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Rehabilitation Video Games for Young Patients Affected by Epidermolysis Bullosa

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Ai bimbi della Clinica Pediatrica De Marchi

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Abstract

Sappiamo tutti che lo sport giova alla nostra salute, e ne conosciamo i benefici. Per molti di noi, tuttavia, allenarsi con continuità è faticoso: possiamo quindi comprendere la ritrosia dei bambini affetti da Epidermolisi Bollosa (EB), una rara malattia genetica che provoca bolle e lesioni sulla pelle, quando si vedono costretti a seguire un programma giornaliero di esercizi fisioterapici. Può essere possibile convincere questi piccoli pazienti a eseguire con diligenza, nella propria abitazione, gli esercizi di fisioterapia studiati per loro? Con questa tesi ci proponiamo di supportare trattamenti mirati di assistenza pediatrica nel delicato settore della riabilitazione con una raccolta di videogiochi, che divertiranno ciascun bambino mentre eseguirà un allenamento specifico di fisioterapia per polso e mani, prescritto per lui dallo specialista. I piccoli pazienti eseguiranno i movimenti fisioterapici che saranno riconosciuti nei videogiochi da un sensore di tracciamento delle mani, il Leap Motion. Questi videogiochi saranno utilizzabili non solo come supporto durante le sedute di fisioterapia ma anche per l'esecuzione di esercizi tra le mura domestiche. Il fisioterapista infatti potrà controllare dal proprio PC le registrazioni di ogni partita eseguita da ciascun bambino, creare livelli personalizzati per i piccoli pazienti, vigilare e verificarne i progressi.

Abstract

We all know: doing sport is good for health, but for most of us it is very hard and, sometimes, even tiresome when we have to repeat always the same movements. In this thesis we have created video games to support wrist rehabilitation for kids affected by Epidermolysis bullosa (EB), a painful genetic skin disease. In the video games the patients have to perform hand and wrist exercises, that are recognized through the Leap Motion, a free-hand interaction controller that is used to control input with hand movements. We focused on designing rehabilitation video games that can be used at home without the physical presence of the therapist, so we developed a framework containing the video games for the patients and modules specific for the therapist, that from her PC can check the progress of any little patient, create personalized video game levels and view the replay of the games played by any little patient.

Ringraziamenti

Un ringraziamento speciale al Prof. Pier Luca Lanzi, relatore di questa tesi e fonte inesauribile di conoscenza, per i confronti costruttivi e mai banali, gli approfondimenti e gli stimoli offerti, oltre che per la sua disponibilità. Inoltre voglio ringraziare di cuore la Dott.ssa Amalia Lopopolo per l'aiuto e la competenza dimostrate durante le giornate di gioco con i bambini.

Sommario

L'avvento di nuove tecnologie per la Realtà Virtuale, come il Leap Motion controller, ha permesso agli sviluppatori di esplorare nuovi utilizzi nel campo dei videogiochi, combinando il divertimento con un diverso scopo quale l'apprendimento o l'allenamento fisico.

I videogiochi creati non solo a scopo di intrattenimento sono chiamati serious games, o "giochi seri", poiché in questi giochi il divertimento è un mezzo con cui raggiungere un diverso obiettivo quale insegnare al giocatore nuove conoscenze, nuove abilita o supportarlo durante l'attività fisica. Divertire il giocatore è essenziale: è fondamentale creare un prodotto accattivante e divertente che ne catturi l'attenzione affinché il giocatore apprenda nuove conoscenze, o svolga nuove attività mediante il gioco. Sono stati sviluppati videogiochi con fini di apprendimento in ambito militare, in ambito scolastico e in ambito medico, e in particolare come supporto alla riabilitazione.

In questa tesi ci siamo focalizzati proprio sullo sviluppo di videogiochi per supportare i bambini affetti da Epidermolisi bollosa (EB) nella riabilitazione di polso e mani. L'EB è una rara malattia genetica che colpisce i bambini fin dalla nascita, ed è caratterizzata da un insieme di malattie epidermiche causate da fattori genetici che hanno come comune denominatore la tendenza a formare vesciche, scollamenti della cute e delle mucose dovuti a traumi o a sfregamenti anche minimi. Purtroppo non c'è cura per questa patologia, che spesso comporta l'insorgenza di complicanze molto diverse tra loro. I bambini affetti da EB sono perciò seguiti con controlli periodici organizzati come macroattività ambulatoriali ad alta complessità in cui saranno sempre presenti, oltre al pediatra, il dermatologo, il chirurgo plastico, la dietista e infermieri specializzati e a seconda delle necessità il genetista, il dentista,

il chirurgo digestivo l'oculista, l'ortopedico, il pneumologo, il fisioterapista, l'anestesista esperto in terapia del dolore, l'esperto in medicina rigenerativa, l'assistente sociale e lo psicologo. Il bendaggio delle ferite, il dolore, gli esiti cicatriziali retraenti, la malnutrizione e l'anemia grave possono determinare una riduzione della motilità e una conseguente ipotonia o ipotrofia muscolare, generando un pericoloso circolo vizioso. La presenza di un fisioterapista è fondamentale per il sostegno dei piccoli pazienti. Questi bambini potrebbero provare dolore eseguendo qualsiasi movimento, anche quelli di fisioterapia, perciò giocattoli e videogiochi sono un buon supporto per il fisioterapista: intrattengono il bambino spostando l'attenzione dal timore di provare dolore muovendosi al divertimento del giocare.

L'introduzione in commercio di nuovi prodotti tecnologici (quali Nintendo Wii con il Wii Remote, un controller sensibile al movimento, e Xbox con il Kinect, un device sensibile al movimento del corpo umano) ha rappresentato un'opportunità per i fisioterapisti di ampliare la gamma di giochi utilizzabili come supporto durante la riabilitazione di pazienti in giovane età. Tuttavia i videogiochi in commercio hanno il solo fine di intrattenere, mentre il terapista necessita di un reale supporto alla fisioterapia che sia adattabile alle necessita specifiche di ogni paziente. Per tale motivo in ambito scientifico si è studiato come creare videogiochi che combinassero il divertimento con le necessità del terapista e dei pazienti sfruttando le tecnologie esistenti.

Abbiamo lavorato con i terapisti della Clinica Pediatrica De Marchi a Milano, che ci hanno spiegato quali fossero gli esercizi per la riabilitazione di polso e mani, come si svolgessero le sedute di fisioterapia e le qualità che un videogioco deve avere perché sia di supporto alla riabilitazione. Abbiamo progettato e sviluppato i giochi combinando le necessità espresse dal fisioterapista con i principi di progettazione di videogiochi tradizionali, creando videogiochi che siano divertenti e non frustranti, che catturino l'attenzione del paziente e che abbiano livelli personalizzabili affinché il terapista possa decidere le attività da eseguire nei videogiochi in base alle necessità dei singoli pazienti, e che premino i comportamenti corretti, come gli esercizi ben eseguiti, e penalizzino i comportamenti sbagliati. Un sistema che premi i giusti comportamenti è fondamentale all'interno dei videogiochi per la riabilitazione poiché siano corretti gli errori compiuti dal paziente e perché comprenda quali movimenti ed esercizi deve svolgere mentre gioca.

In questa tesi abbiamo sviluppato un framework composto da cinque moduli: quattro videogiochi, un modulo per impostare la difficoltà degli esercizi di fisioterapia inclusi nei giochi, un modulo per controllare i progressi dei pazienti, un generatore di livelli personalizzati e un modulo per il fisioterapista in cui può visionare le repliche di tutti gli esercizi svolti da ogni paziente giocando. I videogiochi supportano diversi esercizi per polso e mani, il giocatore interagisce con i giochi attraverso il Leap Motion controller, un sensore di tracciamento delle mani, che raccoglie dati sulla posizione delle mani e permette al sistema di riconoscere i movimenti eseguiti dal giocatore. Abbiamo sviluppato quattro giochi differenti tra loro per invogliare pazienti con gusti differenti a giocare e compiere gli esercizi di fisioterapia. I quattro videogiochi che abbiamo sviluppato sono: un gioco musicale intitolato Music Beats, in cui il bambino gioca muovendo le mani seguendo il ritmo della musica; un gioco di corsa di automobili intitolato Rich Race, in cui il bambino controlla l'automobile con il movimento della mano; un gioco di tiro al bersaglio intitolato Shooting Gallery, in cui il bambino può colpire i bersagli controllando il mirino di un fucile con i movimenti della mano; un gioco in cui combattere contro un'invasione aliena intitolato Alien Invasion, in cui il bambino controlla la navicella spaziale che spara agli invasori, questo gioco si ispira a Space Invaders e Galaga. Abbiamo progettato il game-play perché fosse il più intuitivo possibile per i pazienti, affinché iniziassero subito a giocare senza il bisogno di ragionare per comprendere delle regole del gioco eccessivamente complicate. Nei giochi è presente un sistema a punti per premiare la corretta esecuzione di un esercizio incrementando il punteggio e per correggere i movimenti sbagliati.

Nella tesi ci siamo focalizzati anche sullo sviluppo di strumenti utili al fisioterapista, come le registrazioni degli esercizi svolti dai pazienti e il generatore di livelli. Il terapista può riguardare tutti gli esercizi svolti da ogni paziente in ospedale e a casa, infatti durante i giochi ogni esercizio svolto viene registrato, cosicché il terapista possa analizzare i progressi dei pazienti e verificare che eseguano correttamente gli esercizi. Il terapista potrà anche riguardare la registrazione con il paziente indicandogli quali movimenti ha eseguito correttamente e quali invece sono da correggere.

Una volta sviluppato il framework abbiamo eseguito cinque trial nella Clinica Pediatrica De Marchi, osservando le reazioni dei pazienti e ascoltando i loro suggerimenti. I pazienti hanno apprezzato i giochi trovandoli divertenti e coinvolgenti, in particolare il gioco Alien Invasion ha riscosso successo tra i bambini. Durante i trial abbiamo anche controllato che i bambini interagissero con facilità con il Leap Motion e che le risposte dei giochi agli input dei pazienti fossero quelle attese.

Chapter 1

Introduction

Nowadays new technologies gave us the opportunity to develop new software to support the traditional physiotherapy rehabilitation, Virtual Reality tools, like Leap Motion controller, have received great attention in the recent few years because of their potential applications in gaming, education or as a support for rehabilitation. Therefore a new kind of video games, called serious games, has become increasingly relevant. The main idea of serious games is combining the video games goal of entertaining the player with the purpose to help the player to gain or acquire knowledge, new skills, abilities or to train her. Researchers developed serious games for learning purposes, for military training, for healthcare, and much more.

In this thesis we focus on the development of serious games to support physical rehabilitation of the upper limbs for young patients with Epidermolysis bullosa (EB), an epidermal disease caused by genetic factors that causes blisters and detachments of the skin. There is no cure for this condition and the management of the disease involves support from various doctors with the goal of improving the quality of life of these children: from the pediatrician, to the expert anesthesiologist in pain therapy, to the dentist, to the physical therapist. The pain and the medications are all causes of a possible reduction of the ability to move in patients affected by EB and then they may cause Hypotonia, a state of low muscle tone. The physiotherapy rehabilitation is important to keep the patients trained and improve their physical functionality. Often these patients refuse to perform rehabilitation exercises due to the pain they feel and also the fear of the pain they might feel if they move. As a consequence patients either perform their exercises irregularly or, in the worst case, quit the physiotherapy, lowering their quality of life due to a loss of motility. Rehabilitation toys and video games are a support for therapists to help the patient to cope with the real pain and the fear of pain, in fact the patient is more willing to perform the exercise if she plays with games that draw her attention.

The introduction of new gaming consoles off-the-shelf with new technologies designed to obtain the position of game players in real time (like the Nintendo Wii with the Wii Remote, a controller with motion sensing capability, and the Xbox with the Microsoft Kinect, motion sensing input device) represented an opportunity for therapists to use the games as a support during the rehabilitation session, but the games are designed for the only purpose of entertainment and they limit the therapist when she needs to personalize the rehabilitation sessions according to patients needs. The solution is to develop new serious games for rehabilitation exploiting the new technologies off-the-shelf.

Besides the hardware, video games for the rehabilitation can capture the player's attention and can be useful for health, they combine entertainment with the other purpose of helping the patient to perform the physiotherapy exercises. We worked with the therapist of the De Marchi pediatric clinic in Milan, she explained the requirements of a physiotherapy session for upper limbs, and we combined these requirements with the video games design principles in order to develop useful and engaging rehabilitation games. The games should be challenging but not frustrating, should engage the player but also give the possibility to personalize the levels according to the patient's needs, and should reward correct performances of the rehabilitation exercises and penalize the wrong ones.

As said before, in this thesis we focused on the hand rehabilitation, in particular on the exercises performed using the wrists and the forearm. The goal was to develop video game to support the rehabilitation at hospital and at home, without the presence of the therapist. We developed a framework containing four video games that support different hand and wrist exercises, a module to setup the games difficulty, a module to check patient's progress, a replay module for the therapist that allows to playback the exercises performed by the patient while playing, a level editor that allows the therapist to generate personalized levels. To track hand movements we exploited the Leap Motion controller, an hand tracking sensor, that the patients use to interact with our video games.

We wanted to design a set of games that entertain and support the patients during the rehabilitation session. In order to do so, we designed different types of games to entertain patients with different tastes and different gaming background. In particular we designed four different types of game: a rhythm game entitled Music Beats, where the patient has to move the hands following the rhythm, a driving game entitled Rich Race, where the player controls a car that is moving along a racetrack, a shooting game entitled Shooting Gallery, that is set in a luna park shooting gallery and where the player has to move the hands pointing at the targets to shoot, and a shooting game entitled Alien Invasion, that is inspired by Space Invaders and Galaga and where the player controls the spaceship and fights against aliens. We designed the gameplay of all the games to be as intuitive as possible. We wanted the patient to immediately understand how the game works and start playing it. To reward correct performances and penalize the wrong ones we introduced a scoring system, adding points when a task is successfully completed inside the games.

We also focused on the design of a set of helpful features for the therapist to analyze patients' data. We developed a replay mode where a 3D hand playbacks all the movements performed by the patient while playing, so that the therapist can view the exercises performed by each patient at home or at hospital and she can also show the replay to the patient illustrating the performances she did wrong and the ones she performed well.

Finally, we performed five trials with the patients of the De Marchi pediatric clinic to collect patients' and therapists' feedback. Patients found the games fun and engaging, in particular the Alien Invasion and the Rich Race. They enjoyed playing with the games and the therapist was satisfied by the replay module that allows to see the playback of players' performances. Then we focused on how patients interacted with the games, if they performed the exercises correctly and the system's response to their actions.

The thesis is organized as follows:

- In chapter 1 we give an overview about video games for rehabilitation, the

Epidermolysis bullosa, the video games design principles and the requirements we followed and the result of trials with patients.

- In chapter 2, we describe the Epidermolysis bullosa, the management of the disease and the physiotherapy exercises for hand, wrist and forearm.
- In chapter 3, we describe what is a serious game and analyze the existing games for rehabilitation.
- In chapter 4, we describe the aim of our work.
- In chapter 5, we describe the design principles and the rehabilitation requirements that we followed when we designed the framework.
- In chapter 6, we describe how we developed the framework.
- In chapter 7, we describe the trials we had with patients and analyze the data.
- In chapter 8, we draw conclusions and present possible future improvements of our work.

Chapter 2

Epidermolysis Bullosa

In this chapter, we describe the genetic skin disease known as Epidermolysis bullosa (EB)[1]. At first, we discuss the clinical manifestations and the suggested therapy. Then, we focus on physiotherapy rehabilitation outlining the common exercises for patients with EB and patients with the rheumatic disease known as Juvenile Idiopathic Arthritis (JIA)[2]. Finally we describe a set of physiotherapy exercises for hand and wrist rehabilitation.

2.1 Epidermolysis Bullosa (EB)

Epidermolysis bullosa is a rare genetic disease that affects children from birth, and it is characterized by a set of epidermal diseases caused by genetic factors that have in common the tendency to form blisters, detachments of the skin and mucous membranes due to trauma or minimal chafing. The cutaneous manifestations are the most visible but also other parts of the body are subject to the formation of blisters, such as the internal mucous membranes (eyes, mouth, esophagus, bowel final stretch). One person in two hundred twenty-seven has a defective gene that causes Epidermolysis bullosa and the world average of people affected by the disease is one in seventeen thousand. The disease affects both sexes equally and all ethnic groups, for a total of about five hundred thousand sufferers in the world and in Italy affecting one in eighty-two thousand births (*Epidermolysis Bullosa, inaugurated the first*

[1] https://www.osservatoriomalattierare.it/epidermolisi-bollosa/1636-epidermiolisi-bollosa-inaugurato-il-primo-centro-multidisciplinare-del-nord-italia

[2] https://www.sciencedirect.com/science/article/pii/S0140673607603638

Center Multidisciplinary Northern Italy 2012). The common therm used to describe the children affected is “butterfly children” as the skin is fragile as a butterfly’s wing.

There is no cure for this condition and the management of the disease involves support from various doctors with the goal of improving the quality of life of these children: from the pediatrician, to the expert anesthesiologist in pain therapy, to the dentist, to the physical therapist. The [Debra-Italia-Onlus 2016] explains the best practices to take care of patients affected by EB:

(i) Take care of patients’ skin, bandaging blisters and scratches. They may suffer also of detachments of the skin that is treated with specific medications and, in some cases, surgery.

(ii) Check patients’ teeth and the eye heath.

(iii) Take care of patients’ correct nutrition. In fact the patients’ diet has to be adapted to their needs increasing the quantity of food rich in vitamins and in other elements useful to recover the skin health. It may happen that patients have the alimentation compromised by poor appetite due to blisters developed in the oral cavity, in this case a nutritious food diet is fundamental.

(iv) Take care of patients’ pain through the pain therapy, giving them paracetamol and ibuprofen in case of low level pain and opioids and anxiolytics in case of an high level of pain, that the patients feel when there is a replacement of bandages.

(v) Take care of patients’ pruritic dermatitis. The patient with skin itch desires to scratch, but scratches causes new blisters that cause more itch when they are cicatrizing, leading to a vicious circle of skin damaging. Often the skin itch causes in patients insomnia and depression and sometimes an high level of itch is more damaging than the pain.

(vi) Take care of patients’ cleaning, like the bath. The blisters in the skin may get infected during a bath, but also the personal cleaning is fundamental to prevent the infection. The solution is doing a bath with water added with antibiotic or a little quantity of vinegar or bleach or performing “’salt baths” (a solution constituted by 99.1% of water and 0.9% of a combination of antiseptics and salt) that are appreciated by a lot of patients because of the osmotic effect that prevents pain.

(vii) Take care of patients' psychological health. Depression, social isolation and despair may affect these patients, and may also affect their family components. The patients and their family need to be always supported by therapist to cope with the disease.

(viii) Take care of patients' fitness. These patients due to pain and wounds does not move upper or lower limbs, seriously lowering their muscle tone. Physiotherapy is important to keep the patients trained.

The pain, the medications, the scars, the rehabilitation postoperative are all causes of a possible reduction of motility[3] in patients affected by EB and then they may cause Hypotonia, a state of low muscle tone (*Epidermolysis Bullosa: diagnosis and therapy* 2012). This is why physiotherapy is fundamental for these patients, to avoid the reduction of motility keeping them trained, even if some movements result painful.

The reduction of the ability to move hands and wrists is common in patients affected by the Epidermolysis bullosa (EB), but it is also common in patients affected by another, completely different, rare disease: the Juvenile idiopathic arthritis (JIA). The patients affected by EP have skin blisters and the patients' ability to move is limited due to the pain caused by the disease and due to the bandages used for medicating the blisters. The physiotherapy rehabilitation is fundamental to train their motility, in fact these patients, if not treated by therapists, often refuse to move because of the pain they feel and this causes muscle weakness and a reduction of motility. Instead, the Juvenile idiopathic arthritis is a chronic rheumatic disease that affects joints. The patients affected by JIA have a reduction of their ability to move caused by joints inflammation, pain and deformity of joints; also for these

[3](i) URL: `http://www.treccani.it/vocabolario/motilita/` Definition for motility noun: In human beings, motility describes the motor manifestations involving the muscles that are controlled through the nervous system or the autonomous muscles such as the cardiac muscle (ii) URL: `https://www.merriam-webster.com/dictionary/motile#medicalDictionary` Definition for motile adjective: exhibiting or capable of movement

patients the physiotherapy rehabilitation is fundamental to recover their ability to move.

The term Juvenile idiopathic arthritis describes all forms of rheumatic disease of unknown causes that begin before the age of 16 years and persist for more than 6 weeks. These forms of arthritis can differ in clinical signs, in symptoms and in some cases have a genetic background (Ravelli and Martini 2007). One child in every one thousand develops some type of juvenile arthritis. There is no cure for JIA, as for EP, and even to manage this disease the physiotherapy is fundamental, it helps to keep the patients fit, to minimize pain and to prevent joints' deformity and disability. The rehabilitation of patients with EB and JIA involves the same physiotherapy exercises for hands and wrist.

2.2 Physiotherapy

Since many years the "Clinica Pediatrica De Marchi"[4], a pediatric clinic in Milan specialized in the management of rare disease, has adopted the "innovative multidisciplinary care model", an advanced system to take care of patients globally through several therapists with different specializations. The therapists in the De Marchi clinic help the patients affected by rare diseases as Epidermolysis bullosa or Juvenile idiopathic arthritis. The goal is to help and take care of them, offering in the same place all the medical services.

The clinic has a physiotherapy department where therapists take care of children that need rehabilitation. The physiotherapy rehabilitation is fundamental for patients with EB because of they do not train muscles due to pain caused by blisters. This patients' behaviour causes a loss of muscle tone and a low motility condition called Hypotonia. Hypotonia is a state of low muscle tone often involving reduced muscle strength, it is not a specific medical disorder, but a potential manifestation of many different diseases[5].

In the De Marchi clinic the specialists take care of each patient affected by EB weekly. Each patient takes part to a day hospital where her skin blisters are medi-

[4] *Clinica Pediatrica De Marchi di Milano, nella lotta alle più gravi malattie dell'infanzia* 2018 URL: `http://www.fondazionedemarchi.it`

[5] *Hypotonia* 2018 URL: `https://en.wikipedia.org/wiki/Hypotonia`

cated with bandages and then she attends a physiotherapy session to correctly train the body muscles and avoid Hypotonia. It is important to manage this aspect of the disease because the loss of motility causes a worsening of patient's quality of life, making everyday tasks more difficult, and, as a consequence, worsening her psychosocial condition. The therapist guides the child, and the family, in the process of understanding which are the moving capabilities in spontaneous activities improving her quality of life, with the result of increasing her self-confidence and her psychosocial condition. The physiotherapy should be customized for each patient and should take place both at the hospital and at home to increase the benefits of rehabilitation.

During this process, the therapist also helps reducing the patient's fear of pain and the family's tendency to overprotect the child. Often the child is afraid of performing physiotherapy exercises because of the fear of pain, and toys and video games represent fundamental tools to support this aspect of the physiotherapy capturing the attention of the child and distracting her from the fear. The therapist helps the patient and her family to cope with this fear and to understand which are her real moving capabilities.

The physiotherapy performed at hospital and at home comprehends a series of repetitive exercises specific for each joint, from the knees, to the shoulders, to the wrists, to the hands. In this work we focused on the exercises for hand, wrist and forearm rehabilitation.

2.2.1 Wrist and Forearm exercises

For patients with EB it is important to train the hands muscles with physiotherapy exercises, because the hands are often exposed to scratches that in these patients leads blisters and, due to the pain that they cause to children, they also limit their ability to move. The same exercises are performed by patients affected by JIA that have to train the wrist joint, since this disease causes joints inflammation limiting their ability to move.

In the video games, that we developed, we support the three main wrist exercises: (i) *wrist extension and flexion*, (ii) *wrist radial and ulnar deviation*, (iii) *forearm*

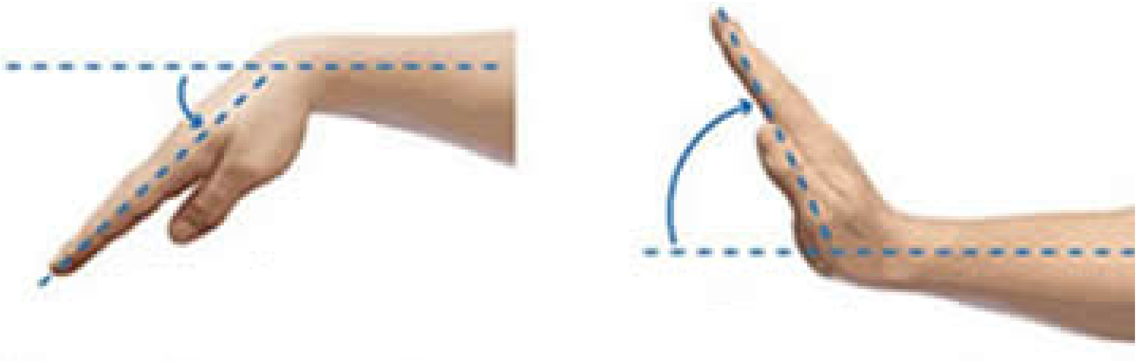

Figure 2.1: Flexion and Extension movements

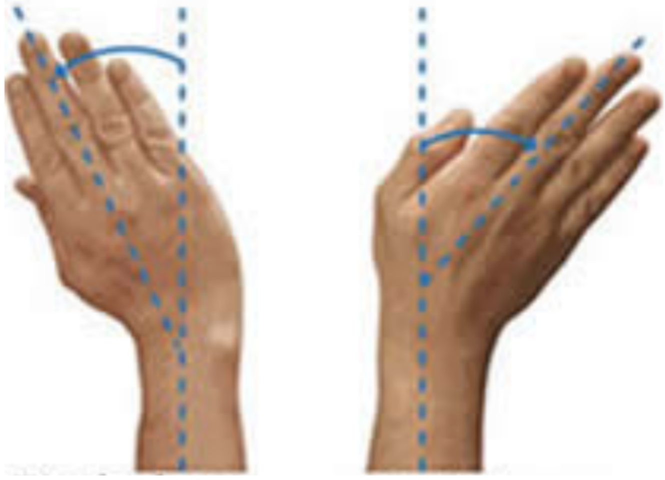

Figure 2.2: Radial and Ulnar deviation movements

pronation and supination.

The *extension and flexion* exercise consists in positioning the hand, that can be opened or closed, with the palm down and then moving it up and down. This exercise manages the ability to move the wrist up and down. Figure 2.1 shows the movements performed in this exercise.

The *radial and ulnar deviation* exercise consists in positioning the hand, that can be opened or closed, with the palm down and then moving it to the left and to the right. This exercise manages the ability to move the wrist left and right. Figure 2.2 shows the movements performed in this exercise.

The *pronation and supination* is an exercise that involves the hand, the wrist and the forearm. It consists in positioning the hand, that can be opened or closed, with the palm down and then rotating the hand and the forearm to the left and to

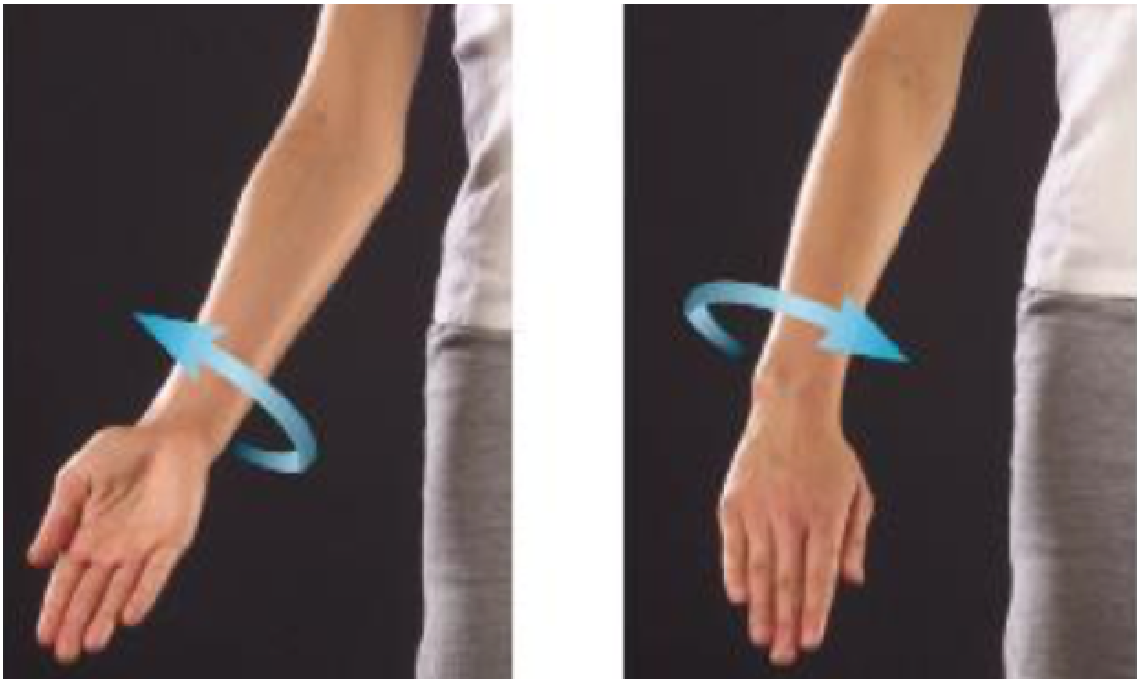

Figure 2.3: Supination and Pronation movements (Saladin 2011)

the right. The pronator teres and the pronator quadratus are the two muscles of the forearm that are trained.

In this exercise the elbow must be positioned outlining a ninety degree angle, in fact if the exercise is performed in the wrong way, for example keeping the upper limb outstretched, the muscles of the shoulder are trained instead of the ones of the forearm. Figure 2.3 shows the movements performed in this exercise.

2.2.2 Finger exercises

For further information we describe a set of exercises for fingers rehabilitation, very useful for patients with EB[6]. The hands and the fingers are always exposed and rarely covered by gloves, so the hands of patients affected by EB are the part of the body that is more at risk of being wounded and therefore developing painful blisters.

The main exercises for fingers are the *hand opened and closed exercise*, the *thumb flexion and extension*, the *thumb abduction and adduction* and the *finger opposition.*

The *hand opened and closed exercise* consists in slowly open and close the hand repeatedly, while opening hand all fingers must extended and separated from each

[6] A possible extension of our work is to support also finger exercises with specific video games

Figure 2.4: Hand opened and closed exercise (*Hand* 2018)

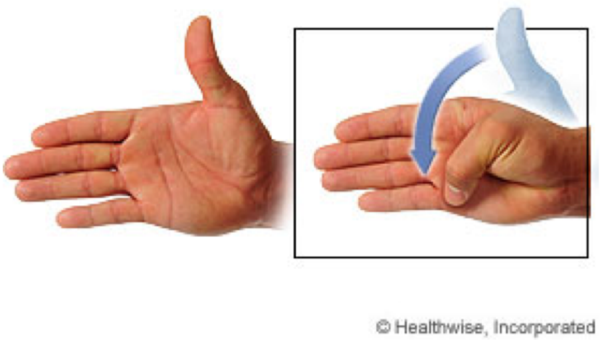

Figure 2.5: Thumb flexion and extension (*Finger: Exercises* 2018)

other. The exercise manages the ability to move the fingers. Figure 2.4 shows the movements performed in this exercise.

The *thumb flexion and extension* consists repeatedly move the thumb up and down. The patient has to place the forearm and hand on table with the thumb pointing up, and then she has to move the thumb down in order to touch the palm of the hand. Figure 2.5 shows the movements performed in this exercise.

The *thumb abduction and adduction* consists repeatedly move the thumb to the left and to the right. The patient, with one hand, has to point the fingers and thumb straight up, keeping the wrist relaxed following the line of fingers and thumb. Then the patient has to move the thumb away from the palm as far as she can, hold that

Figure 2.6: Thumb abduction and adduction (*Finger: Exercises* 2018)

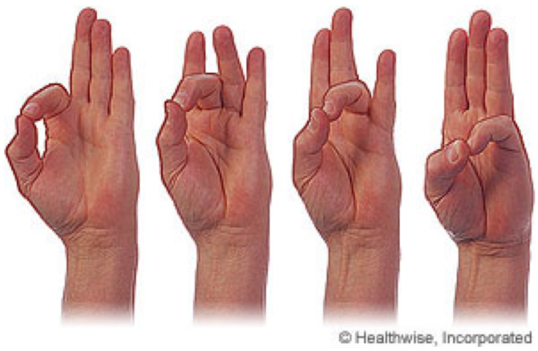

Figure 2.7: Finger opposition (*Finger: Exercises* 2018)

position for some seconds and then slowly move the thumb back to the starting position, with the thumb resting against the index finger.

Figure 2.6 shows the movements performed in this exercise.

The *finger opposition* consists repeatedly move the thumb and another finger. The patient, with one hand, has to point the fingers and thumb straight up, keeping the wrist relaxed following the line of fingers and thumb. Then the patient has to touch the thumb with each finger, one finger at time. Figure 2.7 shows the movements performed in this exercise.

Chapter 3

State of the Art

In this chapter, we define serious games and discuss how serious games can support rehabilitation. Then, we give an overview of the state of the art approaches in the literature and, in particular, we focus on existing video games for rehabilitation and more specifically the ones that use the Leap Motion controller[1].

3.1 Video Games for Rehabilitation

[Rego, Moreira, and Reis 2010] define 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”. That “specific purpose” can be an educational one or a training one, but it may also concern heath issues like a physiotherapy rehabilitation purpose. According to them the serious game is a genre of video games it has different purposes that the traditional video games for the entertainment: a serious game is not created only to entertain but also to train or educate the player about a specific topic. “The serious games are not only the application of games and games technology, they are entertaining, enjoyable and fun, but their main purpose is other that was conceived by the game designer when designing the game or that the user defined when played the game.”

The authors focused on analyzing the benefits of serious games for rehabilitation, that exploit the combination of video game entertainment with the “specific purpose” of rehabilitation, that can be physical or cognitive, motivating the patient to

[1]URL: `https://www.leapmotion.com`

keep playing and face challenges. This sub genre of video games is useful to support physiotherapy, that is essential to manage disabling diseases, either chronic or acute, and to improve patient's physical condition and quality of life. It usually consists in performing a series of exercises that the patient has to perform frequently at home or at hospital.

According to the authors, the absence of patient's motivation, caused by the repetitive nature of the exercises, is the major problem that the therapist has to manage and the use of serious games as a support during rehabilitation sessions helps the therapist to cope with this problem, increasing the motivation of the patient.

It is important to notice that the problem of low motivation of patients it is not the only one that the therapists have to cope with. The therapist of the De Marchi pediatric clinic in Milan explained us that during the rehabilitation sessions it may happen that the patient feels pain, due to her health condition. This feeling is another important problem that the therapist has to manage: the pain limits the patient more than the low motivation, since if a rehabilitation exercise is painful, the patient, especially if she is a kid, refuses to perform the exercise. The patient may also refuse to do the exercise because of the fear of pain instead of real pain, this happens because she has a memory of a painful movement performed in the past and she fears that executing the rehabilitation exercise causes her the same pain. Rehabilitation toys and video games are a support for therapists to help the patient to cope with the real pain and the fear of pain, in fact the patient is more willing to perform the exercise if she plays with games.

[Rego, Moreira, and Reis 2010] also outlined the criteria that developers have to follow when they design serious games for rehabilitation. (i) The developers have to identify the domain area in which the serious game can be applied, like psychological, cognitive or physical rehabilitation. (ii) The developers have to identify the technology that the patient is able use to interact with the system and that more fits the rehabilitation domain area. It can vary from the traditional methods using a mouse or keyboard to VR based methods. The video games that use technologies like Wii Remote, Wii Balance Board or the Microsoft Kinect are potentially useful for physical rehabilitation, instead for psychological rehabilitation video games that use mouse and keyboard might be enough. (iii) The developers have to select a standard game difficulty or an adaptable difficulty, according to the patient performance in the game. The serious games can use standard levels to compose difficulty or record and analyze player's action to change dynamically the difficulty of games and maintain an adequate level of challenge. The decision to introduce an adaptable difficulty in the games depends on the domain area of the game and on the kind of patients for whom the game is intended. (iv) The developers have to give performance feedback to the player, the game has to transmit to the patient the results of her interaction with the system, so that the patient can be able to measure her progress in skills and in goals' achievement. (v) The developers have to design a module to monitor the patient's progresses in the rehabilitation process. (vi) The developers have to design the games to be usable at home and at hospital. When developing a rehabilitation video game another important aspect is to keep in mind that the final users of the game are patients and therapists, the game must be easy to use and the presence of a technical expert must not be necessary.

The identification of the technology to use is fundamental to develop rehabilitation video games, new technologies appeared on the market of video games, in particular VR tools like the Leap Motion controller and consoles like Xbox with the Microsoft Kinect[2], the Nintendo Wii with the Wii Remote[3] and the Wii Balance Board[4] and the newest Nintendo Switch with the Joy-Con[5], a controller with motion sensing capability and a motion camera capable to detect shapes and hand movements. These off-the-shelf technologies are less expensive than a new potential technology specifically designed for rehabilitation, so when developing a serious game for rehabilitation it is better and less expensive to exploit an existing technology and adapt it for the rehabilitation purpose.

Off-the-shelf games for consoles have been developed with the entertainment purpose, however many pediatric clinics use these off-the-shelf devices as a support for physiotherapy exercises, social interaction and rehabilitation because they are affordable, fun and can be used within the clinic and home. [Lange, Flynn, and Rizzo

[2]URL: https://en.wikipedia.org/wiki/Kinect
[3]URL: https://en.wikipedia.org/wiki/Wii_Remote
[4]URL: https://en.wikipedia.org/wiki/Wii_Balance_Board
[5]URL: https://en.wikipedia.org/wiki/Nintendo_Switch

2009] carried out a usability evaluation of off-the-shelf video games consoles, and in particular of Nintendo Wii's, for the rehabilitation of patients affected by physical disabilities. They observed that off-the-shelf games are useful only for patients that have to perform exercises that match with the ones offered by the games. In a physiotherapy session, however, it is fundamental that the therapist adapts the exercise according to the child's abilities, but the customization of exercises is not possible if she uses off-the-shelf video games as a physiotherapy support, making these games not suitable for every patient. The solution is to develop video games specific for rehabilitation exploiting existing technologies off-the-shelf.

[Burke et al. 2009] focused on developing rehabilitation video games for patients with stroke. They explained that the rehabilitation video games are useful to stimulate and entertain the patient, to avoid the boredom caused by the repetitive nature of rehabilitation exercises, and to help the patient motivating her to continue the therapy even if the she is affected by depression. In fact "it is not uncommon for stroke survivors to experience depression and therefore may find it difficult to concentrate on a therapy programme" and "people with stroke commonly report that traditional rehabilitation tasks can be mundane and boring due to their repetitive nature". New technologies, like VR and other off-the-shelf systems, allow to create new virtual supports for rehabilitation tasks exploiting these technologies in the development of virtual environment specific for rehabilitation. This environment must provide video games for rehabilitation with a customizable training system, that can be adapted to the patient's needs, a progress monitoring system, to monitor patient's progress and encourage her to train, and if the technology is suitable for home deployment, the virtual environment could support also home therapy. In this case the system should record performance data, such as the number of sessions attempted, the length of exercise session and the success rate, and upload to a remote clinical site via the Internet, so that the therapist can analyze them. It is important to choose the technology that best fits the purpose, like rehabilitation after stroke, because that decision can affect both the user's experience and performance ability.

The authors explain some features that a rehabilitation video games should have. This features of game design are fundamental not only to keep the patient effectively engaged, but also to teach the rehabilitation movements to perform to the player rewarding correct behaviours and penalizing the bad ones. First they say that the game must have “a meaningful play”, i.e., there must be a relationship between the player’s actions and the system’s outcome. To obtain a meaningful play the game should give feedback to the player, without them the player is not able to understand her success in the game and the play loses meaning. The interaction relationship between the player and the system should be both discernible, so that a player can perceive how her choice is affecting the game, and integrated, so that the choice does not only affect the game in the immediate term, but also at a further stage of the game. “Feedback is how the game responds to the changes or choices made by the player and is central to creating and maintaining meaningful play”, give feedback to the player is also useful to signal correct and incorrect actions done. Numerical scores, progress bars, sound, achievement of new weapons or medals are all possible feedback that engage the player.

According to the authors in rehabilitation video games the management of failure is more important than in classical video games. In off-the-shelf commercial games, failure is often not only present but expected, like a car crash in a driving game, but in rehabilitation video games the failure has to be more “conservatively”. In fact the goal of a rehabilitation game is to reward correct game performances and correct the wrong ones. They does not say that the player character should never die and that there must not be a game over condition, but that the game should initially be peaceful and without catastrophic results, to encourage the patient to play. If the failure is not correctly handled the patient may feel frustrated due to the failure and less motivated to continue playing, losing all the benefits that a video game to support rehabilitation should give her. Another way to motivate patients is to design rehabilitation games that are challenging for everyone. The rehabilitation video games should have a system module that the therapist can use to increase or decrease the level of difficulty to an almost infinite degree, in order to support the rehabilitation of different patients with different abilities.

The design of rehabilitation video games exploiting off-the-shelf devices offers a valuable contribution in the rehabilitation area. We focused on studying existing rehabilitation video games for upper limb training that use the Leap Motion controller, and hand tracking sensor compatible with PC, affordable and that supports different game engines and programming languages[6].

3.2 Video Games for Upper Limb Rehabilitation

In this section we focus on existing video games for rehabilitation that use the Leap Motion controller. The Leap Motion is a free-hand interaction controller developed by Leap Motion Inc. It is used to control input with hand movements and it does not require hand contact.

According to [Alimanova et al. 2017] existing video game consoles represent an opportunity in the creation of rehabilitation video games, in fact existing consoles "are designed to obtain the 3D position of game players in real time, and because of that, researches focused on the Leap Motion, Myo armband, Microsoft Kinect, Nintendo Wii, PlayStation Move, and others VR technologies". The authors developed a video game for hand rehabilitation after injury and geriatric complications, such as stroke, using the Leap Motion controller, that was chosen as the device for the game because it is affordable, portable and easy to use for patients that have to play at home. They state that to eliminate boredom of the therapy it is a better low-cost option to adapt an off-the-shelf device in the game than creating a new one specific for the purpose.

The game, they developed, is called "Escape game" and it helps patients to train the muscle tone and to increase their precision in performing gestures. Through the video game elder patients can perform the intense and repetitive functional tasks of the therapy in a fun interactive environment. The therapy to manage injuries requires the continual repetition of the exercises, and that may be boring for patients, therefore Escape game has different modes that concern different hand rehabilitation tasks, like grabbing, reaching, pointing, lifting and throwing exercises.

The authors observed an improving of upper limb functionality in patients that repeated the rehabilitation tasks daily at home playing with the video game in addition to the conventional therapy. Rehabilitation and health care centers are interested to have a virtual environment with a game that supports the therapist

[6] list of game engines and languages supported by Leap Motion URL: `https://developer-archive.leapmotion.com/documentation/v2/unity/index.html?proglang=unity`

during the rehabilitation sessions and with modules that collect data and monitor patients' progress in performing correctly the exercises. In fact it is simple to collect patients' data through video games or other virtual environments, since each patient, when she plays, interacts with the device that collects data to recognize the player's movements (in this paper the Leap Motion collects data to recognize the movements of hands). For the therapists it is important to collect and analyze data about patients, in order to check patients' progress and also to better personalize the rehabilitation exercises for each one of them.

[Khademi et al. 2014] leveraged the technology of free-hand interaction to rehabilitate patients with stroke, they modified the Fruit Ninja video game to support the stroke rehabilitation using the Leap Motion controller to track hand movements. The game supports rehabilitation for stroke patients with arm and hand weakness to practice their finger individuation. In the game the patient has to move the finger to cut the fruits, instead of interacting with the touch screen.

This adaptation of the Fruit Ninja game reflects what [Burke et al. 2009] stated about the feedback and the failure condition. Fruit Ninja game has a numerical score and does not have a real game over: a fruit cut increments the score and a bomb hit decrements it, in simple levels bombs may not appear and the score depends only on the amount of fruit cut. The authors performed a pilot study in which they recruited 14 patients with chronic stroke to play the game. The authors observed that the Fruit Ninja modified game was a good indicator of patients' hand functionalities and Leap Motion hand data could be useful for rehabilitation purposes, like the analysis of data and the customization of the therapy.

[Oña et al. 2018] developed a tool, containing a series of video games, to support the rehabilitation therapies for upper limbs in patients with Parkinson's disease (PD). Parkinson's disease is the most common movement disorder and the most frequent neurodegenerative disease after Alzheimer. Currently, there is no curative treatment for PD and it is managed focusing on the symptomatology to avoid a fast progression of the disease.

The video games they developed support the physiotherapy exercises for hand, wrist and forearm, in particular palmar prehension, fingers' flexion, extension and hand pronation-supination. The games can be personalized according to each patient's needs, considering the injuries and the physical conditions.

The authors explained the design principles behind the creation of the video games, their idea was to develop a flexible game platform which allows the patient to play at home and the therapist to use the games as a support during rehabilitation sessions. It is fundamental do develop games that use common technologies, the player should be able to play at home with her personal laptop in an easy and intuitive way.

The games should have an attractive graphics to engage the player and motivate her to perform rehabilitation tasks. The user interface of the games should contain "simple and clear instructions": in fact it is important for the patient to easily play the games and to understand how to execute the correct movements. During a game few conditions are imposed so that the patient performs the exercises while playing; it is required to the player to perform specific actions to achieve the goal, forcing her to make the movements that are part of the rehabilitation therapy. Inside the games there is a rewarding system that gives positive feedback when the player performs the exercises correctly, the rewarding system also motivates the player to get a better result the next time she plays.

In the games, that the authors developed, the hand data are collected with the Leap Motion and then saved, all the data of each patient can be analyzed by the therapist that can check the patient's performances and progress. As stated by the authors of the other papers, the data of the games played by each patient are easy to save when it is used a device for the interaction between the game and the patient. All the data collected by the device can be saved and then analyzed by the therapist, and that data can give information about the progress of each patient, so that the therapist can personalize and adapt the future rehabilitation sessions to the patient's needs.

Adaptability is important feature of video games for rehabilitation: the therapist should be able to adapt the games to each patient's condition, as different patients may need to execute different exercises. So in the video games, that they developed to support upper limb rehabilitation for PD, the therapist can design the sequence of exercises to be performed by the user "generating the specific treatment protocol scheme as a recipe for the specific disease and patient".

The authors performed a pilot study on five individuals with PD, these individuals played with the rehabilitation games two times per week with the presence of the therapist. At the end of the trial they observed a correlation between the increase of health condition and the management of the disease with therapy supported by the video games.

Chapter 4

Motivation

The video game technology has made an important step forward with the introduction of new input interfaces like the Wii Remote, the Kinect, the Leap Motion and other VR technologies. So, as [Alimanova et al. 2017] stated, today new video game consoles and new controllers like the Leap Motion represent a low-cost opportunity in the creation of rehabilitation video games that can be used at the hospital and also at home by the patients. We focused on the creation of rehabilitation video games to support physiotherapy exercises for wrist and forearm for patients affected by Epidermolysis bullosa, and we decided to use the Leap Motion to collect hand data. Leap Motion is an hand tracking sensor that supports many platforms to enable the implementation of new applications, it allows to collect hand data, record them and also playback hand movements.

The patients are little kids affected by EP that risk losing the ability to move because they does not do physical training due to the pain caused by blisters and skin bandages. Physiotherapy is fundamental for these patients to train muscles, and the training must be performed at hospital but also at home, repeating the movements they perform during the physiotherapy sessions. We decided to create video games for physiotherapy rehabilitation to support the player during the performance of wrist and forearm exercises at home or at the hospital. The video games for wrist and forearm exercises are useful to support also the rehabilitation of patients affected by Juvenile idiopathic arthritis, since the physiotherapy sessions involve the same exercises that patients with EB have to perform.

Our goal is to create a framework containing a module for the therapist and a module for the player, in this way the player can play the video games at home and the therapist can use the same games as a support during the physiotherapy session, check the progress in every moment and create personalized levels

We developed the framework satisfying the following requirements. (i) **Create video games as a support for therapists to manage the patient's rehabilitation at the hospital**. Often patients refuse to do painful movements that they have to perform during a physiotherapy session, but when it is required to them to do the same movements while playing a video game they perform the movements without complaining. It happens because playing a video game "moves" the patient's attention from the pain she feels to the desire to complete successfully the tasks inside the game. The result is an effectively reduction of the pain that the patient feels when she plays. (ii) **Create video games as a support for patients to perform physiotherapy exercises at home**. At home, without the presence of the therapist, the patient may loose the self confidence necessary to practice the same exercises alone. With the support of video games that require to perform the same movements of the physiotherapy exercises the patient feels more serene in practicing the exercises and also has fun playing the games. (iii) **Collect data useful for the therapist to check patient's progress**. The use of Leap Motion allowed us to collect hand data, that are useful for the therapist to analyze the patients' progress. In addition the therapist asked us to record the exercises performed at home by the patients, she wanted to check if each patient executes them correctly. (iv) **Develop video games that involve physiotherapy exercises that the patient can perform at home**. We worked with the therapist to individuate the wrist exercises that the player can perform alone at home, then we selected three of them to include in the video games. The therapist also explained us the duration that a wrist exercise should have inside the game. We designed the games following the therapist's guidelines about the exercises and then we developed the games using the iterative design approach, a cyclic process that comprehends prototyping, testing, analyzing and refining the games. We developed the games' prototype, then we asked a patient to play the games checking if the prototype worked properly, then we analyzed therapist's and patient's feedback and then modified the games.

We mapped the exercises that the player should perform in the movements recognizer inside the video games. Our goal is to create games that bring the player to perform correctly the exercises, penalizing wrong player's behaviours and rewarding the correct ones. When we developed each video game we kept in mind that the exercise performed by the patient while playing should correspond to the one that it is expected inside the video game, and that the exercise that it is expected inside the video game should correspond to the one performed during a physiotherapy session. It is fundamental that the final result is a correspondence between the exercises that the player performs and the physiotherapy exercises.

Chapter 5

Game Design

In this chapter, we describe the design of the rehabilitation framework we developed for children affected by Epidermolysis bullosa (EB), a painful genetic skin disease which separates the body's skin layers from its internal lining, forming blisters as a result of contact. The framework comprises (i) four video games targeting three types of wrist rehabilitation (**Rich Race**, **Music Beats**, **Shooting Gallery**, and **Alien Invasion**); (ii) a module to tune the setup and tune rehabilitation protocols; (iii) a module to monitor the patients' physical abilities; (iv) a module to let therapists create rehabilitation exercises; (v) a module to let therapists remotely monitor the patients' performances.

5.1 Designing Video Games for Rehabilitation

The most important principle of video game design is entertaining, a game must capture the player's attention, inducing her to play again and again. The most important principle of physiotherapy rehabilitation is to perform correctly each exercise. We combined these two principles in our video games using a scoring system to provide an immediate feedback about something right or something wrong that player did during a match.

To encourage patients to play games and to focus on the performance we increase the score during a match as a reward for the correctness of the exercise, but with substantial differences between the four games.

In the Rich Race, Music Beats and Shooting Gallery the points are added to the score every time the exercise is performed correctly but bad actions are not penalized with any penalty in order to avoid the risk of frustrating the player (even if in some levels earn all the points results more difficult than others) although in the Alien Invasion subsection 5.1.4 in the complex levels the score is reduced by a small penalty every time the player does a wrong movement.

In fact every person can approach differently when she sees for the first time a new video game, someone can be more skilled than others and may have played more video games before, so we decided to tune every video game differently, but always keeping them simple (it is important to remember that the patients are kids around ten years old), in order to cover a wide range of young video games players. When we designed the games we performed a difficulty tuning: we adjusted the games difficulty every time we observed the reaction of a little patient approaching our game for the first time.

We wanted to avoid the risk that someone could find the video game boring while others could find the same game too difficult. An example is the first time when we show the prototype of the Alien Invasion subsection 5.1.4 to two male kids having the same age, both played the same level and the first one, who had experience with video games, won the game with few efforts, the other one, that was a beginner, won with much more efforts, commenting that the game was very difficult, even too much.

After that experience we tuned the difficulty differently introducing a wider range of levels.

In the four video games we divided the levels into two categories: the *Training mode*, in which the levels are created through a *Level Editor Module* that is a level editor where the therapist can personalize the level path according to the patient needs, and the *Standard mode*, in which we designed the levels in an ascending difficulty of gaming.

The target of the video game are kids, around ten years old, that need to do rehabilitation exercises. Since different people have different preferences, we mapped each rehabilitation exercise with one more video games, in order to cover as much different tastes as possible.

The Figure 5.1 shows the hand gestures involved in each video games.

	Radial/Ulnar Dev.	Flexion/Extension	Pronation/Supination
Rich race	✔	✔	✔
Music beats		✔	
Shooting gallery	✔	✔	
Alien invasion	✔	✔	✔

Figure 5.1: Physiotherapy exercises involved in the video games

5.1.1 Rich Race

Rich Race aims on helping patients executing flexion and extension, ulnar and radial deviation, pronation and supination. Since all these wrist exercises involve the movement of a hand only in two opposite directions, we designed **Rich Race** as a driving game where the player can move a car only to the left and to the right. Every hand movement the player does is recognized as a gesture and commuted in a car movement. The player can move the car using only one hand and, before starting a new match, the player can choose what exercise perform: the flexion and extension training, the radial and ulnar deviation training or the hand pronation and supination training. In **Rich Race** a car moves on a race track and diamonds are positioned along it. The player can move the car left and right trying to collect as many diamonds as possible. The Figure 5.2 shows the beginning of a match. Every time the player moves the car correctly and collects a diamonds she obtains a certain amount of points, added to the score. If the player has wrong behaviours, like a wrong gesture, the car skips and does not collect some diamonds, with the consequence that no points added to the score. We adopted this scoring method in order to penalize wrong behaviours but not frustrate the player with too strong penalties.

The player can also choose the car's color between blue, green, yellow, red; when, on two different occasions, two kids tried this video game, both decided to drive the

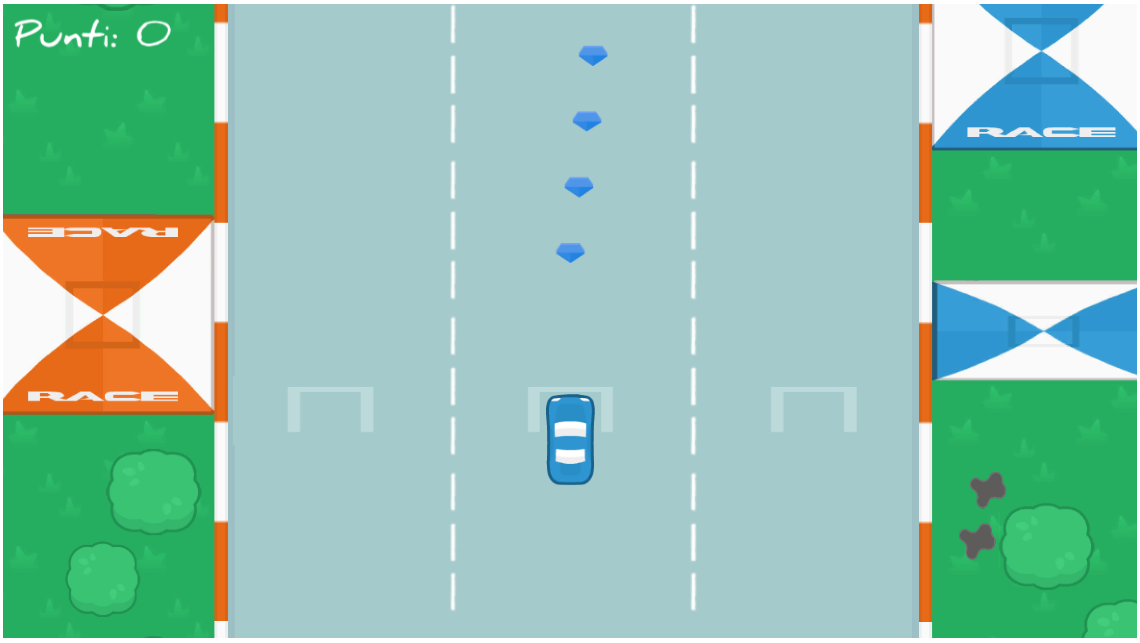

Figure 5.2: Screenshot of Rich Race

blue car stating that "the blue is my favourite color".

In this game all the levels are designed through the *Level Editor Module*.

5.1.2 Music Beats

Music Beats focuses on helping patients training the wrist's flexion and extension. We designed the **Music Beats** as a rhythm game, that involves the movement of a hand up and down and recalls the movement done by the hands when someone beats the time. In this game, while the music plays in the background images of a blue right hand or a pink left hand appear on screen, these images move from left to right. When a hand image arrives into a green zone the player has to move up and down the hand shown by the image. Every time the player performs the gesture correctly and in the right moment some points are added to the score. The Figure 5.3 shows the screenshot of a match. We designed each level using the open-source library librosa (McFee et al. 2015) to recognize beat times in songs and compute the moments in which generate the hands images. Each level corresponds to a different song.

Figure 5.3: Screenshot of Music Beats

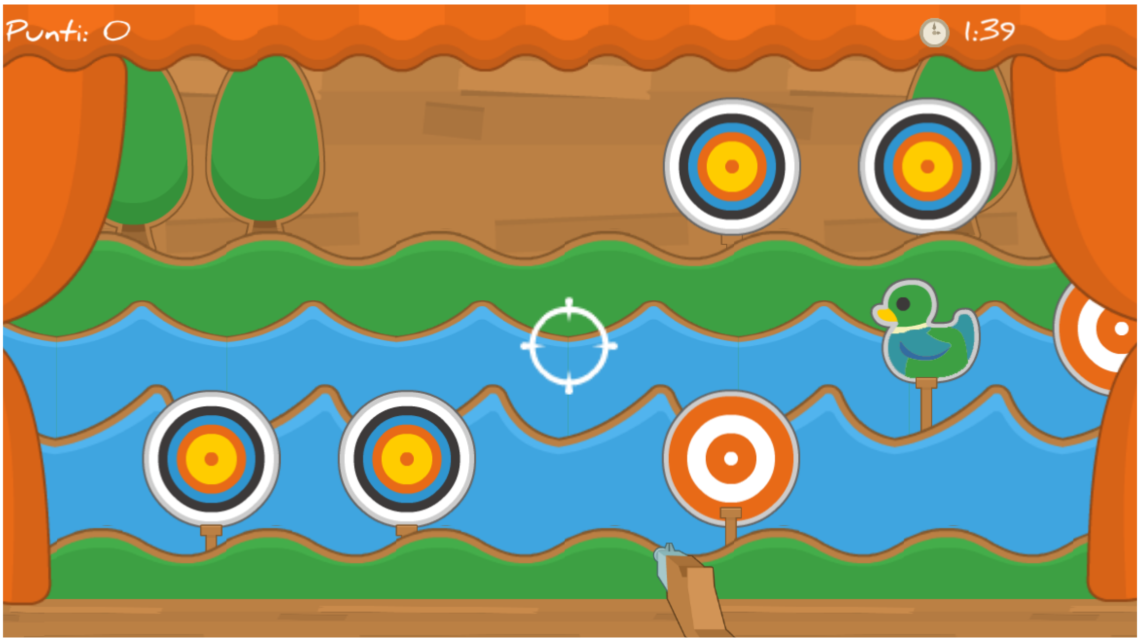

Figure 5.4: Screenshot of a standard level in Shooting Gallery

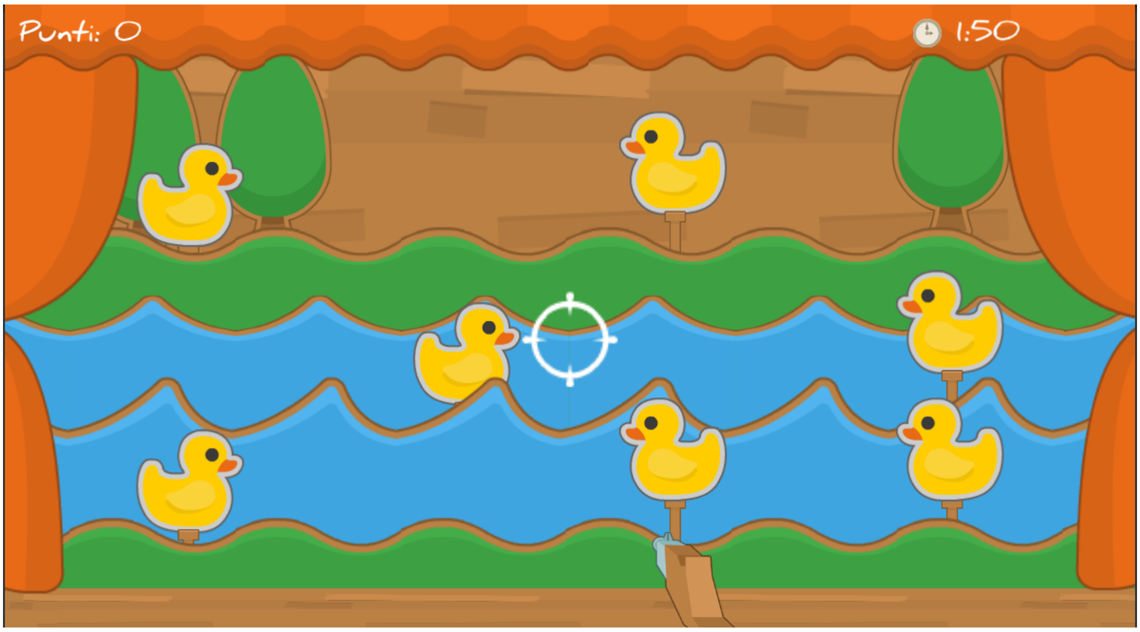

Figure 5.5: Screenshot of a training level in Shooting Gallery

5.1.3 Shooting Gallery

Shooting Gallery aims on helping patients training the wrist's flexion, extension, ulnar and radial deviation, all combined in one exercise in which the children moves the hand up, down, left and right. Since hand movements performed in this exercise are similar to the ones of someone pointing an object with the hand, we designed a game where the player controls the pointer of a gun with the hand gestures. In this game, a gun is controlled by the player and the main goal is to hit all the targets in the scene. Every movement of the hand in a direction corresponds to a movement of the gun's pointer in the same direction. The player has to move the gun's pointer and to hit all the targets. Every time the player hits a target some points are added to the score. To keep the game simple and to allow the player to focus only on the gestures, we automated the shot: a target is hit when the gun's pointer moves on it. In this game there are ten *standard levels*, but in addition the therapist can design new levels through a *Level Editor Module*.

The *levels generated* contain only the targets representing a yellow duck, Figure 5.5 shows a training level. In the *standard levels* there are different types of target, even fixed and moving targets, Figure 5.4 shows a standard level. Every type of target adds a different amount of points to the score.

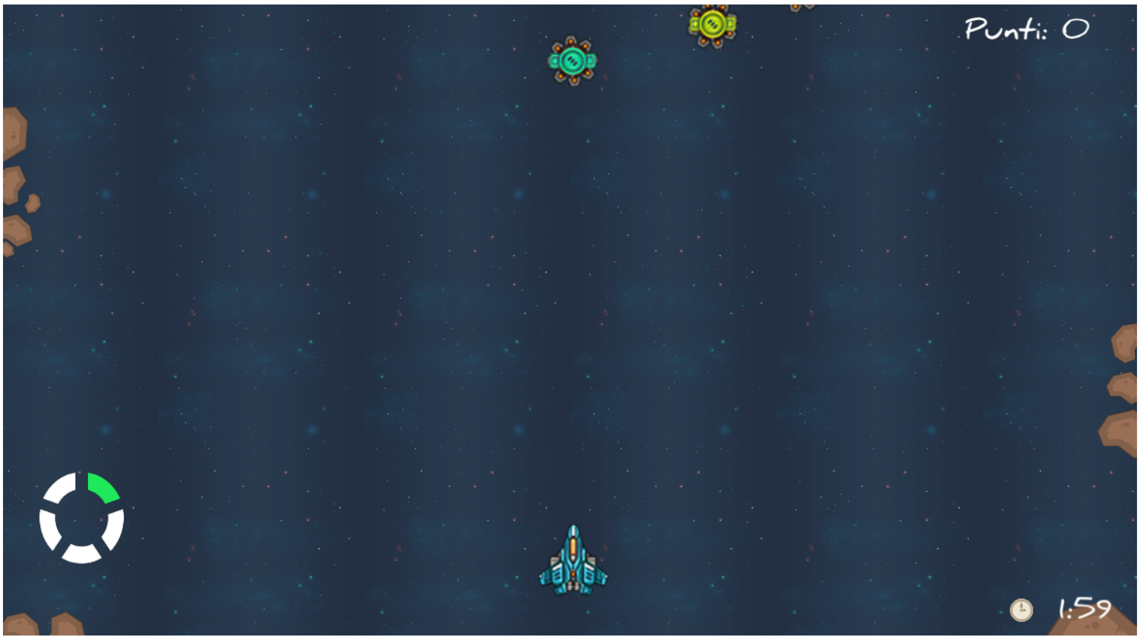

Figure 5.6: Screenshot of a custom level in Alien Invasion

5.1.4 Alien Invasion

Alien Invasion is a shooting game inspired by Space Invaders and Galaga. In this game a spaceship has to fight against an alien invasion in the outer space. This video game supports the patients in the execution of the three wrist's exercises: flexion and extension training, ulnar and radial deviation training, pronation and supination training.

The player controls the spaceship, that can move only to the left and to the right. This game supports the same exercises of the Rich Race subsection 5.1.1, so we mapped the hand movements in the same way: when the player moves the hand in a direction also the spaceship moves in that direction, commuting every gesture the player does in a spaceship movement.

The aliens are instantiated at the top of the scene and then, at intervals, they step down getting closer to the spaceship. In order to simplify the controls and to allow the player to focus only on the gestures, we automated the spaceship's shots and we put a loading bar in the scene that indicates when it is ready to shoot. In this game there are different types of aliens, some of them only move, but others are able to shoot against the spaceship. Every time an alien is hit some points are added to the score and every time the spaceship is hit some points, less than the

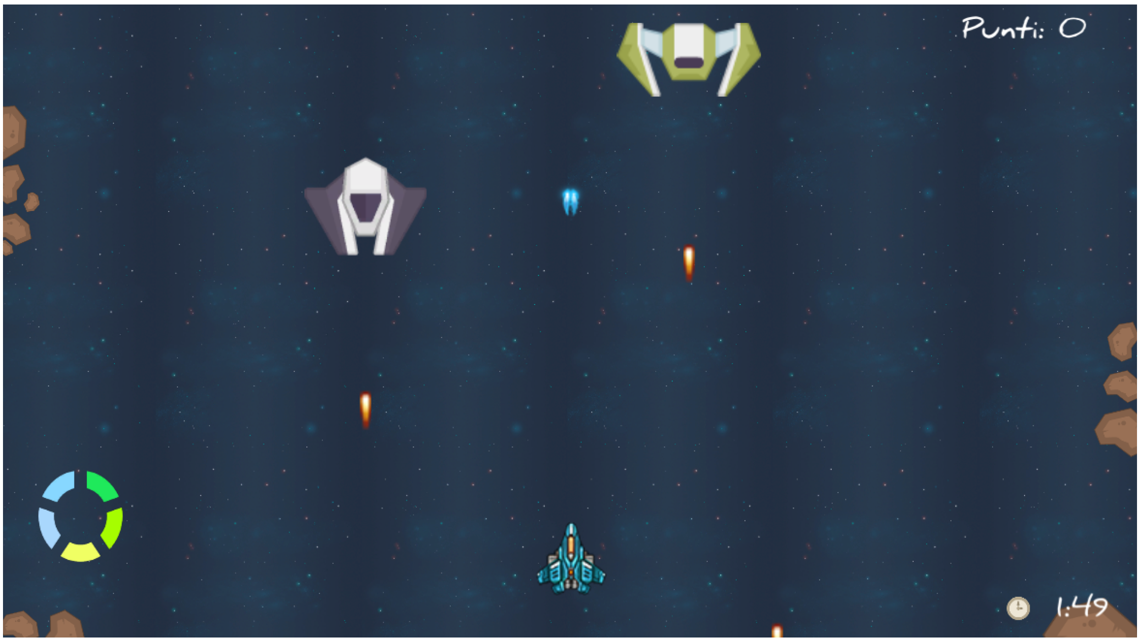

Figure 5.7: Screenshot of a standard level in Alien Invasion

ones added in case of an enemy hit, are subtracted from the score, if the score is zero and the spaceship is hit it remains zero. Some aliens are stronger and can be defeated only after some hits, in this case every shot that hits the alien adds points to the score. The therapist can generate levels through a *Level Editor Module*, but there are also ten *standard levels* that we designed.

In the custom levels the only enemy that appears is the alien that moves but does not shoot, Figure 5.6 shows the beginning of a match in custom level. In the *standard levels* there are different types of alien, the aliens only able to move, the aliens able to shoot and even some alien spaceships, Figure 5.7 shows a standard level with two alien spaceships.

5.2 Tuning Module

During the physiotherapy sessions the exercises are divided in degrees of difficulty and the therapist adapts the exercises to the patient's capabilities. We developed a settings module, the *Tuning Module*, to select the degree of difficulty of the physiotherapy exercises inside the video games. In the games the hand movements the player does are recognized as gestures and commuted in a events (like a car movement in the Rich Race subsection 5.1.1). The gesture performed by the player has to respect some parameters in order to be recognized: the therapist can change the setup of these parameters and personalize it for each patient. This setting are important also to tune the difficulty of the games, playing games while doing exercises with a high degree of difficulty is more challenging than playing the same games while doing exercises more easy. In fact a well performed gesture has to respect some parameters, that the gesture recognizer

For example if a patient is able to move the hand to the left and to the right designing a wide angle, the therapist will setup the parameters in the *Tuning Module* selecting a high minimum angle that the player has to do moving the hand to the left and to the right, below that angle the gesture is not recognized.

5.3 Progress Monitoring Module

In this module we store information about the patient's current range of motion. We ask the patient to achieve the maximum of her range of motion in flexion, extension, radial and ulnar deviation. At the end of the performance we show the results and store them online.

With the *Progress Monitoring Module* the patient can check the progress over time while the therapist can analyze this useful information: she can check the patient's level of motion and improvements, but can also rely on that data to update the settings in the Tuning Module section 5.2.

This module is coupled with the games, through the same interface the patient can decide to play or to check the progress.

5.4 Level Editor Module

In addition to the *standard levels*, the therapist can generate custom levels for the specific needs of the patients through the *Level Editor Module*. The editor is part of an application specifically designed for therapists.

In the *Level Editor Module* the therapist can edit some parameters and then the application will generate automatically the correspondent level. The parameters are

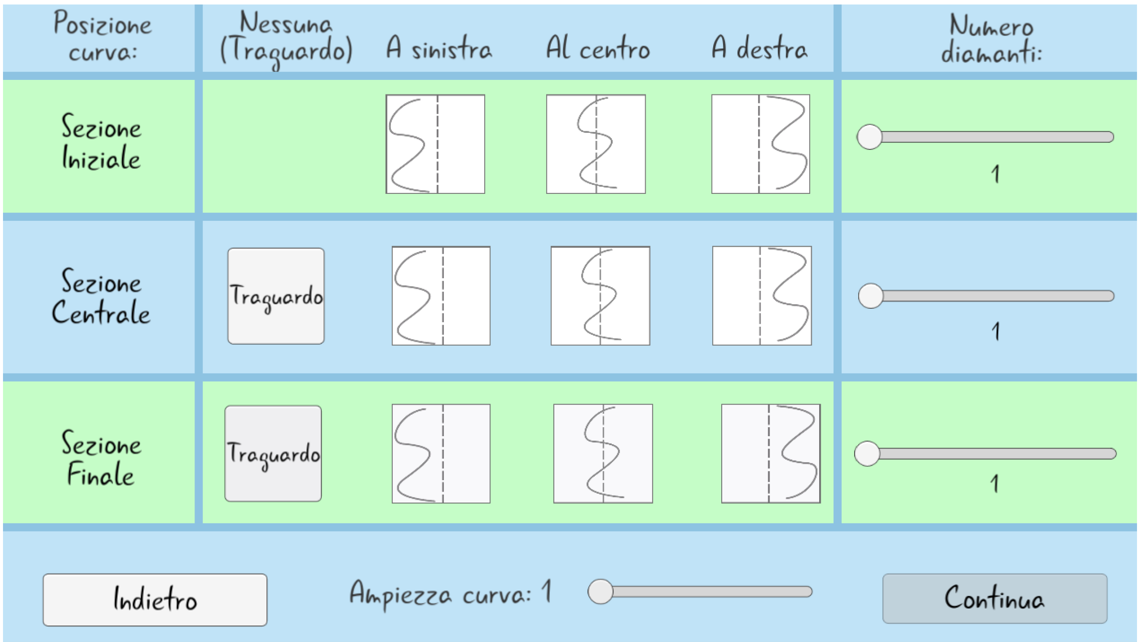

Figure 5.8: Rich Race level editor

different for each video game: when editing a level of Rich Race subsection 5.1.1 or Alien Invasion subsection 5.1.4 the therapist has to choose the length of the path, the position in the level of the elements, respectively the diamonds and the moving aliens, and the number of elements. The Figure 5.8 shows the level editor of Rich Race. When editing a level of Shooting Gallery subsection 5.1.3 the therapist has to select the number and the position of the yellow duck targets in the level. The Figure 5.9 shows the level editor of the **Shooting Gallery**.

In the four video games the custom levels are called *training levels* to differentiate them from the *standard levels*.

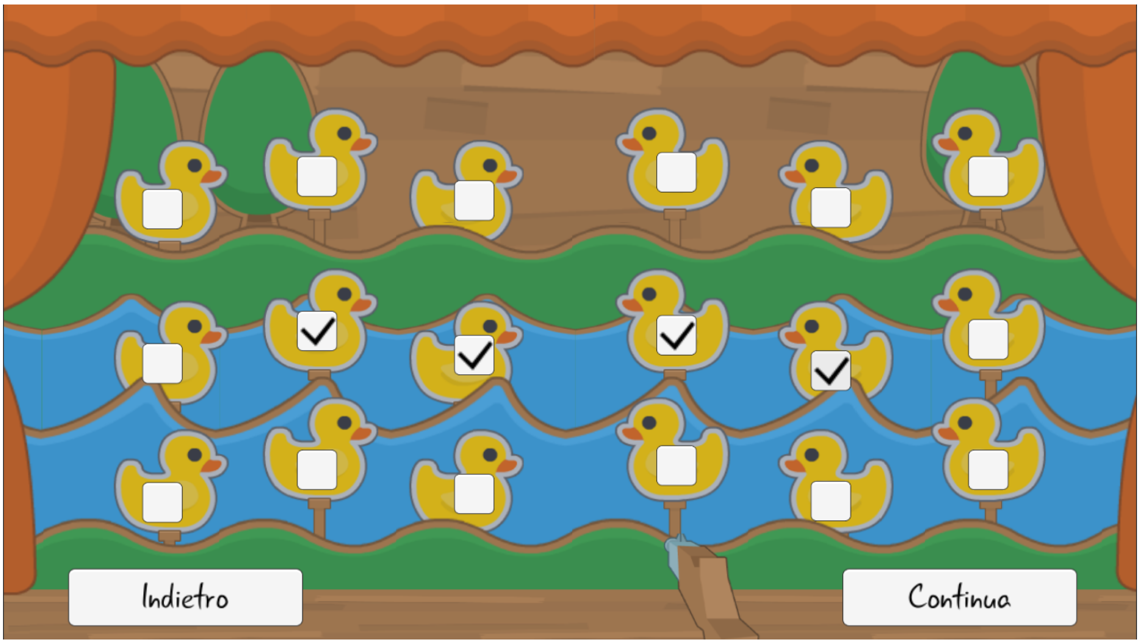

Figure 5.9: Shooting Gallery level editor

5.5 Replay Module

A benefit of using video games to support rehabilitation is the possibility to save the hand data of the patients. The data are collected during the execution of the Progress Monitoring Module section 5.3 and in the games when the player performs the exercises. We designed the *Replay Module* to allow the therapists to see how the patient performs the exercises. The therapist can monitor the exercises executed looking at a 3D hand replicating the real movements that the patient performed during the game. Figure 5.10 shows the 3D hand replicating an ulnar and radial deviation exercise performed by the player in Rich Race.

This feature is useful because the therapist can monitor the exercises performed at home by the patient, checking for possible mistakes that the patient did during the exercises execution, and it is useful also at hospital, for example, if the therapist needs to see again the performance of the patient. The therapist can also show the replay to the patient illustrating the performances she did wrong and the ones she performed well.

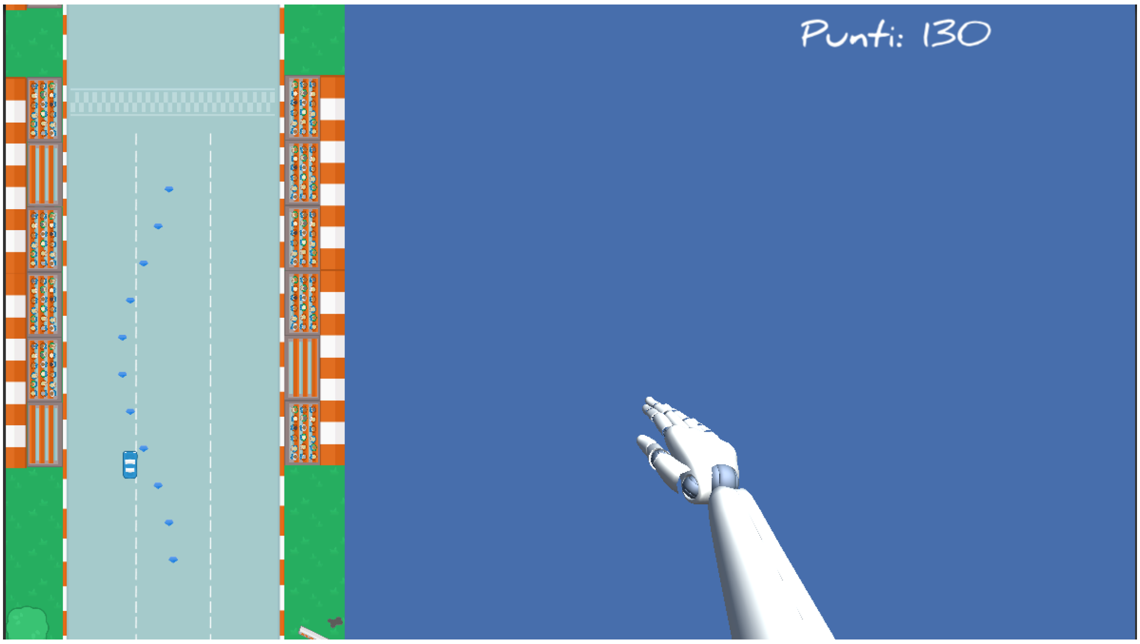

Figure 5.10: Replay of a game with Rich Race

Chapter 6

The Rehabilitation Framework

In this chapter, we describe the modules of the framework we developed and the tools we used. In particular we explain how the interaction between the player and the video games works through the Leap Motion, how the hand data are saved and stored online, how the playback of patients' performances works and how we implemented the level editor.

6.1 Framework Overview

Our goal was to develop a system that patients could use at home as a support while executing the rehabilitation exercises. So we decided to develop a framework containing modules specific for the patient and for the therapist to support rehabilitation exercises, to exploit the customization of the exercises and to allow the therapist to analyze patients' performances and progress in the rehabilitation. The framework contains five modules: (i) video games for wrist rehabilitation; (ii) a module to setup the rehabilitation protocols, the Tuning Module; (iii) a module to monitor the patients' physical abilities, the Progress Monitoring Module; (iv) a level editor module, the Level Editor Module; (v) the Replay Module, used to see the playback of patients' performances.

The fist module is the one containing the games, the patient can play with the video games individually at home or at hospital with the presence of the therapist, while playing the hand data are collected through the Leap Motion and then saved. The four games are Rich Race, Music Beats, Alien Invasion and Shooting Gallery.

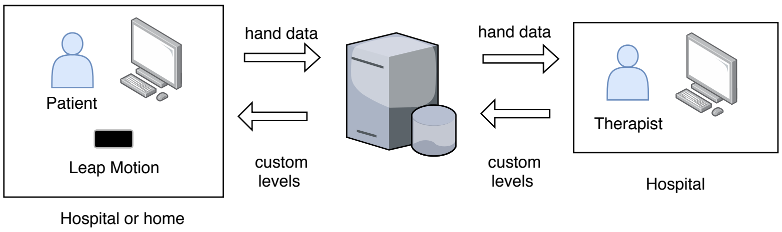

Figure 6.1: Framework for the upper limb rehabilitation

The second one is the module to setup the exercises that the patient has to perform while playing. The third is a module that asks the patient to perform a special exercise to evaluate her maximum ability in hand movements. The fourth is a level editor that the therapist can use to generate personalized levels for patients. The fifth is a replay module, through which the therapist can view the playback of patients' performances. The interaction between the modules needs to be transparent to the players and the therapist, to let them concentrate only on the rehabilitation and not focusing on the technical details. For this reason we decided to store data on a specific server online, so that the patients can play at home and the therapist can analyze hand data or create new levels remotely. The Figure 6.1 shows the interaction between modules in the framework.

6.2 Hardware and Software Requirement

The patient interacts with the games through the Leap Motion controller that it is used to control input in the games through hand movements. To make Leap Motion controller work on laptop it must be downloaded the V2 tracking SDK software[1]. The hand data collected during the games by the Leap Motion are saved on a json file and loaded on a specific web server. Leap Motion costs 70-80 euros. We decided to use the Leap Motion because it allows to collect hand data and to playback, in

[1]URL: `https://www.leapmotion.com/setup/desktop/`

Figure 6.2: Leap Motion controller's view of hands in desktop mode

order to replicate the hand movements of the player. To let the framework behave correctly there is a specific server active online able to store a SQL database and containing a PHP interpreter, we used the Unity package Easy Save 2 to store data online, Easy Save allows to save to a MySQL server on the web using the PHP file and MySQL database provided with the package[2].

6.2.1 Leap Motion

The Leap Motion Controller (LM) is a small device used to control input with hand movements and it is compatible with PC via USB cable connection. It is a free-hand interaction controller developed by Leap Motion Inc. that supports the "Desktop Mode" and the "VR mode", it has size: height 1,27 cm, width 3 cm, depth 8 cm. In the "Desktop Mode" the Leap Motion is positioned on top of a table and the player has to place the hands over it, as it is shown in Figure 6.2. In the "VR mode" the Leap Motion is positioned atop the Virtual Reality headset and the player has place the hands in the Leap Motion's field of view, as it is shown in Figure 6.3.

The Leap Motion controller uses optical sensors and infrared light. The sensors have a field of view of about 150 degrees. The effective range of the Leap Motion

[2]URL: `https://docs.moodkie.com/easy-save-2/guides/saving-and-loading-from-web/`

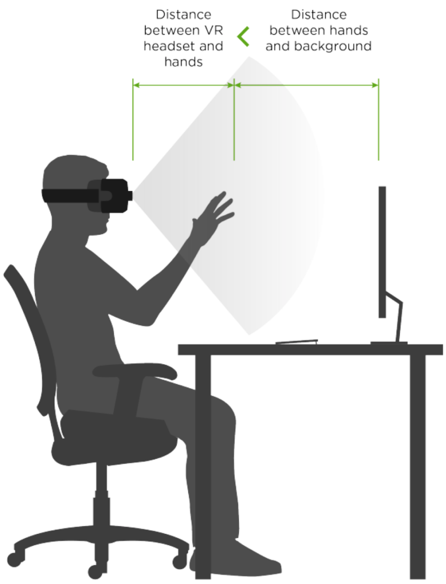

Figure 6.3: Leap Motion controller's view of hands in VR mode

Controller extends from approximately 0.03 to 0.6 meters above the device. Detection and tracking work best when the controller has a clear, high-contrast view of an object's silhouette. The Leap Motion software combines its sensor data with an internal model of the human hand to help cope with challenging tracking conditions.

The Leap Motion can track more that one hand at the same time, typically two hands of the same player but also three or more hands in case of a multiplayer game that uses this device. For each hand it can track every finger and the relative phalanges, the palm and the forearm. Actually a real thumb has one less bone than the other fingers, but, for programming reasons, the Leap Motion thumb model includes a zero-length metacarpal bone so that the thumb has the same number of bones at the same indexes as the other fingers. Using the API we can retrieve the position and rotation, in the Euler angles with rotation axes yaw, pitch and roll, of the hand, the position of the forearm and of each bone in the fingers, according to the coordinate system of Leap Motion.

As it is explained in [*Unity Plugin Overview* 2018], the Leap Motion controller uses a right-handed Cartesian coordinate system, the origin is centered at the top of the Leap Motion Controller, the x- and z- axes lie in the horizontal plane, with the x-axis running parallel to the long edge of the device; although Unity3D, the

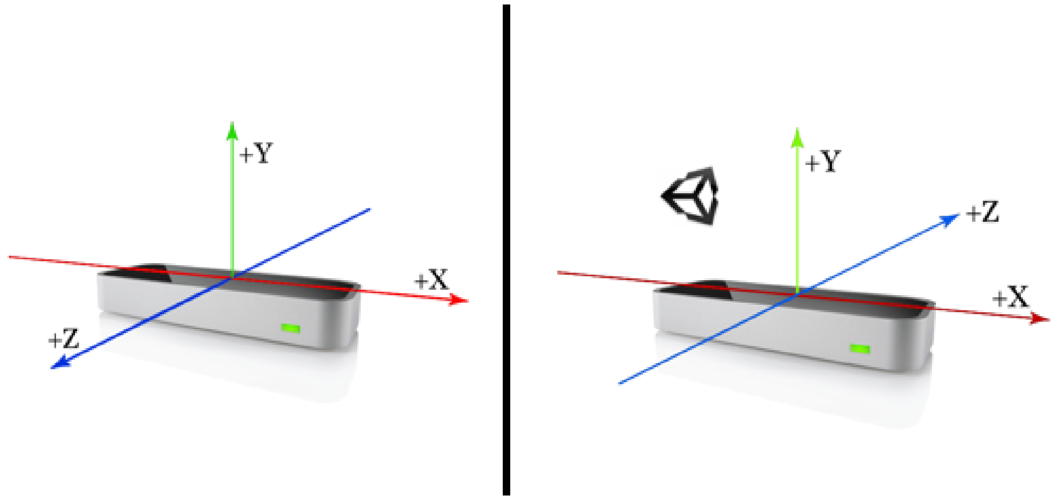

Figure 6.4: Leap Motion coordinate system vs Unity 3D coordinate system superimposed on the Leap Motion device in "Desktop Mode" orientation

game engine we used to develop the framework, uses a left-handed convention for its coordinate system, so z-axes points in the opposite direction from the one of the Leap Motion's system convention. Another difference between Unity3D and Leap Motion is the default unit of length, Unity uses meters, whereas the Leap Motion API uses millimeters. The Leap Motion plugin internally transforms the tracking data to support Unity3D left-handed coordinate system and meters unit of length, the Unity3D coordinate system on Leap Motion device can be seen in Figure 6.4.

6.3 Interaction Description

In this section first we describe how the patients interact with the system through the Leap Motion, then we describe how the therapists interact with the system to view the replay and to create custom levels.

The patient has to run the video games module and the Leap Motion V2 tracking SDK software, setting the mode on "Resume Tracking" in order to allow the Leap Motion to collect hand data. The user to play should run the video games module and then follow the instructions: she has to login and then to select the game she wants to play, to run the *Progress Monitoring Module* or to run the *Tuning Module*. Figure 6.5 shows the flowchart of the video games module.

To recognize the rehabilitation movement we developed a gesture recognizer in-

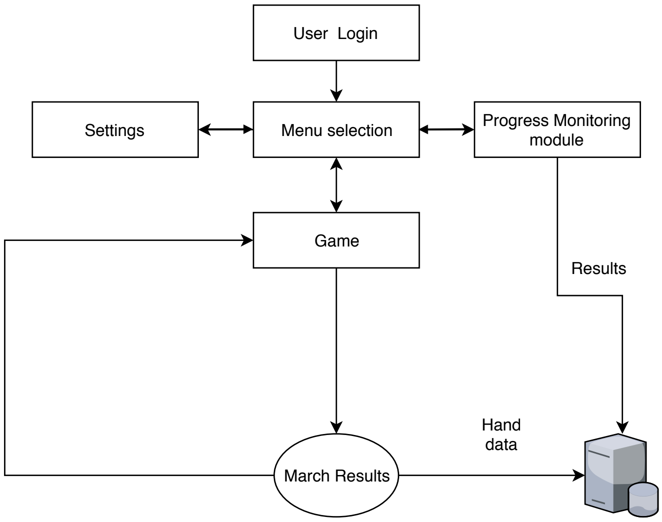

Figure 6.5: Flowchart of the video games execution

side the video games module following the instructions given by [*Create Gestures* 2014]: in the game the hand data are stored during every update, at frame rate time, and every time the data collected are enough (we fixed the value of data collected at six, as the author states) the system checks if the average of the data collected is above a threshold, if it is, the gesture is recognized and the game react accordingly. When the hand data are saved after a game, also the thresholds are saved to playback the game accurately. The thresholds are set through the *Tuning Module*, where the threshold are setup in the system. The user can set two thresholds, one to recognize the flexion and extension and one to recognize the radial and ulnar deviation, the higher is the threshold, the higher it has to be the angle designed by the player's hand. The hand data that we check for flexion and extension movements are the pitch rotations of the hand on every frame, for ulnar and radial deviation are the yaw rotations of the hand, for pronation and supination the roll rotations.

In the json file, where we save the hand data after a game, we save the Leap Motion Frames, collected at every update. The Leap Motion Frame class represents a set of hand and finger tracking data detected in a single frame, the Leap Motion software detects hands and fingers within the tracking area, reporting their positions, orientations, gestures, and motions in frames at the Leap Motion frame rate. So the Leap Motion Frame contains all the information about the user's hand in a frame, from the position to the rotation. We decided to store this information because if the therapist decides to analyze data in a different mode than the playback of hands during the game or wants to check different kind of hand data, they can be easily extracted by the Leap Motion Frames.

From the main menu the player can also decide to run the *Progress Monitoring Module*, to check her progress. In this module it is required to the player to move the hands up, down, to the left and to the right, trying to achieve the maximum of her range. During the performance the hand data are collected with the Leap Motion: the pitch rotations of the hands are collected when the player moves the hands up and down and the yaw rotations are collected when the player moves to the left and to the right, the data are divided into four lists: pitch values major than zero, pitch values less than zero and the same for yaw data, then the results are calculated as the four averages, one for each list. The results are shown on the laptop screen and saved in a json file stored on the database.

6.3.1 Replay Description

The therapist has to select the *Replay Module* to view the playback of the patients' performances. First the therapist has to choose the patient who wants to check, then the kind game (Alien Invasion, Rich Race, etc.), then the performance she wants to view. The games are the same as the ones in the video game module, but in the Replay Module also a 3D hand that performs the exercises is shown. When the therapist selects the performance she wants to view, the Leap Motion Frames are loaded in the game from the json file and then the playback starts, replicating all the hand movements. The Figure 6.6 shows the picture of the player while performing the exercise and the corresponding view in the replay.

6.3.2 Level Editor Description

The therapist can generate custom levels of Rich Race, Alien Invasion and Shooting gallery through the *Level Editor Module*. In a Rich Race custom level the therapist can choose how many diamonds generate and their position. In the level the diamonds are positioned along three sequential curves, for each curve the therapist can choose to put it in the centre of the game screen, in the left or in the right, the

Figure 6.6: Picture of the patient playing the game and the corresponding replay

therapist can also choose where to position the finish line. In a Shooting Gallery custom level the therapist can choose how many duck targets generate, the duck targets have fixed positions and for each target the therapist can only choose if generate it or not. In an Alien Invasion custom level the therapist can choose how many enemies generate and where to put them in the game scene. The enemies are positioned along three sequential curves and the therapist can choose where to put each curve, like in the Rich Race custom levels.

The positioning of the enemies and diamonds along three curves was a requirement of the therapist, in fact the player to collect all the diamonds or hit all the enemies, while playing with Rich Race or Alien Invasion, has to move the hand following the direction of the curve, so the therapist has a visual idea of the exercise that she is preparing for the patient. The Figure 6.7 shows the settings of a level generated through the Level Editor, while the Figure 6.8 shows the final result in Alien Invasion. The levels are saved in json file and then loaded on the database, when the player runs the video game the custom levels are automatically downloaded.

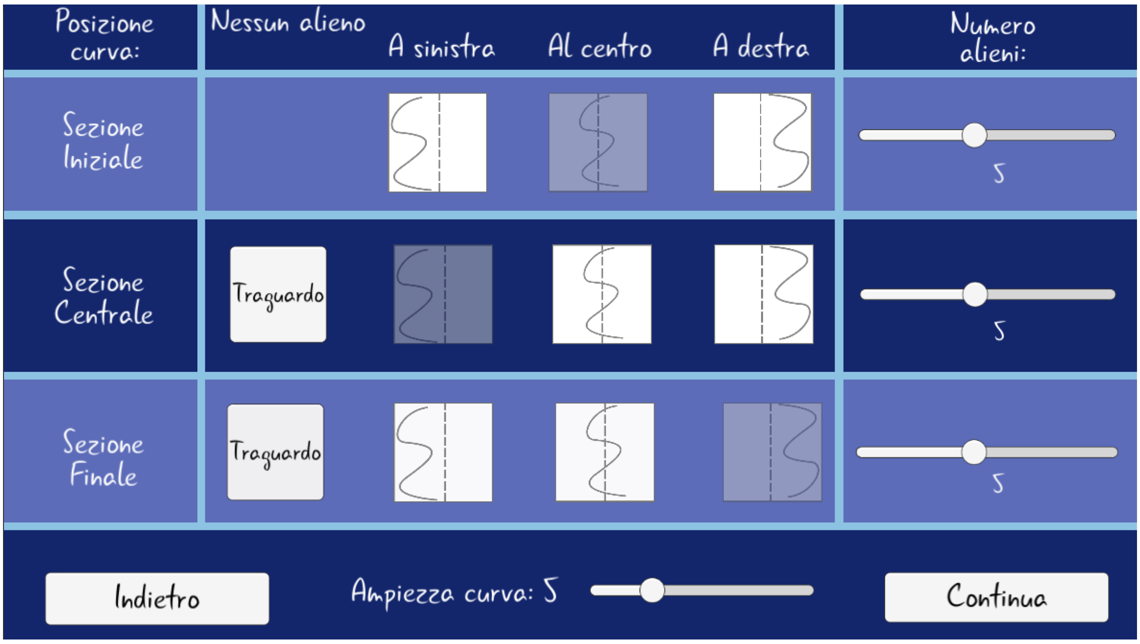

Figure 6.7: Alien Invasion level editor

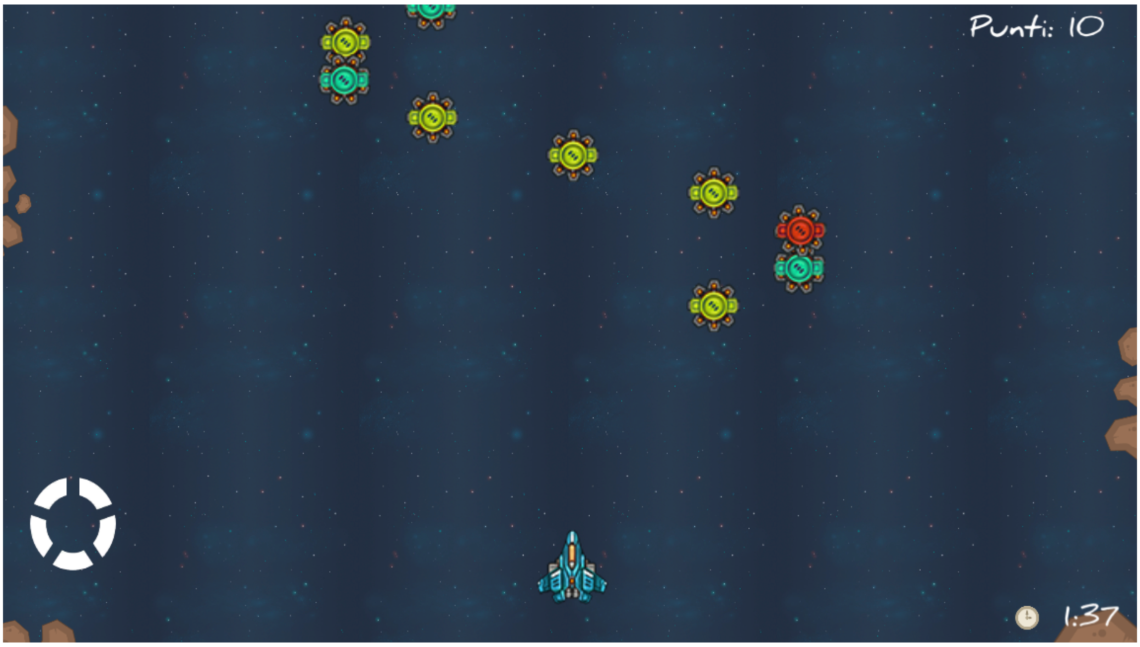

Figure 6.8: Alien Invasion edited level

Chapter 7

Testing and Data Analysis

In this chapter, we describe the trials of our framework that we performed in the De Marchi pediatric clinic with the help of the therapist and the little patients affected by Epidermolysis bullosa or Juvenile idiopathic arthritis. During five rehabilitation sessions in the pediatric clinic the patients used our video games as a support for the exercises. Then the therapist and the patients gave us feedback and tips on how to improve the video games.

7.1 Experimental Setup

Five trials has been held at the De Marchi pediatric clinic with one therapist, and each session involved only one patient per time. We used the same devices in all the sessions, the Leap Motion controller and the PC where the framework was installed, an Intel NUC NUC5i7RYH, a powerful Mini-PC ten per ten centimeters, with 3,40 GHz Intel Core i7-5557U (4 MB of cache) running Windows 10. The games were developed with Unity3D game engine version 2017.4.4f1, the Unity asset for Leap Motion V2 tracking, the Easy Save 2 Unity package. We performed the trials in the gym of the De Marchi pediatric clinic, we connected the PC with the television already present in the gym, and in front of it we positioned a desk and a chair specific for kids. On the desk were placed the PC and the Leap Motion controller.

We performed five trials with three different patients under the supervision of Dr.ssa Ft. Amalia Lopopolo and with the presence of the parents of patients. The patients participated individually to the trials.

7.2 Patient One

The firs patient, we call Patient 1, is a ten years old male kid affected by Epidermolysis bullosa. Unfortunately he resides in another city and we had the possibility to perform only one trial with him.

At the beginning we set the interaction distance of Leap Motion at 100 millimeters, we setup the rehabilitation protocols to recognize gesture of hand movements higher that five degrees and, before start playing, the therapist edited personalized levels for each game. When we carried out the first trial there weren't already the standard levels in our games. The Patient 1 played with two levels of Rich Race and two levels of Alien Invasion, selecting the radial and ulnar deviation mode in both games. The Patient 1 found our games engaging and funny, and wanted to repeat again the second Alien Invasion level to achieve the best score, since at the first attempt he was not able to defeat all the enemies.

This first trial helped us to validate our design choices. We could see that the patient was entertained by the games and the therapist gave us positive feedback confirming that these games are a useful support for rehabilitation. Patient 1 also gave us some useful hints on how to change and improve our games. He told us that the only presence of the training levels was not enough to engage the player for a long time, in fact he was able to successfully complete at the second attempt the Alien Invasion level that was classified as the highest difficult in the level editor. We followed this hint creating the standard levels. He also told us to include a loading bar in the Alien Invasion to indicate when the spaceship is ready to shoot, and now the loading bar is included in the game. The feedback about the visual aspects were useful as well, helping us improving the gaming experience and making the games more appealing for the users.

The therapist, during the performance in first Rich Race level, noticed that at the beginning the patient moved the arm to the left and to the right instead of the hand, this movement is called "compensation" and it is a wrong movement. The gesture recognizer works only with the correct movements and not with compensation movements, so the patient, while playing, naturally corrected his performance executing the correct movement to complete successfully the game.

7.3 Patient Two

The second patient, we call Patient 2, is a seven years old male kid affected by Epidermolysis bullosa. We performed three trials with this patient one time per week. Since the kid was very young, he had small hands that the Leap Motion didn't recognized completely (it is important to take in account also that the hands were damaged due to scratch and wounds). Therefore we decided to set the smallest interaction distance that corresponds to 70 millimeters in the Leap Motion settings and then we asked to Patient 2 to keep the hands at 100 or 150 millimeters far from the Leap Motion. Through this ploy we "tricked" the Leap Motion that recognized the hands as far hands of an adult. We positioned the Leap Motion on another chair lower than the one where Patient 2 was sitting, in order to position the Leap Motion around 150 millimeter far from the patient's hand. We setup the rehabilitation protocols to recognize gesture of hand movements higher that five degrees.

In the first trial Patient 2 played all the games: Rich Race, Alien Invasion, selecting the radial and ulnar deviation in both games, Shooting Gallery and Music Beats. As done for Patient 1, before starting the trial the therapist edited one personalized level for each game. The first game that Patient 2 chose to play was Rich Race. He completed the personalized level successfully, so he asked to play again with a more difficult level, that was edited at the moment, and then he completed also the second level successfully. The second game chosen was Shooting Gallery, even in this game he completed the personalized level successfully, shooting all the targets. The third game was Alien Invasion, Patient 2 found this game quite difficult, even if he obtained an high score he wasn't able to eliminate all the enemies generated in the level. The four game he played was Music Beats, that has only standard levels. At the end of the trial Patient 2 commented that the Alien Invasion was more difficult than the other games.

In the second trial Patient 2 played with Rich Race, Alien Invasion, selecting the radial and ulnar deviation in both games, and Shooting Gallery. First he tried a new personalized level of Rich Race playing with the right hand, then he performed the first two standard levels of Shooting Gallery and the first two standard levels of Alien Invasion playing with the left hand. He used different hands to play different games to train both hands, and we verified that the gesture recognizer in the games worked equally with the left and the right hand. He completed successfully all the levels and he found our games funny and engaging, he wanted to keep playing completing other levels but he interrupted the session because the father reminded him that he had to go to school.

In the third trial Patient 2 played with Rich Race, Alien Invasion and Shooting Gallery. First he played two new personalized levels of Rich Race with the right hand, one playing with the pronation and supination mode and one with the radial and ulnar deviation mode. Then he played two standard levels of Shooting Gallery and one standard level of Alien Invasion with the left hand, selecting the ulnar and radial deviation mode. At the end he decided to play another level of Alien Invasion, classified as difficult because it required wider movements, and he completed also this complex level successfully.

In this trials we checked that the remaining two game worked properly and we analyzed the reaction of Patient 2 to the changes we have done following the hints given by Patient 1. The standard levels have actually caught the player's attention, the kid remembered the index of the level he played during the previous trial and he wanted to deal with levels more difficult. The Shooting Gallery was appreciated in the standard mode and also in the training mode, the Music Game was fun but he told us that the music was too long making the performance of the exercise quite exhausting, so we were asked to reduce the levels' difficulty.

The Patient 2 told us that his favourite game was the Rich Race, but he also found very engaging the Alien Invasion. It is interesting to notice that the first time Patient 2 played with an Alien Invasion level he found it difficult, but in the third session he successfully won against a mini-boss in one of the most complicated levels inside the Alien Invasion, so after three sessions he acquired new abilities and gained confidence in playing using the Leap Motion controller.

After the third trial, we watched, with the therapist, the replay of the Patient 2 performances when he played Alien Invasion. The therapist really appreciated the possibility to see again the patient's performances, and she told us that this feature is useful to check and evaluate the exercises performed at home by the patients.

7.3.1 Hand data analysis

We collected the data of Patient 2's performances during the second and the third trial, then we analyzed the data to check the effectiveness of the game as a rehabilitation support.

Patient 2 played the Rich Race with the right hand, the Table 7.1 compares the average performance executed during trial two and one executed during trial three. It is interesting to notice that Patient 2 increased the ability to move both ulnar and radial deviation of more than ten degree from the second to the third trial.

Table 7.2 shows the average ability to move pronation and supination. The data were collected during the third trial when Patient 2 performed the pronation and supination exercise in Rich Race. The patient was able to perform correctly the exercise, keeping the elbow near the body and the forearm in the correct position, and to end the game successfully, but he found the exercise more exhausting than the same game in the ulnar and radial deviation mode.

Table 7.3 shows the comparison of the average performances executed with the left hand during trial two and during trial three, while playing at Shooting Gallery. The data collected during the third trial indicates that the patient performed less extensive movements during the game, this happened because Patient 2 has gained confidence in interacting with the game through the Leap Motion, and with slower and less extensive movements he completed successfully the exercise with more precision.

Table 7.4 shows the comparison of the average performances executed with the left hand during trial two and during trial three, while playing at Alien Invasion. The player found this game difficult but also very engaging and challenging. Both times he played two different levels, and during the third trial one of the two levels he played was classified as a difficult level and it required to perform wider movements. The Table 7.4 shows that Patient 2 was able to execute wider movements during the third trial than the ones performed during the second trial.

	Second trial	Third trial
Right hand Radial	10, 30	24, 8
Right hand Ulnar	7, 13	21, 5

Table 7.1: Average degree values of right hand ulnar and radial deviation of Patient 2 while playing Rich Race

	Third trial
Right Pronation	60, 37
Right Supination	52, 6

Table 7.2: Average degree values of right forearm pronation and supination of Patient 2 while playing Rich Race

	Second trial	Third trial
Left hand Extension	30	24, 3
Left hand Flexion	14, 12	16, 8
Left hand Radial	25, 18	23, 3
Left hand Ulnar	13, 1	13, 9

Table 7.3: Average degree values of left hand flexion, extension, ulnar and radial deviation of Patient 2 while playing Shooting Gallery

	Second trial	Third trial
Left hand Ulnar	24, 44	27, 73
Left hand Radial	18, 55	28, 77

Table 7.4: Average degree values of left hand ulnar and radial deviation of Patient 2 while playing Alien Invasion

7.4 Patient Three

The third patient, we call Patient 3, is not a kid, but a seventeen years old girl affected by Juvenile idiopathic arthritis. She came to try our games after a session of injections of anti-inflammatory drugs.

At the beginning we set the interaction distance of Leap Motion at 100 millimeters. Before playing the therapist asked her to perform the exercise included in the Progress Monitoring Module section 5.3 to check her current abilities to move the hands and wrists. The goal of the therapist was to check her ability of moving after the injections.

She played a training level of Rich Race, selecting the pronation and supination mode, she found the game fun and engaging. Then she played a level of Music Beats, that we fixed after the feedback given by Patient 2. She completed successfully the level obtaining the highest score possible and she told us that the game was fun and also easy to play. At the end she played the first three standard levels of Shooting Gallery and the first four standard levels of Alien Invasion, playing two with the ulnar and radial deviation and two with the pronation and supination. She completed successfully all the levels with the exception of the third level of Alien Invasion that she repeated two times without being able to defeat all the enemies.

After the exercises Patient 3 repeated the exercise in the Progress Monitoring Module. The comparison between the data collected in the first session and in the

Figure 7.1: Patient 3 while playing with Shooting Gallery

second session is shown in Table 7.5. The data shows that Patient 3 has increased her ability to move hands after playing with our games and that she also gained confidence in the interaction with the Leap Motion, however the flexion data are underestimated in both the sessions: she was able from the beginning to reach 90 degree of hands' flexion but the hand positioned perpendicular to the Leap Motion is not well recognized, as we explain in subsection 7.4.1,

7.4.1 Comparison between Framework Data and Protractor Data

After the exercises Patient 3 repeated the Progress Monitoring Module and the therapist decided to calculate the same data manually with the protractor to check if the data saved in the Progress Monitoring Module were correct. The comparison between the flexion data collected with our framework and the ones calculated by the therapist is shown in Table 7.6.

The therapist observed a correspondence between the values calculated through the Leap Motion and the ones calculated through the protractor. In fact looking at the left and right extension values, there is no difference between the data collected with Leap Motion and the data calculated with the protractor, however there is a huge difference between the flexion values. This gap in collected data exists because the Leap Motion is able to recognize only hands that have the fingers or the palm visible, but during the performance of the exercise palm and fingers may "disappear"; in fact the movement, that the player has to perform to calculate the flexion ability, is to move down the hand, but when the hand is moved down at ninety degree the palm and fingers are perpendicular to the device that is no more able to see them. When Patient 3 performed the exercise in the Progress Monitoring Module she noticed that the Leap Motion wasn't able to recognize her hand when she performed a flexion movement reaching an angle of ninety degree, so she limited her performance stopping her movement around 40 degree.

	Before playing	After playing
Maximum Left hand Extension	71.1	80.5
Maximum Left hand Flexion	28.5	36.3
Maximum Left hand Ulnar	40.5	44.5
Maximum Left hand Radial	37	37.7
Maximum Right hand Extension	61.4	67.7
Maximum Right hand Flexion	27.1	43.6
Maximum Right hand Ulnar	31.2	34.5
Maximum Right hand Radial	42.5	43

Table 7.5: Table of degree values of Patient 3 hands movements before and after playing the video games

	Progress Monitoring data	Protractor data
Maximum Left hand Extension	80.5	79
Maximum Left hand Flexion	36.3	90
Maximum Left hand Ulnar	44.5	45
Maximum Left hand Radial	37.7	35
Maximum Right hand Extension	67.7	70
Maximum Right hand Flexion	43.6	90
Maximum Right hand Ulnar	34.5	32
Maximum Right hand Radial	43	40

Table 7.6: Table of the degree values of movements of Patient 3 hands after a session with rehabilitation video games, collected by the Progress Monitoring Module vs calculated with the protractor

Chapter 8

Conclusions and future work

We designed and developed a framework to support hand, wrist and forearm rehabilitation of patients affected by Epidermolysis bullosa at home and at hospital. We wanted to create games engaging for players in order to combine fun with physiotherapy exercises and to develop a useful support for the therapists to analyze patients' hand data and to check patients' progress.

Our goal was to create games useful and engaging, to motivate the patients to perform the rehabilitation exercises, preventing them from quitting the rehabilitation due to low motivation, depression or pain that they feel due to the disease.

To achieve our goal we designed the framework comprehending five modules: four video games, a settings tuning module, a progress monitoring module, a level editor and a replay module that allows to view the playback of patients' performances.

We mapped the four games with different hand exercises in order to cover as much tastes as possible. We started from the literature about serious games, and in particular we have studied the experience of previous researchers who developed games for healthcare, they explained that a rehabilitation game should achieve the goal of usefulness combined with the fun of playing. We designed the rehabilitation games for upper limb following the video games design principles to make the game fun, engaging and not frustrating and combining them with the rehabilitation requirement of creating a virtual support for physiotherapy. We developed also a replay mode, that allows the therapist to view the playback of each patient performance and to check the correctness of the exercise executed, and a level editor to generate personalized levels for patients' needs.

We participated to trials with patients at the hospital, and the patients, most of them kids, gave us positive feedback finding the game engaging and fun, and the therapist, looking at the patients' performance, told us that the games are a useful support for home and hospital rehabilitation. Furthermore they confirmed the usefulness of some specific features, such as the replay module and the progress monitoring module for the evaluation of the actual ability to move of each patient. The therapist noticed also that the patients were focused on the achievement of the game's tasks and this is useful since the patients don't pay attention to the pain and the fear of feeling pain while moving caused by the disease.

However this is just a starting point for future evolution. New video games could be added to this framework, for example games that supports finger exercises. Or a different setup of the rehabilitation protocols might be implemented; now the settings are included in the tuning module where the user can select the difficulty of the exercises, in the future the tuning might be automated, adapting dynamically the difficulty during the game. Or adding new modules for the therapist, for example showing the hand data on screen in addition to the replay of performances or improving the level editor leaving more freedom in the design of the exercises to the therapist.

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