation of the healthy state of her knee and also that the patient is reaching confidence with the exercise and the new game settings. We can easily see that the patient has performed the exercise for 3 minutes and 43 seconds, nearly the triple of the first test of this session, reaching a score of 1320 points.

We can notice that the data obtained by the accelerometer this time are showing a very positive behaviour of the injured joint: we can notice that even on a longer time span the knee presents ample and frequent oscillations with just few pauses in between, positioned in the moments when the ball has fallen or the moment when the patient had broken all the bricks present in the room and the patient has been given the five seconds to restart the game. We can also highlight that the amount of exercise the patient has experienced is very high and good quality: we can see that a high frequency of the movements means that the patients knee is able to perform the complete movement form the rest position to the desired position (and often the maximum position) in a limited amount of time, demonstrating also a good reaction time of the knee. Moreover the fact that F2 had not suffered from fatigue to the knee after such an intense exercise with her damaged joint means that our game was able to let her express all her potentiality.

7.4. Second Therapeutic Session

The second therapeutic session has been held in two consecutive days under the supervision of Dr. Ft. Lopopolo, with the presence of the parents of the patients. During this second therapeutic session we had the participation of four patients, all four females. Between the participants there were two patients, F3 and F4, who had already participated to the first therapeutic session.

7.4.1. Patient F3

The first patient was F3, one of the female patients of the first therapeutic session. She was not affected by JIA, but has been hospitalized after a massive cardiac surgery. She still does not verbally communicate, even if her clinical condition is improving. Her test has been divided into two days, because during the first day she had a visit from a neurologist, who has tired the patient with some check exercises. So we decided to perform in the first day the exercises for the ankles and the following day exercises for the leg.

7.4.2. Patient F5

The second patient, who we call F5, was a girl of 5 years old, the youngest between all of our patients. She was affected by JIA, especially to the knees, and she was hospitalized for further analysis. Her principal problem was not in the management of the pain or in the lack of mobility, which were problematic but on a lower level of importance in this phase of her treatment, but mainly we had to focus on her control of the movement: the patient did not understand yet the limitations her pathology provoke, so she overuse her knees causing increase of the pain and swelling.

Due to her very young age the principal difficulty of her session was to teach her how to play the games and to be to her side to help her. It has been difficult to understand the feedback to the games, except that she was very pleased and had a lot of fun in playing.

7.4.3. Patient F6

The following day we were presented with the third patient, who we call F6, a girl of 10 years old, affected by JIA to both knees. Her knees are improving, meaning that the range of mobility permitted by her knees is increasing such that there is the hope that it could be considered not invalidating, but her condition does need more exercise to gain the complete mobility of the knees and for this reason she was asked to perform a high amount of very repetitive exercises of flexion and extension of the knee, which she did not perform constantly due to boredom. Her ankles, instead, do not present significant sign of JIA and for this reason have not been considered in the decision of her exercises.

The feedback we have received from her has been absolutely positive: she has taken the exercises with more interest and using more attention and effort than usual, being able to perform movements that generally she would have avoided due to the pain felt in doing them. Her mother, who was present to her performance, was also extremely pleased by the positive relation that was established between her daughter and her rehabilitation therapy through the games.

7.4.4. Patient F4

Last patient we have seen was F4, one of the patients who had taken part in the first therapeutic session. While in the previous session we tried with her the inversed control system, this time the therapist has decided to make her perform the exercise with the addition of load, standing over the board.

However due to the difficulties that the patient had to face in performing the exercise with the addition of load, she was asked to perform one exercise normally, a second one to familiarize with the track to be performed with load, some training without the game, only with the board and finally the exercise with load.

7.4.5. Analysis of Second Therapeutic Session Data of Patient F3

The first patient we have seen has been F3. She has not been affected by JIA, differently from the other patients, but her condition does require a general rehabilitation of all the muscles of the body after a huge cardiac surgery. In this situation together with physical rehabilitation the patient, that is hospitalized, is subject to checks from both psychologist and neurologists, and one of this control visit has been held before the first part of the therapeutic session. We do not have assisted to this moment but we know that the patient has been asked to perform some exercises, like stand on her feet, try to walk, and similar tasks that had exhausted her. Due to her fatigue during the first day of the session F3 was asked to perform just two exercises for the ankles, postponing the exercises for the knee to the following day.

Before the use of personalized exercises on Gyroscope the patient has performed again the basic tutorial to regain confidence with the game. After that the patient has performed one of the personalized exercises we had designed for her: the exercise called eserciziomacchia2.

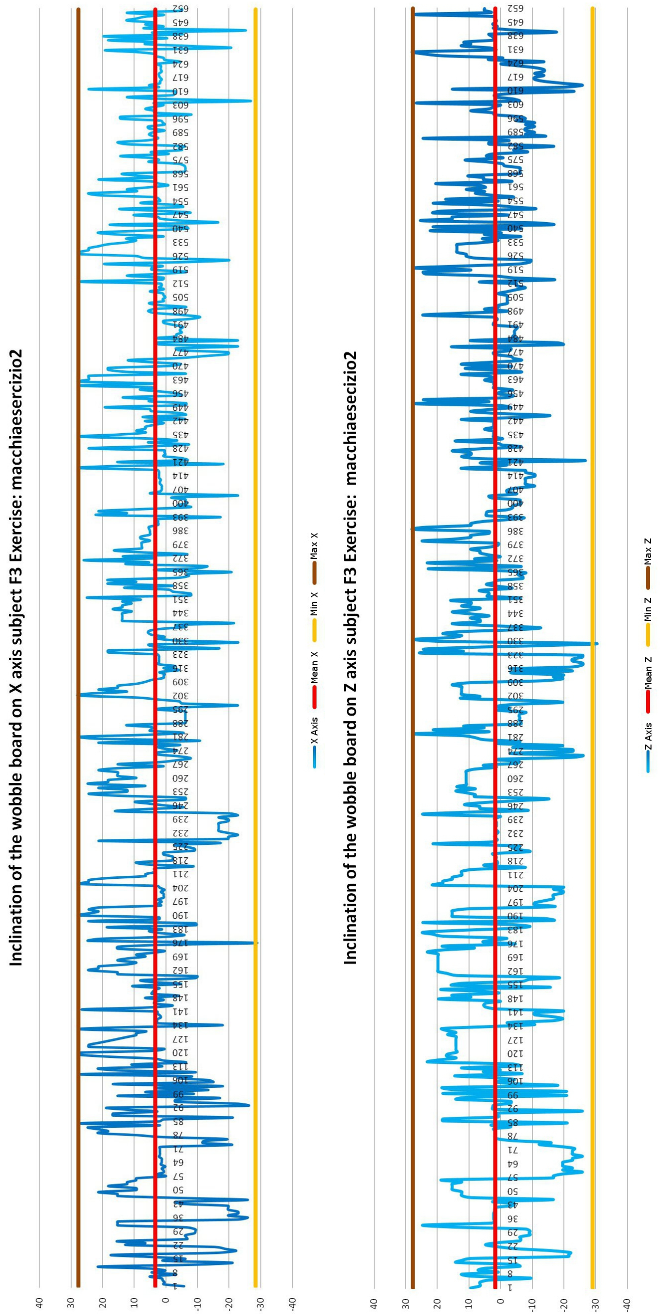


Figure 7.18: The performance of F3 while playing Gyroscope, track eserciziomacchia2 during the second therapeutic session.

We can notice that from the previous time the patient was able to improve her ability and reactivity. We can highlight that as we can see form the Figure 7.18 about the inclination around X axis, the oscillation of the values has been generally more intense, meaning that the patient has been able to reach the maximum deflection both frontally and backside multiple time in a small amount of time. We can also notice that this improvement is clearly visible with respect to the previous time, where being equal the track, the patient had difficulties in reaching the extreme positions permitted by the wobble board.

We can also see that he patient has used more the backside deflection of the angles as we can graphically see from the plot and also we can notice that the medium value of the plot has dropped to a very low value meaning that the movement is more balanced in the two directions (downward and upward).

We can also notice how the precision that the patient has already demonstrated in the previous session had been confirmed in this therapeutic session: the patient has performed very precise movements so that the need to correct the speed was limited to the minimum. Plus the patient has demonstrated that she desired to test her abilities by reaching a considerable speed and performing precise and intense brakes to stop before falling.

We can also notice that there are almost no pauses or significant flat area in this plot, so we can deduce that the patient had not the needs to concentrate and figure out a solution, but thanks to the fact that the track was already known she was able to perform the exercise without the need to focalize her attention on how to overcome the obstacles, but on the speed to reach the end, and she was able to establish a new record for the track.

As for what we can deduce from the plot about the inclination around Z axis we can notice that the plot is still preponderant on the right side of the board, but that the oscillation is more uniform than what happens in other patients' data. We can notice also that the plot, differently from the one relative to the X axis, present some flat area instead of peaks and also the number of extreme peaks is diminished from the previous session: this is probably because the patient has acquired the ability to perform controlled rotation until a desired angle is reached with a minimum correction afterwards. However we see that this behaviour is kept until the patient had faced the ice path obstacle, while after it the movement has been again oscillatory and almost all centred on the right side of the game, but this is probably caused by the fatigue of the patient, since keeping the position is more difficult than performing fast movements.

From the game data we can confirm the improvement of the performance has also translated in a gratification in tem of game result, since the patient has completed the track in 3 minutes and 23 seconds, improving her previous record time.

As a second exercise the patient was asked to try a new and more complex exercise, since we wanted to increase the difficulty level of her exercise in order to stimulate her more both mentally and physically.

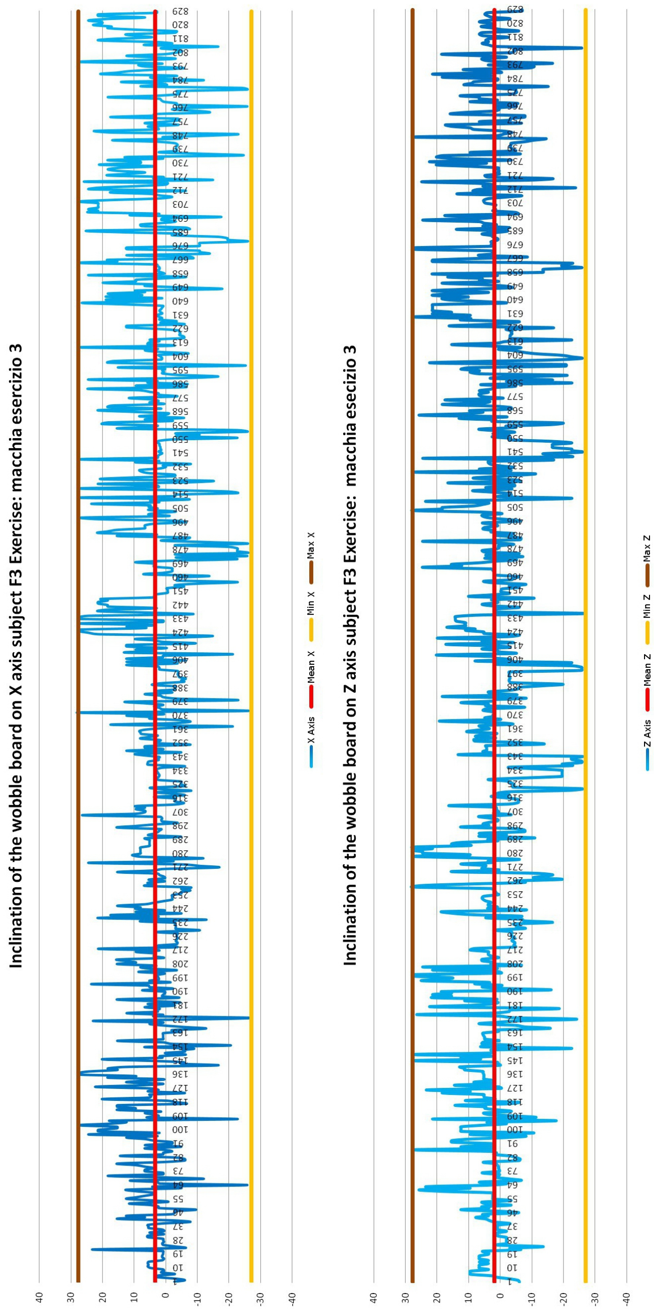


Figure 7.19: The performance of F3 while playing Gyroscope, track esercizio macchia 3 during the second therapeutic session.

The track that was proposed to her, that was called esercizio macchia 3, was composed of a linear connector, a turn to the left, a turn to the right, a closed door, a turn to the right, a turn to the left the ice path a turn to the left, a turn to the right and finally a linear connector.

The difficulty of this track was not in the novelty of the track, since is obtained by repeating the pattern of the previous exercise with the addition of a new obstacle, but there is the difficulty of the length of the track that has been increased and also the novelty of a completely new obstacle the patient had never seen, even if is simple overcome. We had also considered the fatigue that the patient had already sustained.

From Figure 7.19 we could notice that the movement around the X axis has been more controlled in the first half of the screen, until the end of the new obstacle, while in the second half, where the track has been known to the patient we can see an increase of the speed and the consequent increase of the use of the braking position.

We can detect that the fatigue of the patient has a huge impact on the performance of the patient, but not on her mobility differently from what happens with the patients affected by JIA. The other patients when they feel fatigued limit their movements to feel less pain and slow the movements and the reactivity, in case of F3 the frequency of the movement increase and also the magnitude of the values is pushed to the maximum in order to complete exercise as fast as she can before resting. This is a peculiar behaviour that is quite interesting because the intensity of the exercise the patient is performing increase with the tiredness of the patient.

This effect s les visible in the lateral movement registered in the inclination around the Z axis, because the movement has been oscillating both in the sing and in the magnitude.

The game data we have collected shows that the patient has performed very well, and probably even better than before, even if there are still difficulties for her on the ice path obstacle: she has performed the exercise in 4 minutes and 19 seconds, falling just 6 times.

The following day the patient was asked to play a game to strengthening her knees: it was decided to try Break Out.

She was asked to perform game because it can be easily performed for a longer time span, resulting in an important exercise for the knee with the goal of increasing the resistance, reflexivity and strength of the muscles around the knee. The patient has sustained the exercise for a huge amount of time, greatly exceeding our hopes, for 8 minutes 31 seconds; during this time span she was able to break 51 bricks, totalizing a score of 162 points, entering also in the top scores of all the patients in this game.

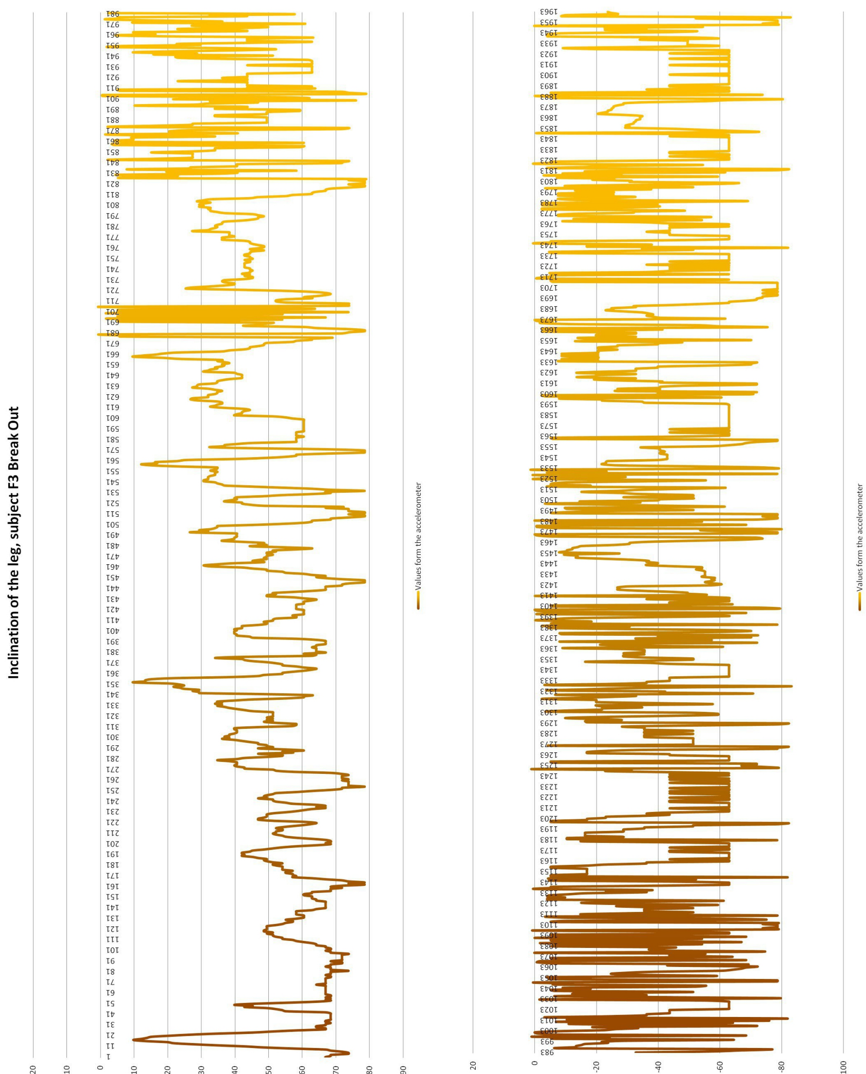


Figure 7.20: The performance of F3 while playing Break Out during the second therapeutic session.

We have decided to use a mild-low difficulty setting for her in order to stimulate her but not to overstress her muscles that were still debilitated by the therapy of the previous day. For what we can deduce from the plots representing the accelerations, instead, the performance can be divided into two parts: in the first half of the game the patient was experimenting with the game, using very posed and controlled motion, just as she was studying the reaction of the game to her movements.

What we would have not expected and were very pleased to detect was the increase of the frequency of the movement: we would have expected an limited increase of the frequency and also an increase of the range of the oscillation of the leg, however the patient has kept for around 5 minutes an fast oscillation of the leg almost without the need to stop. We can detect only small stalls in the second half of the execution of the exercise, when the ball has fallen and the patient was deciding the new starting position.

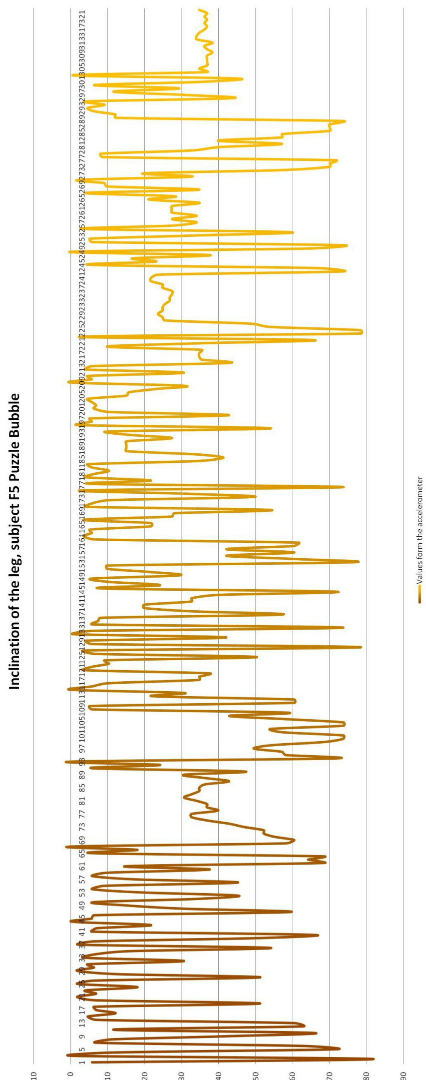
The patient has performed a very complete and intense exercise and she was completely exhausted in the end.

7.4.6. Analysis of Second Therapeutic Session Data of Patient F5

The second patient who has participated in this second therapeutic session has been F5. She was the youngest between all of the patient who has participated to our tests and for this reason there was also a major problem in helping her understanding how to play the games and to guide her while playing.

Her illness affected the knees and for this reason we have decided to perform the exercises that are relative to the knees using Puzzle Bubble and Break Out. She had been prescribed to perform exercises in which it was important to train the control over the knees position and for this reason we have decided to start with Puzzle Bubble, a game in which the control must be more accurate; in consideration of the young age of the patient there was the necessity to guide her.

We have done two experiments with this game in order to make her understand the game mechanics and simultaneously playing the game, represented in Figure 7.21 and Figure 7.22.



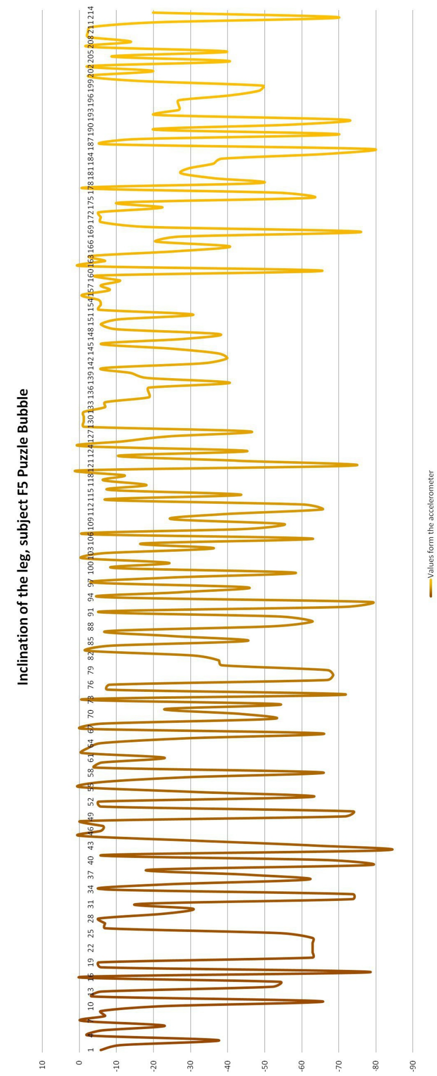


Figure 7.21: The performance of F5 while playing Puzzle Bubble during the second therapeutic session (on the right).

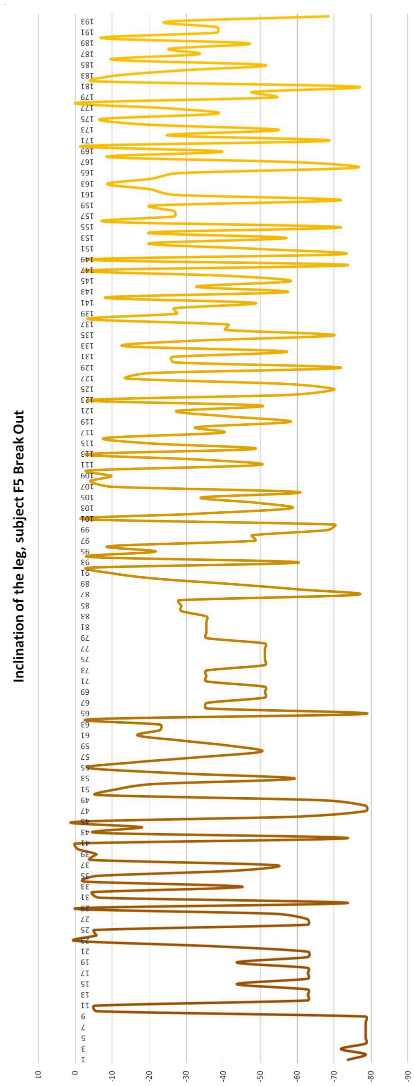
Figure 7.22: The performance of F5 while playing Puzzle Bubble during the second therapeutic session (on the left).

The first time she was directly followed by us that were guiding her in the positioning of her knee. However from Figure 7.21 is easy to see that the oscillatory movement that the patient has performed was not precise: she was trying to move the knee randomly at the beginning. After few seconds we can detect that her movement, once she was correctly guided, were also correctly controlled: during the stalls, or what should be the moments in which she had kept the position her vibrations are very limited, meaning that the pain was not a problem. However it was not sufficient to play correctly the game. The match has ended in just 1 minute and 23 seconds.

After the first test we modified the parameter set so that the game was less difficult. Unfortunately F5 was not able to play autonomously the game as we can see from Figure 7.22: she was not able to correctly position any of the bubbles she had shot during her 55 seconds of game.

However the patient has played enough to let us make some observations about her condition during the exercise: we can notice that her range of motion is large since she is able to reach the maximum angle that she imposed as her maximum deflection angle.

After this we have decided to change the game to Break Out, which is a simpler game but has been designed to perform a meaningful exercise for her.



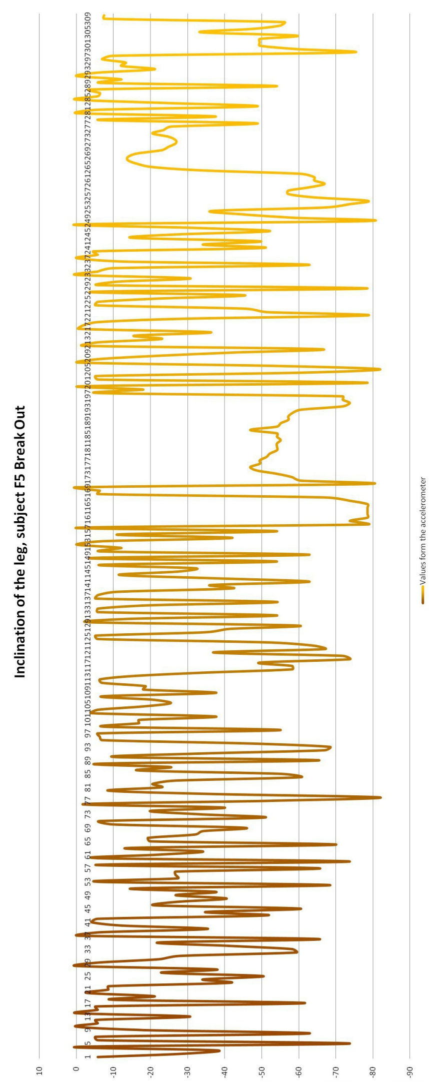


Figure 7.23: The performance of F5 while playing Break Out during the second therapeutic session (on the right).

Figure 7.24: The performance of F5 while playing Break Out during the second therapeutic session (on the left).

We have tried with three settings. The first one, shown in Figure 7.23 has demonstrated to be too difficult: the patient was able to follow the movement of the ball, but she was too imprecise. However we can still notice that the movement is correct in the beginning when we were guiding here directly, while after that moment she started to exaggerate the movements not being able to reach the deliverable position.

The second setting was obtained by slightly reducing the speed of the ball so that the patient would have had more time to reach the correct position. Results are shown in Figure 7.24. Unfortunately during this test we were not able to guide the patient, so we can see that the patient have a complete random approach to the positioning of her legs instead of following the ball.

However by hearing what she was saying we could understand that the patient had finally understood the general rule of the game, even if she was not able to play alone.

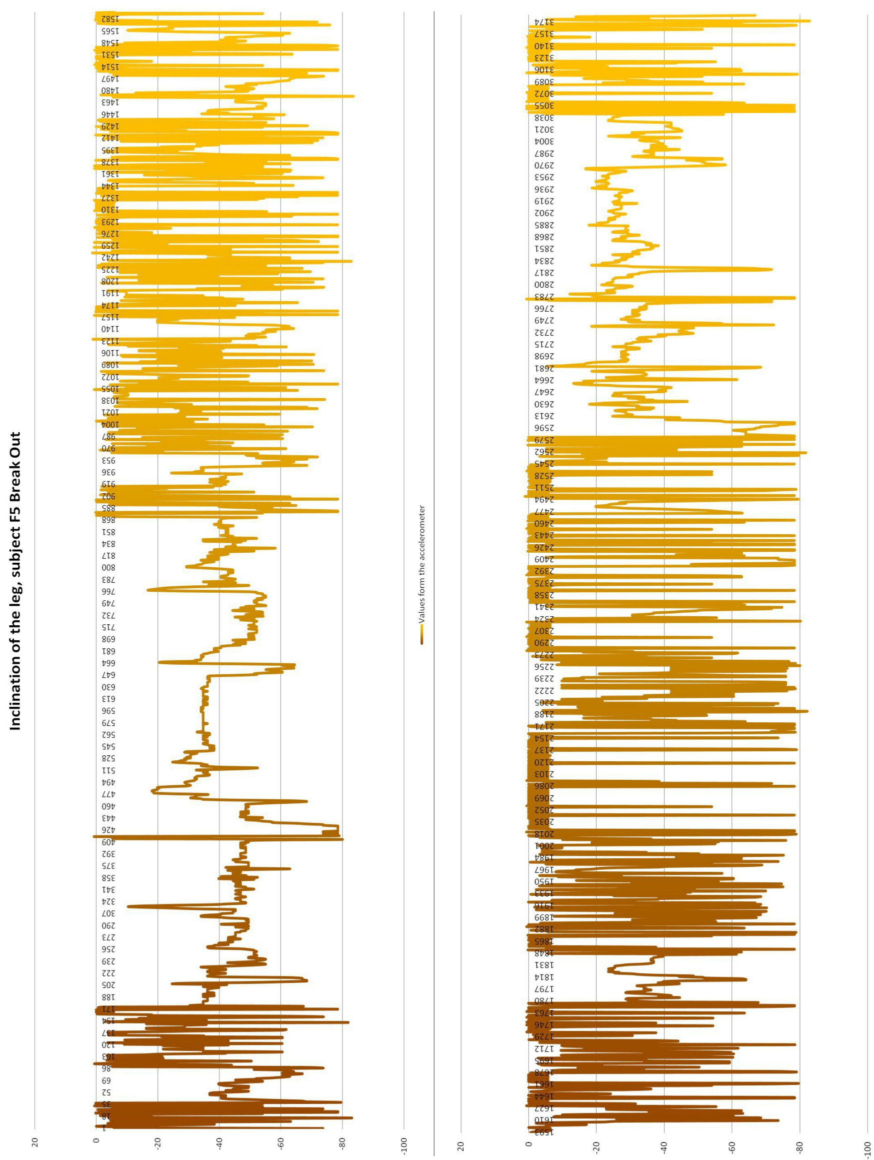


Figure 7.25: The performance of F5 while playing Break Out during the second therapeutic session.

The third setting was obtained by setting the speed of the ball to a very low value, so that the patient had all the time she required to perform the choice of the position of her knee. This time to guide the patient there was a therapist, in order to control better her movement and also to decide if the movement was correct and how eventually to correct it. Results are shown in Figure 7.24.

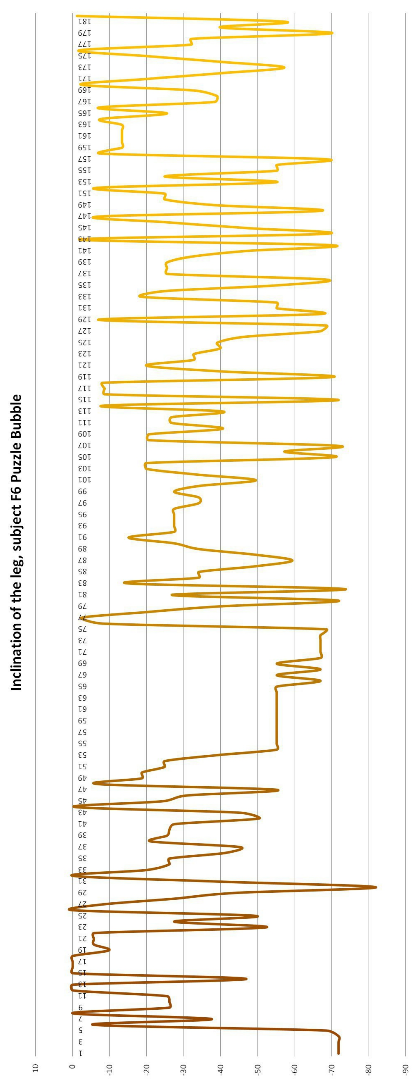
We can notice that the first result we can appreciate this time is that the patient was able to keep playing for a considerable amount of time, and more specifically 12 minutes and 56 seconds, while before the durations were around one minute. This was achieved both thanks to the fact that the child had almost understood how the game should be played and to the ability of the therapist to follow her during the game.

We can notice also that the therapist has made her perform two kind of exercises, the first one is characterized by a slow movement of adjustment following the movement of the ball; it forces the patient to control the position of her knee with a precise movement of correction and adaptation while keeping the muscles under effort to keep the position. We can detect that the physician has also let the patient play with a continuous set of quick change of position between the rest position and the maximum angle the patient was able to reach, and this repetition is being repeated with a high frequency.

7.4.7. Analysis of Second Therapeutic Session Data of Patient F6

The second day we have met patient F6. Patient F6 is affected by JIA to the legs and she was asked to perform the three kinds of exercises for her knees we have adapted in our games, in this way the therapist desire to stimulate the knees in different ways: we firstly have decided to test the player capacity of keeping the position with the Puzzle Bubble game.

The result has been collected into two experiments, reported in Figure 7.26 and Figure 7.27:



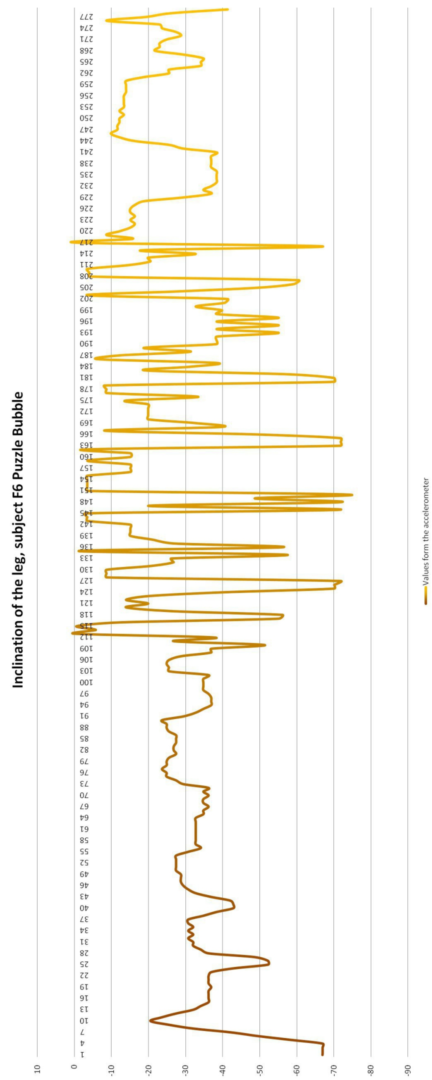


Figure 7.26: The performance of F6 while playing Puzzle Bubble during the second therapeutic session (on the right).

Figure 7.27: The performance of F6 while playing Puzzle Bubble during the second therapeutic session (on the left).

In Figure 7.26 we can notice that the patient had problems in keeping the position, but differently from F5 case, this time is not due to misunderstanding about how to play, but this was caused mainly by the pain she was feeling during the moment of keeping the position. For this reason we can see that at the beginning the patient is keeping the position, while in the end of the exercise there are more vibrations, even if the patient is still trying to keep the position. We can also understand that this pain is not intense, otherwise the patient would have asked to stop the game immediately, and it was a nuisance, so by adjusting the exercise's parameters we should limit this effect. The patient was able to perform this exercise for almost 1 minute before stopping due to game over and this identify a new aspect of this game that is different from the other games we have designed: in this game one match is generally very short and can be repeated multiple time alternating rest and exercise in a more simple way than Break Out or Gyroscope.

We can however notice that the game is however balanced, as we can see that the movement is moving from the rest position to values that are near the maximum. In Figure 7.27 we can notice a different type of behaviour with respect to the previous performance for two reasons: we have changed the parameter set of the game for F6, such that the patient should stay less time in the critical position, in this way we have reduce the nuisance for the patient and the patient has acquired experience with the game mechanic. The result is quite good and we can notice that the exercise has been done in a more precise way and with more effort by the patient. The values she has reached are very encouraging, especially because the oscillations we can detect in the middle of the game reaches interesting values and the patient was able to keep this positions even for seconds. Even if these matches have lasted only about 1 minute the patient has performed a good quality exercise, according to the therapist.

Figure 7.28: The performance of F6 while playing Break Out during the second therapeutic session.

After the test with Puzzle Bubble we have decided to change the type of exercise by using Break Out, represented in Figure 7.28.

From the confrontation between the two previous plots (Figure 7.26 and Figure 7.27) and Figure 7.28 we can see how the exercises have different behaviour: while in Puzzle Bubble the plot was characterized by the research of stalls and planes here the plot is characterized by an oscillating movement and the faster and ampler the better it is. This exercise has been designed to make the patient exercise rapid movements, especially considering that the ball has been set to be mildly fast. It is important to notice that the game has be performed changing the leg used in the exercise at half of the performance in order to reduce the pain that the knee of the patient was starting to feel after such an intense exercise.

From the game data we can also notice that the effort that the patient has put in this particular game has been greater than the one in playing Puzzle Bubble, and we can see that the results are very good, with an exercise that has lasted for 16 minutes and 38 seconds, impressively amount of time, collecting 4170 points. This is caused principally by the fact that the patient has found easier and more amusing Break Out than Puzzle Bubble.

After this game we have also asked the patient to participate to a different exercise, in which we have asked her to test Puzzle Bubble version 2. The goal of the therapists was to increase the motion range of the knee. We know that she was already and comprehensibly tired, but the therapists were very interested in the kind of effort this exercise would have had on her. The patient was very kind and played for us a short match on Puzzle Bubble version 2.

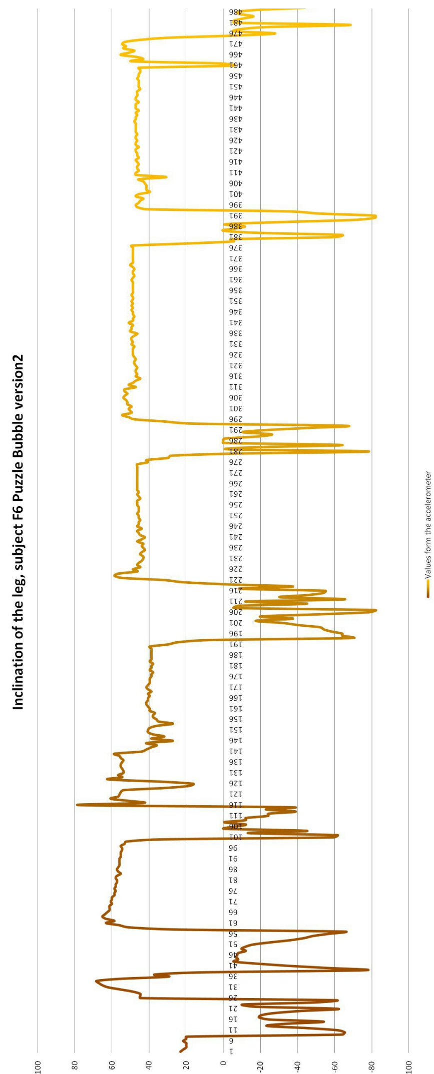


Figure 7.29: The performance of F6 while playing Puzzle Bubble version 2 during the second therapeutic session.

In Figure 7.29 we can clearly see a difference form all the other plots about Puzzle Bubble and Break Out, because in this plot there is the need to perform the movement to push the foot behind the knee at the maximum height it is considered possible form the patient during the calibration phase. The game has lasted for 2 minutes and 9 seconds, more than what had happened with respect to what has happened with Puzzle Bubble version 1. We can also notice that the patient has spent most of the time with the knee flexed behind and that this position is quite uncomfortable, especially for her clinical condition and the current state of stress of her joints after all that previous exercise, and for this reason the patient has terminated the exercise after just two minutes. Nevertheless we were able to get some interesting data about the behaviour of the patient during this exercise: it has been correctly performed and we can detect a huge effort in push the knee to the maximum position it is possible to reach behind the knee.

7.4.8. Analysis of Second Therapeutic Session Data of Patient F4

The last patient we had seen during this session was F4. The situation of this patient has not changed in the time span between the two visits, with the exception of the self confidence that has been developed. Also the ability of the patient in our game has not diminished and, in consideration of her needs to start performing the exercises over the wobble board with some load, we have decided to perform some exercises t verify her mobility in the ankles and that try one exercise performed with load.

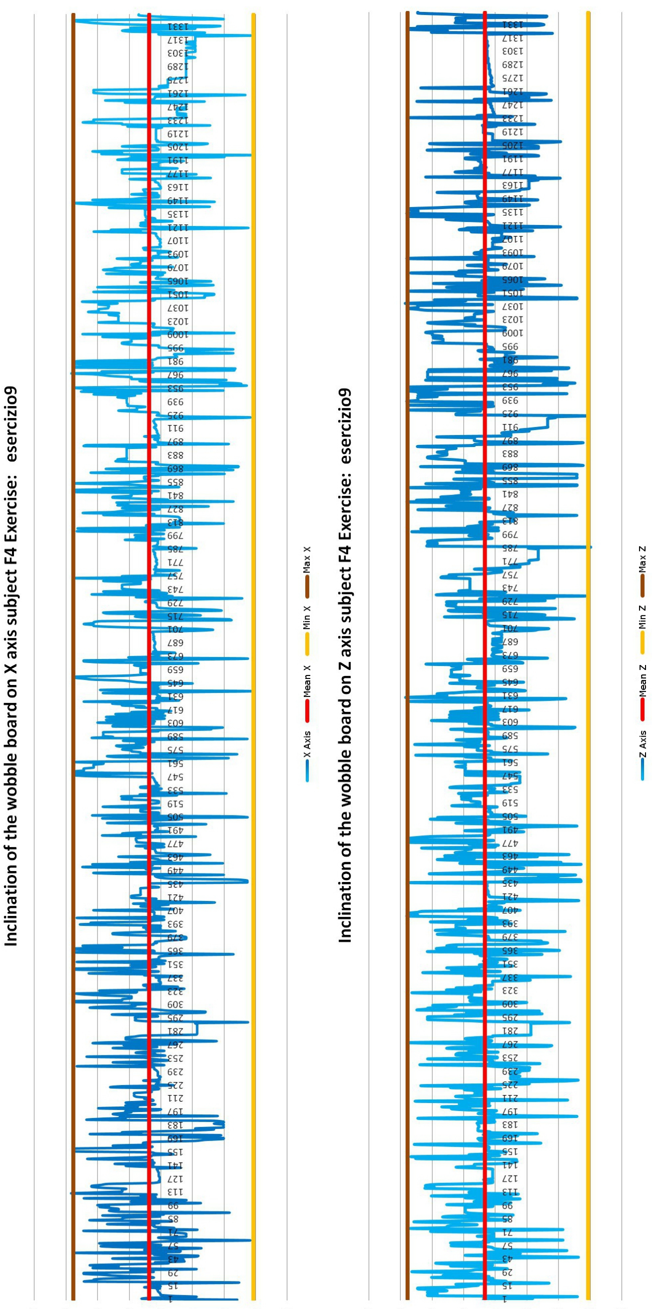


Figure 7.30: The performance of F4 while playing Gyroscope, track esercizio9, during the second therapeutic session.

In Figure 7.30 we can see the performance of patient F4 on the track esercizio9. This track has already been used by her and it was an exercise that has given us good information about the state of her ankles. In this case we can see that the movement is fairly balanced around the X axis, meaning that the track has been correctly designed, with the correct amount of speed requirements and the consequent number of brakes; considering the values reached on both sided we can deduce that the health condition of the ankles of the patient in that moment was pretty good, permitting her a good mobility and also a good reaction time.

This is also more evident if we analyze the movement around the axis, that the previous time had denoted some problems, while this time demonstrate that the patient was able to perform correctly all the movements in all four directions. The time of completion has been of 6 minutes and 49 seconds, much similar to the previous time. This similitude however is tainted by the fact that in the previous session this has been the last exercise, while this time it has been the first one without warming playing the tutorial according to the desires of the patient herself.

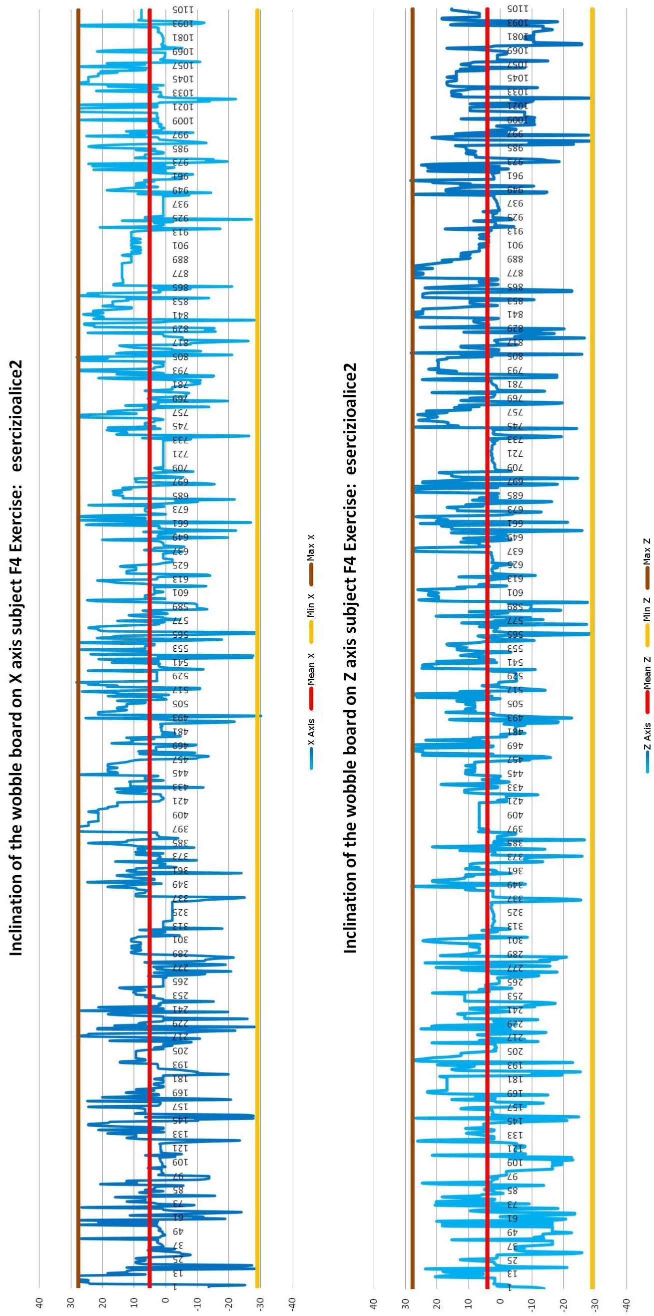


Figure 7.31: The performance of F4 while playing Gyroscope, track esericzioalice2, during the second therapeutic session.

In this second exercise we have presented a new track, and specifically the track named esericzioalice2. This has been decided to let the patient have fun with a new challenge while warming her ankles. We have collected some interesting data shown in Figure 7.31, where we can see a substantial prosecution of the performance of the previous exercise, and the fatigue seems to be of none importance even after 5 minutes and 33 seconds of this exercise and the almost 7 of the previous one. In this way we can say that the patient has really improved in her skills with the table and also probably has increased her mobility from really rigid ankles to mildly free movements permissive ankles. We can also see that the reactivity is quite interesting especially in the lateral movement of the ankles.

The results have been very encouraging not only for us, but also for the patient who has demonstrated more self-confident in her abilities and this are surely good both for her mid and her body.

Before the execution of the exercise with load the patient has done some exercises without the game in order to get confidence with the different condition in which she had to behave, since even in the home exercises she was asked to perform the exercise without load, so that the risks for her to damage her ankles have dropped.

With the supervision of the therapist the patient has tried to keep the equilibrium on the table by staying still over it. It is a very complex situation that put under effort not only the ankles or the lower limbs but also the whole body. To help her, since it was her first time, we have put a chair in front of her so that she could lean on it.

What we can immediately notice is that the patient has been asked to perform a simpler track, and specifically eserciziomacchia2. We have chosen a simple track so that the patient can focus less on overcoming the obstacles and more on the difference in the movement.

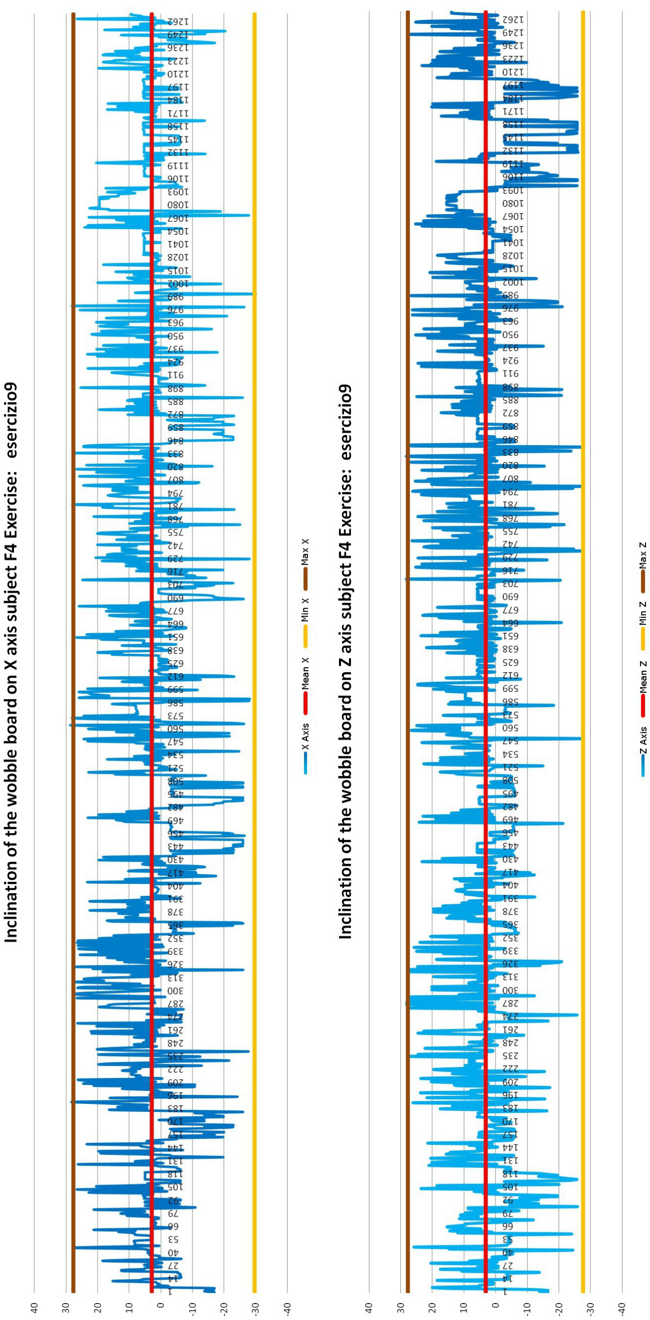


Figure 7.32: The performance of F4 while playing Gyroscope, track eserciziomacchia2, during the second therapeutic session.

As for the data represented in Figure 7.32 we have collected we can see that the values near to zero are very difficult to keep and also the backside movement has become harder to perform. We have to notice that the number of brakes is limited, but this is due mainly to the nature of the track that requires very few of these movements; however we can see a discrete number of them and this is because the control of the table is completely different from what the patient had experience till then seated on a chair: while standing on the board is difficult to create small movements, but it is very easy to lose the control and perform a maximum intensity movement even if not desired. This effect is also more evident in the plot relative to the rotation around Z axis, since here the movement of the injured right ankle is more difficult to compensate than before and the result is that the movement is often high on the right side of the plot and require highly intense rotation towards left to correct the direction.

Chapter 8

Description of the Auxiliary Applications

In this chapter we describe the two elements of our system that have auxiliary role with respect to the whole system: the server architecture and managing application for the therapists. As for the server we describe first the structure and then we face the issue related to the privacy and the security of the data, while for the therapist tool we describe the application and the three different functionalities that are available.

8.1. Server Description

8.1.1. Description of the Content

Our system require that the different application exchange information in order to behave correctly according to the therapist's instructions and to communicate to the therapists the results of the patient. We wanted to have the most simple and transparent system for our users (both patients and therapists) for data exchange, so we decided to use an online server accessible through the network.

The advantage of this solution is that data transfer happens in the minimum time possible and it does not require any action performed by the patient to send data or by therapists to retrieve them. Besides this the other fundamental advantage is that the server can manage, organize and store the data coherently, without the risk of losing them for a long period of time and can also control the access to them, limiting the number of users who can access the relevant information. The disadvantage of this solution is that the data are stored on a machine located in an unknown place and that can be attacked by hackers, data can be read by unauthorized agent on the net through sniffing and similar privacy issues that are crucial due to the kind of data we are treating and we need to design carefully this communications and to adopt security measures to ensure the protection of our users.

It is important to describe the server and its interface with the network for two main reasons: the first one is to describe the data that our applications are exchanging and secondly to start to illustrate the security systems we have implemented and what is needed to ensure the system to work.

We want to state initially that our system is a RESTful system: this means that it uses client-server architecture and can caches the responses. However the two most important characteristics are that our system uses stateless communication between the server and the other application and the system is layered, so that there is an intermediate layer between the application and the database to enforce security measures.

We are not considering here privacy issues, which will be dealt with in the next section, but we are just considering the issues due to correctness and reliability of the data we are recording in the database: for the moment we just focalize on how to ensure that our data are not faked. This is important because we are using this data to monitor the patient condition and it is important that all the information we are deriving from the extracted data present in the database are truly collected while the patient is performing his/her rehabilitation: while we cannot verify that the person who is playing the game is the patient until a test with the therapist and the patient at hospital, we can ensure that all the data present in the database are obtained by the games, and not artificially inserted. For this reason our system uses some auxiliary programs to interface the network with our database. For this purpose we had decided to use PHP language to write our server-side scripts. The creation of an interface between the network and the database can be accomplished by using suitable web pages requests, requests that are correlated with a suitable set of parameters, that are collected by the PHP scripts that will use the parameters to complete SQL queries to search in the database the requested information and then respond back to our applications with the required information obtained by the database, if needed.

Regarding the database we have decided to use an SQL database. We know we could have used different types of database, but our choice was to use a relationship database since our data are structured and follow templates that were designed ahead the implementation of the database, making not necessary the capabilities of NoSQL databases to store data in any possible format and content and avoid us some complexity in analyzing the data. Another important reasons is that SQL databases and relationship models can ensure data integrity through the foreign key system, that cannot be achieved with a NoSQL system: we want that when a data is inserted in our database it is consistent with all the other elements of the database resulting in the impossibility of insertion of information that are badly formatted, incomplete or not coherent with the other information already present in the database. We can also assert that the drawbacks of the SQL database technology with respect to the NoSQL technology are of limited impact and in particular the relationship model has been designed before the need to record data and there has not been any need to modify that design, plus there is no need of high scalability due to the limited amount of data that is collected.

To have a simple and comprehensible representation of our database we resort to Entity and Relationship diagram: this diagram is a graphical representation of the schema of our data and represents for each important group of information, called entity, all the characteristic data that represent it and all its relationship with other entities.

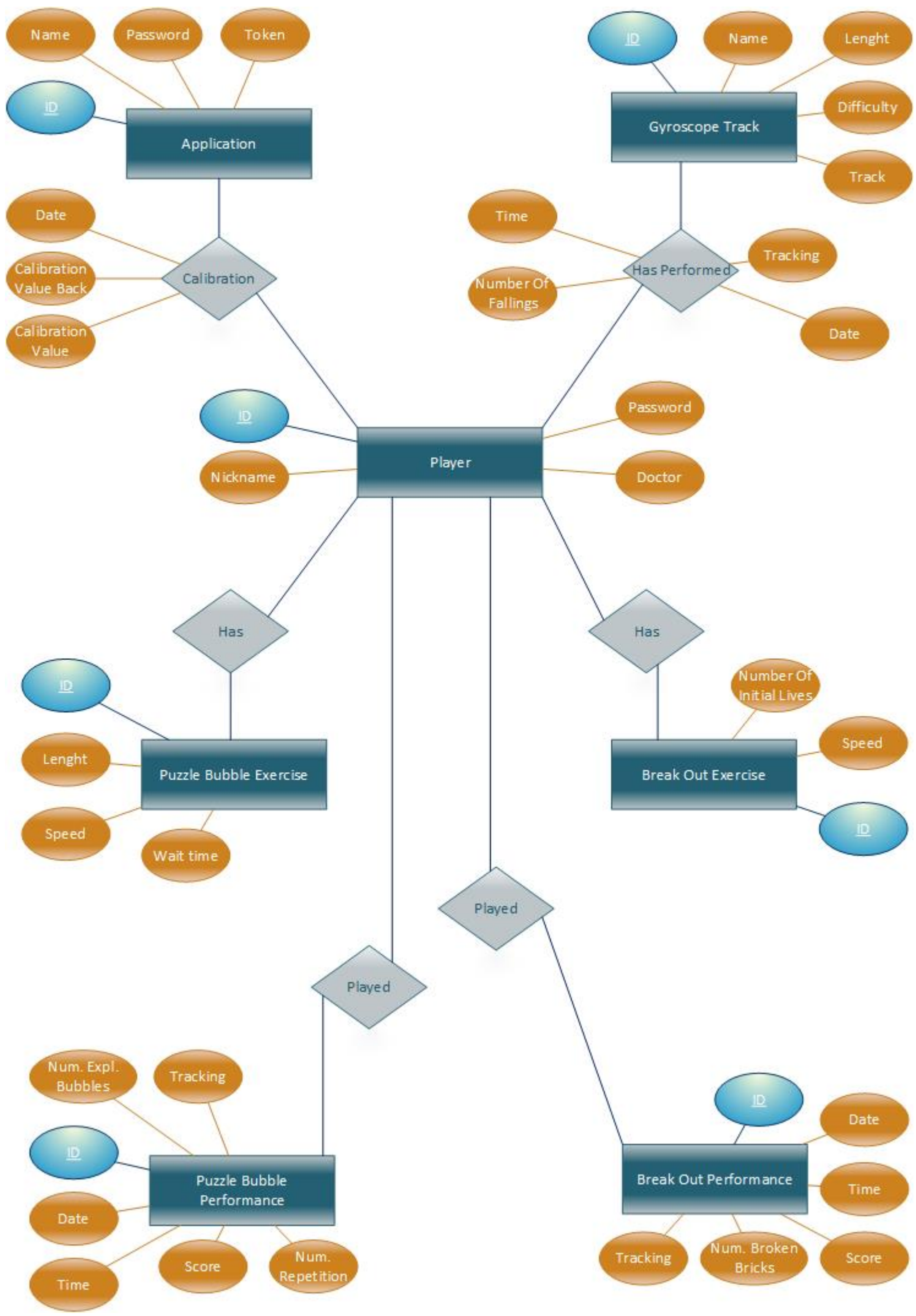


Figure 8.1: ER diagram describing the database

We analyze separately each of the entities and after that each relationships to explain their importance. The entities we are considering are:

Application: this entity contains all the information that the system need to identify from which application the request is coming. It can be also used to understand if the application is updated and contains some of the information used by the PHP scripts to check that the requests are made by authorized application. It is characterized by a numeric identifier ID, the name of the application, a password and a token.

Player: this entity contains the information relative to each user of the system. Each of them is identified by an unique numeric identifier, an unique nickname, a password and a parameter doctor: it is used to discriminate between normal users, the patients, and special users, the therapists.

Gyroscope Track: this entity contains all the information that the system need to correctly identify and use the exercises for the game Gyroscope. An exercise is identified by a unique identifier, a name, a length, a difficulty and a coded string that is used to store the sub element list of which the track is composed, here represented by the attribute track.

Break Out Exercise: this entity contains all the information that the system need to correctly identify and set the exercises for the game Break Out. An exercise is identified by a unique identifier, a value for the speed of the ball and one value for the number of initial lives given to the patient.

Break Out performance: this entity contains all the information that the system save after the patient has performed one time his/her exercise on the game Break Out and that are useful for the therapist to monitor the patient and to understand if the current exercise is appropriate for him/her. It has as attributes an identifier, the date in which the performance has been registered, the amount of time the patient has played, the score the patient has reached, the number of bricks that have been destroyed by the player and the tracking of the legs of the patient expressed as a list of coded accelerations of the device.

Puzzle Bubble Exercise: this entity contains all the information that the system need to correctly identify and use the exercises for the game Puzzle Bubble. An exercise is identified by a unique identifier, a value for the length of the exercise, a value for the speed of the exercise and one value for the speed of the fall of the bubbles.

Puzzle Bubble Performance: this entity contains all the information that the system save after the patient has performed one time his/her exercise on the game Puzzle Bubble and that are useful for the therapist to monitor the patient and to understand if the current exercise is appropriate for him/her. It has as attributes an identifier, the date in which the performance has been registered, the amount of time the patient has played, the score the patient has reached, the number of bubbles that have been destroyed by the player, the number of repetition of the exercise and the tracking of the legs of the patient expressed as a list of coded accelerations of the device.

The relationships instead are:

Has exercise on Break Out: this is an elementary relationship between each player and an exercise of Break Out game; each player has at most one exercise on this game and each exercise can belong to one and only one player. Some players may not have an exercise on the game, there could not be an exercise who does not belong to any user and no player can have more than one exercise, avoiding incorrect association between the patient and his/her therapy.

Has exercise on Puzzle Bubble: this elementary relationship is the symmetric of ”Has exercise on Break Out” between each player and an exercise of Puzzle Bubble.

Performed Break Out: this is an elementary relationship that associate each player to his/her performance. One performance is saved for each time the player has completed one exercise. However it is important to keep track of each solution of the exercise, for every user there could be a multitude of performances, but each performance could be assigned only to one player.

Performed Puzzle Bubble: this elementary relationship is the symmetric of ”Performed Break Out” between each player and each performance of Puzzle Bubble.

Performed Gyroscope: this is a complex relationship between players and exercises of the game Gyroscope. Each exercise could be played by every patient, so it is important identify the unique identifying information of each performance in order to infer the behaviour of the player from correct data: each performance is identified by the player, the exercise and the date of the performance. For each performance the system save also the number of time that the player has fallen, the amount of time that he/she needed to complete the exercise and the tracking of the inclination of the wobble board used by the player during the exercise on two axis.

Calibration: this is a complex relationship between a patient and a game. Not all the game required calibration values stored in the database: the games requiring the use of the legs are stored in this table as the couple of values of calibration (one for the maximum inclination angle reached by the patient in front of her, one for the minimum angle reached by the patient bending the knee backside) and the date in which they have been taken, since they do not vary every time, while the calibration in Gyroscope is different every time the game is started, so it is not saved in the database.

8.1.2. Privacy Issues

An important drawback of using an online database is that the enforcement of security policies to secure and protect the data that users have entrusted to the system is a complete responsibility of us designer of the system. This is not just merely a matter of correctness towards the users, both patients and therapists, but it is also law enforcement about this. In particular in Italy these rules have been defined the 30 June 2003 in the unified privacy's code. This is reporting all the definitions of the different types of data, the definition of treatment of data, the minimum security measures needed in case of treatments according to the type of data, the description of the rights of the owner of the data, the obligations for the various actors involved in the management of the data and the civil, penal or administrative sanctions to make provision for the actors if the owner of the data has identified treatments not compliant with the law itself. Each country has a specific law about privacy and different minimum security measures to be adopted, however we are localizing our system for Italy and so our effort was to compliance the Italian regulation.

At first our effort was directed to understand why, when a healthcare system is designed, there is the need to take in consideration that the data are sensible, and what does it means that data are sensible.

It is easier to start form the second question and to derive the answer to the first one. In fact there are innumerable different possible definition to identify what is a sensible data; there is one definition that rise above all the others that is simply contained in the law; according to the previously cited privacy code we know that:

«*b) "dato personale", qualunque informazione relativa a persona fisica, identificata o identificabile, anche indirettamente, mediante riferimento a qualsiasi altra informazione, ivi compreso un numero di identificazione personale;*

c) "dati identificativi", i dati personali che permettono l'identificazione diretta dell'interessato;
d) "dati sensibili", i dati personali idonei a rivelare l'origine razziale ed etnica, le convinzioni religiose, filosofiche o di altro genere, le opinioni politiche, l'adesione a partiti, sindacati, associazioni od organizzazioni a carattere religioso, filosofico, politico o sindacale, nonche' i dati personali idonei a rivelare lo stato di salute e la vita sessuale; »

Legislative decree of 30 June 2003 n 196 article 4 [15]

According to the law we can say that every information that is linked to a person which can be used to identify directly (and in this case is called identificative data) or indirectly that person is a personal data and needed to be ensured by minimum security measures expressed in later articles of the same law. A data is sensible if it is a personal data that can be used to identify a characteristic of the person afferent his origins, ideals, religion, political militancy, and more important in our system the health state of the person.

Another important element is that, nevertheless form the importance of not breaking the law, we also want to let the different users of our system to trust us and the best way to do it is to make them confident that their data are secured and kept safe. It is also important to let the users know that our system does not misuse the data and that all the treatments of their data are correctly made. Once these two basic elements are made clear and the users will trust our system it could be really used.

To ensure this safeness we need to analyze what security measures has been implemented in our system.

The first security measure consists in the restriction to the accesses to the database: to be able to retrieve, insert or modify the information that our system is collecting, as we have already said, there is the need to pass through the PHP scripts, otherwise no other access is possible to the database. This is not a sufficient measure, but this is needed to apply other security measures on the database that are effective only with the assumption that no other entry point to the database is available.

For example thanks to the fact that there is no other entry point except our PHP scripts and that PHP scripts are not indicized by any search engine a supposed attacker must first of all identify the web URL of the script to execute it.

Another important security measure that we have decided to use to avoid SQL injection is represented by the use of two elements: the first is the use of the ”post parameter passage” to send information from the application to the scripts. This hides the parameters that should be used and also forbid to do simple parameter identification from the send URL of the script as it would have been possible using the ”get parameter passage”. This is also enforced by the use of the routines available in PHP language to perform escaping to avoid SQL injection: in this way even if an hypothetic attacker would have been able to send the correct request with malicious code to retrieve data different from what he/she is authorized to read, this code is made unusable and would not harm the system.

Another security measure that has been inserted in the PHP scripts is an authentication factor: each time a script is called before performing the required query on the database, it performs two checks to verify that the application is correctly identified and that the user is correctly registered in the system. And while the user data can be discovered, the application identification is based on a token given only to the application after it has correctly authenticated with a password that is hardcoded in the code of the application. This token is a string of 20 randomly chosen characters and it can be changed anytime and this makes the parameter mostly unpredictable for any attacker. If any of these two checks does not succeed the script does not perform the requested query.

However on top of all of this security measures we have decided to put an even more powerful security measure to secure the data of our users: we have made the data impersonal. The data in our system are not personal data because it is impossible to infer from any information extracted from the database the real identity of a user, except the human factor since therapists do know, or can know at least, the association between the nickname of an user and the patient name. However since this knowledge is not present in the database our data could not be used to reconstruct the identity of the patient and even if are intercepted, discovered or altered, except of the inconvenience that the data are no longer usable patients and their families could not be damaged, discovered or identified. This is a strong security measure not in the sense that the data are technically safer than without this decision, but in the sense that the impact of attacks is lowered to minimum: even if an attacker is able to obtain a copy of the whole database he/she could not use it in an harmful way against patients or therapists.

8.2. Meditool

8.2.1. Description of the Functionalities

In our system there was the necessity to have a subsystem dedicated to the therapists needs: the first reason is to have a tool to set the parameters of each exercise and secondly there was the need to check the performances of the patient both in terms of ability in playing the game and in terms of correctness of the movements.

We have developed the subsystem called Meditool, a program for personal computer in the exclusive use of the therapists. It is important to make some considerations about the reasons that lead us to the decision of producing a desktop application instead of a mobile application or a web application for this subsystem. Firstly there is a reason strictly linked to the functionalities that have been made usable in this program and cannot be achieved by a web application and in particular these functionalities are the Reply Mode, which requires the interaction with the Microsoft Kinect™V2 usable only on machines mounting as operative system Windows. Secondly in Reply mode there is the need to save and read large files containing the body tracking of the patient and would be very difficult to link this information to the database for the high risk of errors in the linkage between the record of the performance and this body tracking, so the best solution is to save locally a file that is of considerable size. A third reason is that it is somehow hidden the database location and the scripts that interact with it so that there is no direct entry point to the scripts except to identify the correct script URL. A fourth reason, always connected to the security, is that web application can be accessed anywhere and by anyone, putting in more danger the data present in the database and requiring more solid security policies that can be found inconvenient by the operators, in comparison to a desktop application that can be used only on the devices where it has been installed and are easily controllable. Finally a fifth reason is the size of the screen: when the therapist has to visualize the patient performances data a lot of data should be visible, so a larger screen can be useful.

However we had to ensure that just the therapists are allowed to use this program. We are trusting in the correctness of the therapists about the distribution of this program, so we are assuming that the program can be accessed only at the hospital.

The system before letting access to the functionalities ask for a login and accepts only a restricted group of nickname and password couples that are related to the special group of users called ”doctor” in the database.

To be executed this program needs a machine running Windows operative system. We have tested it on Windows Xp and Windows 10 and we can say that the program can perform well in both cases, however the Reply mode has the need to have a Microsoft Kinect™V2 device connected to the computer and this fact make the requirement for this program to run at the fullest of his potentiality to be installed on a machine mounting Windows 10 operative system that has availability of a USB 3.0 port. However the use on older machines does not create problems until this functionality is not required. The system obviously requires also an internet connection in order to communicate with the database.

Notice that this is the only part of the system that is able to show all the patient's information, the patient's performances and to read and modify all the exercise's parameters and for this reasons it is important that is kept in the exclusive use of the physicians and therapists.

We have decided to analyze singularly the different features offered by Meditool because they can be considered each feature as a separated program that have been grouped in a single application just for simplicity in the usage. These functionalities can be summarized as "Reply mode", "Exercise management" and "Patient control".

8.2.2. Reply Mode

Reply Mode functionality requires the use of Microsoft Kinect™V2 in order to record the movement of the whole body of the patient while performing the exercise. It is not useful if the patient are seated on a chair due to some inefficiencies of the device itself, however it can be useful with some specific users, for example that are playing Gyroscope with load on their ankles and that have problems of keeping the equilibrium. Through this functionality the therapist can see live streamed a good approximation position of the skeleton's joints of the patient seen from the front and from the side as recognized by the Microsoft Kinect™V2 sensors and can identify possible critical situation that affect the patient, such as corrective movements that could go unnoticed during the normal execution of the exercise.

In order to help the therapist even more the system is also provided with the possibilities to save the recoding of the movement on a file so that it could be reanalyzed later or confronted with successive recording to identify trends of worsening of the patient dynamics.

8.2.3. Exercise Management Tool

The Exercise management tool is the functionality of Meditool dedicated to the generation or the modification of the personalized exercises that are authorized by the therapist for each patient that are stored on the database and that when the patient performs this exercises granted that the results of their performances are stored back in the database. This conceptual functionality is separated into three different sub-functionalities, one per game, because each of these sub-functionalities has its unique features and importance.

The exercise management dedicated to Gyroscope is dedicated to the management of the tracks that the patient has to face while performing the exercise for which it has been dedicated this game: the training of the ankles with the wobble board.

The management of an exercise for Gyroscope is related to the creation or the modification of a track, so that it is sufficiently balanced: the track must be constituted of obstacles that are useful for the patient's treatment, but also guarantee a sufficient degree of challenge and variability for the user to let the patient have fun while playing.

Since our focus is on the patient's health there is the need of a therapist in charge of deciding a track and why it is fundamental that this part of the Meditool program has been designed to be as most intuitive and clear possible giving the therapist all the tools that he/she needs to create a good exercise.

"Gyroscope exercise manager" tool is composed of an intuitive and informative interface to help the therapists to create tracks.

The system permits to both modify the tracks already present in the system, to remove them or to create new ones.

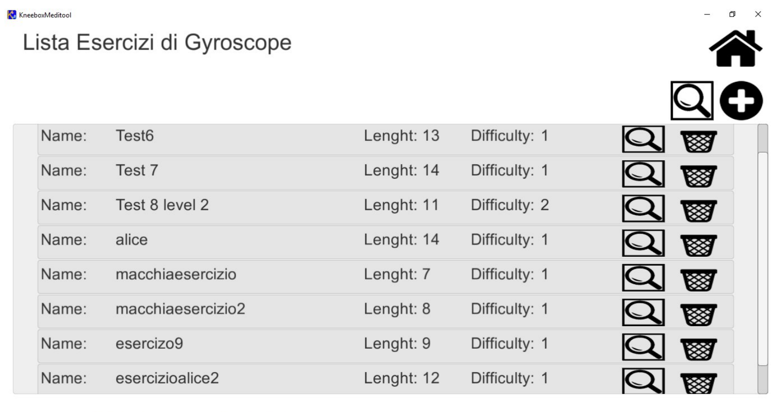


Figure 8.2: The list of prepared exercises for Gyroscope seen in Meditool

This tool firstly proposes a button to create a new track and a list of all the tracks already present in the game and for each of them presents the core information, that are the identification name, the length and the difficulty of the track. This information are the ones that we consider the most important in order to identify a specific track among all of them present in the system because are the name is the elements that most of humans may find easy to remember to identify something, while the length and the difficulty are the two components that can be used to understand immediately the complexity of the level, giving the most important information to the user of this application.

The system permits also to search for a specific track by inserting part of the name of the track in the appropriate input field and pressing on the search icon.

Beside each track's information in the list, two button represented by two icons give immediately the user the two basic command on an existing track, and in particular the modification of the track and the deletion of the track. Concerning the deletion one important notice is that this operation is irreversible, since it affects directly the deletion form the database.

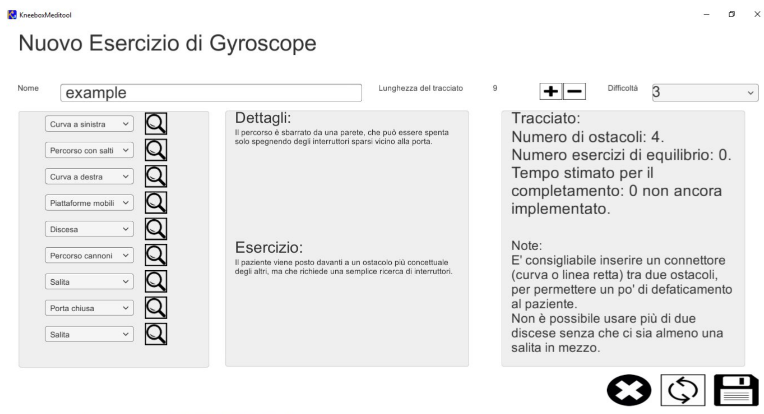


Figure 8.3: Creation of a new Gyroscope track

When the therapist, who in this subchapter is considered as the user of the program, decide to create a new track a panel is shown. In this panel the user have to input a track name, the difficulty, the length and the track elements. As for what require the name a certain care is required since it is the means through which the patient will recognize the exercises that is authorized to do, so it should be a significant name to avoid confusion. All the players will be able to see the complete list of tracks so to increase the simplicity names are fundamental. The difficulty can be set with a dropdown menu from 1 to 5 and it affects the complexity of all the obstacles eventually present in the tracks, while the connectors are not affected.

To set a track the system uses an incremental system: the tool has two buttons, one identified by "+" and one identified by "-" that increases or decreases the length of the track. For each of the elements it is added or removed from the list on the left side of the screen an element composed of a dropdown menu and a button: by choosing an element of the dropdown menu the type of the component in that position of the track is assigned, while by pressing the lens' button the system provides a description of the element and a description of the kind of exercise the element will force the patient to perform.

On the right side of the screen there are useful information about the track that is being generated and there is a reminder of the rules that the track generations have to respect.

For what it concerns the modification of an existing track the sequence of actions is very similar to the creation of a new track, with two basic differences: first the creation panel is initially filled with the information of the existing track and secondly the name of the track cannot be modified.

The management of the exercises on Puzzle Bubble and Break Out are quite similar so we can present them together. This happens because the games are controlled by a limited amount of parameters. Since we are using a desktop application it is impossible to use this application to define directly the maximum angle of deflection of the knee for the patient and this is also not feasible to use the Microsoft Kinect™V2 device to register it due to the limits of the device with the obstruction of the view and the seated position recognition. For this reason this parameter is not controlled in this subsystem but directly from the game.

When we are considering the exercise management for Puzzle Bubble or Break Out, Meditool presents at the beginning a button to add a patient and a list for which the exercises has been already defined.

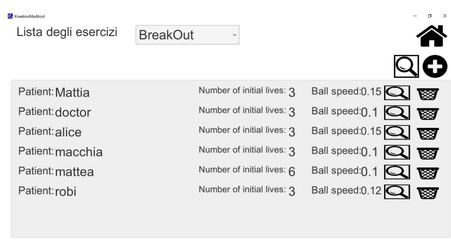


Figure 8.4: The list of exercises for Break Out

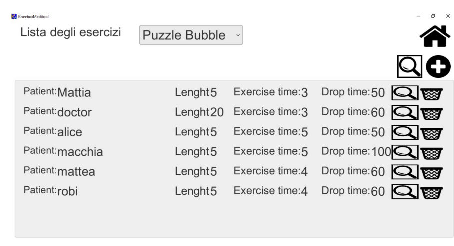


Figure 8.5: The list of exercises for Puzzle Bubble

When the therapist decides to create an exercise for a patient not present in the list a new panel is showed: there is present on the left a list of patients for which the exercise on the game in examination has not been set up. Once the patient has been decided the therapist can insert the parameter of the exercise that depends on the specific game. All the parameters are coupled with a description of their meaning. Notice that the parameter do not differ between Puzzle Bubble version 1 and Puzzle Bubble version 2, but the system adapts the same parameter in the two scenarios.

If the patient, instead, has already an exercise he/she would not be shown in the list of patient in the creation of a new exercise, but is present in the first panel list: in this case the therapist can access the exercise and modify its parameters directly from the list by pressing the corresponding button next to the nickname of the patient.

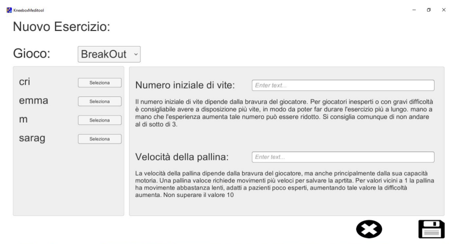


Figure 8.6: Creation of a new exercise for Break Out

Figure 8.7: Creation of a new exercise for Puzzle Bubble

8.2.4. Patient Control Tool

Main objective of this system is to let the patient perform their rehabilitation exercise in a different and more amusing way. However we notice that there is a key need for the therapist: how can the therapist understand if the patient is performing in the correct way the exercise and how he/she can understand if the ”exercise parameter’s set” are suitable for the level of ability and the mobility capacity of the patient.

This is not something a machine can do automatically, at least until much more information will be collected in order to use some machine learning techniques on the data. And even in this future step a key role will be of specialized humans, the therapists; this is very important because first of all the patient is under the care of the therapists, not the computer, so unless the therapist says that a certain set of parameter’s value is approved for the patient the machine has to be forbidden to change them. Secondly, and not for importance, the system is not able to supervise one of the fundamental parameter of the patient’s health during the exercise, that is the pain: only trained human beings are able to detect problems, for example, in the joins of the patient that may occur during the exercise and that sometimes can present pain and other times does not but are still present.

This problem becomes even more important when the therapists are not present, because the exercise has been performed not in the hospital but at home: there it is impossible, with the exception of some very specific situations, to have a qualified person controlling the clinical situation of the injured part of the body, or even if the therapy is really perpetuated by the patient. And this is one of the main problems in the physical rehabilitation, especially for children and adolescents that due to boredom do not perform home exercises. To answer some of these questions we have developed the Patient Control tool in the Meditool program.

This functionality is dedicated to the analysis of the behaviour of the patient both in the context of the single performance and in the long period of time.

The first thing that the system asks the therapist using this functionality is to select a specific nickname from the list of all the nicknames of the patients.

Figure 8.8: Real control tool of a dummy user, not a patient

After the patient has been selected, the program shows a complex window where lot of different elements can be identified. At the top left of the screen there is the dropdown menu of the setting, where the therapist can decide which data have to be considered according to the game or a global counter for which we consider the four games together and analyze the general behaviour.

On the left side of the screen there is a list of performances of the players complete of the key data about the performance. On the upper-right side of the screen there are two components: one is a selector to identify a specific parameter in analysis, while the other represents the extreme values of that parameter. The right bottom part of the screen can be used by the program to show the user two different types of information. The first type is a scatter plot graph of the values of the parameters in exam; the other type of information is the reconstruction of the player's movement during the exercise.

Our system is collecting different type of information during the performances and we can expect some kind of behaviours for each of them.

If we are considering the game Gyroscope we can see that, once the performances have been filtered by the track, we can see that the player's performances should show a decreasing behaviour in both time needed to complete the exercise and number of falls. This is a natural phenomenon due to the accumulation of game experience of the patient: this should help the therapist to identify when a track is becoming too simple. Variation of this behaviour is going to be interesting because if the tendency of the player is not following this rule it can be one of the following cases: the indicator value may increase continuously; it may be stabilized on a high value or can be stable on the bottom of the graph. The first case is the less common one, but it can be a sign that the patient condition are worsening and this may alert the therapist that probably the therapy is not appropriate or that new issues are rising. The second case is expected to happen more frequently and it can happen when the track is too difficult for the player. This means that the set of parameter of the track should be adjusted and lowered both to make the game fun for the patient and to avoid stressing too much the patient's injured joints. The last case is expected to be the most common and the most desirable situation: when the value such as the time needed to complete the track and the number of falls are stabilizing on a low value this is the clear sign that the patient has gained enough experience and the track is currently too simple and he can get bored. Solutions to this problem may be the increase of the difficulty of the track or modification of the track itself.

Of course there is also another type of behaviour that is related to unstable trends. We start from the reasonable assumption that players getting experience generally make better performance each time they play, but this is not real since sometimes bad luck, lack of concentration, variation is the health state, etc. may influence the result of a performance: this can be seen in the graph as a turbulence of the previously expressed ideal behaviour. However if this turbulence are minimal in entity and confined in small amount of time it does not require special attention. However when the results are really turbulent, where no trend can be identified this is really a critical situation and probably can be expressed by the fact that the patient is not the only one using the device, but different players are saving the results on his account. A similar problem can be noticed if there is a clear discrepancy between the performance at home and the performance during the control session at hospital.

These statements are still valid when we consider the other games, Break Out and Puzzle Bubble, even if in this cases the behaviour is ascending. This effect is caused by the fact that while in a racing game like Gyroscope the goal is to complete the track in the less possible time, in arcade games like Break Out or Puzzle Bubble the goal is to reach the highest possible results. In this scenario, however, there is an increase of the significance of the turbulence caused by luck: in Puzzle Bubble the initial setting of the grid of bubbles and the colours of the bubble to shot, in Break Out the order of the rooms are totally random. This means that some outliers are not errors of the patient or of the parameter's value, but simply bad luck in the setup of the game. This of course does not means that bad luck makes the results unpredictable and unreasonable: large gaps between results, unreasonable variance on long period of time and discrepancies between home results and hospital sessions have still to be considered as probable undesirable behaviours.

Finally there is also another graph that is important and it is the cumulative graph: in this special graph is shown the amount of time that the player has spent on the games cumulated in the days of the period of 7 or 30 days. This aggregation is done in consideration of all the performances registered in the database in the specific day recorded by the specific user; this is a clear measure of how much time the patient has dedicated to his therapy and with which constancy it has been taken. It also can show the evolution of the calibration value, the maximum and minimum deflection of the knee registered by Puzzle Bubble and Break Out game, so that the therapist can monitor the progress of the patient in the gain of mobility of the knee.

The other important element of the Patient control tool is the reconstruction of the player's movement: this tool has been designed to let the therapist graphically see the movements that have been made by the patient during the exercise. It has two different versions, according to the game, since for Gyroscope performances it can be shown the movement of the wobble board, while in Puzzle Bubble or Break Out is shown the deflection of the leg.

Figure 8.9: Reconstruction of patient performance on Gyroscope in patient control tool

Figure 8.10: Reconstruction of patient performance on Break Out in patient control tool

This element may seems of lower interest, but it can become very helpful for the therapists that can prescribe the exercises, because this recording can be accessed multiple times letting the therapist to confront data from different moment of time, reanalyze the results in order to identify undesirable behaviours or to check improvements of the patient. This is simpler when we can reconstruct the movement of the real leg. It can still be useful to see the movement of the wobble board, in order to see how the movements are distributed along the two rotational axis of the board, especially when the exercise has been done in absence of weight, so that the movement of the board is due only to the movement of the ankles. Last important notice we want to make is that we are using the world reconstruction instead of representation because the movement of the patient is neither a "live representation", meaning that what is shown on the screen is a representation of what happened in the past, and it is neither an exact instant-per-instant representation, but it is a sampled representation, and even if the sampling period is very small it presents holes that can only be filled by interpolation. However, regardless of how much effort we use in developing this reconstruction mode, we have the awareness that the interpretation of this results can only be done by expert therapists or doctors and not by the computer due to the extreme variety of possibilities and variety of the patients and their medical issues.

Chapter 9

Conclusions and Future Work

9.1. Conclusions

Our goal was to design and realize a system composed of a set of rehabilitation games and a tool for the analysis of the patient performance and the management of the personalized exercises for each patient affected by Juvenile Idiopathic Arthritis. The secondary goal was to create games that were useful, valuable and entertaining: useful since in our design the games can provide a good alternative to traditional rehabilitation; valuable since the therapist would use a tool that can give them and to the patients something more than the normal rehabilitation; entertaining since the patient while playing the game must be amused in order to avoid the boredom that can lead to quit the rehabilitation process before the time has come. We started from the literature about serious games and in particular we have started from the experiences of the previous researchers who had experiment in this field of healthcare and we have applied both rehabilitation principles and the principles of the design of a common game, and we have obtained games that have relevance both in the medical part and that are amusing to play.

We have also conducted some experimental sessions, in which we have collected some data about the performance of the patient and also the feedback of the users. The feedbacks we have received were a substantial confirmation that our designing choices were effective. The patient have enjoyed the games and helped us also by making some suggestions about additional changes that we could make to have a more appealing product.

Therapists noticed that the patient concentrated more on the game than on the exercise and this is useful since the patients don't make much of attention to their impediments due to their illnesses, move faster and more intensely that what they would do on a normal session. Therapists also noticed that during the games patient expressed more confidence in their movements and also in some cases also have demonstrated capacities, in terms of mobility, that have not been seen during the traditional rehabilitation. Therapists have also confirmed the importance of the monitoring tool for the evaluation of the patient on long term rehabilitation.

The system we have designed has met the expectations: the games on the mobile device are fluent, easy to install and to use. The accelerometer present in the device has proved to be sufficiently precise for the measurement of the movements of the patient. The Chromecast device is extremely easy to install and to use. From the parent's feedback we have also confirmed that our effort to condense the economic cost of the product has been appreciated by the families of the patients, since all of them have said to be willing to afford this cost without problems.

However this is just a starting point for future evolution: in the future more games and context should be added to please an even wider range of patients, so that we can personalize the experience of the game not only with the parameter set, but also in the general aspect of the game.

Another important motivation to increase the number of games is that these games could be used to increase the number of different exercises that the patient can perform, since the system we have designed is modular and can be easily integrated. This increased se t of exercises could also be used to increase the number of pathologies that may have benefits from the use of our system: we have already considered the case of F3, who is not affected by JIA, but also the therapist have suggested to use this game also for the opposite problem to the JIA, the articular hypermobility, like the Ehlers-Danlos syndrome. Finally another important future development would be the verification of the long term benefits that the therapy based on these games could bring to the patient and the efficacy of the games in an at-home monitored rehabilitation process.

We cannot derive any medical trend in the patient's data with the data we have collected, since there are too few data on a too small amount of time, and we cannot have statistically significant results due to the scarcity of results. However it is an important aspect that had to be considered for the future development of this project.

Appendix A

Acronyms and Term Definition

- Ankle's dorsiflection: upward frontal rotation of the ankle.
- Ankle's eversion: lateral rotation of the ankle towards the extern of the foot.
- Ankle's inversion: lateral rotation of the ankle towards the intern of the foot.
- Ankle's plantarflection: downwards frontal rotation of the ankle.
- JIA: Juvenile Idiopathic Arthritis.
- Knee maximum deflection: The maximum angle reached through the flexion-extension movement, when the foot is in front of the knee and at the maximum height reachable by the patient.
- Knee minimum deflection: The minimum angle reached through the flexion-extension movement, when the foot is in beside the knee and at the maximum height reachable by the patient.
- REST: REpresentational State Transfer.

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