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# Rehabilitation games for Juvenile Rheumatic disease to the lower limbs

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*ai miei genitori*

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# Abstract

In the rehabilitation process, the standard physical therapy involves repetitive and tedious exercises. The consequent loss of interest of the patient affects the regularity and the quality of the rehabilitation. Thus, it is important to find ways to make the therapy more bearable.

We designed a framework, with a set of rehabilitation games and features for the analysis, that could help children, affected by Juvenile Idiopathic Arthritis to the lower limbs, in their physical therapy. We started from "*serious games*" principles, and applied the rehabilitation rules of "*exergames*" to obtain games both medical relevant and fun to play, based on the Kinect v2 sensor.

Our work was carried out at Clinica Pediatrica G. e D. De Marchi where we have been helped by a team of therapists and a group of patients, and where we performed a set of experimental sessions in order to validate our games. In particular, we tested how the patients interacted with the games, and verified how our data could help therapists in the evaluation of the rehabilitation. Feedbacks were good from both the subjects, who appreciated the games, and the therapists, who were satisfied with our designed features for the analysis and with the patients' reactions to the games.

# Sommario

Durante il processo di riabilitazione, la terapia fisica è comunemente svolta tramite esercizi ripetitivi, che alla lunga risultano noiosi. Ne consegue una perdita di interesse da parte del paziente, che può inficiare la regolarità della riabilitazione e la qualità del processo di recupero. È importante, quindi, trovare strade alternative per rendere più sopportabile la terapia.

In questa tesi, descriviamo il nostro lavoro di progettazione di un sistema, provvisto di giochi riabilitativi e funzionalità di analisi, che possa aiutare i bambini affetti da Artrite Idiopatica Giovanile agli arti inferiori. Siamo partiti dai principi dei "*serious games*", ovvero dei giochi che sfruttano il divertimento per insegnare, e ci siamo concentrati sulla categoria degli "*exergames*", videogiochi che hanno lo scopo di far compiere attività fisica. Abbiamo combinato questi principi per ottenere un risultato che fosse allo stesso tempo divertente da giocare e di interesse medico, utilizzando il sensore Kinect v2 come interfaccia di input.

Il nostro lavoro si è svolto presso la Clinica Pediatrica G. e D. De Marchi dove, con l'aiuto di terapisti e pazienti, abbiamo condotto una serie di esperimenti per validare il nostro sistema. Abbiamo testato l'interazione tra pazienti e giochi, e abbiamo verificato l'efficacia dei nostri dati nell'aiutare i terapisti a valutare l'esito della sessione di riabilitazione. Abbiamo ricevuto riscontri positivi sia dai pazienti, che si sono divertiti provando i giochi, che dai terapisti, che sono rimasti soddisfatti delle funzionalità offerte dal sistema e dalle reazioni dei pazienti durante gli esercizi.

# 1 Introduction

Rehabilitation is the process by which, after a serious injury, illness or surgery, someone regains strength, relearns skills or finds new ways of doing things done before [1]. Physical therapy is essential for the rehabilitation process of disabling pathologies, and it usually consists of a series of repetitive exercises. In order for the patient to improve his/her physical condition, this therapy must be performed frequently and for a long period of time. The main issue with this approach is that patients tend to lose interest in doing repetitive exercises [2], compromising the effectiveness of the rehabilitation process. It is important to find ways to make more bearable the therapy.

The introduction of input devices such as the Wii Remote, the Wii Balance Board or the Kinect, that require the players to move more than their fingers in order to play a game, induced researchers to consider the possibility of using videogames in the physical therapy. The major characteristic that led researchers to study a possible application of videogames in rehabilitation is the intrinsic ability of games to draw the player's attention using entertainment and challenge. This engagement is really important in rehabilitation since, if a game encourages patients to keep playing it, it will result in the regularity of their physical therapy. Many studies have been conducted (e.g. on Kinect [3]) to validate these new input devices as suitable rehabilitation tools, testing the effectiveness of some off-the-shelf games. These commercial games proved to be unfeasible for every patient because they require speed and movements that someone, with physical impairment, cannot easily perform. As a result, researchers and therapists defined design rules that a rehabilitation game should have. Those rules combine the entertainment and challenge of the common game design, with the specific rehabilitation principles to obtain games both medical relevant and fun to play.

In this work we focused on rehabilitation games, also known as exergames (exercise games), which are those kind of games that help people to perform physical activity and, in our case, to help people with physical impairment to perform their physical therapy. In particular, we focused on the lower limbs rehabilitation of children affected by Juvenile Idiopathic Arthritis (JIA). JIA includes a set of rheumatoid diseases for which has not been defined a cause, yet. The main common symptom of this several types of arthritis is chronic joint inflammation. This inflammation begins before patients reach the age of sixteen and if the symptoms last from six weeks to three months, the disease is called chronic. About one child in every one thousand develops some type of juvenile arthritis [4]. JIA may involve one or many joints, and cause other symptoms such as fevers, rash and/or eye inflammation.

We designed a framework, with a set of rehabilitation games and features for the analysis, that could help patients affected by JIA, to the lower limbs, in their physical therapy. We applied the specific rehabilitation principles to the ones of the common game design, to obtain games both medical relevant and fun to play. We applied the iterative design approach, a methodology based on a cyclic process of prototyping, testing, analysing, and refining of the games. Our aim was to design a set of games that would be entertaining for everyone to play, while helping patients performing their exercises. We opted for a really intuitive and simple gameplay, that way the child can quickly play the game without long training sessions. We also designed a balanced reward system, based on scores and sounds, which rewards a correct performance but, at the same time, does not penalize too much the possible errors. We created multiple contexts in which set our games, trying to reach a range as wide as possible of patients' interests. The first context we made is the dungeon theme. The player's avatar is a mage in a mysterious dungeon that has to face monsters and magical traps. The second context we made involves bees. The player's avatar is a nice bee that has to collect flowers. For the gameplays, we took the five base rehabilitation exercises with the pillows, seen at Clinica Pediatrica G. e D. De Marchi, and tried to make them fun. The first type of game uses three pillows in a horizontal row and is based on the "*endless runner*" games: the player's avatar cannot stop its forward momentum, and has to dodge several obstacles. The second type of game uses nine pillows disposed on a 3x3 grid. There is a countdown within which the child has to move to the highlighted pillow to avoid penalty. To break monotony, we added the possibility to change the conditions for every game (time, lives, shifts or any combination of them). To further personalize the game experience, we added the possibility to change some game's parameters (e.g. changing the time allowed to shift from one pillow to another). We also focused on the design of a set of helpful features for the therapists' analysis. We save two kinds of information: the 3D spatial coordinates of every skeleton's joints of the player, and the video captured by the camera. The first information is useful to see if the therapy is helping the patient in reducing his/her movement limitations and in correcting the bad compensatory postures. The second information is useful to see the replay of the games. This feature is useful both because it provides the chance to see exercises guided by the colleagues (or performed directly at home), so without the therapist being there; and also because, overlaying computed data like the ones of the postures, it provides a qualitative feedback more intuitive and immediate than the common plots. This helps therapists to find possible mistakes in the exercises and to directly show them to the patient, in order to let him/her recognize what was wrong.

Finally, at Clinica Pediatrica G. e D. De Marchi, we performed a set of experimental sessions, in order to validate our framework. We have been helped by a team of therapists and a group of patients. We inserted our games in the normal rehabilitation sessions, and substituted them to the canonical pillow exercises. We tested how patients interacted with the games, and verified how our data elaboration would help therapists in the evaluation of the rehabilitation. With the tuning session, we wanted to obtain a first feedback to validate our work, both from a rehabilitation point of view and with respect to the subjects' engagement. In the following therapeutic sessions, we focused more on the user experience. Feedbacks were good from both the subjects, who appreciated the games, and the therapists, who were satisfied with our designed features for the analysis and with the patients' reactions to the games. In particular, they noticed that the patients, concentrated on increasing the score, didn't pay much attention to their impediments and moved faster than the usual.

## 1.1 Thesis Organization

The document is organized as follows:

*Chapter 2* is an overview of the games for rehabilitation. We discuss what they are, their aim, their characteristics, and present some of the developed solutions for rehabilitation, focusing on those for the lower limbs.

In *Chapter 3,* we present the Juvenile Idiopathic Arthritis (JIA), its causes, symptoms and treatment. Finally, we present the five exercises performed at Clinica Pediatrica G. e D. De Marchi during the rehabilitation sessions of patients affected by JIA, to the lower limbs.

*Chapter 4* presents the framework we designed. We initially discuss the design process, from the rehabilitation principles of the literature to our work. Then, we describe the preliminary meeting hold at Clinica Pediatrica G. e D. De Marchi and the requirements that brought us to use the Kinect v2 sensor as input device. Finally, we show an overview of the framework.

In *Chapter 5,* we analyse the data retrieved during the experimental sessions. We describe the experimental setup of each session, the feedback received from therapists, subjects and relatives. We present and comment the plots relative to the data collected.

In *Chapter 6*, we draw our conclusions and present possible future developments of our work.

# 2 State of the art

In this chapter, we discuss serious gaming, in particular we focus on the sub-genre specific for rehabilitation, a.k.a. exergames. We define what a serious game is and the evolution that led videogames to be used for rehabilitation. We present some specific game design principles found in the rehabilitation literature. Finally, we give an overview of the state of the art for generic rehabilitation, ending with the specific solutions for the lower limbs.

## 2.1 Serious Gaming for Rehabilitation

The term "serious game" has been used long before the introduction of electronic devices into entertainment. In 1970, Clark C. Abt gave a useful general definition which is still considered applicable in the computer age: "*We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement"* [5]; so gaming, according to Abt, is not seen just like a fun distraction, but as a valuable teaching tool.

Serious games are spreading thanks to the new technologies involved in the development of video games. They have important applications in several areas such as: military, health, government, and education [6]. In particular, games of the health environment can be valuable in diagnostics, prevention, training, fitness, rehabilitation, etc. In our case, we focused on the application to rehabilitation. The aim of this kind of games is to help people who have compromised physical functionality, as a consequence of a disease or traumatic event, to perform their physical therapy throughout the rehabilitation progress.

Rehabilitation is the process by which, after a serious injury, illness or surgery, someone regains strength, relearns skills or finds new ways of doing things done before [1]. Physical therapy is essential for the rehabilitation process of disabling pathologies, and it usually consists of a series of repetitive exercises which, most of the time, are also painful. The aim is not necessarily the full restoration of the lost functionality, but rather the optimization of the quality of life for those not able to achieve full restoration. In order for the patient to improve his/her physical condition, this therapy must be performed frequently and for a long period of time, both at the hospital and at home. The main issue with this approach is that patients tend to lose interest in doing repetitive exercises [2], compromising the effectiveness of the rehabilitation process. If it is difficult for a grown man to resist to depression and pain, it is certainly true for a child. The issue worsen when the patients have to perform their exercises at home, without a therapist that supervises and encourages them.

The increasing popularity of videogames drew the attention of the researchers as a possible solution to this psychological problem. The success of videogames is undeniably due to their ability to entertain and engage people, motivating them to keep playing even after long periods of time. Researchers wanted to use this kind of engagement to boost the patients to keep performing their therapy. As virtual reality (VR) and videogames were introduced in the rehabilitation process, two limitations raised. Firstly, the VR systems were not affordable to the general users (both researchers and patients); secondly, it was needed the presence of technical experts during therapy sessions [7]. These limitations prevented patients from performing the exercises whenever and wherever they wanted, affecting the regularity of the rehabilitation.

The introduction of new input devices such as the Wii Remote, the Wii Balance Board or the Kinect, helped to overcome those limitations. Unlike the classic tactile controllers like joysticks, mouse or keyboards, these new devices required the players to move their body in order to play. The cost of the devices, and relative platforms, was relatively cheap making the games development on these platforms more accessible. Studies were conducted (e.g. on Kinect [3]) to validate these instruments as suitable rehabilitation tools, testing the effectiveness of some off-the-shelf games. These commercial games proved to be impractical for every patient because they require a speed and a range of movements that someone, with physical impairment, cannot easily perform. As a result, came the need to define specific game design rules that would guide developers in designing therapeutic games.

Nixon and Howard [8] define a set of five principles useful to create engaging rehabilitation games. The first principle regards the in-game story. They say that an engaging story or context is crucial when trying to appeal players. It is also important to design an intuitive user interface, since the player’s concentration should focus on how to beat the game, not on decrypting the screen messages. They remark the importance of providing immediate feedback to the player about the right or wrong behaviours kept while playing. Additionally, the game should encourage the player to explore and become familiar with his/her capabilities within the game; this helps the player acquiring better control over his/her avatar. Finally, the player should be rewarded in order to keep him/her engaged in the game and to encourage him/her to play again, increasing his/her skills in order to get better rewards.

Mader et al. [9] argue that two fundamental features to the game designer's work are challenge and variability. These aspects are strongly related to the repetitiveness of the physical therapy. In order to keep the player motivated, the game has to notify him/her of his/her progression towards the goal. Also adapting the challenge level prevents boredom in the player. Variability accounts for the motivation in the long run. As Mader et al. state "*it is not enough to give the player the same task with an adapted difficulty level, we must also make him learn new patterns, gather new informations, explore the consequences of making different choices*". Mader et al. [9] also propose a model to evaluate a therapeutic game. This model is based on three entities (the game, the therapy and the player) and on the relations between them. Starting from the therapy-player relation it is necessary to evaluate if the player has a particular condition that can be improved by the treatment. Then should be evaluated what is the context of play (e.g. at the medical facility or at home, with a therapist or alone), what is the place of the game within this context, which game features are therapeutic (e.g. the gameplay) and which game features have only motivational purpose. As a final point, it should be evaluated whether the player is able to play the game, if the game is enjoyable and if it is safe for the patient's health.

Many studies have been conducted in the field of rehabilitation and much work has been done. Now we propose some of the principal solutions for the generic rehabilitation.

Borghese et al. [10] worked on the Intelligent Game Engine for Rehabilitation. They integrated user interfaces, like Microsoft Kinect, with a fully "*adappatient's current statustive*" game engine, a system that can be used for rehabilitation at home. To maximise the patient's motivation and rehabilitation effectiveness, they implemented a variety of game scenarios, a balanced scoring system, quantitative and qualitative exercise evaluations, automatic gameplay level adaptation to patient's current status, and audio-visual feedbacks. The system is integrated into a multi-level platform that provides continuous monitoring by the hospital.

Gil et al. [11] designed a low-cost framework that lets to use generation tools to customize standing exercises. It allows less dependence of the patient in relation to the specialist, providing objective measures of the exercises evolution, and increasing the patient's motivation in the rehabilitation process. It is based on catadioptric velcro strips attached to the patient feet and on two cameras. Targets on the floor are shown to the patient and disappear when walked over.

Cameirao et al. [12] developed a system for the rehabilitation of patients suffering from different neuropathologies, such as those brought on by stroke and traumatic brain injury. Cameirao et al.'s Rehabilitation Gaming System (RGS) uses a vision based motion capture system with gaming technologies and continuous monitoring. Game design, game adaptation and usability were all evaluated in strict collaboration with clinicians.

Zhang et al. [13] created a system for post-stroke hand rehabilitation that integrates videogames, augmented reality (AR) and an instrumented glove. The game consists in a virtual piano that the patient can play with his/her fingers. They designed different levels of difficulty both to challenge the single patient and to take into account the different physical conditions of the patients. They also implemented a quantitative feedbacks for the therapist to analyse.

Burke at al. [14] presented a series of games for the upper limbs rehabilitation. They developed a couple of games that use a webcam as input, and a marker (e.g. a glove) to keep track of the patient's hands positions. They also used a magnetic sensor to track upper limb movements. It is a "whack a mole"-like game, in which the player has to use his/her hand as a hammer and hit a mouse moving on the screen.

Ustinova et al. [15] developed a game called Octopus, to improve arm and postural coordination in patients with traumatic brain injury. The goal of the game is to pop the bubbles blown by an octopus, either with the left or the right hand. Patient-computer interaction is obtained using a 6-camera system with three reflective markers attached to each hand. When the bubbles are intercepted, the game rewards the player with scores and new characters. The game also keeps track of the patient's movements and analyses his/her coordination.

Friedman at al. [16] developed the "MusicGlove", an instrumented glove that requires the user to practice gripping-like movements and thumb-finger opposition to play. They used a customized version of Frets on Fire, an open-source music game inspired by Guitar Hero. They tested the glove effectiveness in post-stroke hand rehabilitation. Results support the hypothesis that hand therapy, that is engaging and incorporates high numbers of repetitions of gripping and thumb-finger opposition movements, is a promising approach to improving an individual's ability to manipulate small objects.

## 2.2 Rehabilitation of the Lower Limbs

Rehabilitation of the lower limbs is a research field less explored compared to the one of the upper limbs. This is probably due to the fact that, in the past, it was easier to develop input devices controlled by the hands. Nowadays, with optic input devices like the Kinect, it is possible to capture all body movements without wearing constraints. Carlos Luque-Moreno et al. [17] developed a systematic review of the literature to describe the different virtual reality and interactive videogames solutions applied to the lower extremity of stroke patients. Even if we worked with arthritis patients, there are many design challenges in common and it is interesting to see the existing solutions.

Jaffe et al. [18] compared two training groups: real and virtual. In the first one, real obstacles were used while in the virtual group a head-mounted device was used to observe the simultaneous registration of the legs' real movement, introducing virtual stationary images of obstacles and getting a patient's feedback. The virtual obstacle training generated greater improvements in gait velocity compared with real training during the fast walk test and the self-selected walk test [17].

Gil-Gómez et al. [19] compared an intervention program with the Nintendo Wii Balance Board (WBB) with eBaViR to a conventional physiotherapy treatment in patients with brain damage. Although 6 of the 17 patients had hemiplegia not secondary to a stroke, this trial was also included for the treatment approach that it shows since flexible software for Wii, specific for rehabilitation, was designed. Patients using the Wii Balance Board had a significant improvement in static balance, compared to patients who go through traditional therapy. With regard to dynamic balance, there were no differences between study groups [17].

Fritz et al. [20] compared an experimental group that used Nintendo Wii (Wii Sports and Wii Fit) and Play Station (Eye Toy Play 2 and Kinetic) with a control group that underwent no intervention. No statistically significant differences in the comparison between or within groups were found, either in the short term or in the follow-up process [17].

Chen et al. [21] used a human-computer interactive videogame based rehabilitation device (LLPR) for the training of lower limbs muscle power in the elderly. Twenty over forty participants in the exercise group received a 30-min training, twice a week, using the LLPR system. The LLPR system allows participants to perform fast speed sit-to-stand movements. Twenty age-matched participants in the control group performed slow speed sit-to-stand movements, as well as strengthening and balance exercises, with the same frequency and duration. Results showed that in the exercise group, all the mechanical and time parameters showed significant improvement. In control group, only the maximal vertical ground reaction force improved significantly. For clinical assessments (balance, mobility, and self-confidence), exercise group showed significantly better scores.

## 2.3 Summary

Physical therapy is essential for the rehabilitation process of disabling pathologies, and it usually consists of a series of repetitive exercises. In order for the patient to improve his/her physical condition, this therapy must be performed frequently and for a long period of time. The main problem with this approach, is that patients tend to lose interest in doing repetitive exercises, compromising the effectiveness of the rehabilitation process. A solution may be found in the "*exergames*", which are videogames that teach the player to perform physical activity and correct movements.

Many studies have been conducted in the field of rehabilitation, using both videogames and virtual reality solutions. Most of them focus on the upper limbs rehabilitation, because in the past it was easier to develop input devices controlled by the hands. Nowadays, with optic input devices like Kinect, it is possible to capture all the body movements without wearing constraints. The upper limbs still remain, though, "easier" to be inferred by sensors due to the lower reference points, usable by optic devices, in the lower limbs.

At Clinica Pediatrica G. e D. De Marchi, Rocco et al. [22] worked on the rehabilitation of the upper limbs, while we focused on the rehabilitation of the lower limbs.

# 3 Juvenile Idiopathic Arthritis

In this chapter, we describe the rheumatic disease known as Juvenile Idiopathic Arthritis (JIA). At first, we discuss the disease cause, its progress, the disease onset types and the suggested therapy. Finally, we describe a set of exercises for the lower limbs rehabilitation performed at Clinica Pediatrica G. e D. De Marchi, which are the base of our work.

Arthritis is an inflammation of the joints that is characterized by swelling, heat, and pain.

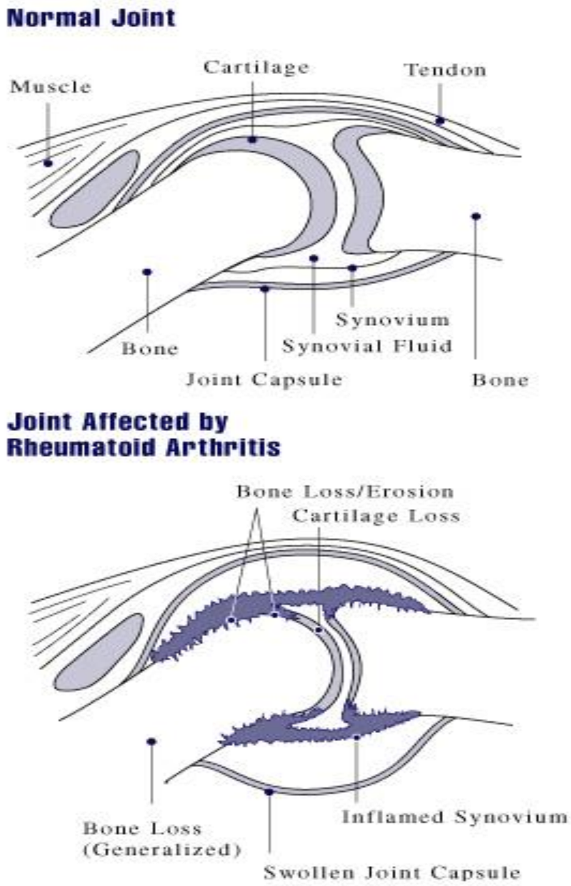


*Figure 3.1 Arthritic joint scheme [23]*

The juvenile idiopathic arthritis (JIA), also known as juvenile rheumatoid arthritis (JRA), is a broad term that describes a clinically heterogeneous group of arthritis of unknown cause, which begins before 16 years of age. If these conditions last for at least six weeks, the arthritis is considered chronic. About one child in every one thousand develops some type of juvenile arthritis [4]. This term incorporates several disease categories, each of which has distinct methods of presentation, clinical signs, symptoms and, in some cases, genetic background. The cause of disease is still poorly understood but seems to be related to both genetic and environmental factors, which result in the heterogeneity of the illness [24]. Research also indicates that it is an autoimmune disease. In autoimmune diseases, white blood cells can't tell the difference between the body's own healthy cells and germs like bacteria and viruses. The immune system, which is supposed to protect the body from these harmful invaders, releases instead chemicals that can damage healthy tissues and cause inflammation and pain [23].

*Figure 3.2 Juvenile idiopathic arthritis on legs [25]*

Arthritis Research UK [26] defines five compact onset types for JIA:

*Systemic arthritis*: affects the whole body. Symptoms include high fevers that often increase in the evenings and then may suddenly drop to normal. During the onset of fever, the child may feel very ill, appear pale, or develop a rash. The rash may suddenly disappear and then quickly appear again. The spleen and lymph nodes might become enlarged. Eventually many of the body's joints are affected by swelling, pain, and stiffness.

*Oligoarthritis*: the most common type, affects about two thirds of young people with arthritis. Disturbs four or fewer joints. Symptoms include pain, stiffness, or swelling in the joints. The knee and wrist joints are the most commonly affected. The two types of oligoarthritis, persistent and extended, are determined by how many joints are ultimately involved. Also, an inflammation of the iris (the coloured area of the eye) may occur with or without active joint symptoms. This inflammation, called iridocyclitis, iritis, or uveitis, can be detected early by an ophthalmologist.

*Polyarticular arthritis*: the second most common type of JIA. Symptoms include swelling or pain in five or more joints. The small joints of the hands are affected as well as the weight-bearing joints like the knees, hips, ankles, feet, and neck.

*Psoriatic arthritis*: psoriasis is a skin rash. Kids with this have the psoriasis rash themselves or a close relative with psoriasis. Their fingernails and/or toenails might be affected by the condition.

*Enthesitis-related arthritis:* most commonly affects the lower extremities and the spine. Kids also might have inflammation where tendons join bones (e.g. where the Achilles tendon attaches to the back of the heel). Enthesitis-related arthritis includes a special group call juvenile ankylosing spondylitis (where joints of the low back are inflamed) and arthritis associated with inflammatory bowel disease (Crohn's disease and ulcerative colitis).

## 3.1 Treatments

A cure to chronic arthritis has not yet been found, but luckily there are many cases of spontaneous remission. Therapy goal is to induce this remission while controlling pain and preserving range of motion, muscle strength, physical and psychological development [27]. Most children with chronic arthritis require a combination of pharmacological, physical, and psychosocial approaches. A main priority is to encourage the normal social growth, in order for the child not to feel left out. Affected children should be involved in the same activities as the healthy ones, at their own level. Activities with other kids, affected by chronic arthritis, can also help the children to realize that they are not the only ones with arthritis.

Concerning the disease treatment, there are four main aspects:

*Pharmacological management*: the treatment should begin as soon as the disease is discovered; the sooner it starts, the less probable it is that there will be permanent *sequelae*[1]. Nonsteroidal anti-inflammatory drugs are likely to be the first medicine used to reduce inflammation and pain [28].

*Nutrition*: together with development, is an important aspect of long-term management. Nutritional and vitamin supplementation are often indicated.

*Physical therapy*: its objective is to minimize pain, maintain and restore functionality, prevent deformity and disability, correct wrong compensatory behaviour.

*Orthopaedic surgery*: it has a limited role in management of chronic arthritis in young children. In the older children it could be helpful in the treatment of joint contractures, dislocations, or joint replacement.

### 3.1.1 Physical Therapy

As discussed in the previous section, one of the main symptoms of the juvenile idiopathic arthritis (JIA) is joint inflammation. If this symptom is not treated, it can result in the loss of articular functionality and in the consequential worsening of the patient's quality of life. Moreover, the child interiorizes incorrect compensatory postures or movements that persist even after a full recovery. These compensations burden on muscles and other joints, leading to new possible physical problems. For these reasons, the main goal of physical therapy is not the healing of the inflammation, but to help the patient managing the symptoms and improving his/her self-sufficiency. The therapist guides the child in the process of understanding which are his/her moving capabilities, both in natural and in sport activities. He/she also helps reducing the patient's fear of pain and the family's propensity to overprotect.

The physical therapy should be customized for each patient and should take place both at the medical structure and at home. In combination with this monitored process, therapists recommend also to play some sports. Indeed, a main aspect of physical therapy is allowing the child to live a life as normal as possible, and sports can help him/her not feeling different.

There are exercises for both large joints, such as the knees or the shoulders, and small joints, such as those of the hand. In this work we focused on the exercises for lower limbs rehabilitation, especially on those where the patient has to stay in equilibrium (static and dynamic) on different ground surfaces. We

[1] Plural of "sequela", sequelae are pathological conditions resulting from a disease, injury, therapy, or other trauma. They are further conditions, consecutive to a first different condition.

now describe the five exercises preformed at Clinica Pediatrica G. e D. De Marchi and that guided us in the design phase. All the exercises are performed without wearing shoes.

*Figure 3.3  JIA rehabilitation exercise with square pillow*

In the first exercise (Figure 3.3), the patient rests in the centrum of the special foam rubber pillow. To achieve equilibrium, the body has to compensate the waning of the feet in the rubber. All the lower limbs system (hips, knees, ankles and muscles) works.

*Figure 3.4  JIA rehabilitation exercise with roll pillow*

In the second exercise (Figure 3.4), the pillow stays on the ground while the patient sits on a chair. The pillow is made of the same foam rubber of the square pillow of the previous exercise. The patient place the feet on the pillow and rolls it back and forward. In the advanced step of the exercise, the patient increases the pressing force, and extends the roll angle of the ankles. This exercise is also useful to stimulate the tactile perception of the lower limbs.

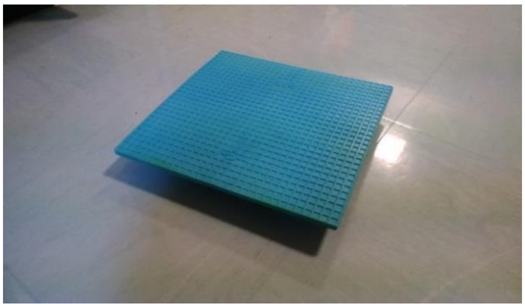

*Figure 3.5 JIA rehabilitation exercise with balance board, squared*

*Figure 3.6 JIA rehabilitation exercise with balance board, circular*

In the third exercise (Figure 3.5), the patient places the feet on the squared balance board. In the easy version, the patient sits on a chair, like the previous exercise, and swings the board back and forward working on knees and ankles; in the advanced version, the patient stands up in equilibrium and use all the lower limbs system (hips, knees, ankles and muscles). An even more difficult version, which is the same used by football players, uses a circular balance board with 360 degrees of liberty (Figure 3.6).

*Figure 3.7 JIA rehabilitation exercise with aero-step*

In the fourth exercise (Figure 3.7), the patient stands on the aero-step. The aero-step consists in a couple of connected air chambers: if you press one chamber, the air flows to the other. The patient shifts the body weight from one leg to the other, using all the lower limbs system (hips, knees, ankles and muscles) to win the air resistance of a chamber and finding an overall balance.

*Figure 3.8 JIA rehabilitation exercise with different surfaces route*

In the fifth exercise (Figure 3.8), the patient walks throw a route of pillows and other obstacles. The pillows have similar shapes, but every ones have different consistence. Some are light and soft, others are heavy and tough, some allows the feet to sink, and others support the body weight. The obstacles are plastic surfaces with different shapes and different degrees of pendency. The patient walks back and forth along the route, adapting to the different surfaces. Every few time, the therapist changes the order of the pillows without being seen by the patient. In this way the patient doesn't learn the schema, and has to constantly work on adapting and balancing. It is a difficult but important exercise, and all the lower limbs system (hips, knees, ankles and muscles) works. It is also important to a cognitive level, due to the "trick" of the switched pillows, in fact the patient has to adapt in real time to different way of walking, just like it happened in everyday life. It helps boosting the patient confidence and reduces the risk of injury in the normal shifts. Due to the importance of this exercise, it is the one who mostly guided us through the games design phase.

# 4 Designing Rehabilitation Games for JIA

In this chapter, we initially discuss the design process, from the rehabilitation principles of the literature to our work. Then, we describe the preliminary meeting hold at Clinica Pediatrica G. e D. De Marchi and the requirements that brought us to use the Kinect v2 sensor as input device. Finally, we show an overview of our rehabilitation framework, focusing on the implemented games.

## 4.1 Designing Rehabilitation Games

When people think about rehabilitation games, they usually don’t consider them as real games, but more as medical applications masked as games. This impression leads to underestimate their potential and, more importantly, might result in the design of non-enjoyable solutions.

An important step forward has been made by the introduction of new input interfaces, such as the Wii Remote and the Kinect. Using these new devices, general public experienced new types of games that did not focus only on pure entertainment, but also have a therapeutic value. This benefited rehabilitation games in two ways: on one side it drew back the researchers’ attention to virtual therapy; on the other side, it shorted the distance separating real games from serious games. Indeed, to shorten the distance, hardware alone is not enough, it is necessary to create games with the idea that everyone can play it and having fun with it. The main focus on rehabilitation still remains in our case, but keeping in mind this ideal allows us to design games that effectively draw the patients’ attention and help them to endure with their therapy. In order to achieve our goal, we needed to apply those general game design rules that characterize every game, and add to those rules some specific ones for serious games.

A good game design is based on entertainment. This aspect is vital, because the ability of a game to keep you stuck to the screen is what differentiates the good games from the bad ones. The entertaining factor is even more important when dealing with rehabilitation games. As seen before, the main issue affecting patients who are going through a rehabilitation process is the monotony of the exercises. Physical therapy is intrinsically repetitive and in the long run it becomes boring. The lack of interest could affect the efficiency and the continuity of the therapy, disturbing the rehabilitation process and, consequently, the quality of life. Therefore, the need to create games that draw the patients' attention, encouraging them to exercise as much as possible.

Creating an entertaining game is not simple. One of the main challenges is to balance the gameplay in order to make the game neither too easy, risking the patient to get bored, nor too difficult, getting frustrating: when the player either loses or performs bad, he/she has to feel like he/she was almost there, like if he/she plays once more he can achieve better. To prevent the loss of interest by the patient, we need to avoid both extreme cases.

Entertainment is not only affected by the gameplay. Another important aspect is the feedback that the game provides to the players regarding their performance. It could be used a rewarding system that encourages players to perform better, aiming to increase the received reward.

Keeping in mind these observations, we designed our games trying to make them as much entertaining as possible, while keeping their therapeutic value. We opted for a really intuitive and simple gameplay, that way the child can quickly play the game without long training sessions. We also designed a balanced reward system, based on scores and sounds, which rewards a correct performance but, at the same time, does not penalize too much the possible errors. The score is incremented every time the player does something good, and it is not decreased when the player makes a mistake. In this way, the child that has done something good and a lot of errors, won't see his efforts nullified by a zero points score, instead he/she will have a score comparable with those of his/her friends. The sounds support the score rewarding system. The sounds made by the player's avatar are different based on the fact that the obstacles is avoided or hit; also the music at the end of the game changes based on the good or bad performance.

Children affected by JIA are both male and female and the gap of ages between them can be considerable. Different people, in different growth states, have different tastes and enjoy different things. Inspired by the design rules for serious games, we created multiple contexts in which set our games, trying to reach a range as wide as possible of patients' interests. To break monotony, we added the possibility to change the conditions for every game (time, lives, shifts or any combination of them). To further personalize the game experience, we added the possibility to change some game's parameters (e.g. changing the time allowed to shift from one pillow to another). Firstly, to help the less responsive patients, giving them more resting time; secondly, to please the more hard-core gamers, making the game faster and more challenging. It could also be used to allow the patients' relatives to play with them in a more connecting way.

We tried to make our contexts as enjoyable as possible for everyone. The first context we made is the dungeon theme. The player's avatar is a mage in a mysterious dungeon that has to face monsters and magical traps. It is born as a male theme, but also females can appreciate it. Nowadays, fantasy is more accessible and stratagems like coloured dancing skeletons improve the entertainment. We added some epic music tracks to increase identification in the avatar. The second context involves bees. The player's avatar is a nice bee that has to collect flowers. It is born as a female theme, but also male can appreciate it. We added some catchy jazz music tracks in harmony with the landscapes.

For the gameplays, we took the five base rehabilitation exercises with the pillows and tried to make them fun. The first type of game uses three pillows in a horizontal row and is based on the "*endless runner*" games: the player's avatar cannot stop its forward momentum, and has to dodge several obstacles. Using only three pillows, this type of game results the simplest because the child has to move "only" along a row, so it is easier to maintain spatial references. We thought that the dynamism of the endless runner could perfectly keep high the entertainment for the more capable children. The second type of game uses nine pillows disposed on a 3x3 grid. There is a countdown within which the child has to move to the highlighted pillow to avoid penalty. This type of game is very difficult not only at a physical level, but also at a cognitive one.

*Figure 4.1 Mirrored avatar*

*Figure 4.2 Turned avatar*

In the game, are the patient's movements to produce the shifts of the avatar on the screen. Basing on the avatar's orientation (mirroring the player as in Figure 4.1, or turned on his back as in Figure 4.2), the patient has to think how to move in order to place the avatar on the right pillow. Some people would prefer the first setting, the mirror like one; others would prefer instead the second case, the one with the direct control. It is an instinctive preference, probably due to the behaviour of the *mirror neurons*[2]. Accordingly, we added

[2] A "mirror neuron" is a neuron that fires both when an animal acts and when the animal observes the same action performed by another [32].

the possibility to choose how to orientate the avatar, making the game simpler or harder. The harder version introduces a cognitive challenge which has been revealed useful not only for the JIA rehabilitation, but also for *cerebellitis*[3] or other similar pathologies.

One of the features of using rehabilitation games for physical therapy is that they allow to retrieve the game's data in order to analyse the patient's performance. Using these data, it is possible to keep track of the patient's progress, and also to have a quantitative and qualitative feedback about his/her movement proficiencies. For this reasons, we chose to save two kinds of information: the 3D spatial coordinates of every skeleton's joints of the player, and the video captured by the camera. The first information is useful to see if the therapy is helping the patient in reducing his/her movement limitations and in correcting the bad compensatory postures. The second information is useful to see the replay of the games.

The replay mode allows therapists to see how the patient performed the exercise. This feature is useful both because it provides the chance to see exercises guided by the colleagues (or performed directly at home), so without the therapist being there; and also because, overlaying some computed data like the ones of the postures, it provides a qualitative feedback more intuitive and immediate than the common plots. This helps therapists to punctually find possible mistakes in the exercises and to directly show them to the patient, in order to let him/her recognize what he/she did wrong.

## 4.2 Preliminary Meeting and Requirements

During the first meeting, therapists showed us how the physical therapy for JIA is performed. After a brief explanation of the inflammation effects on the joint articulations and which are the main goals of physical therapy, therapists presented us a set of exercises. These involved the lower limbs system (hip, knees, ankles, muscles). We searched for the appropriate input devices that would allow us to virtually recreate the movements required by the exercises.

Our attention was drawn by the Kinect sensor (Figure 4.3). The Kinect sensor is a physical device with depth sensing technology, a built-in colour

[3] Post-viral cerebellar ataxia (ACA), also known as acute cerebellitis, is a disease characterized by the sudden onset of ataxia following a viral infection [33]. The disease affects the functionality of the cerebellum region in the brain. With ataxia is intended a neurological sign consisting of lack of voluntary coordination of muscles movements that includes gait abnormality.

camera, an infrared (IR) emitter, and a microphone array, enabling it to sense the location and movements of people as well as their voices. It allows the user to interact with the computer by the movement of his/her own body.

We had to choose between the previous publicly available version (released on February 1, 2012 [29]), and the second version (released on July 15, 2014 [30], in closed beta for developers). The first generation would no longer be supported, and it had less hardware capabilities (Figure 4.4). Thus, we opted for the second generation, known as “Kinect v2” or “Kinect for Xbox One”. It offers a greater overall precision and responsiveness.

Kinect v2 connects to the PC via USB 3.0 cable and requires a 64-bit (x64) processor, a physical dual-core 3.1 GHz (2 logical cores per physical) or faster processor, a graphics card that supports DirectX 11 and, most of all, Windows 8 or 8.1 [31].

The camera space refers to the 3D coordinate system (Figure 4.3) defined as follows: the origin (x = 0, y = 0, z = 0) is located at the centre of the IR sensor; X grows to the sensor’s left, Y grows up (note that this direction is based on the sensor’s tilt), Z grows out in the direction the sensor is facing. The higher resolution depth of 512 x 424 makes it easier to see smaller objects and to view in three dimensions (3D). The sensor’s colour camera is enhanced with full 1080p video that can be displayed in the same resolution as the viewing screen (Figure 4.5).


*Figure 4.3  Kinect for Xbox One [32]*

**Kinect V1 vs Kinect V2**

| Feature | Kinect for Windows 1 | Kinect for Windows 2 |
|---|---|---|
| Color Camera | 640 x 480 @ 30 fps | 1920 x 1080 @ 30 fps |
| Depth Camera | 320 x 240 | 512 x 424 |
| Max Depth Distance | ~4.5 M | ~4.5 M |
| Min Depth Distance | 40 cm in near mode | 50 cm |
| Horizontal Field of View | 57 degrees | 70 degrees |
| Vertical Field of View | 43 degrees | 60 degrees |
| Tilt Motor | yes | no |
| Skeleton Joints Defined | 20 joints | 25 joints |
| Full Skeletons Tracked | 2 | 6 |
| USB Standard | 2.0 | 3.0 |
| Supported OS | Win 7, Win 8 | Win 8-8.1 (WSA) |
| Price | $299 | TBD |

*Figure 4.4  Kinect V1 vs Kinect V2 [33]*

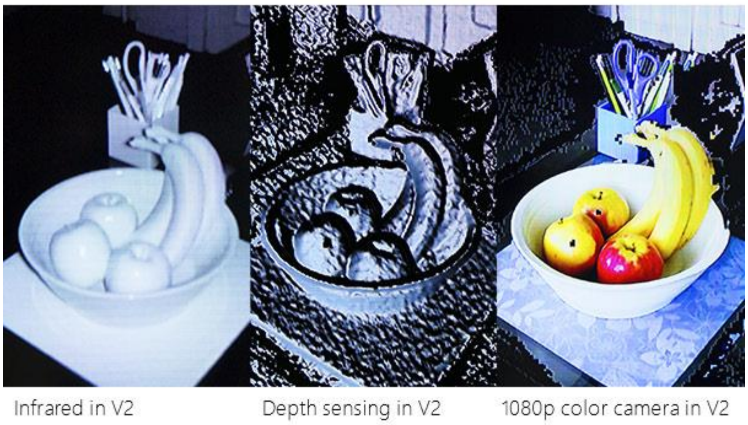


*Figure 4.5  Kinect v2 camera features [34]*

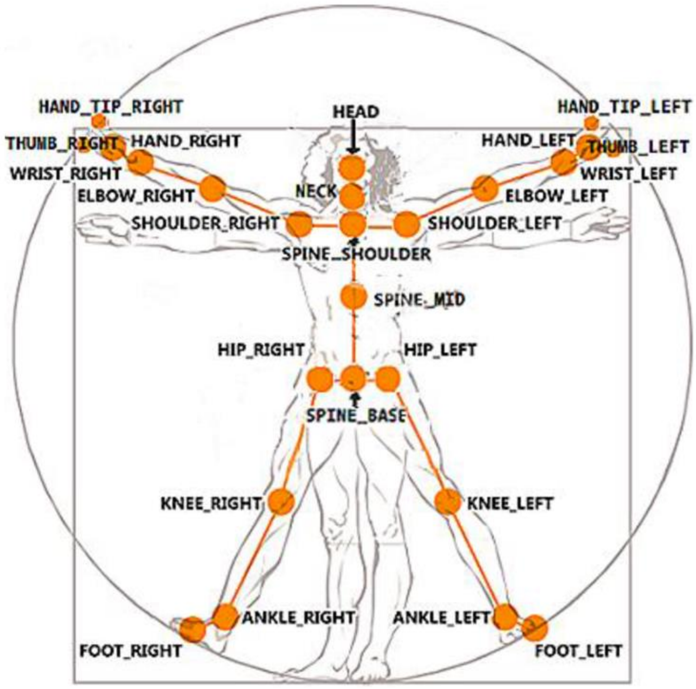


*Figure 4.6 Body joints [35]*

Kinect can tracks as many as six people and 25 body joints per person (Figure 4.6) in a more correct and stable way than the old one, and the range of tracking is broader. The sensor needs to see the head to recognize the human body, and starts to build the skeleton from the spine base joint.

To summarize, we decided to use the Kinect v2 as input device for the following five main reasons:

- the player doesn’t have to hold or wear any physical device, so he can move freely without being frightened by electrodes or cables;
- the precision of the device is quite good, even in an environment with passing people in the background;
- the device has a discrete portability, so the patient can do his/her exercises wherever he/she wants (presuming having access to a PC);
- it is easy to install and to use, so there’s no need for an expert support;
- it is sold with the Microsoft’s gaming console Xbox One, so many patients could already have it in their home.

## 4.3 Main Application and Games

In this section, we present the designed games, developed according to the methodology explained before. We applied the iterative design approach, a methodology based on a cyclic process of prototyping, testing, analysing and refining. We validated our work with the results of the experimental sessions, both in terms of qualitative feedbacks (from therapists, subjects and families) and quantitative (the data collected during the sessions).

All the developed games are part of a single integrated framework. Figure 4.7 shows an overview of the system architecture. The Kinect v2 is the physical interface linking the user and the PC. It tracks the movements of the player's skeleton and sends them as input to the application.

The framework is divided in two parts, one for the therapist and one for the player. Every patient has a profile, in which the system saves stats and preferences (no personal information are stored. Patients are identified by nicknames). For simplicity, every game has default parameters which were set by the therapists. There is, however, the possibility to customize the settings for each profile and for each game, as it is a fundamental feature for a correct rehabilitation process. The therapists can manage these profiles: they can create, edit or delete them; they can view, for each profiles, the trend of the postures of the played games; they can view the replays.

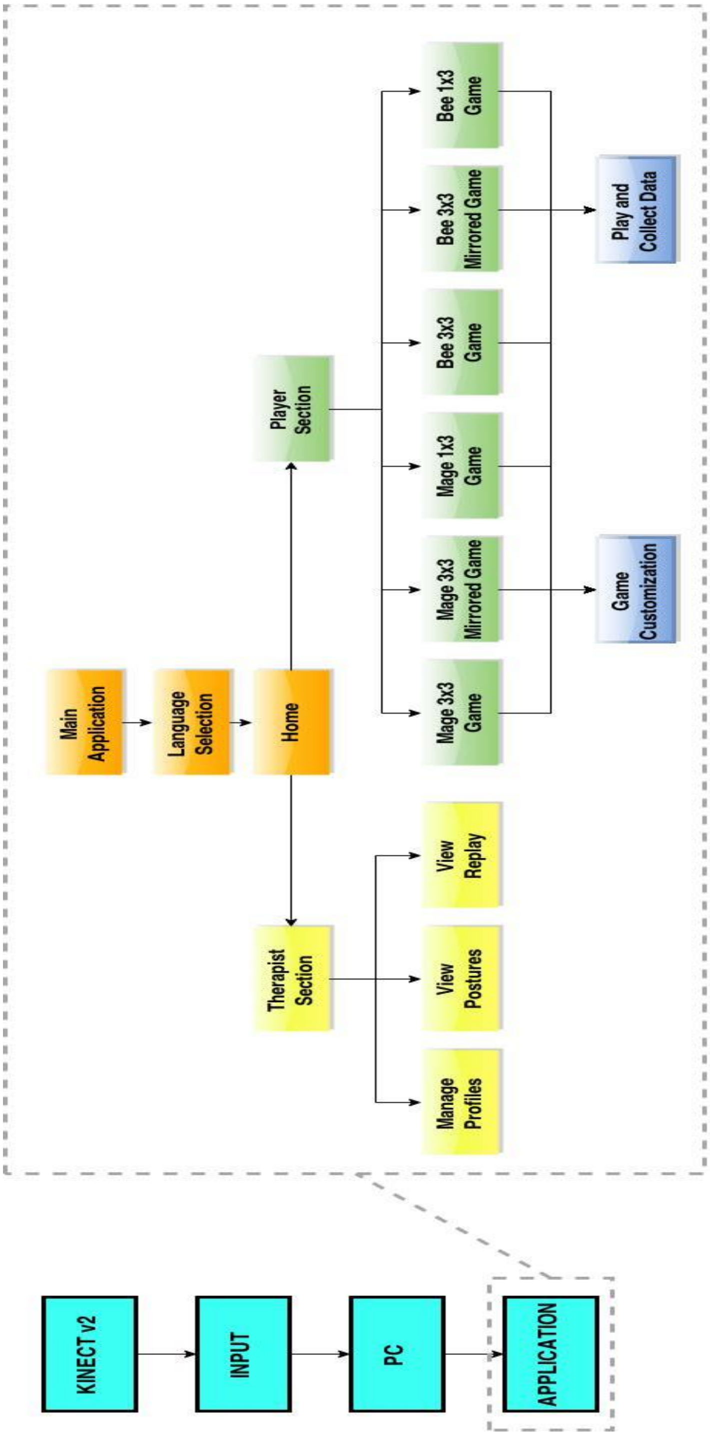


*Figure 4.7 System architecture overview*

Thanks to the replay feature, the therapist can re-watch the performed exercises.


*Figure 4.8 Replay view*

Over the camera registration (Figure 4.8), we overlay the skeleton data captured with the Kinect v2, to help therapists in the evaluation process. On the left of the screen, we show the posture's degrees of the joints of interest (shoulders, hips, knees, ankles). This helps to determinate the wrong postures interiorized by the child to compensate the affected mobility. On the right side of the screen we estimate, based on the Kinect data, the depth distances of the joints of interest from the spine base, which is the skeleton's fulcrum. Even if we worked to implement rehabilitation games for the lower limbs, we also considered the shoulders because they are involved in every body movements, and they are a good marker to detect wrong postural behaviours.

### 4.3.1 Common Games' Setup

Every game required a setup phase to allow the creation of the virtual playground. It is a mandatory step, so we kept it fast and simple. The therapist starts choosing the game's positions. We used the word "positions", instead of "pillows", because actually the pillows are not essential.

*Figure 4.9 Setup with pillows and paper*

*Figure 4.10 Setup with pillows and obstacles*

*Figure 4.11 Setup with pillows, obstacles and carpet*

We use the body position to manage both the playground creation and the gameplay. This is done because currently Kinect is not capable to recognize and virtualize generic objects. Moreover, using special recognizable pillows would have compromised the portability of the application. With our solution, the only requirement is to maintain equidistant positions. In Figure 4.9, the grid is composed by pillows and sheets of paper, where the papers are used only as a patient's spatial reference; in Figure 4.10, the grid is composed both from pillows and obstacles, and it is an example of hard difficulty playground; in Figure 4.11, there is a carpet under the grid, to reduce the pillows' shifting and to modify the pillows' pressure resistance. We don't save playgrounds' configurations because during the exercises the pillows could shift, and from one session to another the same Kinect device could be moved. It would be too time expensive for the therapist to adjust the loaded environment with the current real one, risking also to lose precision.

After the real environment positioning, the therapist lunches the wanted game and the system will automatically load and use the current player's preferences for the selected game. In Figure 4.12, begins the patient's tutorial where, while completing the playground setup, he/she get comfortable with the game spatial references.

*Figure 4.12 Grid Creation*

The game setup uses both texts and speeches to communicate to the patient. We ask the child to positioning on three specific pillows to infer and virtualize the playground. Three is the minimum number of spots to create an accurate 3x3 grid, covering the rectangular diagonal, or a 1x3 line, covering the width space. At each positions of the three needed, the child confirms raising his/her hand over the head and waiting for the confirmation feedback. This was done both to entertain the patient, and to reduce at the minimum the use of mouse and keyboard. In case of physical impediments of the patient's harms, we added a clickable button which the therapist can press to confirm the actions for him/her. There is a skeleton on the screen, which is the joints' representation seen by the Kinect sensor. A green colour indicates a good body visibility, while a red colour a bad one. This is useful as a feedback to confirm the correctness of the setting.

### 4.3.2 3 x 3 Games

This is the category of the games that use 9 pillows disposed on a 3x3 grid.

"*Devix the mage and the magical traps*" is the first game of the category and belongs to the dungeon theme. The player's avatar is a mage who has to survive to magical traps.

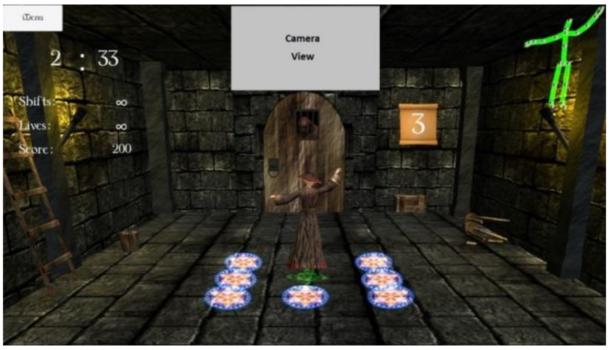


*Figure 4.13 Devix the mage and the magical traps*

In Figure 4.13, the stars on the ground are the magical traps to be avoided, while the green marker is the safe spot. The traps and the green marker correspond to physical pillows in the real space. On the top left of the screen, are listed the game's conditions and the total score. On the right of the screen, the ancient scroll shows the countdown to the next traps' activation.


*Figure 4.14 Devix the mage and the magical traps, explosion*

When the countdown reaches zero, the traps are triggered and the game checks the patient's position (Figure 4.14). If the patient is on the right pillow, therefore the mage is on the green marker, the score increases and the game produces the relative sound; if the patient is on the wrong pillow, therefore the mage is in the magical flames, no points are added or stolen and the mage says "Ouch". Except for the body rotation, every player's movement is mapped over the avatar, so he/she can have fun shaking his arms and legs around.

"*Beatrice the bee and the honey preparation*" is the second game of the category and belongs to the bee theme. The player's avatar is a bee that has to collect all the healthy flowers to prepare the honey.


*Figure 4.15 Beatrice the bee and the honey preparation*

In Figure 4.15, the dried flowers on the ground are the bad positions to be avoided, while the healthy flower is the safe spot. Every flower corresponds to a physical pillow in the real space. On the top left of the screen, are listed the game's conditions and the total score. On the right of the screen, the honey jar shows the countdown to the next position's check. When this countdown reaches zero, if the player is on the right pillow, therefore the bee is on the healthy flower, the score increases and the game produces the relative sound; if the player is on the wrong pillow, therefore the bee is on the dried flowers, no points are added or stolen and the bee produces a noise. Due to the differences in the structure between a human body and a bee, only the translations are mapped on the player's avatar. The bee has, however, a default animation.

Both the games have a mirrored version.

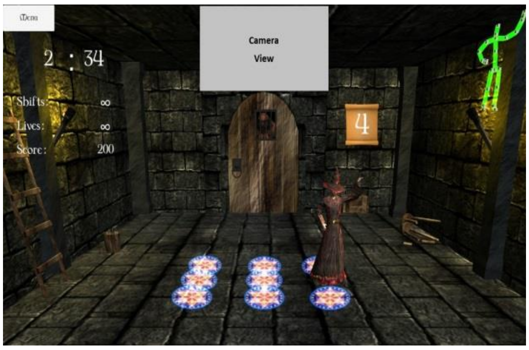


*Figure 4.16 Devix the mage and the magical traps, mirrored*


*Figure 4.17 Beatrice the bee and the honey preparation, mirrored*

As we discussed in the design chapter, having the turned and the mirrored version of a game allows the therapist to choose the right configuration for every patients. If a patient is more comfortable moving a mirrored avatar, for example, the therapist uses the mirrored version for the easy and common rehabilitation session, and the other version when he/she wants to introduce a cognitive exercise. This further cognitive step results very useful even for cases of acute cerebellitis.

### 4.3.3 1 x 3 Games

This is the category of the games that use 3 pillows disposed in one horizontal raw.

“*Devix the mage and the endless run*” is the first game of the category and belongs to the dungeon theme. The player’s avatar is a mage who has to run avoiding obstacles and monsters.


*Figure 4.18 Devix the mage and the endless run*

In Figure 4.18, the mage is at the bottom of the screen and he runs continuously forwards. The green marker on the ground indicates the safe pillow (so in this case the safe position is in the centrum) while the monsters indicates the bad ones. Every time the monsters spawn, the score increases; if the mage hits the monsters the score decreases, otherwise the player confirms the obtained bonus. In this way the player’s mistakes don’t penalize him and don’t undermine his/her esteem. When the player’s avatar hits an obstacle, the mage says “Ouch” while the obstacle makes a characteristic sound based on its nature. To add vivacity, the obstacles selection is randomized every play, so the player doesn’t see the same configuration over and over. The mage has a default running animation, because a full mapping on the player’s movements wouldn’t have made much sense in this type of game.

“*Beatrice the bee and the flowers run*” is the second game of the category and belongs to the bee theme. The player’s avatar is a bee that has to collect flowers avoiding other bees and obstacles.


*Figure 4.19 Beatrice the bee and the flowers run*

In Figure 4.19, the bee is at the bottom of the screen and flies continuously forwards. The flower on the ground indicates the safe pillow (so in this case the safe position is in the left) while the obstacles indicates the bad ones. Every time obstacles spawn, the score increases; if the bee hits the obstacle the score decreases, otherwise the child confirms the obtained bonus. In this way the player's mistakes don't penalize him and don't undermine his/her esteem. When the player's avatar hits an obstacle, the bee makes some noise. To add vivacity, the obstacles selection is randomized every play, so the player doesn't see the same configuration over and over. The player's bee and the other bees have a default flying animation, while the obstacles are garden furniture.

For this type of games, a mirrored version is not feasible, because it would require reaction times too fast for a patient in rehabilitation.

# 5 Testing and Data Analysis

In this chapter, we discuss the set of experiments performed to validate our system. We performed several experimental sessions with human subjects, in a real rehabilitation environment. The initial sessions were mainly used to tune the development of the games, based on the subjects and therapists feedbacks. In the following sessions, we focused more on the user experience.

## 5.1 Experimental Setup and Notes

Every experimental session took place at the Clinica Pediatrica G. e D. De Marchi, with the collaboration of two therapists and a physician. We always used the same notebook, with Intel® Core™ i5-4258U Processor 2.40GHz, 8GB RAM, Intel® Iris™ Graphics 5100 and Windows 8.1 Pro 64bit OS. The games were made with Unity 4.6.1f1, a cross-platform game engine, and using the public preview of the Kinect's plugin released on September, 2014.

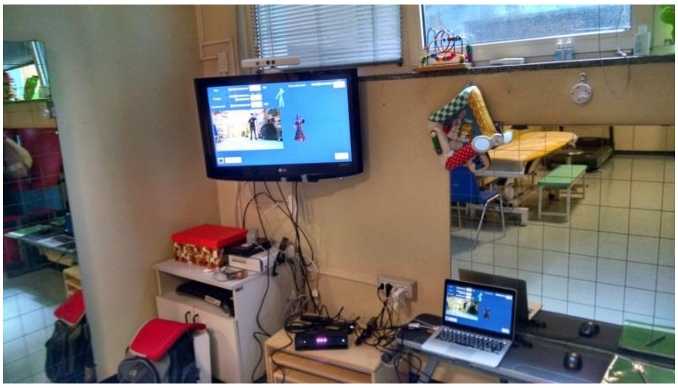

*Figure 5.1 Experimental setup*

We performed the experiments in the therapy gym (Figure 5.1). We placed the Kinect sensor under a TV monitor, connected to our PC. This way, subjects could easily see their avatar while having enough space to move.

We always used the games of the two categories, 1x3 and 3x3, with exercises that lasted 3 minutes.

## 5.2 Initial Tuning Session

Three subjects, one male and two females, took part to the initial tuning session. We will refer to the subjects as M1, F2 and F3. M1 was twenty years old, F2 was twelve years old and F3 was fifteen years old. M1 and F3 suffered of a mild form of JIA, while F2 had knees problems. During F2's rehabilitation were also present her parents.

With the tuning session, we wanted to obtain a first feedback to validate our work, both from a rehabilitation point of view and with respect to the subjects' engagement. We inserted our games in a normal rehabilitation session and substituted them to the canonical pillow exercises.

In this tuning session, we tested two games: "*Devix the mage and the magical traps*", which belongs to the 3x3 type, and "*Devix the mage and the endless run*", which belongs to the 1x3 type. These games were at an early stage, so they lacked of music backgrounds and some details we added afterwards, thanks to the feedbacks.

### 5.2.1 Users' Feedback

The feedback from the subjects was positive. Patients enjoyed the games and appreciated the new way of doing the rehabilitation exercises. They also gave us some feedbacks regarding the look and feel of the games. In "*Devix the mage and the endless run*", for example, the virtual playground had highlighted only the pillows to be avoided, with no marker on the safe pillow where to go to avoid obstacles. Subjects suggested to highlight it to facilitate the shifting phase. A curious fact regards the default time interval allowed to the player to shift from one pillow to another. This value was previously set to fifteen seconds, in according to the therapists' evaluation of the common rehabilitation sessions. We had to change it to ten seconds, because subjects showed more efforts and gait speed then the common sessions, and the games resulted to slow and easy.

F2 parents' feedback was good. They appreciated the new type of rehabilitation and were happy to see their child having fun during the exercises.

The therapists' feedback was also good. They noticed that the patients, concentrated on increasing the score, didn't pay much attention to their impediments and moved faster than the usual.

These feedbacks proved us the goodness of our work and boosted us to continue in the right direction.

### 5.2.2 Data Analysis of M1

Here, we present the data collected during the rehabilitation session of M1. We saved the X,Y and Z coordinates of all the player skeleton’s joints, and the records of the Kinect’s camera. We saved data every 0.15 seconds from the beginning of each play. To analyse the patient postural behaviours, we plotted the postures’ trend during the exercises performed. All plots report the raw data averages and the standard deviations, to facilitate the readings.

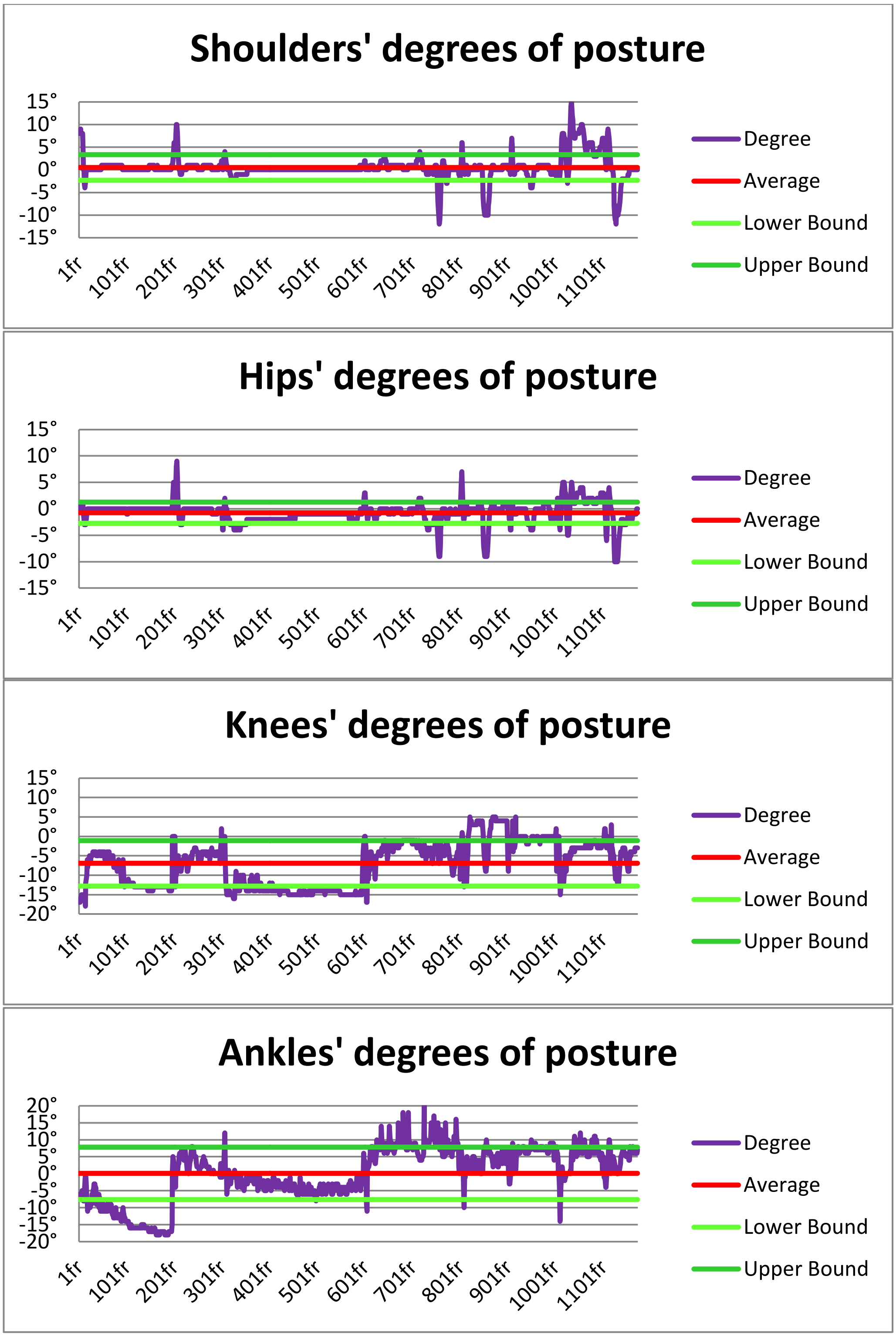


*Figure 5.2  Performance M1, tuning session, game 1, type 1x3*

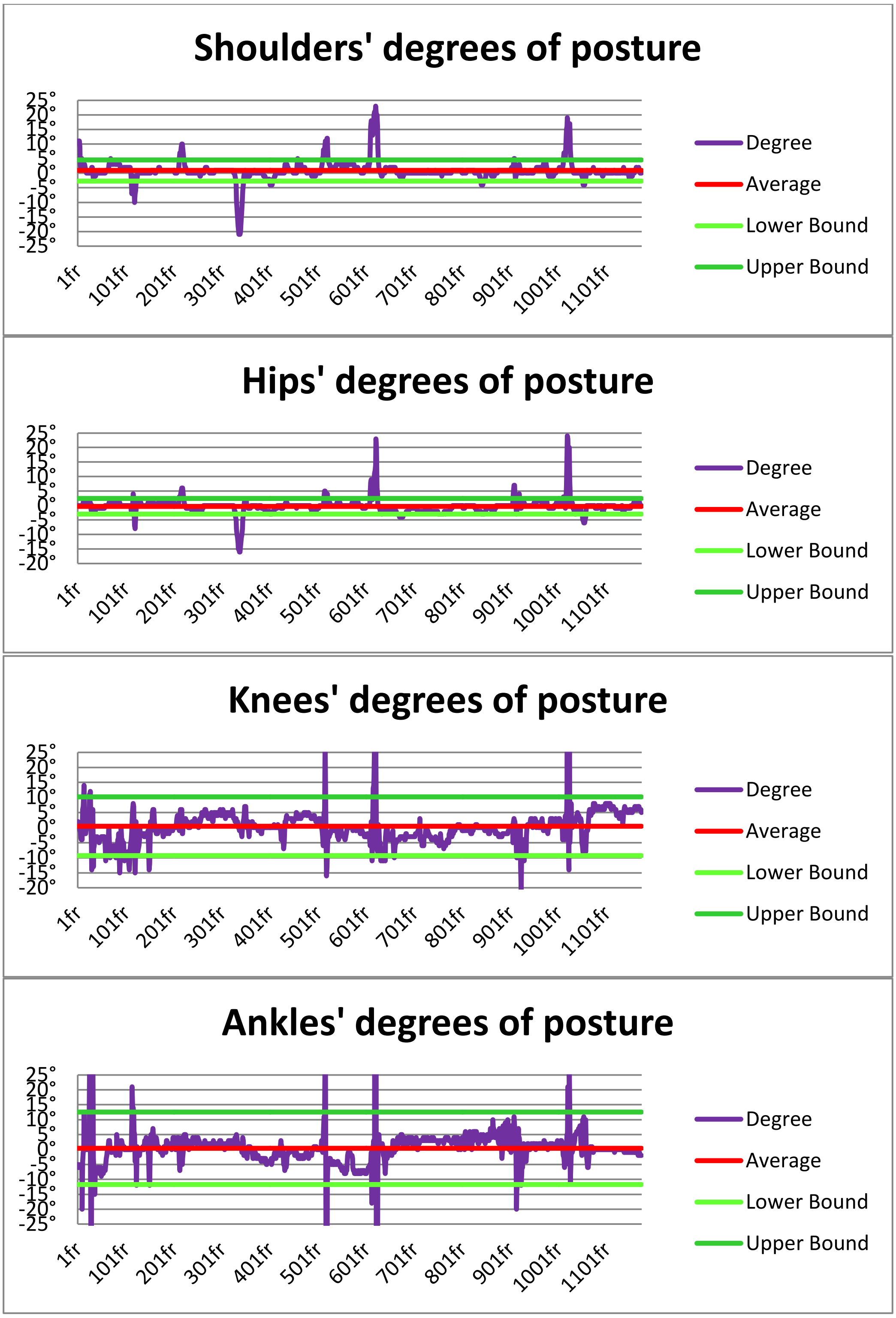


*Figure 5.3 Performance M1, tuning session, game 2, type 3x3*

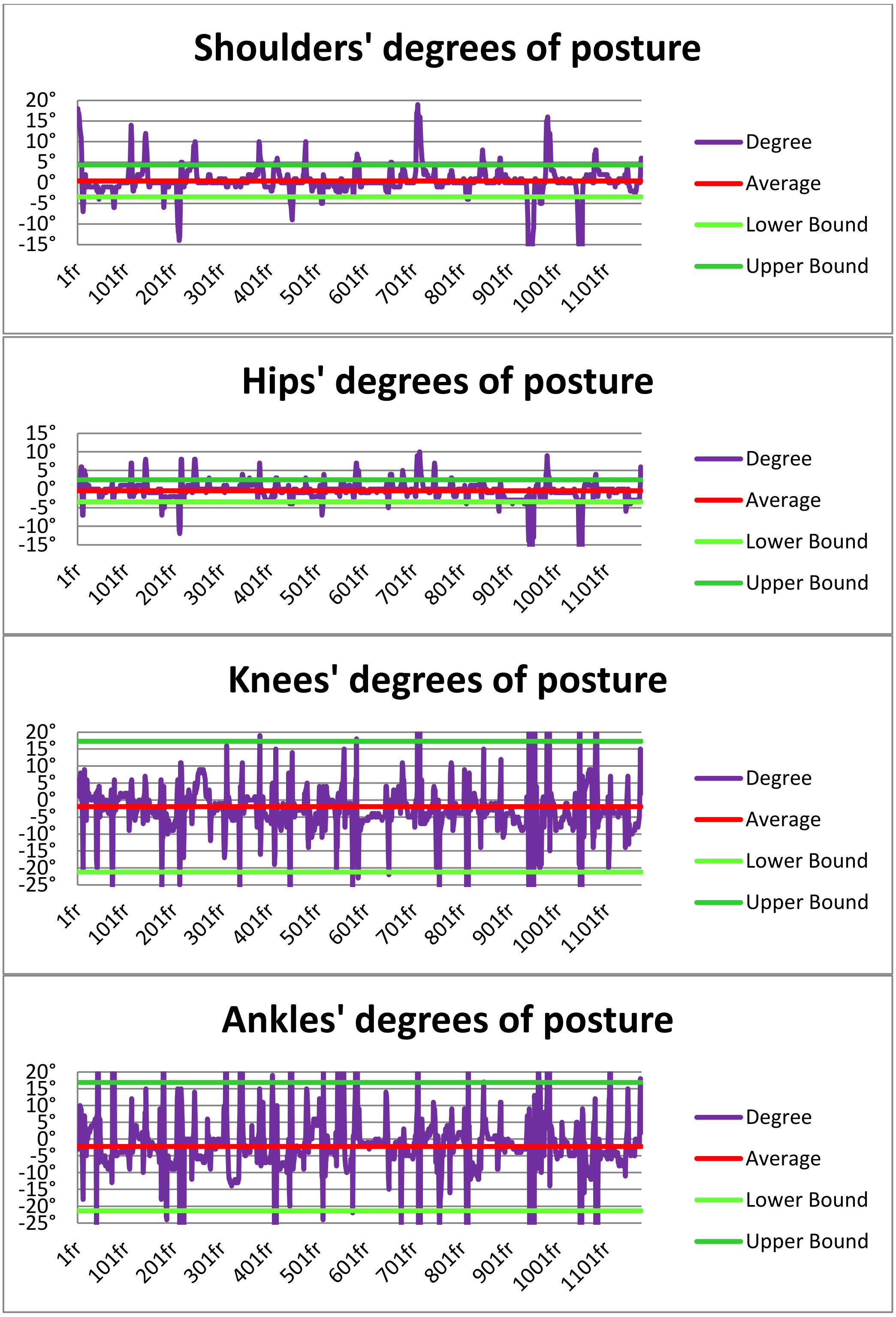


*Figure 5.4 Performance M1, tuning session, game 3, type 3x3*

During the initial tuning session, M1 played three games.

The first game was "*Devix the mage and the endless run*", which belongs to the 1x3 type. Figure 5.2 shows that M1 shoulders and hips' postural behaviours were good, in fact the averages are about 0 degrees and the standard deviations, indicated by the boundaries, are very close. The trends of shoulders and hips are the most stable and have the same peaks outside the boundaries, due to the noises in the Kinect readings during the players shifting from one pillow to another. Knees and ankles have strange trends. Thanks to the replay view, therapists saw that they were due to noises in the readings, caused by the pleats in M1's trousers.

The second game played by M1 was "*Devix the mage and the magical traps*", which belongs to the 3x3 type. Figure 5.3 confirms what therapists noted about shoulders and hips in the first game. Even if the game passed from a three pillows to a nine pillows game, the knees and ankles' trend is more uniform and stable, so probably M1 was more confident and relaxed. He also had adjusted the pleats in the trousers. Both knees and ankles' postural behaviours result quite good.

Finally, M1 played "*Devix the mage and the magical trap*", which belongs to the 3x3 type. This was a special trial. It was done at the end of the session, and M1 showed the will to prove the game in extreme conditions. We kept the 3 minutes timer, but we set the rate of obstacles to 5 seconds: M1 had only five seconds to shift from one pillow to another. Figure 5.4 shows very dynamic data. These data have the same peaks outside the boundary and they are due to the player shifting from one pillow to another. This high variability tell us that the shifting was too fast to properly evaluate postural behaviours. Nevertheless, the short resting phases suggest good postural behaviours, confirmed by the previous game.

From the data results that M1 had good and solid postural behaviours, with no relevant problems to the lower limbs.

### 5.2.3 Data Analysis of F2

Here, we present the data collected during the rehabilitation session of F2. Data were collected in the same conditions of the rehabilitation session of M1.

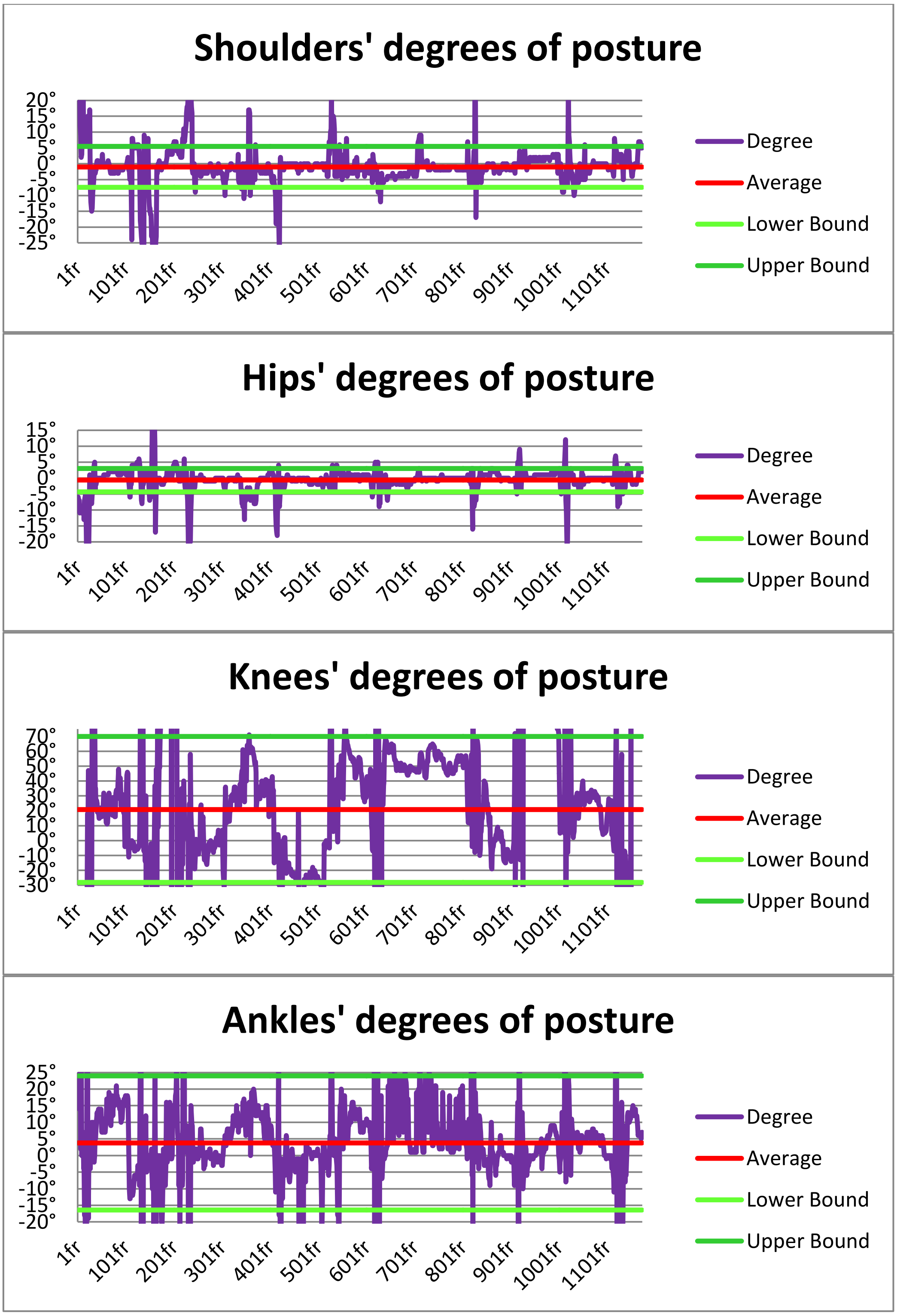


*Figure 5.5 Performance F2, tuning session, game 1, type 3x3*

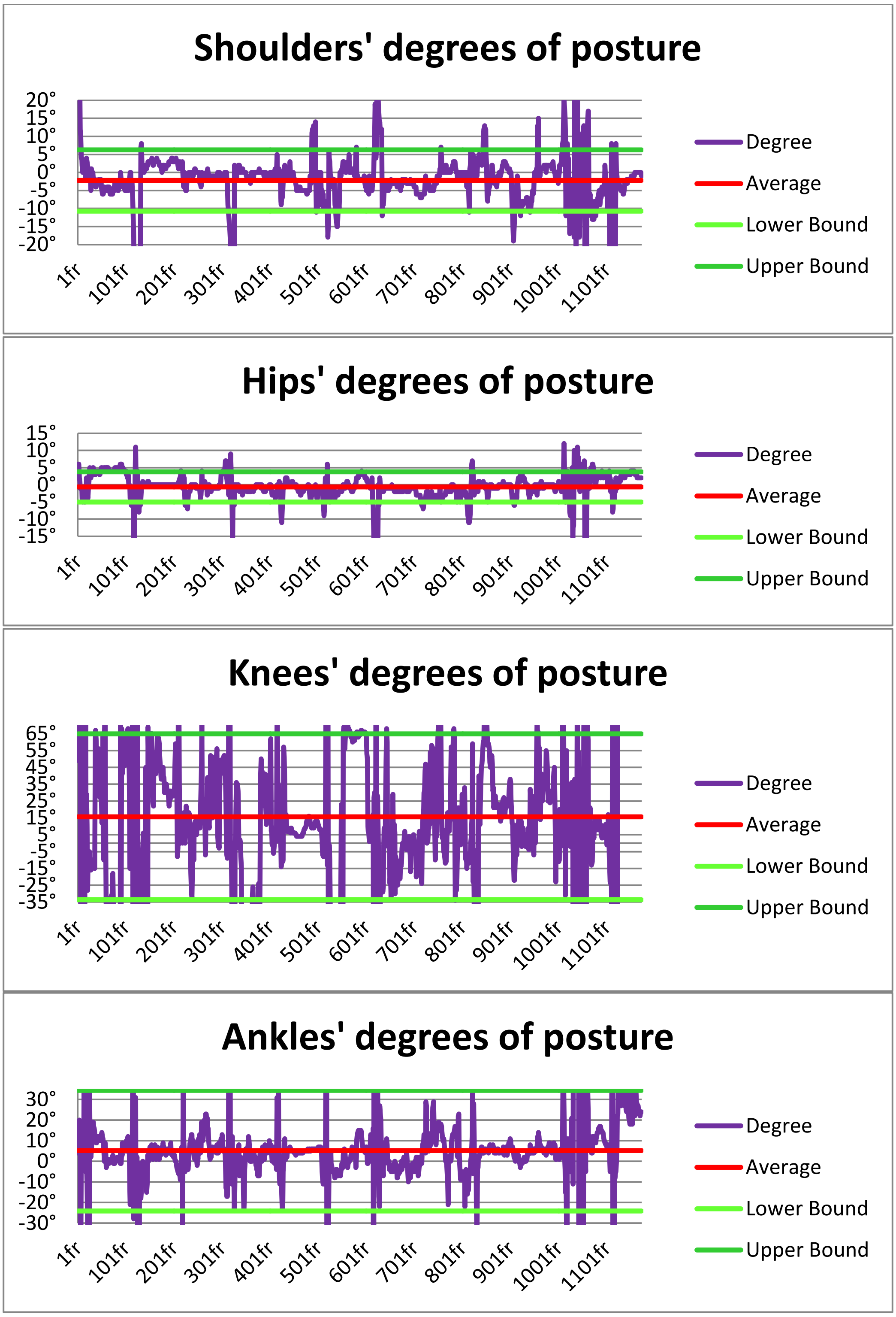


*Figure 5.6 Performance F2, tuning session, game 2, type 3x3*

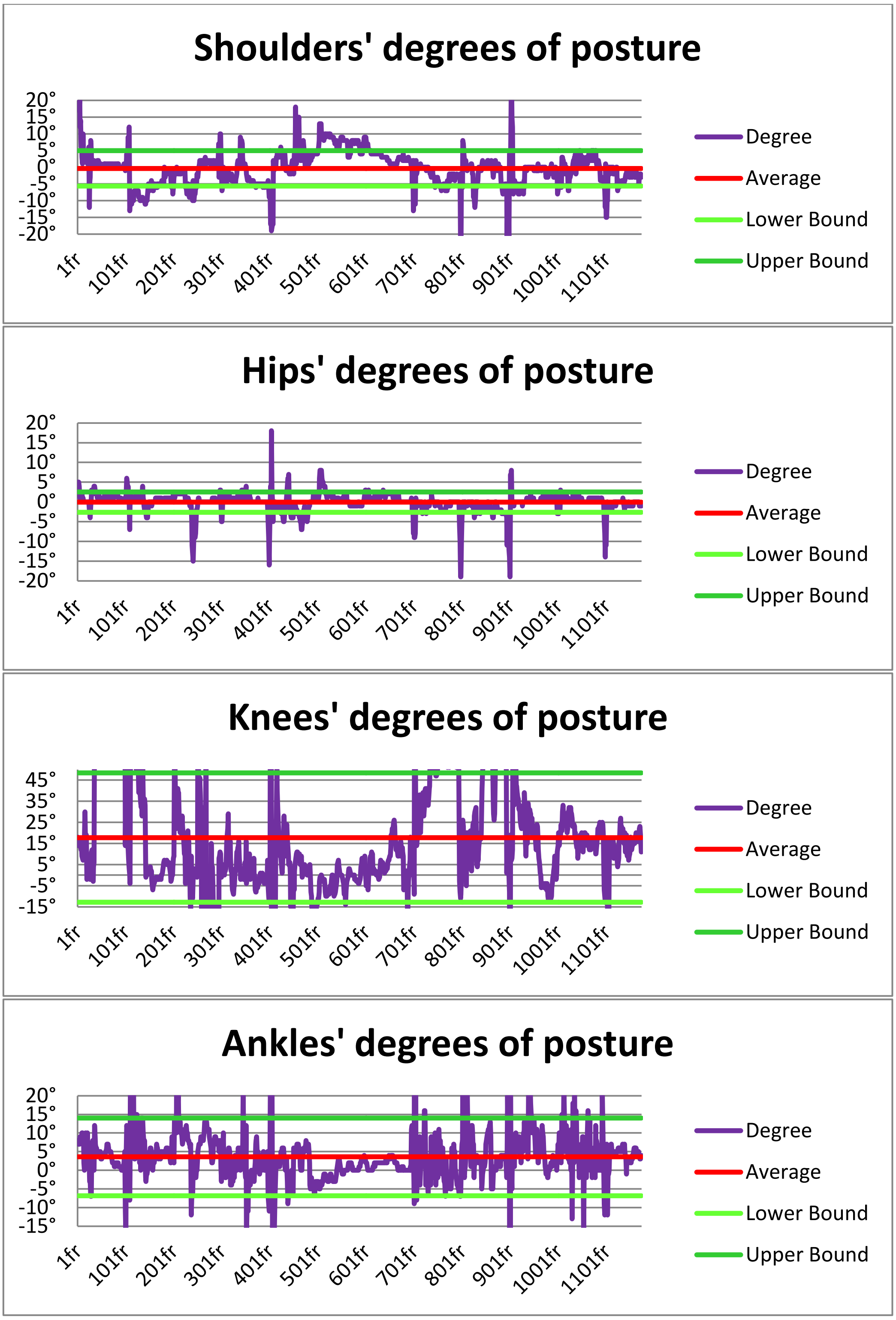


*Figure 5.7 Performance F2, tuning session, game 3, type 1x3*

During the initial tuning session, F2 played three games.

The first game was "*Devix the mage and the magical traps*", which belongs to the 3x3 type. Figure 5.5 shows that F2 shoulders and hips' postural behaviours were quite good. There is a serious problem in the knees, where the average is about 20 degrees and the deviation is very high. Ankles' value is better than the knees' one, but there is still a lot of variability in the data.

The second game played by F2 was "*Devix the mage and the magical traps*", which belongs to the 3x3 type. For this exercise, therapists changed the grid configuration, adding different pillows. Figure 5.6 displays that F2 was more stable during the resting time from one shift to another, but the knees and ankles' values still indicates some problems in the legs.

Finally, F2 played "*Devix the mage and the endless run*", which belongs to the 1x3 type. Figure 5.7 shows that F2 kept more control over the legs, compensating with the shoulders, but without compromising the upper posture.

F2 was a tiny and skinny girl, and her condition brought her to assume resting positions where the knees overlapped, like in a "X" shape. This fact introduced noises and high variability in the data, especially for the lower limbs. The results highlighted the presence of real legs' problems.

### 5.2.4 Data Analysis of F3

Here, we present the data collected during the rehabilitation session of F3. Data were collected in the same conditions of the rehabilitation session of M1.

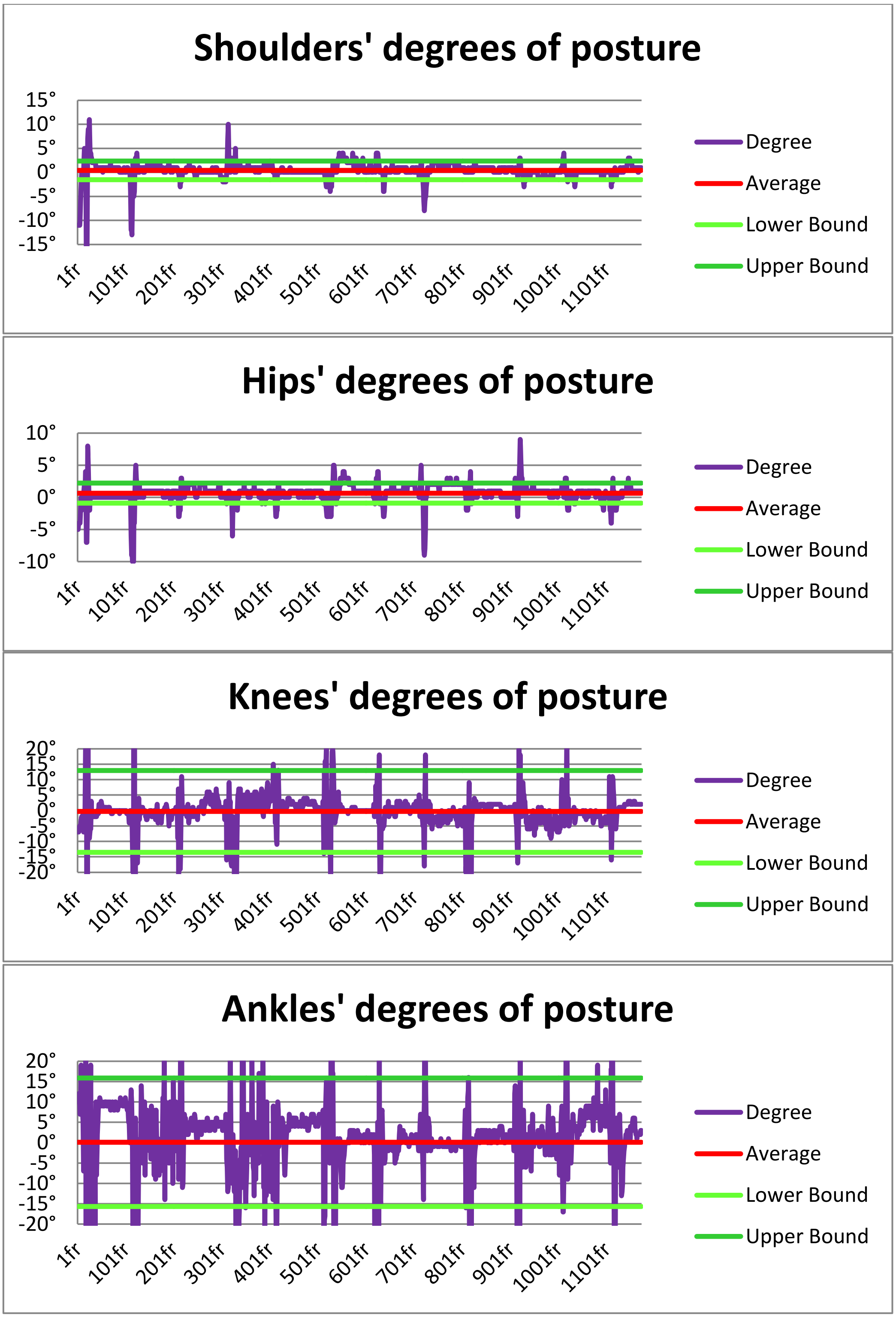


*Figure 5.8 Performance F3, tuning session, game 1, type 3x3*

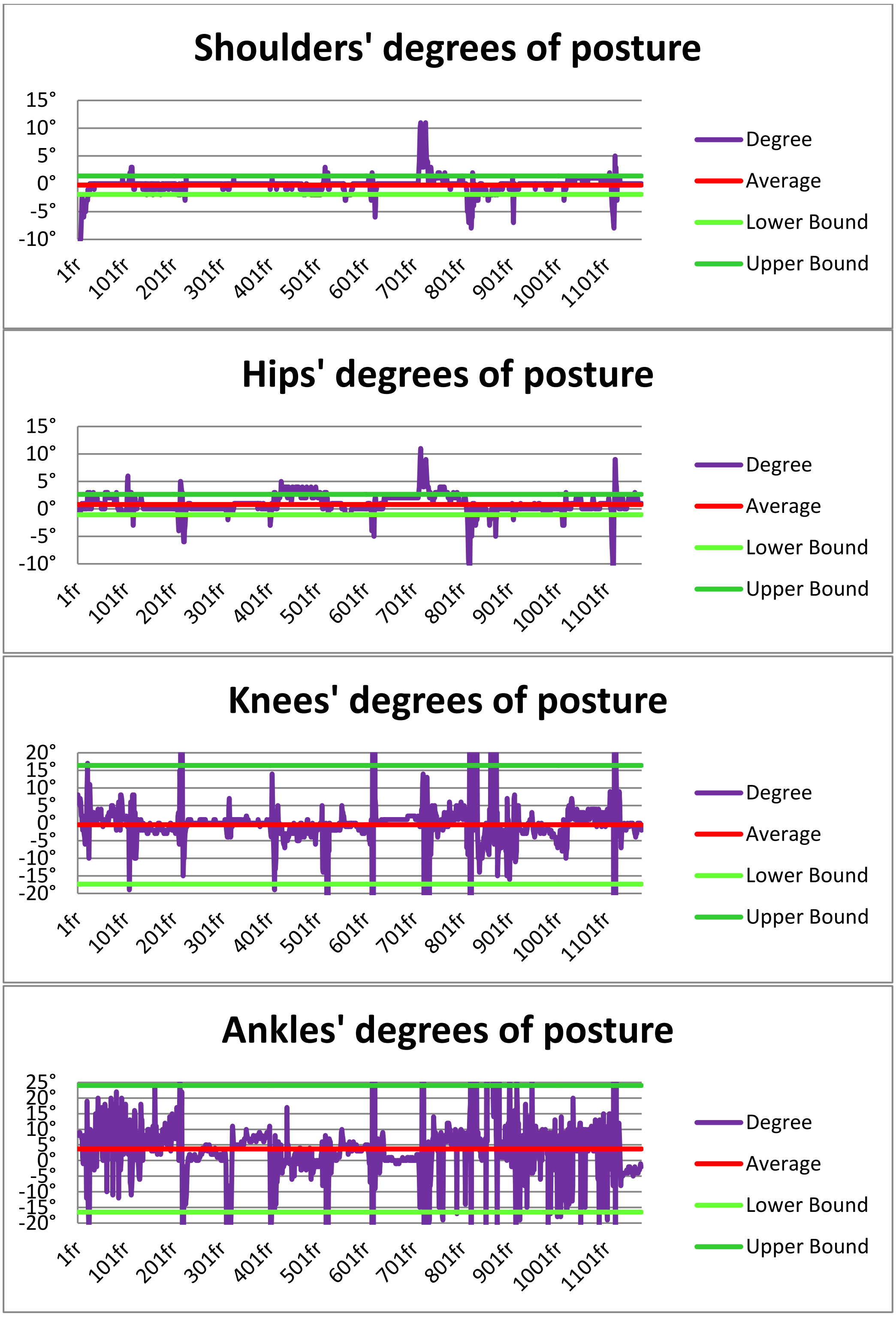


*Figure 5.9 Performance F3, tuning session, game 2, type 3x3*

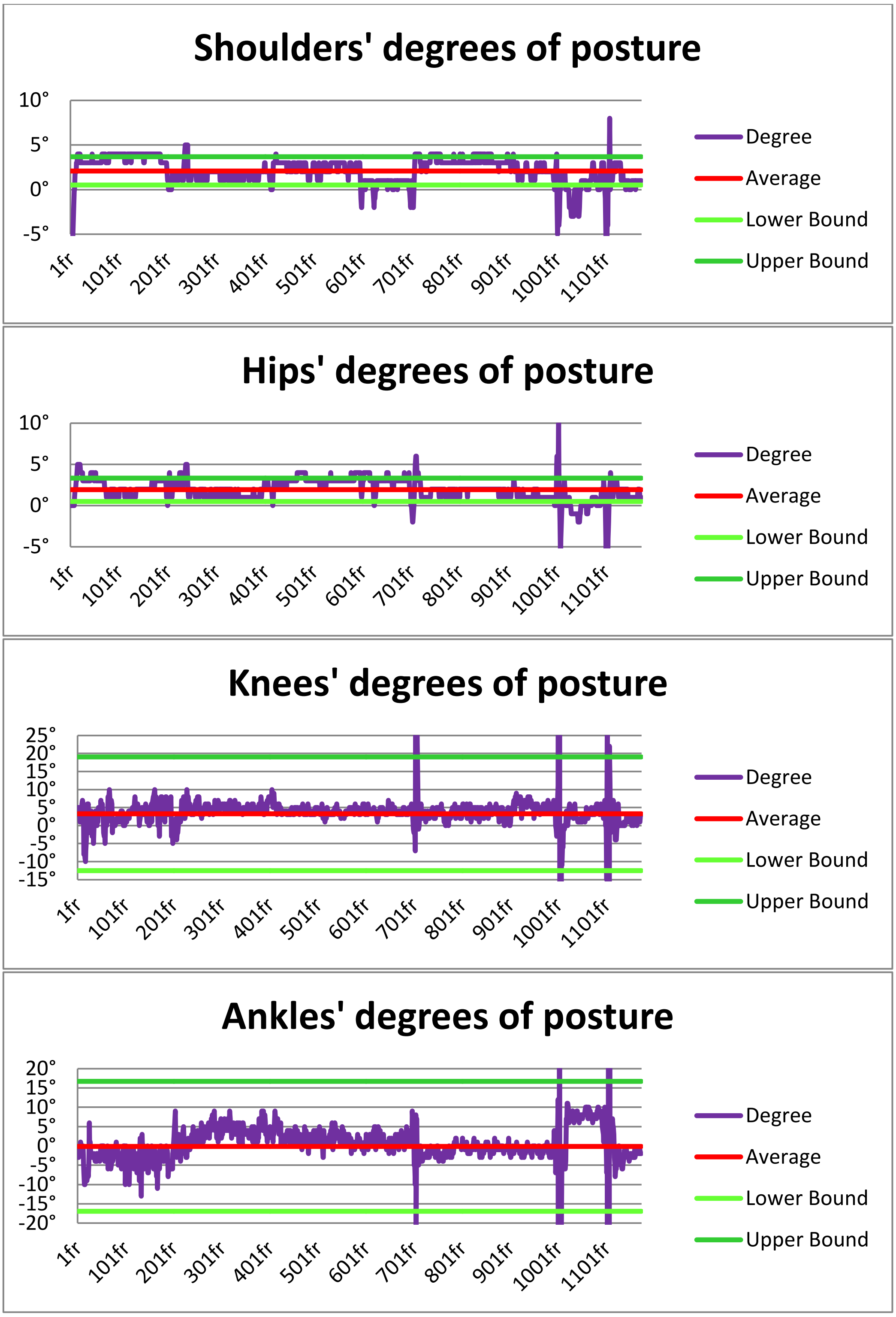


*Figure 5.10* *Performance F3, tuning session, game 3, type 1x3*

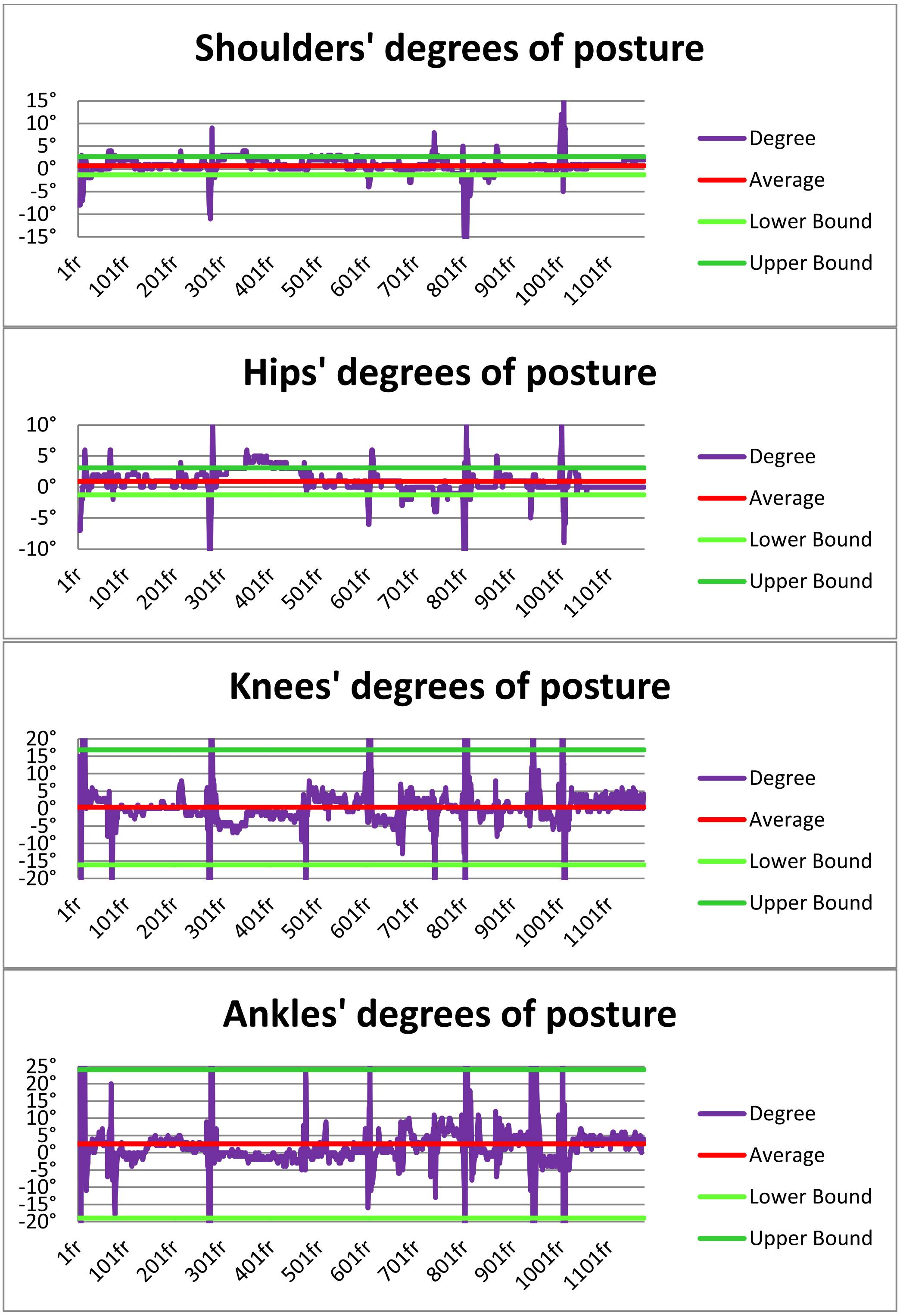


*Figure 5.11 Performance F3, tuning session, game 4, type 1x3*

During the initial tuning session, F3 played four games.

The first game was "*Devix the mage and the magical traps*", which belongs to the 3x3 type. Figure 5.8 shows that F3 shoulders and hips' postural behaviours were good. Even knees and ankles' postures were positive, and the only oscillation in the data are the shifts from one pillow to another.

The second game played by F3 was "*Devix the mage and the magical traps*", which belongs to the 3x3 type. Figure 5.9 confirms the results of the first game for shoulders, hips and knees. Ankle's value could evidences some minor problems, to be evaluate with other data.

The third game played by F3 was "*Devix the mage and the endless run*", which belongs to the 1x3 type. Figure 5.10 shows good values for the ankles, but some compensation with the other joints. In this case, therapists had shown the replay of the second game to F3, and she probably tried to adjust the behaviour in a mechanical way.

Finally, F3 played "*Devix the mage and the endless run*", which belongs to the 1x3 type. Figure 5.11 confirms the results of the second game, therefore there is minor problem with the ankles.

From the data results that F3 was in good condition. She had problems with the ankles, but in a mild form. Checking the replay, therapists saw that there was some fluctuations of the ankles positions don't depending by F3. This didn't compromised the readings, so the problem to the joints was confirmed, but in a very bland entity.

### 5.2.5 Summary

The initial tuning session was more a proof for ourselves than for the patients. Thanks to the feedbacks from the patients, their families and therapists, we understood to be on the right way. We saw what was right and what was to be improved.

The replay screen was a success. Therapists were excited by the possibilities that this feature would give in terms of monitoring. They also validated the goodness and usability of the postural readings.

The entertainment factor was confirmed, both from therapists and the patients, even if the games were at early stages.

The Kinect sensor itself was validated. The upper body readings revealed to be more accurate than the lower ones, both for the device capabilities of seeing the skeleton in depth, and for the dynamic component of the exercises. The reading revealed to be dependent from the shapes of the worn clothes. This confirmed the importance of the replay feature.

## 5.3 First Therapeutic Session

Three female subjects (F4, F5, F6) took part to the first therapeutic session. F4 was ten years old, F5 was twelve years old and F6 was nine years old. F5 and F6 suffered of a mild form of JIA, while F4 had knees problems. During F4's rehabilitation was present her grandfather, while during F5 and F6's rehabilitations were present the respective fathers.

In this session, we tested three games: "*Devix the mage and the magical traps*", which belongs to the 3x3 grid games, "*Devix the mage and the endless run*" which belongs to the 1x3 pillows game, and "*Beatrice the bee and the flowers run*", which belongs to the 1x3 pillows game. We added the background music and the other suggestions resulted from the feedbacks of the initial tuning session.

### 5.3.1 Users' Feedback

The feedback from the subjects was positive. F4 really enjoyed the rehabilitation session, despite her knees problems and the body weight, that made more strenuous the exercises. She showed having great fun, and demonstrated an higher gait speed than the norm. She performed also additional, and not required, shifting from one pillow to another, to be better prepared for the next obstacles. F6 showed lack of initiative in the grid creation phase, probably due to her young age, but then great effort and even some jumps during the gameplay. F5's feedback was a little cold in the beginning, but it improved a little by the end.

The relatives were less participative than the ones of the initial tuning session, but this seems to not had burden the children interest and effort.

Therapists' feedback was still good. They noticed the same benefits of the previous time, therefore that the patients, concentrated on increasing the score, didn't pay much attention to their impediments and moved faster than the common rehabilitation session.

We had also the feedback from other children passing in the nearby hallway. They stopped to see what was happening, and showed the will of playing themselves.

### 5.3.2 Data Analysis of F4

Here, we present the data collected during the rehabilitation session of F4. Data were collected in the same conditions of the initial tuning session. We saved the X,Y and Z coordinates of all the player skeleton's joints, and the records of the Kinect's camera. We saved data every 0.15 seconds from the beginning of each play. To analyse the patient postural behaviours, we plotted the postures' trend during the exercises performed. All plots report the raw data averages and the standard deviations, to facilitate the readings.

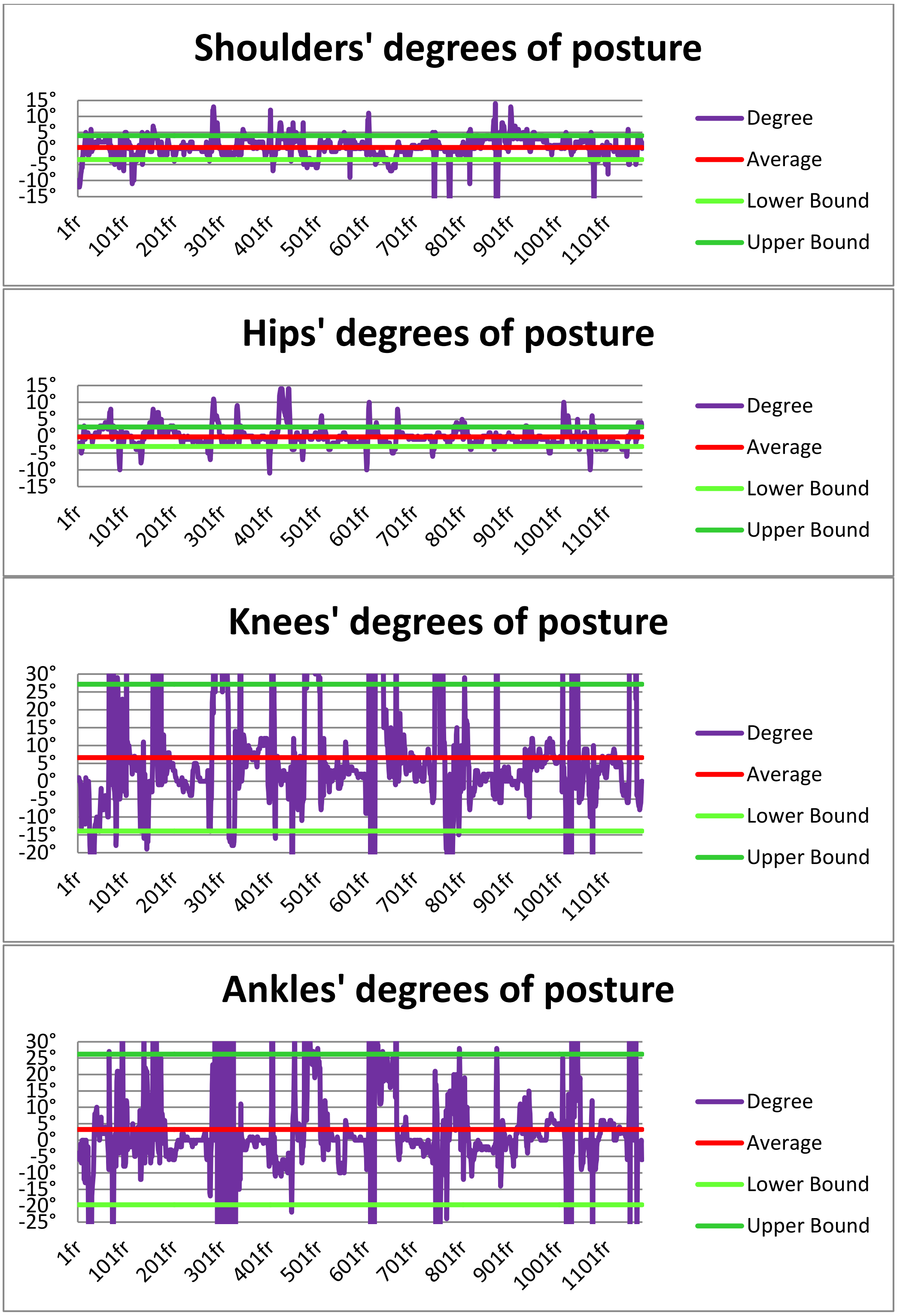


*Figure 5.12 Performance F4, first THR session, game 1, type 1x3*

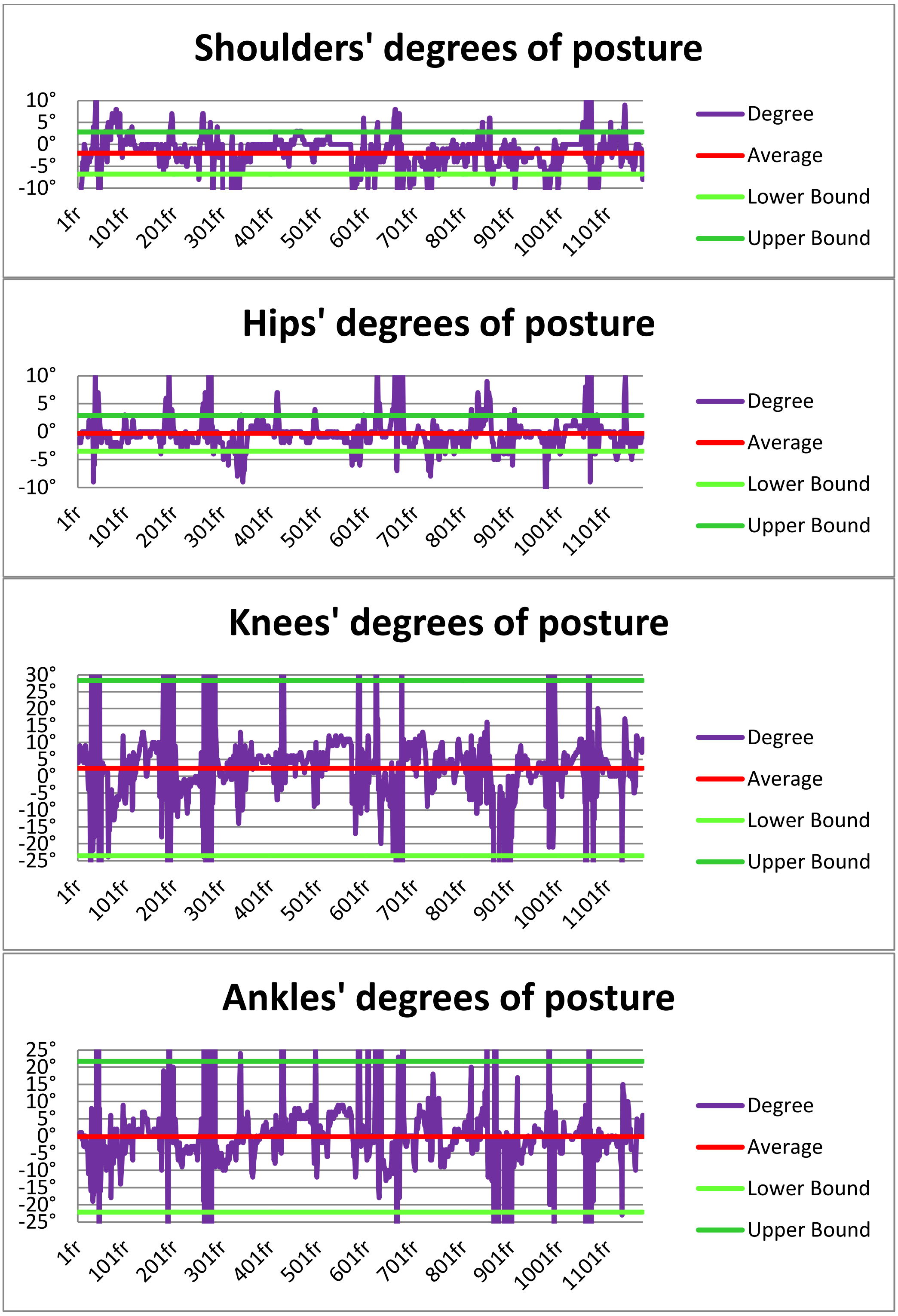


*Figure 5.13* *Performance F4, first THR session, game 2, type 3x3*

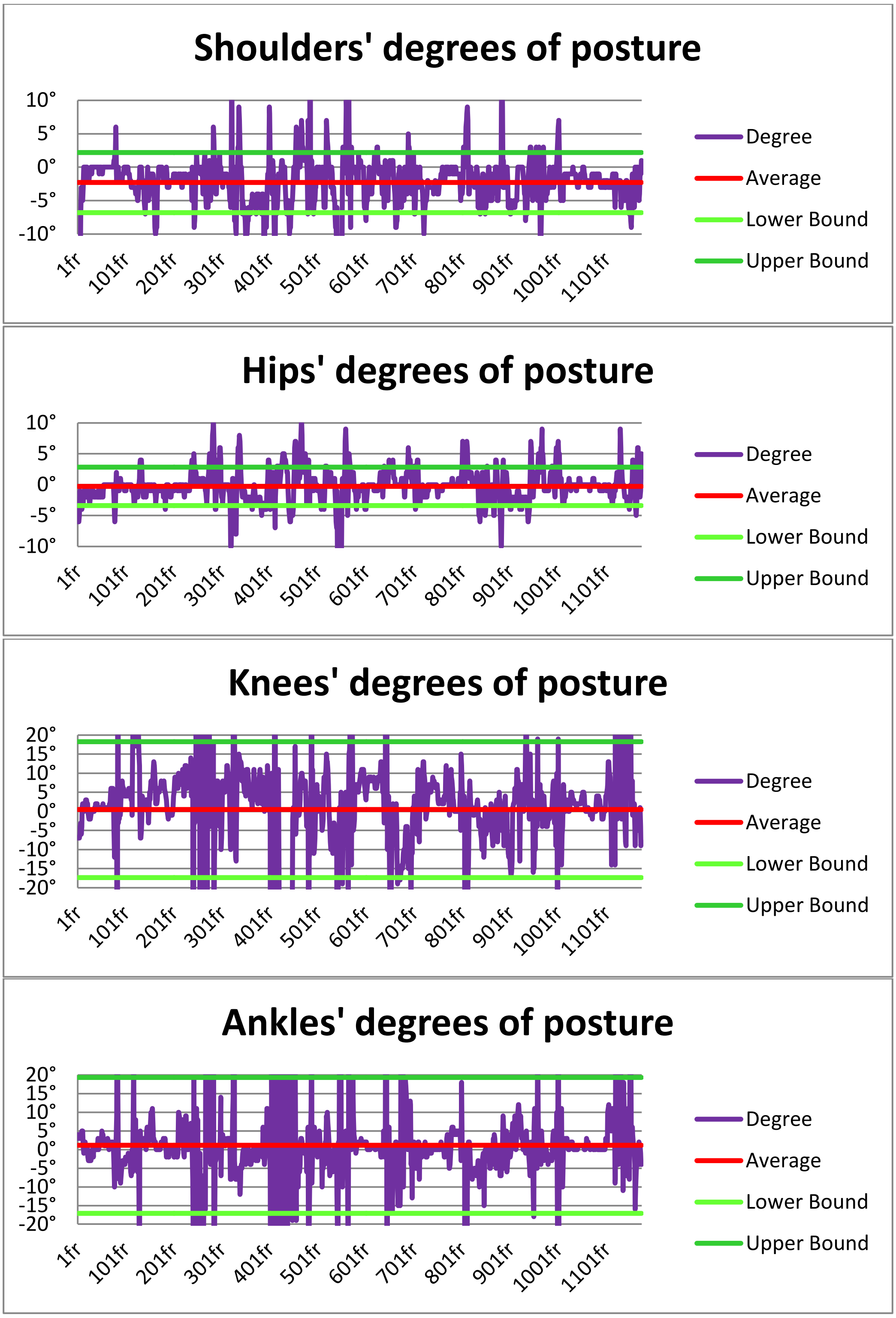


*Figure 5.14 Performance F4, first THR session, game 3, type 1x3*

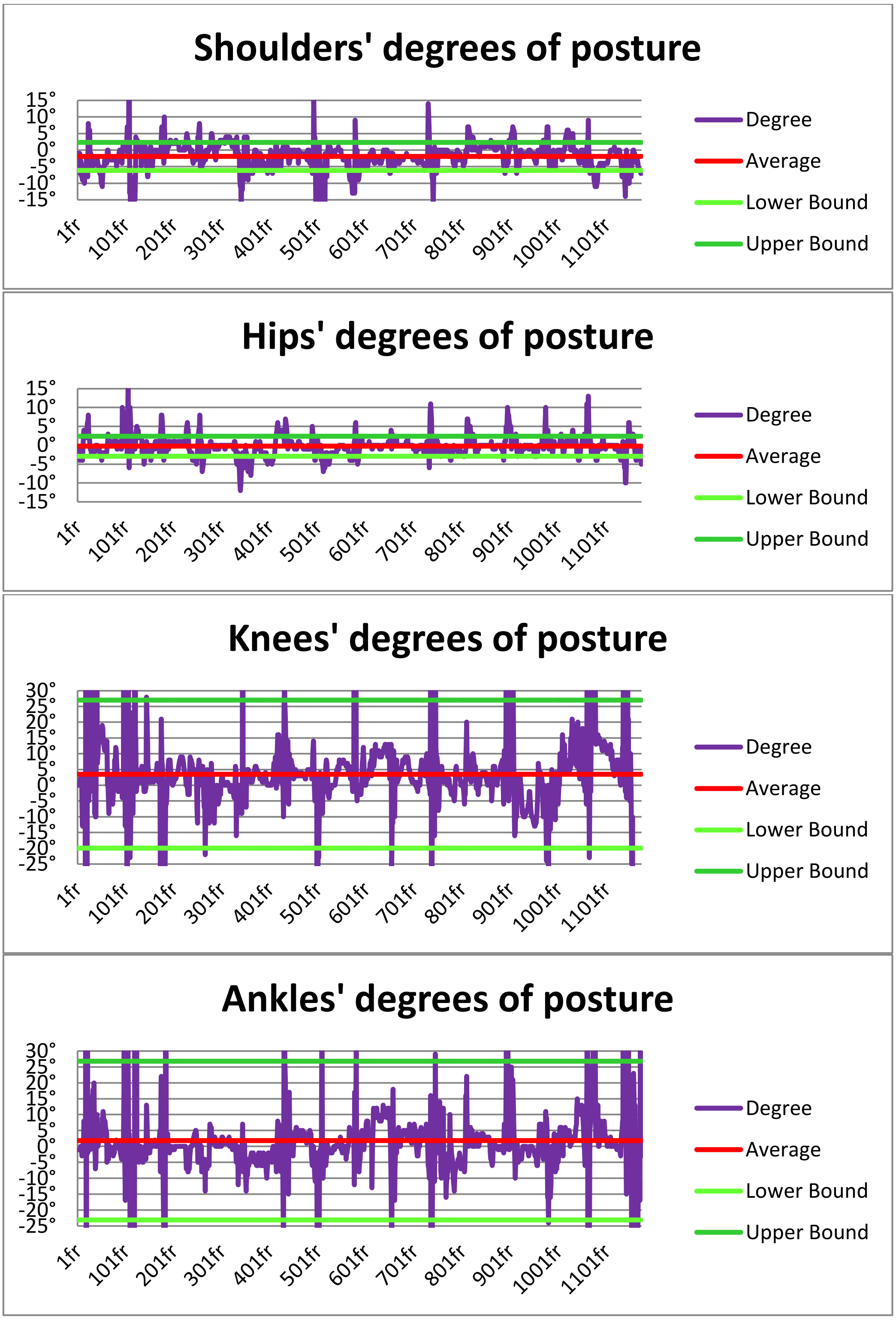


*Figure 5.15* *Performance F4, first THR session, game 4, type 3x3*

During the first therapeutic session, F4 played four games.

The first game was “*Beatrice the bee and the flowers run*”, which belongs to the 1x3 type. Figure 5.12 shows good shoulders and hips’ postures, but with high peaks during the shifting phases. Knees and ankles shows some problems to be evaluate with other data. They confirms the high instability during the shifts from one pillow to another.

The second game played by F4 was “*Devix the mage and the magical traps*”, which belongs to the 3x3 type. Figure 5.13 confirms the results of the first game. The grid playground required more complex movements than the row one, and this is reflected by the more oscillating shoulders and hips.

The third game played by F4 was “*Devix the mage and the endless run*”, which belongs to the 1x3 type. Figure 5.14 shows that F4 improved the resting positions of the lower limbs, using the upper body to compensate.

Finally, F4 played “*Devix the mage and the magical traps*”, which belongs to the 3x3 type. Figure 5.15 reveals the best F4’s performance. The oscillation during the shifting phases are still consistent, but they are more clean and controlled.

From the data results that F4 had legs problems. She had high rigidity in the lower limbs, and this condition brought her to assume a “X” shape with her legs. To obtain balance, she compensated the rigidity of the legs with the upper body, and this results from the high variability of the shoulders during the shifting phases. In the final game, probably due to the physical activity done during the previous plays, she improved the “X” shapes of the legs, obtaining better results.

### 5.3.3 Data Analysis of F5

Here, we present the data collected during the rehabilitation session of F5. Data were collected in the same conditions of the rehabilitation session of F4.

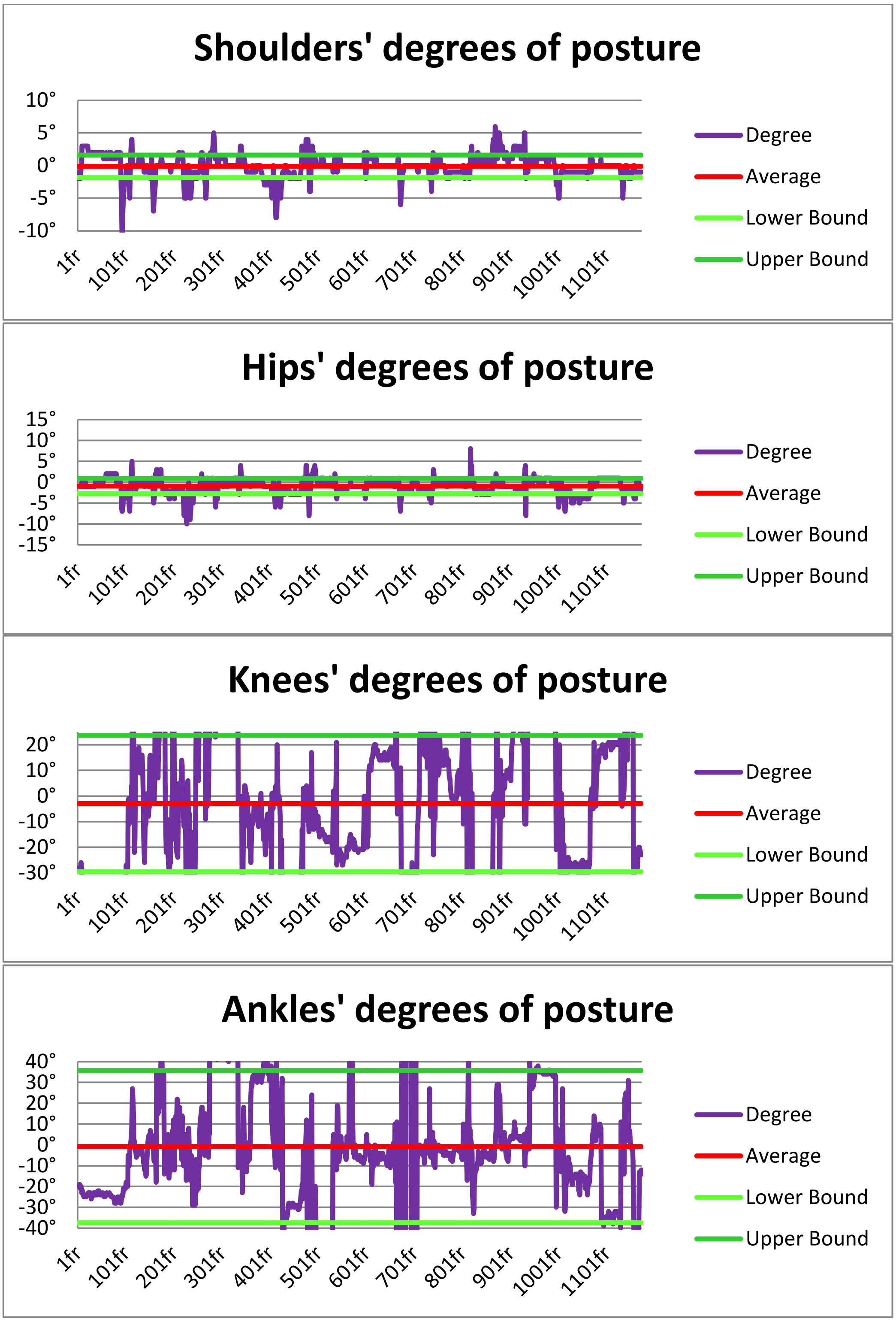


*Figure 5.16 Performance F5, first THR session, game 1, type 1x3*

During the first therapeutic session, F5 played four games. She wore a long dress ending at the thighs, between the hips and the knees. This compromised the lower limbs readings of the Kinect. We now propose the data from the first game.

The first game played by F5 was "*Beatrice the bee and the flowers run*", which belongs to the 1x3 type. Figure 5.16 shows good shoulders and hips' postural behaviours, confirmed also by the other plays. Knees and ankles have good final values, but there is a lot of noise, don't due to F5's performance.

This trial proved that it is fundamental, for a correct reading, that Kinect is able to see both head and hips of the player. The spine mid joint, which is the fulcrum of the virtual skeleton and it is positioned between the hips, was covered by F5's dress. Kinect spatial references of the player's body were "tricked", so the reading resulted compromised.

### 5.3.4 Data Analysis of F6

Here, we present the data collected during the rehabilitation session of F6. Data were collected in the same conditions of the rehabilitation session of F4.

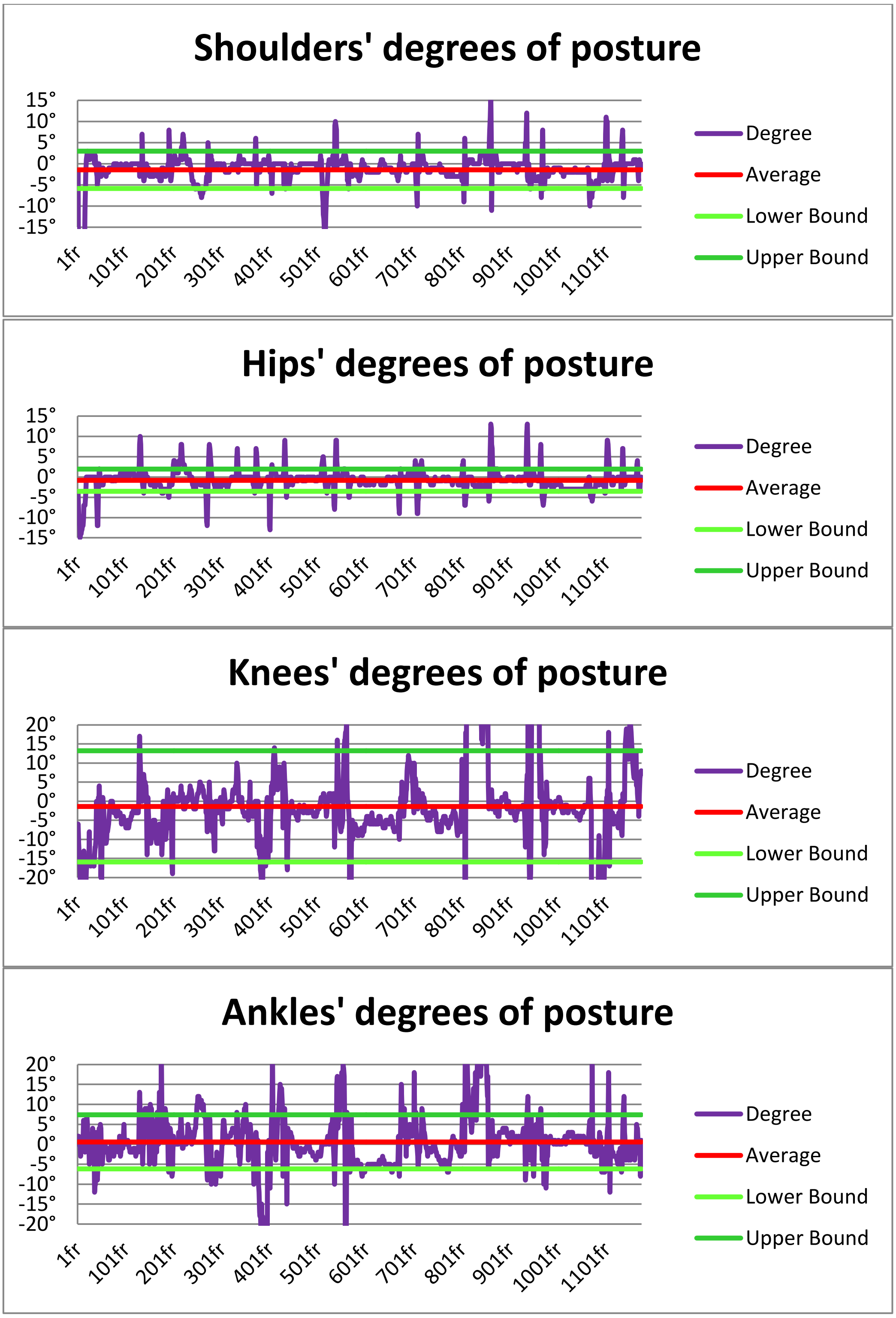


*Figure 5.17* *Performance F6, first THR session, game 1, type 1x3*

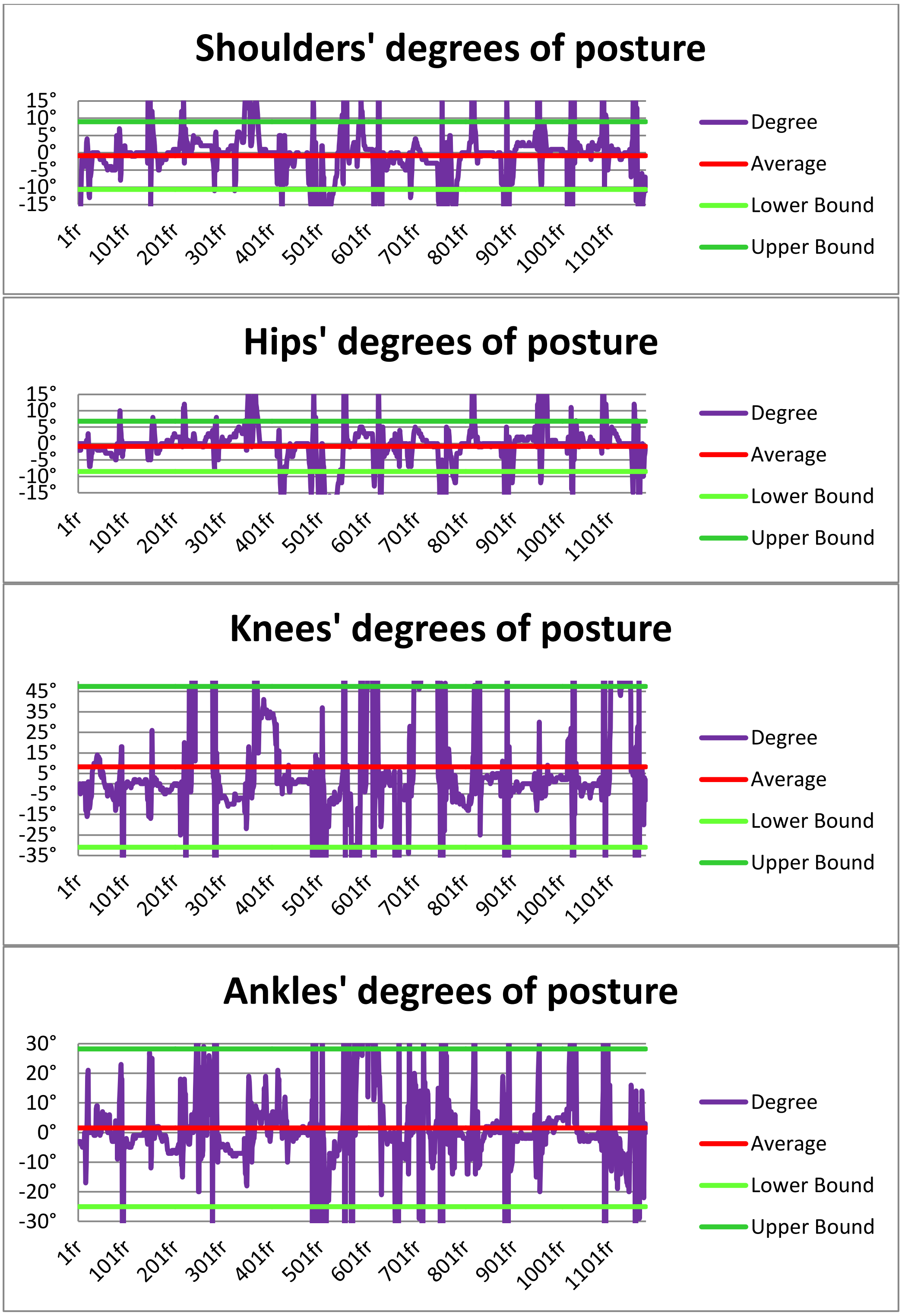


*Figure 5.18 Performance F6, first THR session, game 2, type 3x3*

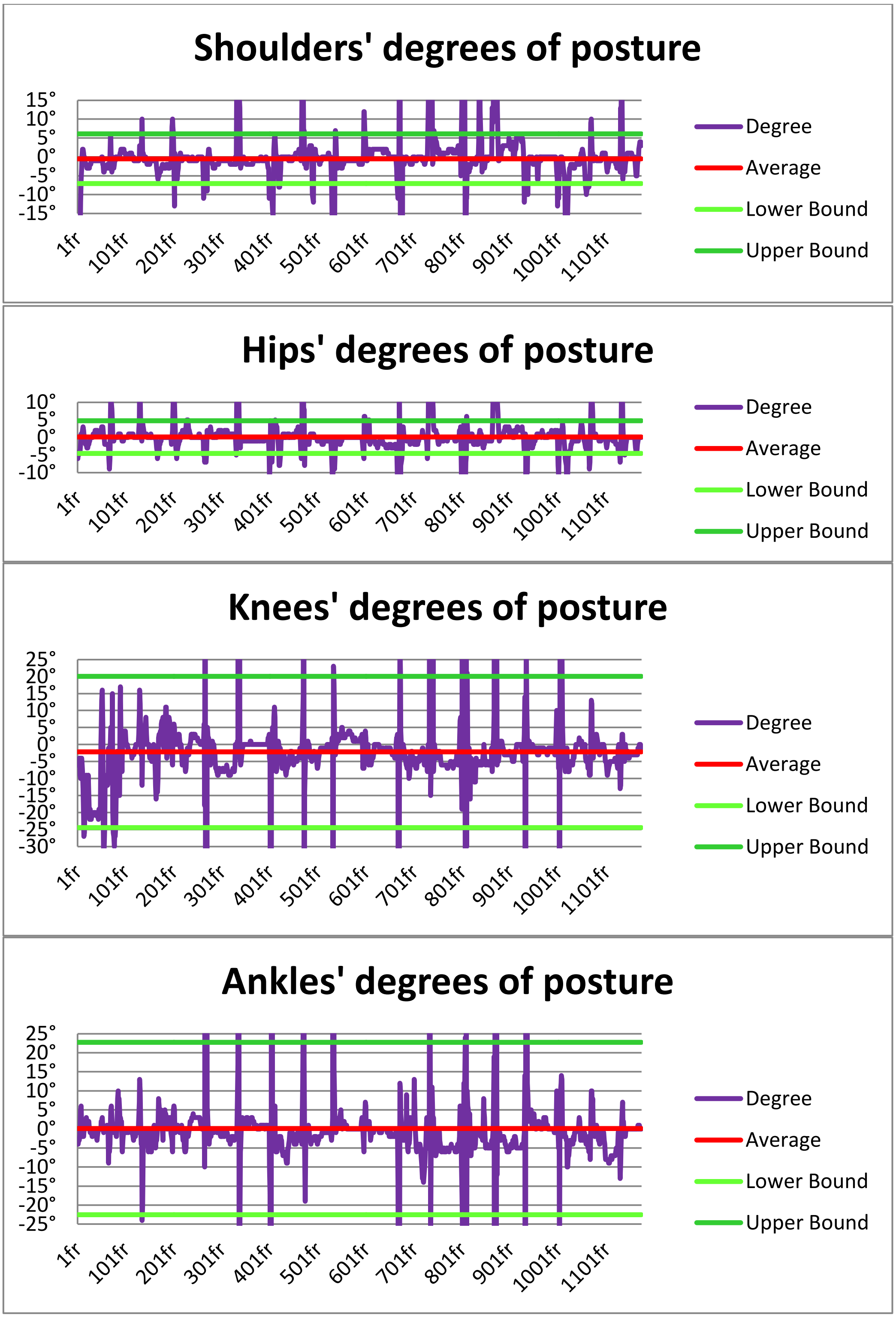


*Figure 5.19* *Performance F6, first THR session, game 3, type 1x3*

During the first therapeutic session, F6 played three games.

The first game was “*Beatrice the bee and the flowers run*”, which belongs to the 1x3 type. Figure 5.17 shows good postures. The knees’ value is due to F6 tendency to keep feet together.

The second game played by F6 was “*Devix the mage and the magical traps*”, which belongs to the 3x3 type. Figure 5.18 seems revealing a worsening of the knees value. Actually, F6 kept a better lower limbs positioning, with the legs more spaced to be more agile during the shifts. During the resting phases, however, she shifted the body weight over one leg, resulting in one lower knee.

Finally, F6 played “*Devix the mage and the endless run*”, which belongs to the 1x3 type. Figure 5.19 reveals the best F6’s performance. The high peaks during the shifting are due the to the considerable agility and speed of F6. Her movement were cleaner and the resting position balanced.

From the data results that F6 had minor balance issues while standing firm. She had to improve her weight distribution over the lower limbs, which resulted very strong.

### 5.3.5 Summary

The first therapeutic session confirmed the results of the tuning session. There was a good engaging factor. The added music tracks improved the identification of the players, and the bee game context pleased the younger girls.

The replay feature remained a must. With the hard grid configuration, there were obstacles with different shapes and pendency, so some degrees in the postures were justified. Plotted data lose this kind of information, and could lead to wrong evaluations. With the replay feature, instead, the therapist can easily verified the patient’s performance and can even show it to him/her in an understandable way.

The players’ clothes showed their importance. To improve the Kinect accuracy, therapists saw that is better to not wear baggy dresses. It is not mandatory for playing the games and for the rehabilitation process, but it is necessary to obtain interesting data to be plotted.

## 5.4 Second Therapeutic Session

Four subjects, one male and three females, took part to the second therapeutic session. We will refer to the subjects as F3, F6, M7 and F8. F3 was the same girl of the first experimental session; she was fifteen years old. F6 was the same girl of the second experimental session; she was nine years old. M7 was fifteen years old, and F8 was eleven years old. M7 presented JIA mostly to the upper limbs, while F8 had ankles problems. During F3 and F8's rehabilitations were present the respective mothers.

In this meeting we tested four games: "*Devix the mage and the magical traps*", which belongs to the 3x3 grid games, "*Devix the mage and the endless run*", which belongs to the 1x3 pillows game, "*Beatrice the bee and the flowers run*", which belongs to the 1x3 pillows game, and "*Beatrice the bee and the honey preparation*", which is a 3x3 grid game.

For F8 rehabilitation, the therapist participated helping the patient to stand firm.

### 5.4.1 Users' Feedback

The feedback from the subjects was very good. F3 enjoyed the rehabilitation session, more than her first trial. F6 showed the same lack of initiative in the grid creation phase, but then the same great effort and agility during the gameplay. M7's feedback was quite good. F8's feedback was good, despite her ankles problems.

Therapists' feedback was still good. Even other medics, outside our working group, showed interest in our system.

### 5.4.2 Data Analysis of M7

Here, we present the data collected during the rehabilitation session of M7. Data were collected in the same conditions of the initial tuning session. We saved the X,Y and Z coordinates of all the player skeleton's joints, and the records of the Kinect's camera. We saved data every 0.15 seconds from the beginning of each play. To analyse the patient postural behaviours, we plotted the postures' trend during the exercises performed. All plots report the raw data averages and the standard deviations, to facilitate the readings.

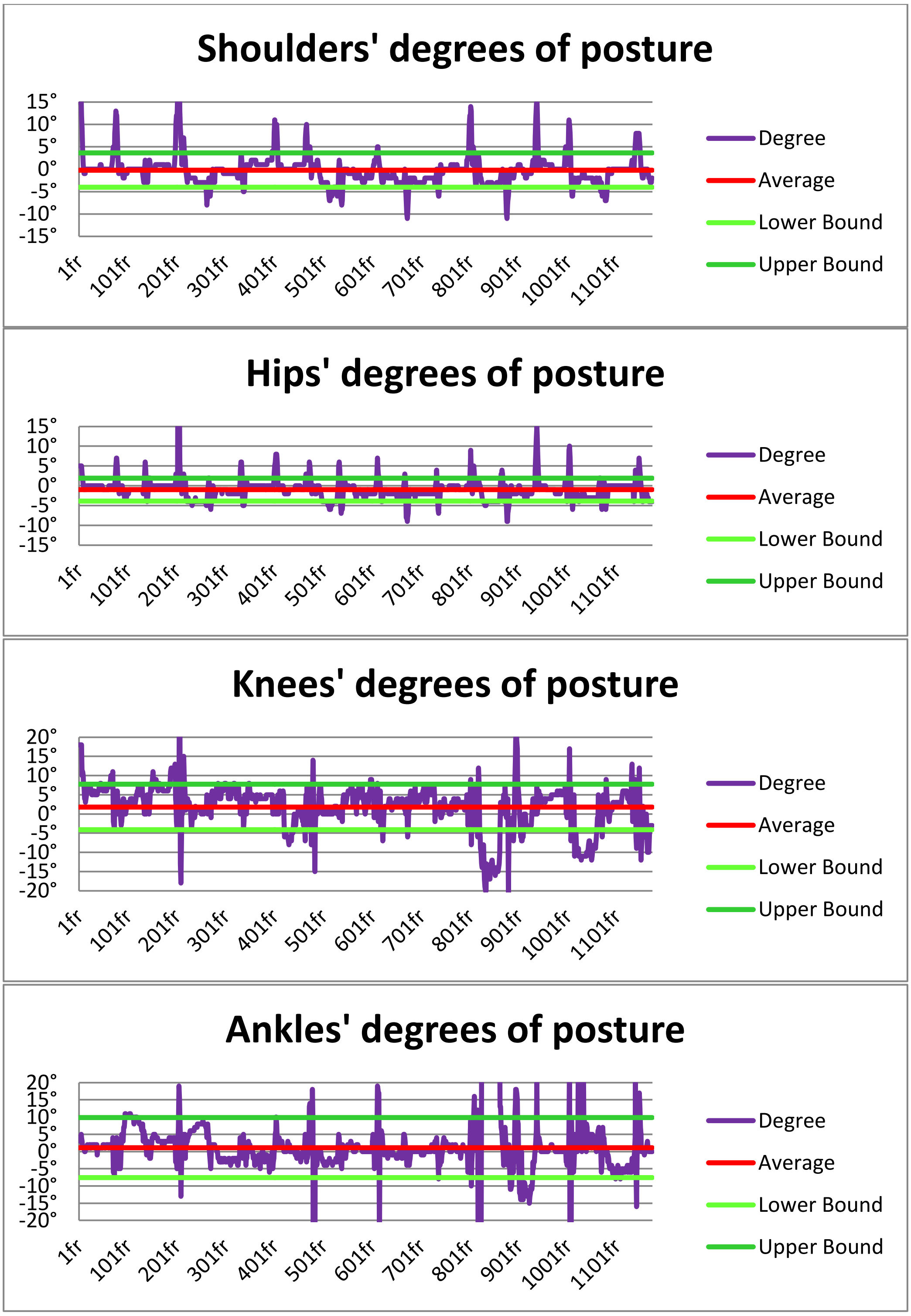


*Figure 5.20* *Performance M7, second THR session, game 1, type 1x3*

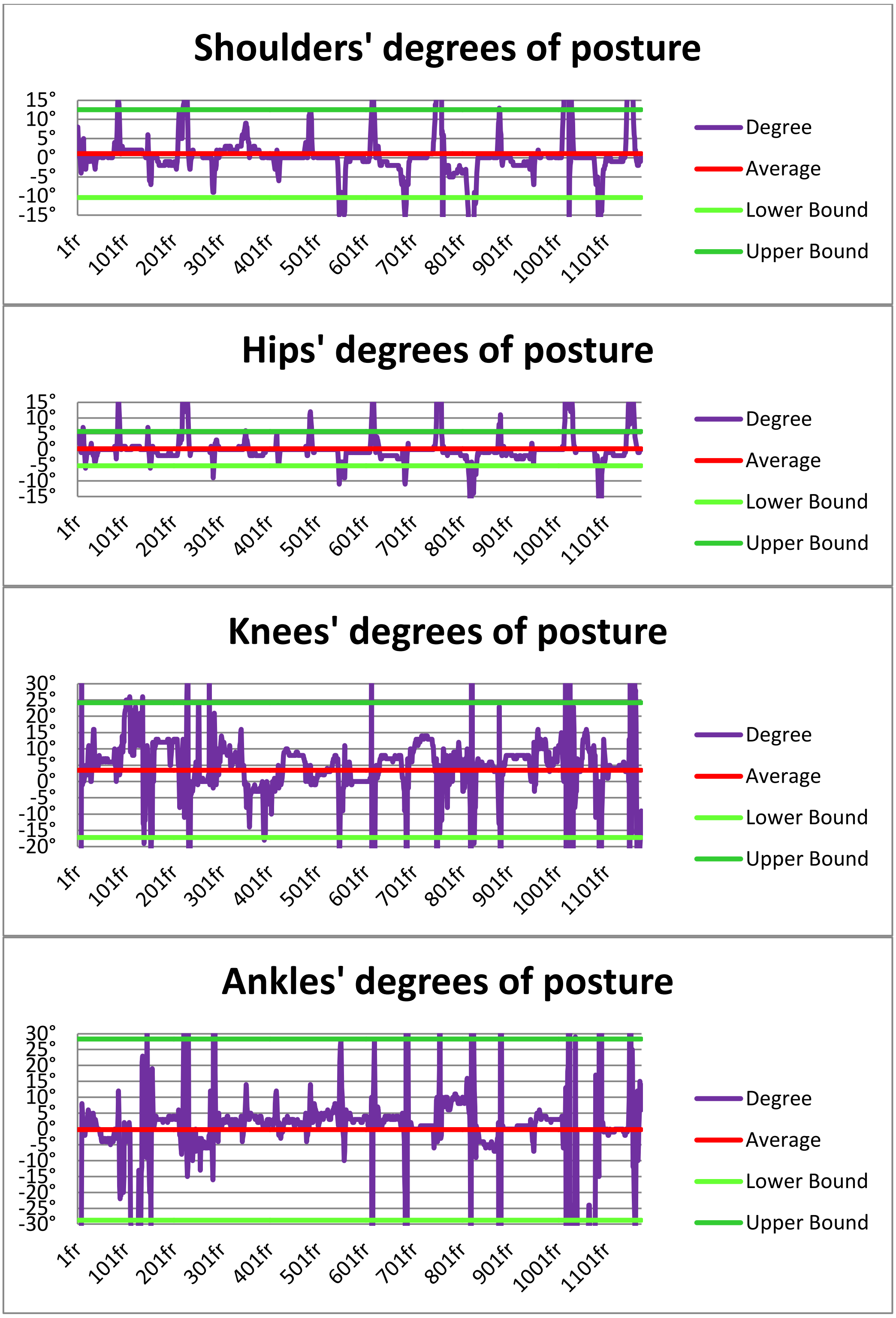


*Figure 5.21 Performance M7, second THR session, game 2, type 3x3*

During the second therapeutic session, M7 played two games.

The first game was “*Devix the mage and the endless run*”, which belongs to the 1x3 type. Figure 5.20 shows good postural behaviours. M7 shifting phases were very clean, and so are the peaks in the plots. The knees’ value is justified by an initial rigidity of the patient.

Finally, M7 played “*Devix the mage and the magical traps*”, which belongs to the 3x3 type. Figure 5.21 confirms the results of the first game. The shifting phases were more dynamic due to the grid configuration.

From the data don’t result lower limbs problems.

### 5.4.3 Data Analysis of F8

Here, we present the data collected during the rehabilitation session of F8. Data were collected in the same conditions of the rehabilitation session of M7.

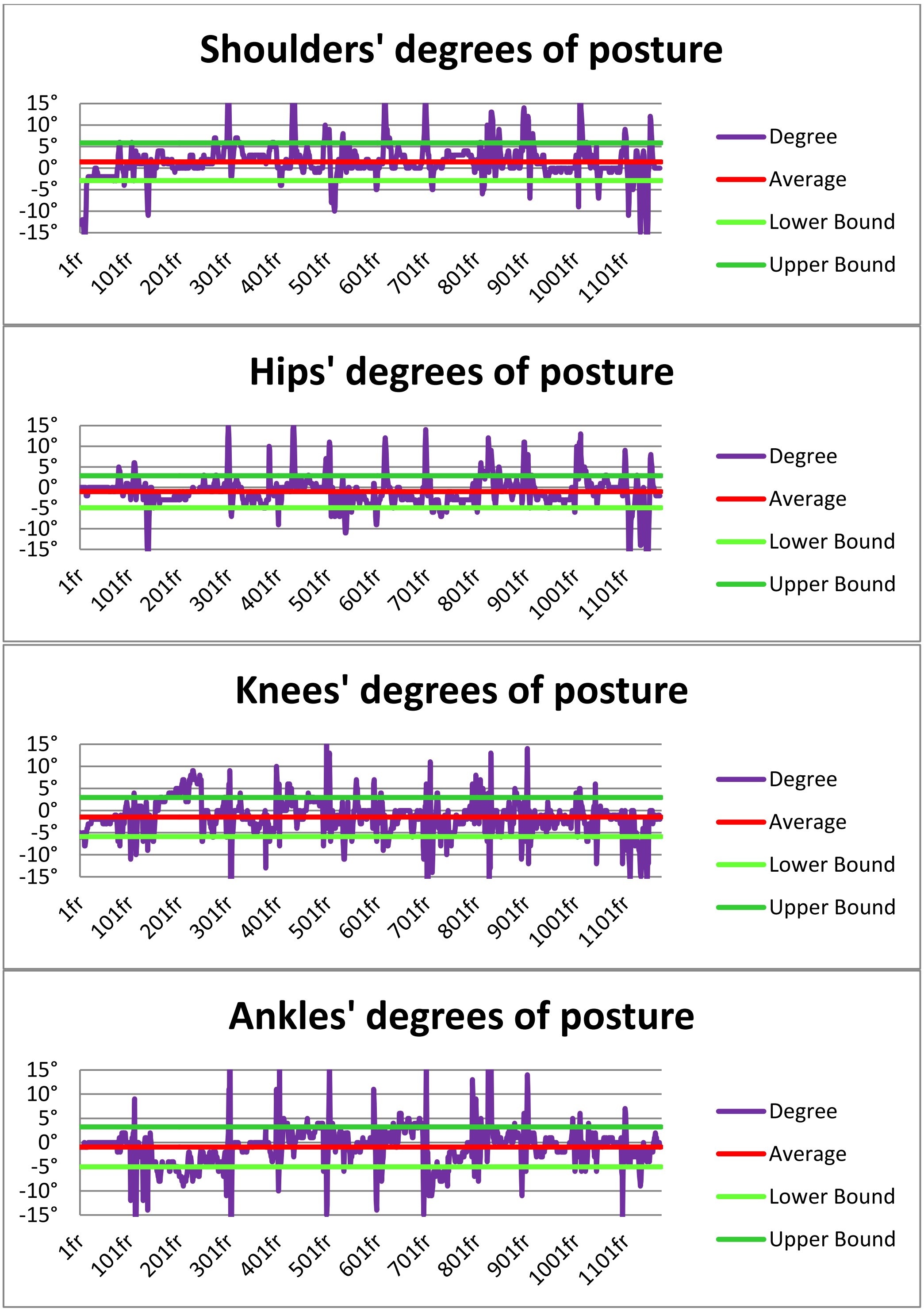


*Figure 5.22 Performance F8, second THR session, game 1, type 1x3*

During the second therapeutic session, F8 played one game.

The game was "*Beatrice the bee and the flowers run*", which belongs to the 1x3 type. This was a special trial. F8 suffered of significant ankles problems, and she was forced to stand tiptoed, both during normal walking and during the exercise. The therapist helped F8 by taking her hand and helping her to find balance after the shifts. Figure 5.22 reveals apparently good postural behaviours. Shoulders have some degrees due to the balancing phases and from the activity of holding the therapist hand. Knees and ankles have very good values, despite the serious ankles condition. This is due to the great postural symmetry acquired by F8. She stood in an unnatural body posture, but her knees and ankles were perfectly aligned; from the readings, there are consequently no feedbacks about something wrong.

This special trial was another confirmation of the importance and the utility of the replay feature.

### 5.4.4 Data Analysis of F3

Here, we present the data collected during the rehabilitation session of F3. Data were collected in the same conditions of the rehabilitation session of M7.

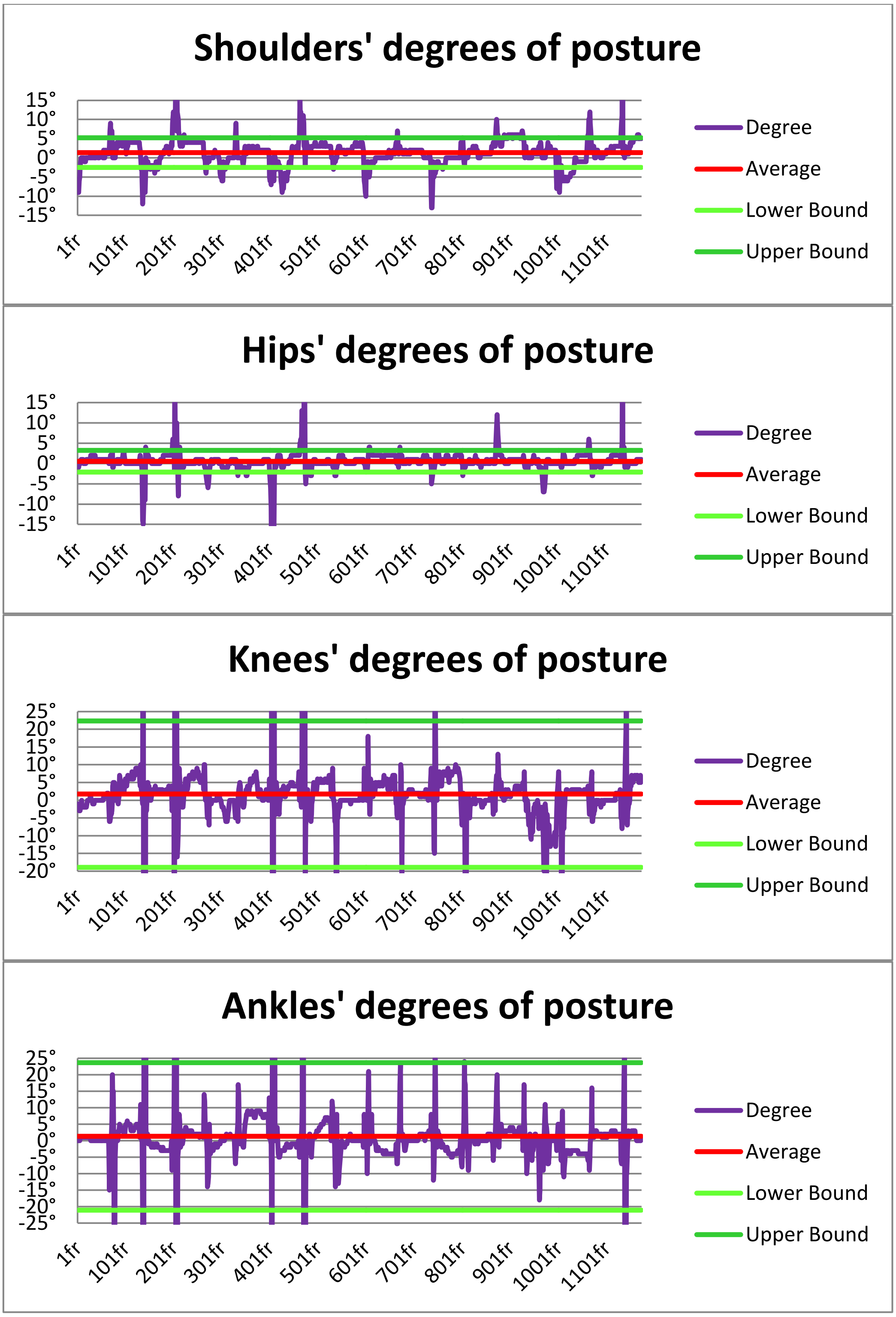


*Figure 5.23* *Performance F3, second THR session, game 1, type 1x3*

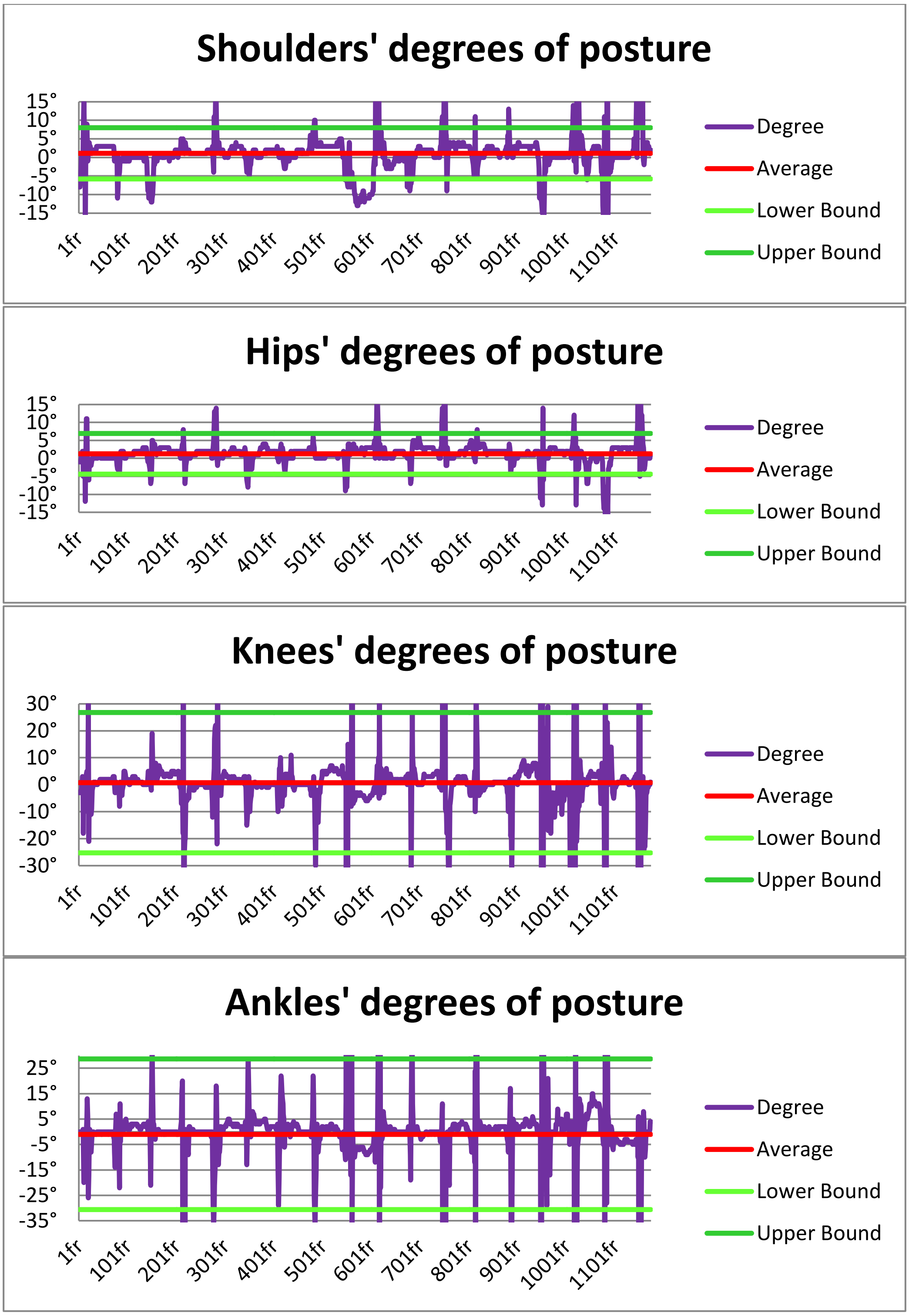


*Figure 5.24 Performance F3, second THR session, game 2, type 3x3*

During the second therapeutic session, F3 played two games.

The first game was “*Beatrice the bee and the flowers run*”, which belongs to the 1x3 type. With this game, therapists added the carpet under the playground. This improved the pillows’ stability, but introduced new pillows’ pressure reactions. Figure 5.23 shows a common trend in the joints’ degrees. This is probably due to the carpet addition.

Finally, F3 played “*Beatrice the bee and the honey preparation*”, which belongs to the 3x3 type. Figure 5.24 shows possible ankles’ problems. The reply proved that they were dependent from the obstacles, with different pendency, in the playground.

From the data don’t result particular complications in F3 postural behaviours, besides a minor problem to ankles. Therapists confirmed that the variability in the data was caused by the obstacles of the playground. F3 kept a better legs positioning than her first rehabilitation session.

### 5.4.5 Data Analysis of F6

Here, we present the data collected during the rehabilitation session of F6. Data were collected in the same conditions of the rehabilitation session of M7.

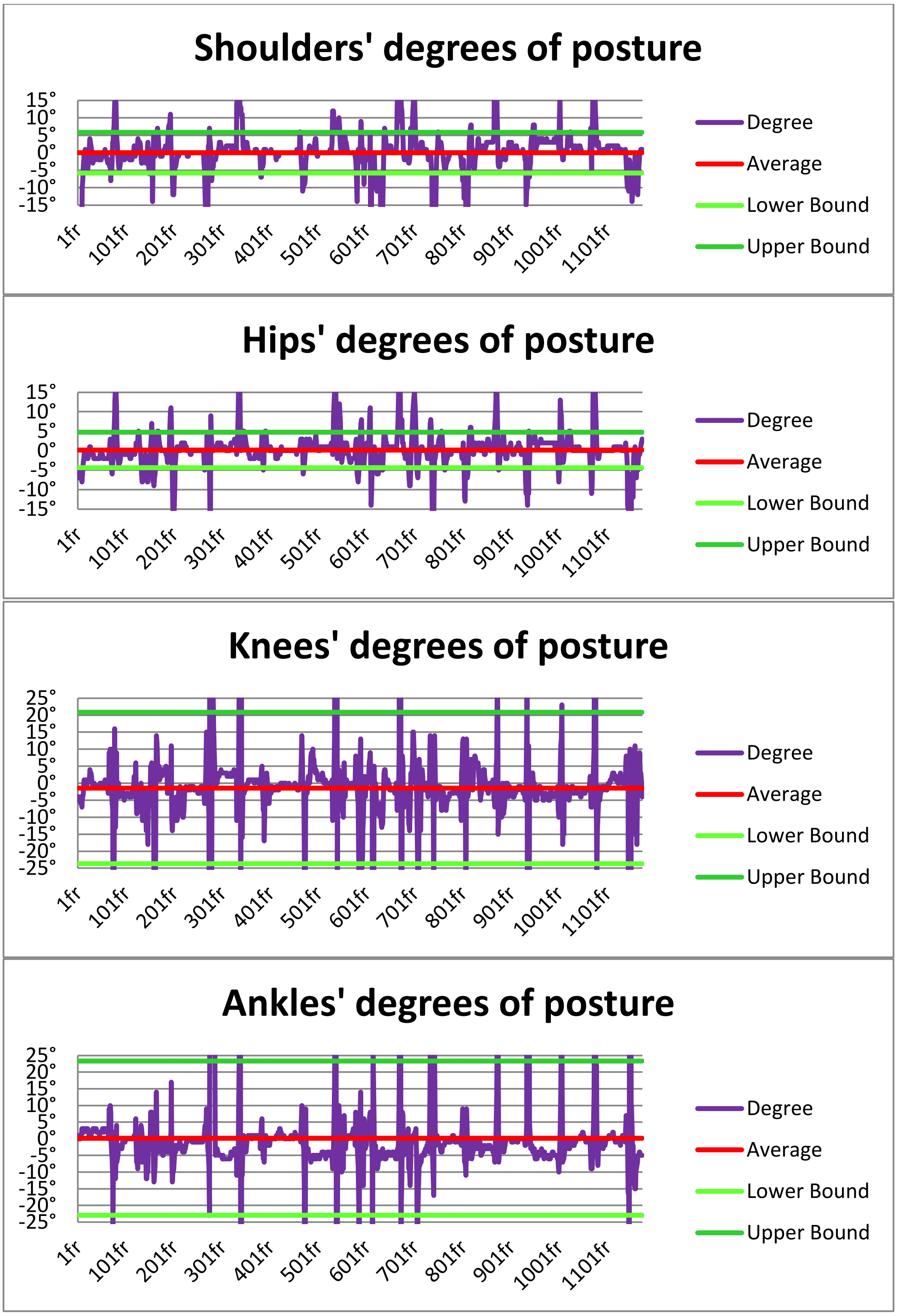


*Figure 5.25* *Performance F6, second THR session, game 1, type 1x3*

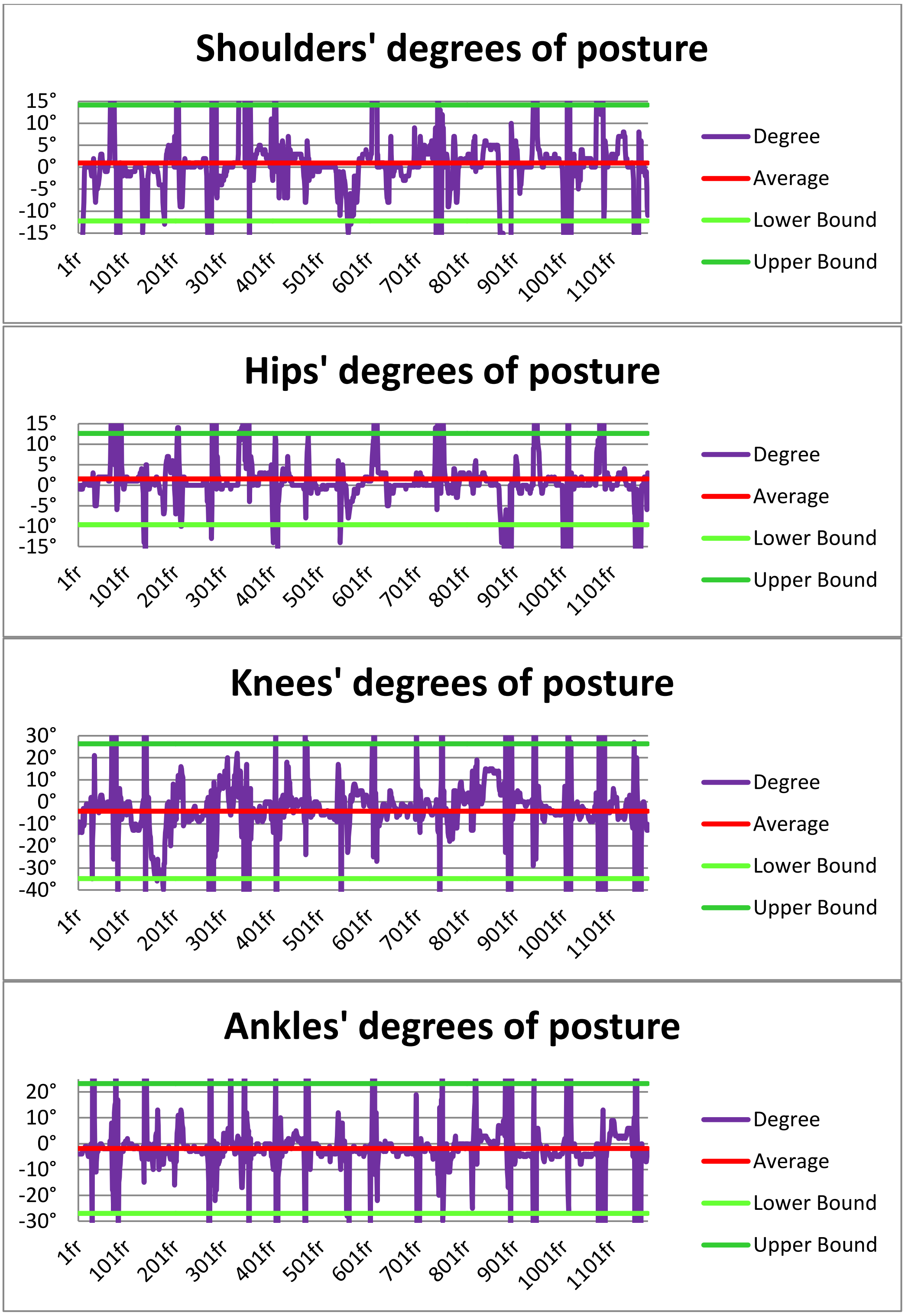


*Figure 5.26* *Performance F6, second THR session, game 2, type 3x3*

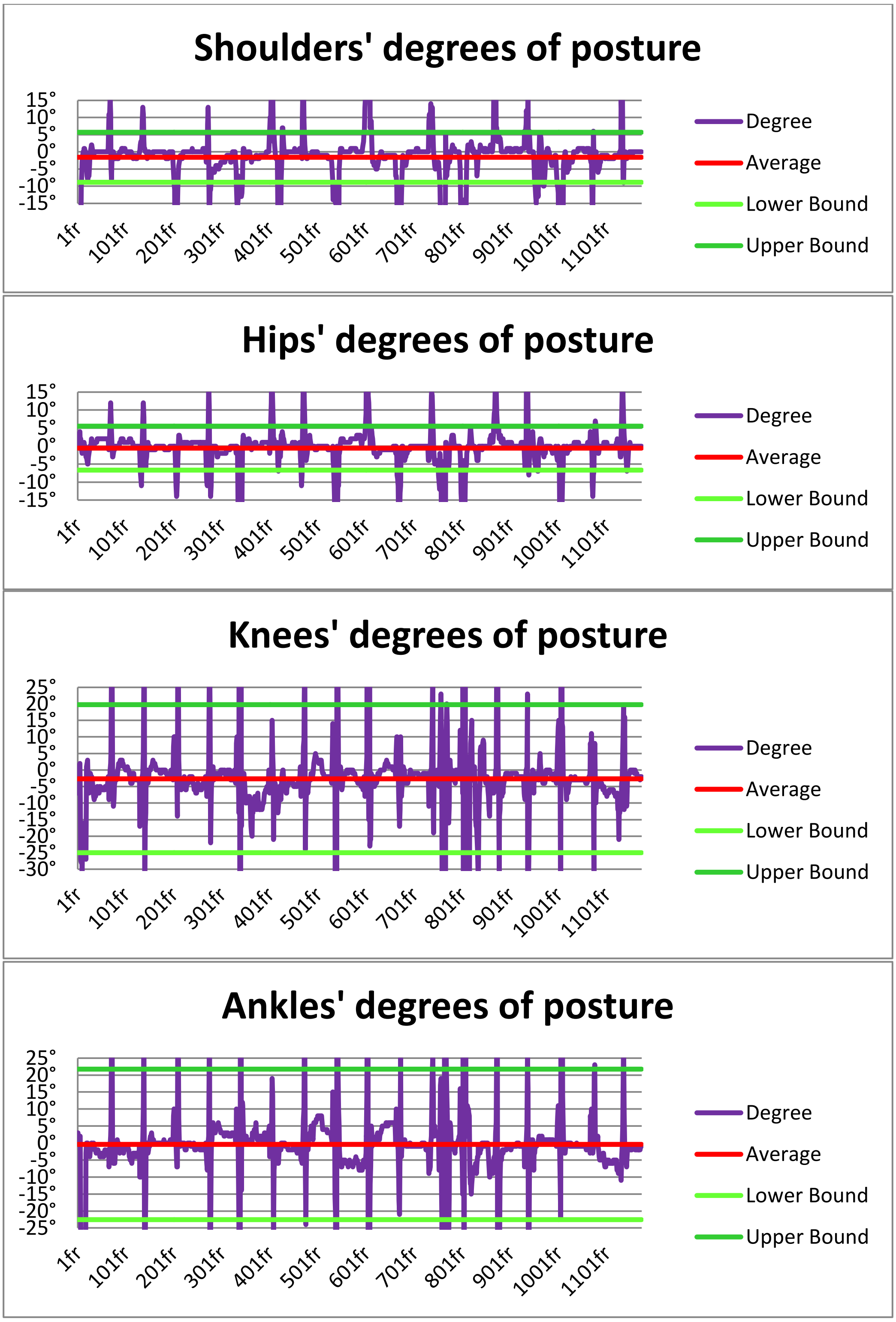


*Figure 5.27 Performance F6, second THR session, game 3, type 1x3*

During the second therapeutic session, F6 played three games.

The first game was “*Beatrice the bee and the flowers run*”, which belongs to the 1x3 type. Figure 5.25 shows good postural behaviours. The high peaks during the shifting phases are due to the high agility of F6.

The second game F6 played was “*Beatrice the bee and the honey preparation*”, which belongs to the 3x3 type. Figure 5.26 has more variability due to the grid configuration, more complex than the row one. F6 still shown great speed and agility, and high dynamism even in the resting positions.

Finally, F6 played “*Devix the mage and the endless run*”, which belongs to the 1x3 type. Figure 5.27 confirms the data of the previous games. The knees’ degrees are due to the obstacles with different pendency.

From the data results an improvement of the legs positions, more spaced and balanced. F6’s speed and strength were confirmed.

### 5.4.6 Summary

The second therapeutic session confirmed the results of the previous ones. There was a good engaging factor, and the different games pleased the patients.

The replay feature remained a must. With the hard grid configuration, there are obstacles with different shapes and pendency, so some degrees in the postures are justified. With the carpet addiction, this was even more evident. Plotted data lose environmental and case dependent information, and could lead to wrong evaluations. With the replay feature, instead, the therapist can easily verified the patient’s performance and can even show it to him/her in an understandable way.

With F8, we had the possibility to test the system with another person in the scene. F8 had specific problems to the ankles, and the therapist helped her to maintain balance. As long as the main joints, like head and hips, don’t become overlapped, the Kinect sensor doesn’t have difficulties in the readings.

# 6 Conclusions and Future Work

We designed a framework, with a set of rehabilitation games and features for the analysis, that could help patients, affected by Juvenile Idiopathic Arthritis to the lower limbs, in their physical therapy. The goal was to create games both useful and entertaining: useful, as a valuable tool for the therapist; entertaining, to prevent patients from quitting the rehabilitation process.

We started from the literature of serious gaming. We applied the specific rehabilitation principles to the ones of the common game design, to obtain games both medical relevant and fun to play.

During the experimental sessions, the feedback we received matched our design. The patients enjoyed the games and helped us suggesting additional changes to make them more appealing. Therapists noticed that the patients, concentrated on increasing the score, didn't pay much attention to their impediments and moved faster than the usual. They achieved movements that, in a common rehabilitation session, they would have performed only if been forced. Therapists also confirmed the importance of the replay feature for the evaluation of the patients' therapy.

Kinect v2 has met the expectations. It is more reactive than Kinect v1, allowing dynamic gameplays, and it collect the skeleton data with better accuracy. In some extreme scenarios, like the ones with the subjects with the most severe cases of JIA, there were some noises and variability in the lower limbs collected data. The replay mode allowed therapists to promptly and easily recognized them and continue, without problems, in the evaluation process. Subject F5's trial proved that it is fundamental, for a correct reading, that Kinect is able to see both head and the spine mid joint, which is the fulcrum of the virtual skeleton and it is positioned between the hips, otherwise the Kinect spatial references are "tricked" and the reading compromised. With subject F8's trial, we tested the system with another person in the scene. As long as the main joints, like head and hips, don't become overlapped, the Kinect sensor doesn't have difficulties in the readings.

In the future, more games and contexts will be added to please an even wider range of patients. Single joints games will be designed to cover other rehabilitation exercises, since have been proved limitations and capabilities of Kinect. Therapists suggested us that the mental challenge introduced by the mirrored/not mirrored versions of the games, could be useful in the rehabilitation of  cerebellitis and other similar pathologies, so it can be extended the range of application of our rehabilitation framework.

# 7 Acronyms

| | |
|---|---|
| **ACA** | post-viral cerebellar ataxia |
| **AR** | augmented reality |
| **IR** | infrared |
| **JIA** | juvenile idiopathic arthritis |
| **JRA** | juvenile rheumatoid arthritis |
| **PC** | personal computer |
| **VR** | virtual reality |

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