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ACTIVE PEDAL EXERCISER FOR LEG REHABILITATION

Dissertação de Mestrado na área científica de Engenharia Biomédica, especialidade de Instrumentação Biomédica e Biomateriais, orientada pelo Senhor Professor Doutor António Paulo Coimbra e apresentada no Departamento de Engenharia Electrotécnica e de Computadores da Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

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Active pedal exerciser for leg rehabilitation

Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Biomédica

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Resumo

A capacidade de mover os membros inferiores é crucial para a maioria das atividades diárias pelo que há uma necessidade permanente de desenvolver novos métodos para melhorar a mobilidade das pessoas. Esta dissertação retrata uma ferramenta de reabilitação da mobilidade das pernas. Os produtos para reabilitação de pernas mais comuns são pedaleiras e bicicletas estáticas. Na sua maior parte, eles são muito rudimentares, porque o treino não pode ser controlado através de software.

O dispositivo de reabilitação a que esta dissertação se refere baseia-se numa bicicleta estática assistida por um motor, que é desencadeada gradualmente de acordo com a pressão exercida sobre sensores de força nos pedais. Se o paciente tiver uma perna com problemas de mobilidade, permite a compensação desta para que se possa realizar o movimento de ciclismo esperado.

Este dispositivo tem um sensor para monitorizar a frequência cardíaca do paciente. É utilizado para assegurar a eficiência do tratamento e a segurança do paciente. Cada perna pode ser a exercitada independentemente usando diferentes parâmetros. Isto é particularmente útil para pacientes com AVC. Também pode compensar um membro perdido ou danificado, imitando o desempenho da perna saudável.

O fisioterapeuta pode gerir os parâmetros do treino (velocidade, força em cada pedal, frequência cardíaca) numa interface de computador e monitorizar a sessão. Foram desenvolvidas duas interfaces para manter os pacientes motivados para ficarem perto dos valores de referência. A primeira interface é composta por gráficos de barras que representam os valores de força, velocidade e frequência cardíaca a cada instante, e as linhas verdes e vermelhas representam os valores de referência e máximos, respetivamente. A segunda interface é um jogo virtual, com uma bicicleta na tela que representa o desempenho do utilizador como seria na vida real. Quanto mais longe dos valores de referência estiver o desempenho do paciente, mais rápido ele vai perder pontos. O valor da meta é representado pela bicicleta ereta e a estrada sem inclinação.

Foram realizados dois conjuntos de testes para testar os controlos da bicicleta e discernir padrões. Na primeira fase, para velocidades mais baixas (600 rpm e 1300 rpm) os ciclos foram mais definidos do que para velocidade mais elevada (2000 rpm). Para baixos valores de resistência consegue-se distinguir um padrão que pode ser explorado no futuro para melhorar os modos de controlo. Este padrão diminui com o aumento de resistência. Na segunda fase, o padrão de ciclismo obtido com a interface do paciente e com o jogo virtual, para a mesma velocidade ou mesma resistência, não diferem muito, pelo que a utilização de uma interface ou da outra não afeta a eficácia da reabilitação.

Abstract

The ability to mobilize the lower limbs is crucial for most daily activities so there is a permanent need to develop new methods to improve people's mobility. This dissertation portraits a tool for motion rehabilitation. The most common leg rehabilitation devices are pedal exercisers and static bicycles. Mostly, they are very rudimentar because the health staff cannot control its use through software.

The rehabilitation device this dissertation concerns is based on a motor assisted static bicycle, which is gradually triggered according to the pressure exerted on the force sensors on the pedals. It allows compensation for a leg with mobility problems so it can perform the expected cycling movement.

This device has a sensor to monitor the patient's heart rate. It is used to ensure the treatment's efficiency and the patient's safety. Each leg can be trained individually using different parameters. This is particularly useful for stroke patients. If the patient has a leg with mobility problems, it compensates that leg so it can perform the expected cycling movement.

The physiotherapist can manage the training parameters (speed, force on each pedal, heart rate) on a computer interface and monitor the training session. There were developed two interfaces for the patient to keep them motivated to stay close to the reference values. The first interface consists of bar graphs that represent the values of force, speed and heart rate at each instant, and the green and red lines represent the reference and maximum values, respectively. The second interface is a virtual game, with a bicycle on the screen that represents the performance of the user as it would be in real life. The farther the patient's performance is to the reference values, the fastest he or she will lose points. The goal value is represented by the bicycle upright and the road with no inclination. Through ergonomic questionnaires it was determined that the virtual game was the preferred interface.

Two separate sets of tests were performed to test the bicycle control and discern patterns. In the first phase, for lower speeds (600 rpm and 1300 rpm) the cycling cycles were more defined than for higher speed (2000 rpm). For low resistance values a pattern can be distinguished, and can be explored in the future to improve the control modes. This pattern fades with the increase of resistance. In the second phase, the

cycling pattern while using the patient interface and virtual game, for the same speed and same strength do not differ much, so the use of an interface or the other does not affect the outcome of the rehabilitation.

List of Acronyms (abbreviations and symbols)

APE – Active Pedal Exerciser
MS – Multiple Sclerosis
OA – Osteoarthritis
DAQ – Data Acquisition System
BMI – Body Mass Index
HFE – Human Factors and Ergonomics
SUS – System Usability Scale
PSSUQ – Post-Study System Usability Questionnaire
SUMI – Software Usability Measurement Inventory

Contents

Chapter 1
Introduction

1.1. Context

The ability to walk is one that we take for granted. We rely on it for every task in our daily lives. Either to go from one division of our home to another, to go shopping or either to practice sports. The lost or impairment of the ability to walk does not threaten our lives, but it makes them a lot harder.

The maintenance of normal gait requires three crucial components: locomotion, which embodies initiation and maintenance of rhythmic stepping; balance; and capacity to adjust to the environment [1]. If one or more of this components is not operational, the gait will be disturbed.

Several diseases and multiple accidents can provoke a diminished or loss of the mobility of the limbs, either inferior or superior. Some of this pathologies cause a discrepancy between the mobility of each limb, making it necessary to train each leg, or arm, individually, for the training to be as effective as possible.

Medical rehabilitation's goal is to reduce deficiency and disability, resistance to work, aerobic exercise, practice of balance and coordination, active and passive mobility and training in activities of every-day life.

The goal of this dissertation was to develop a rehabilitation device to address this need. The device is based on a stationary bike with an electrical motor, which is controlled according to the force exerted on the force sensors existent on the pedals. This device is now called the *Active Pedal Exerciser* (APE). In addition, it was developed a virtual interface, to guide the patient's training, in order to make it as productive as possible.

1.2. Gait Disorders

Gait can be affected by many factors, ranging from accidents, to diseases and age related problems. Some of this causes will be cited bellow.

In elderly populations, gait disorders are very common, and increase drastically with age. Gait disorders can lead to falls, which can be pretty serious to a person well-being [1].

Some of the pathologies that cause asymmetries in locomotion are multiple sclerosis (MS), stroke, unilateral total hip replacement and osteoarthritis (OA) [2]. Individuals with these pathologies pedal with an asymmetrical pattern, rendering asymmetrical training more important than normal cycling.

Robotic devices have been implemented in treatments for both upper and lower limbs rehabilitation. They provide a safe, intensive and task-oriented rehabilitation for patients with mild to severe motor impairments, and is an affordable therapy [3].

Some of their major advantages are: precisely controllable assistance or resistance, good repeatability and measure the subject's performance objective and quantifiably [3].

1.3. Cycling for Rehabilitation

Cycling improves the coordination, the balance and the physical condition. Cycling can be distinguished between active and passive cycling. In active cycling, the person steps on the pedals do perform the motion, whereas in passive cycling, the person follows the movement of the pedals. Both types are efficient for therapy, due to reciprocal movement with alternation between flexion and extension of the joints. As a result, the muscles become stronger [4].

In the beginning of rehabilitation, it is often preferred passive rehabilitation to reduce swelling, alleviate pain and restore range of motion. The following stage is often an active-assistive movement phase, involving the use of external support to assist the muscles in moving the joint in order to reestablish neuromuscular control.

The last stages aim at returning an individual to normal activities through resistance exercises focused at regaining muscle strength [5].

1.4. Publications Resulting from the Dissertation

Taking advantage of the 4th IEEE Portuguese Meeting on Bioengineering (ENBENG), it was done a poster presentation, on the theoretical principle on which the dissertation is based and the initial developments (Feb 2015) [6].

More recently, an updated version of the developed work was submitted for the 4th Baltic and North Sea Conference on Physical and Rehabilitation Medicine in Riga. A poster presentation was also presented (Sept 2015) [7].

1.5. Dissertation Structure

The master dissertation document is structured into six chapters. The first exposes the objective of the APE and its need. The second presents the state of the art of bicycles and devices alike, for lower limb rehabilitation.

The third chapter is a description of the device and its interfaces. The fourth reports the need to analyze the ergonomics of the interfaces. The fifth presents the methods and results obtained in the testing phase. And in the sixth are discussed conclusions and future work.

In the appendices are the questionnaires distributed and their results.

Chapter 2

State of the Art

This chapter describes several approaches to equipment to accelerate recovery after an injury or operation. There are several robotic devices for leg rehabilitation but our focus will be mostly on static bicycles, and variations of them. The first section is a review about products that are already in the market. The second one reviews products in development.

2.1. Rehabilitation Devices Being Commercialized

One of the mostly used approaches for lower limb rehabilitation is the use of bicycles. More precisely, static bicycles and pedal exercisers.

The most part of these systems are very rudimentary, as they only allow control of the resistance exerted on the pedals, and only some have the ability to give output of parameters of the training session, for example session duration, speed, calories spent.

HUR® Devices

The manufacturer HUR® has several models in the market, for lower limb rehabilitation, which are specific to the muscle or region which the training is aimed at. Despite this diversity, none of the devices has control modules implemented via software. These devices were developed to exercise specific leg muscles.

The most recent version of the devices has a SmartCard kit, with a touch screen display and system training programs, repetitions and resistance. As an extra, they can have isometric testing sensor attached, to measure strength and muscular balance.

Some of their products are:

- **Adduction/Abduction Rehab Device** [8] exercises adductor and abductor muscles of legs in a comfortable and easy way (see Figure 1 – A)).
- **Extension/Curl Rehab Device** [9] allows for an effective and safe training of hamstring and quadriceps muscles (see Figure 1 – B)).
- **Leg Press Rehab Device** [10] is an effective machine for exercising all leg muscles (see Figure 1 – C)).

Figure 1 - HUR products: A) adduction/abduction rehab device [8]; B) extention/curl rehab device [9]; C) leg press rehab device [10]

Pedal exercisers

The major part of leg rehabilitation devices are pedal exerciser, mostly due to the ease to store them between uses.

They are suitable for upper or lower limb rehabilitation. But there are some, like the Dual Bike [11], that allows training of both legs and arms at the same time. Its LED screen gives the output of time of exercise, calories burned and distance done.

The simplest models only have one pair of pedals, as the Easy Cycle [12] for example. This equipment can train both legs and arms, by changing the pedals for handles. The Easy Cycle has a built-in computer that records time of session, speed, repetitions, distance and calories burned and has a command. The timer can be set to 5 different times; there are 4 speed options; option pedaling forward/backward; also has security settings, when an alarm sounds when being used inappropriately. It can run a fixed program or customize a workout.

A more advanced version is the Endorphin 300-e4 Tabletop Hand Cycle with 355 Table [13]. It also has the pedals and handles, the display screen and ability for forward and backward movement. Besides those features, it has eight predefined complete programs and displays pulse, time, distance, speed, calories and heart rate.

2.2. Products in Development

There are several patented devices that are more advanced than the ones discussed in the previous sub-chapter, but are not yet being commercialized.

(1) Motorized Lower Body Rehabilitation Device

Disclosed is a motorized device for rehabilitation that trains proper gear, increases blood circulation, relieves stress and reconditions muscles and joints of the lower limbs (see Figure 2). The device combines an exercise bike with visual stimuli in three dimensions on a screen to distract the patient while doing your workout [14].

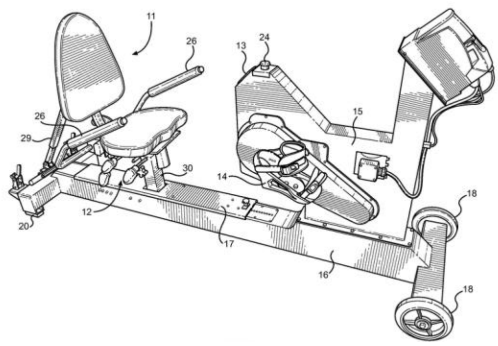

Figure 2 – Motorized lower body rehabilitation device [12]

(2) Rehabilitation device

This is a device for joint rehabilitation after injury or surgery. It reacts to the individual performance to optimize the rehabilitation process. The motor adjusts the bicycle strength to provide variable resistance during the training. Before the train sessions starts, it is necessary to enter preliminary parameter on the computer to do a rehabilitation plan, and monitor the patient's performance to adapt to changes [15].

The motor resistance unit automatically adjusts the rotational speed or the simulated resistance. The motor resistance acts as resistance to movement through microcontrollers placed on the pedals. The screen used to enter data or select programs is tactile (see Figure 3.)

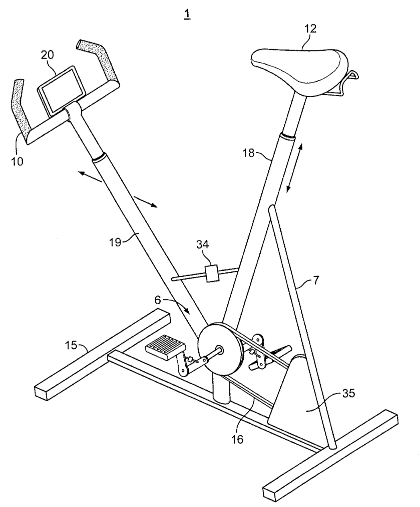

Figure 3 – Rehabilitation device [15]

(3) VRACK

This device consists of a cycling rehabilitation mechatronic system with a virtual interactive environment called Virtual Reality Augmented Cycling Kit (VRACK). This system combines commercially available stationary bicycles and an interface with a personal computer for process simulation and data acquisition [2].

The exercise bike has sensors to integrate physiological and biomechanical parameters, providing feedback to the individual in the virtual environment of the screen while running your workout (see Figure 4.) The modules are mounted in a normal exercise bike.

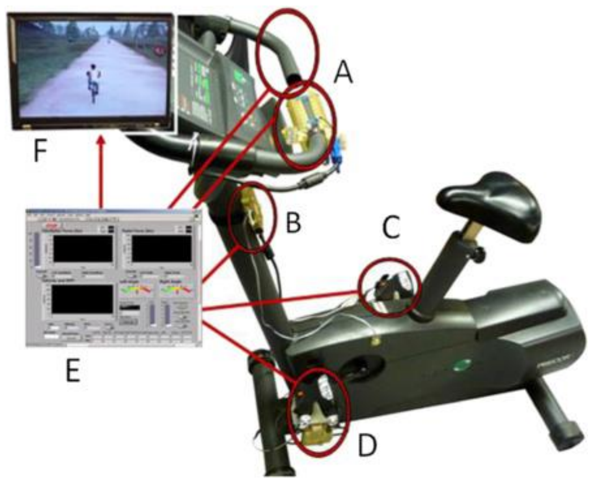

Figure 4 - VRACK [2]

The parameters obtained from these systems are communicated to a therapist to customize and monitor the training session.

The handle system uses a hydraulic dynamometer that measures the force applied to control the cyclist in the virtual environment.

(4) MedExercise® ST

This is the first device designed to train bilateral lower limbs. The flexion and extension movements used during the training session are similar to those performed for walking, so it is an appropriate device to train the march. The device plays movement of low-impact walking (see Figure 5.) Plays the benefits of walking on a treadmill with the convenience of exercising while sitting. The device can be used as sitting or lying down [16].

Resistance levels and range of motion of the joints are adjustable for each leg, allowing unilateral and bilateral training. It is possible to connect the two pedals, causing a leg helps to move the other leg. It measures the cadence and workout intensity.

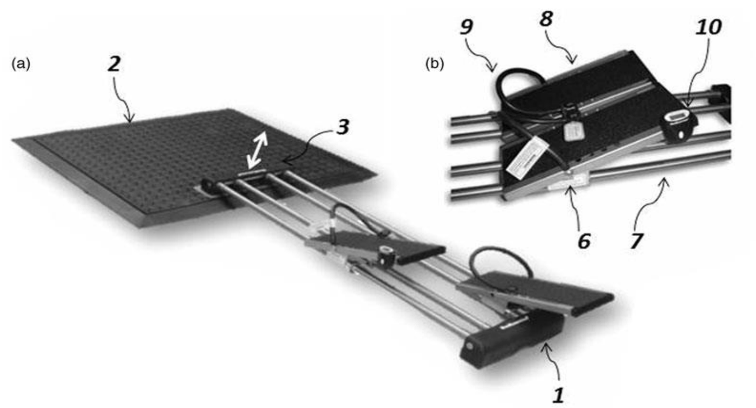

Figure 5 - MedExercise® ST [16]

(5) Brushless DC motors keeping muscles in shape

The device consists of a recumbent bicycle equipped with an electric motor that provides additional power to feed the FES (functional electrical stimulation) [17].

The DC motor is required to support the initial stimulation, and keeping the legs of the moving subject. Also controls the training changing between walking frontward or backwards, or acts as a wave generator, depending on the capabilities of the patient. The motor impels the patient’s legs to move, till they can generate force themselves, and then acts as a brake (see Figure 6.)

Figure 6 - Brushless DC motors keeping muscles in shape [17]

After this research, it could be concluded that there is no device with all of the features we applied in the APE. But they can be seen in some of these devices. The devices (1) and (3) are rehabilitation bikes with a virtual environment. The device (2) does not have a virtual environment, but the training can be programmed and the motor adjust to the training. The (4) trains legs bilaterally, and although it emulates better the walking pattern, but lacks every other feature. The (5) is also very alike the APE but does not train bilaterally.

Chapter 3

The Device

3.1. Active Pedal Exerciser

The *Active Pedal Exerciser* is aimed at the rehabilitation of the lower limbs. It is an adaptation of a stationary bike, where the goal of design is a pedal exerciser instead of a stationary bike.

To the stationary bike was added a DC motor, a gear box, a power supply, a Data Acquisition System (DAQ), three force sensors in each pedals, an ESCON controller, a Zener diode and a sensor to monitor the heart rate (Figure 7.)

The APE's motor is gradually triggered, depending on the pressure exerted on the force sensors existing on the pedals, allowing to compensate the leg with mobility problems, helping it to perform the expected cycling movement. The data acquired is transmitted to the software in real time.

It has the ability to train each leg in a different way, through the prior introduction of training parameters, on the physiotherapist interface. It can also compensate for a missing or impaired limb by mimicking the performance of the healthy leg.

The training can occur in passive or active mode, depending on the patient's capabilities. The modes are named after what the bicycle does. So in the passive mode, the motor works as a brake because the person can mobilize the leg to do the intended training. In the active mode, the motor aids the leg to perform the movement. The bicycle does not have to be in either one mode or the other, it can be in passive mode on the healthy leg and in the active mode for the impaired one.

A computer interface allows the physiotherapist in charge to set the required parameters for each patient. The patient also has an interface to keep track of his or hers progress and stay motivated. The patient's interfaces are described in sub-chapter 3.2.

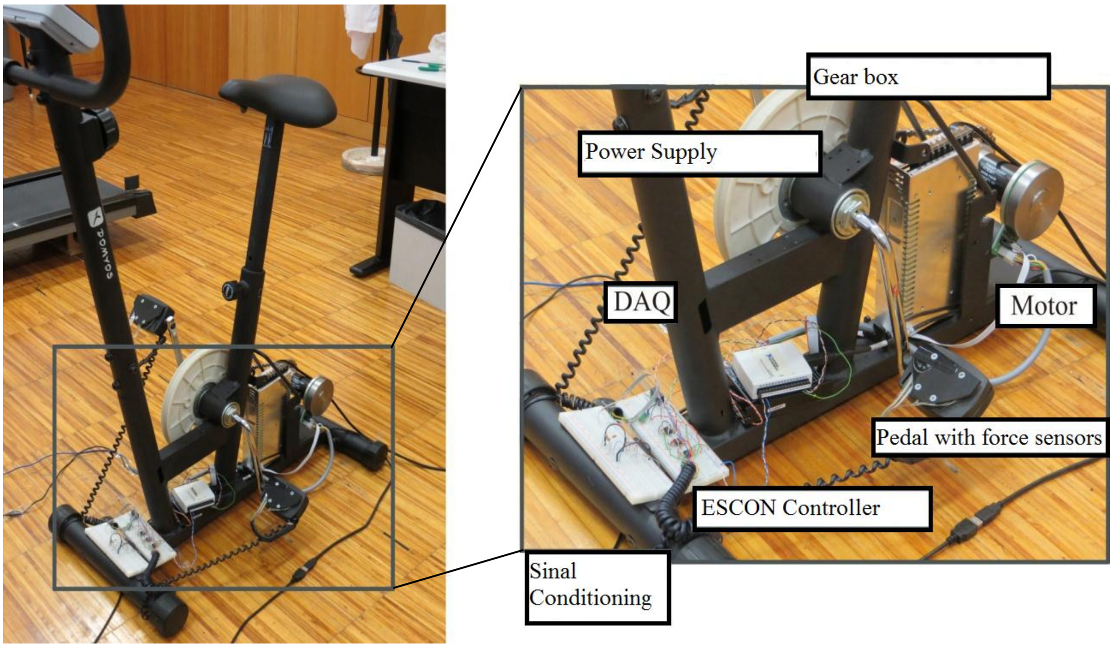

Figure 7 - Active Pedal Exerciser

3.2. Interfaces

3.2.1 Physiotherapist Interface

The physiotherapist interface has three blocks (Figure 8.) The first block is for the user's data. All the fields are editable, except for the BMI (Body Mass Index), or IMC in Portuguese, that is calculated using the height and weight of the person. It uses the standard formulae, in which the BMI is the ratio between the weight in kilograms and the square height, in meters.

The second block is the crucial one. The first step of the physiotherapist is to choose the control mode. There are four modes implemented. The therapeutic ones are the control by force and the control by speed.

After this selection, some options will be enabled (the ones that are needed for the control) and other will be disabled (the ones not pertinent to the control mode.) This editable text catches errors. It only accepts integer numbers in a pre-set range. This range wasn't yet evaluated by a health physician, so it might not be appropriated for therapy. When the control by force is selected, the editable fields are reference force for each leg, the percentage of operability for each leg and the maximum heart rate. When is selected the control by speed, the enabled fields are the reference speed and the maximum heart rate.

The section on the right side of the screen is for visualization only. It shows the force in each sensor, for each pedal, and the sum of the total force for each pedal in front, in Newtons (N). As well as the current and injected speed, in rotations per minute (rpm), and the current heart rate, in beats per minute (bpm). In the section Graph Visualization, the physiotherapist can select which graphs he wants to see, in the area below.

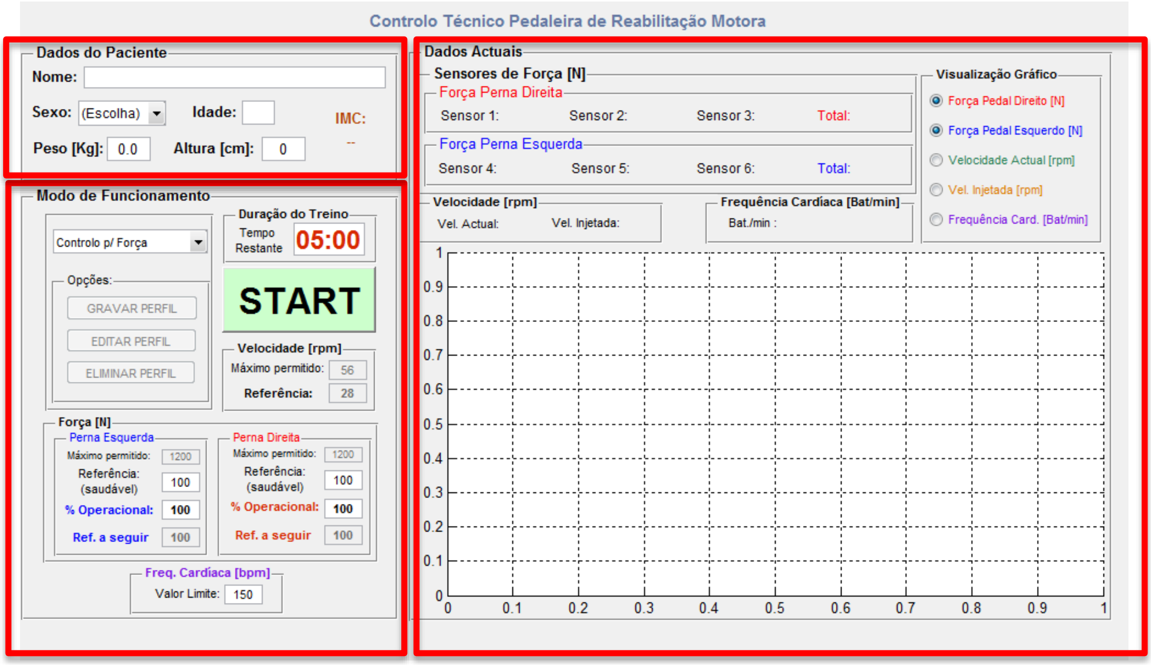

Figure 8 - Physiotherapist Interface

3.2.2. Patient Interface

For the patient's interface, two different types were planned and executed. Initially it was though that the best way to guide the user would be with bar graphics with horizontal lines indicating the range of therapeutic values, and one representing the reference or goal value. An initial sketch was made in Balsamiq Mockups® and is represented in Figure 9.

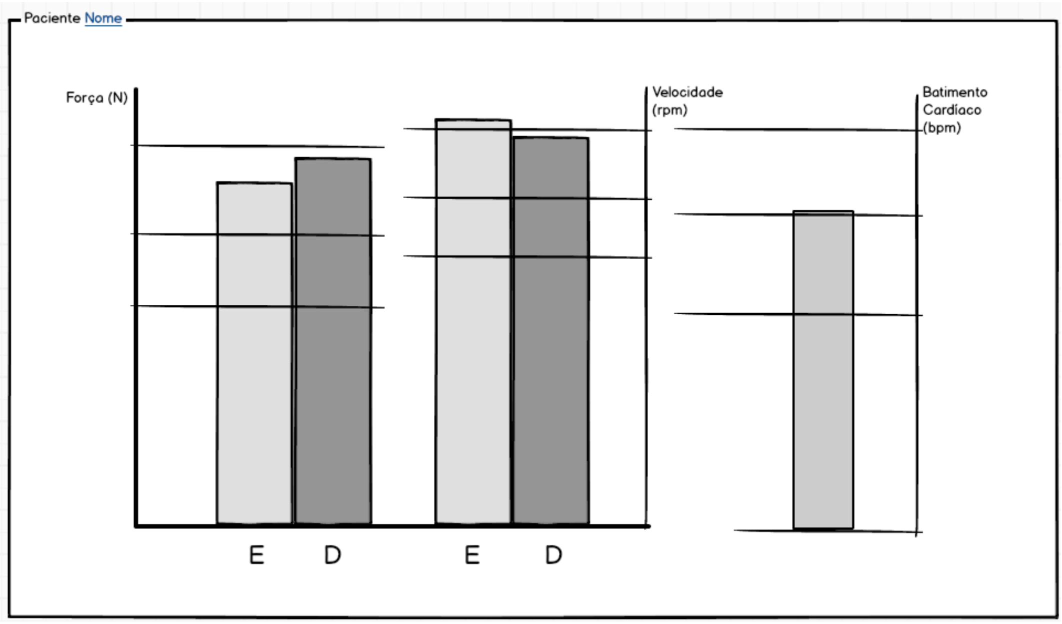

Figure 9 - Initial mockup of the interface

It was also planned that each bar would change colors such as: if the actual value was greater than the maximum, the bar would turn red; if the actual value was below the minimum, it would turn yellow; and if the value was between the maximum and the minimum, it would be green. This step of development is shown in Figure 10.

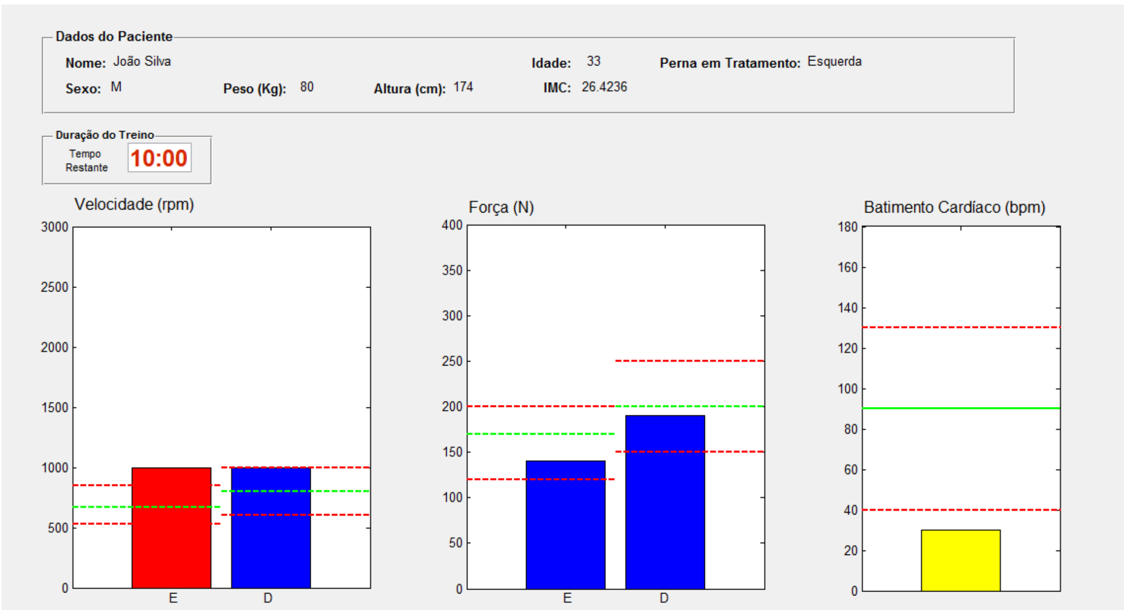

Figure 10 - Patient Interface, version 1

The concept for the control values was changed and the minimum value disappeared, and so did the condition for when the value was lower than the minimum. The option for the selection of the leg in treatment was replaced by the percentage of operability of each leg, so it disappeared from the patient interface.

The final interface is not editable. It only receives information and shows it on the screen. The information received comes from the physiotherapist interface.

It has a similar field of user data to the physiotherapist interface. All the data is imported from there. The field for training duration is also imported. The timer is initialized by the physiotherapist.

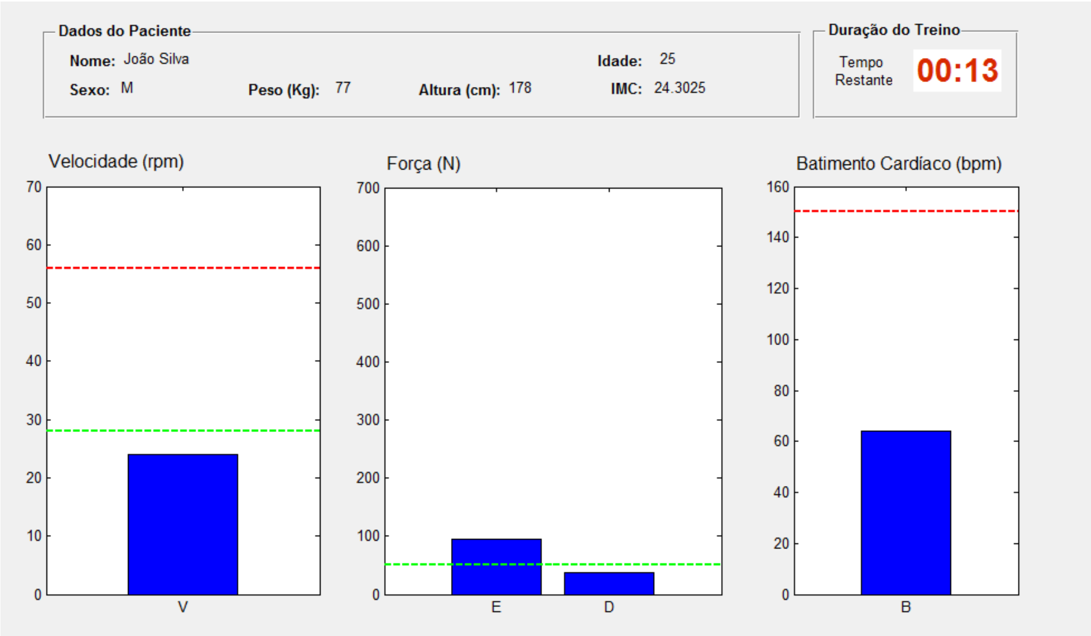

Figure 11 - Patient Interface, version 2

The last field is composed by three graphs. The first one is the speed in rotations per minute (rpm) on the pedals. The second is the force exerted by the user. Each of the pedals has three sensors, so the force shown is the sum of the three. The first column is the force from the left leg and the second column is representative of the force from the right leg. The third graph is the heart rate in beats per minute (bpm). When these values are within the therapeutic range, the bars are green. If the patient is above the maximum limit, the bars will go red, as to instruct the patient to slow down. The reference lines, in green and red, represent the reference and the maximum value, respectively.

3.2.3. Virtual Environment

In the virtual environment, or virtual game, is composed by a bicycle on a road, in a forest. There were used two programs to develop the game. The model of the bicycle and the trees was found on the Internet [18]. After this models were obtained, the complete interface was developed in *Matlab 3D World Editor®* and *Cinema 4D®*. The road was designed from scratch in Cinema 4D®.

The main goal of this game was to motivate the user to stay close to the reference values. The farther the patient was from the reference values the faster he will lose points. The score starts in 5000 and diminishes from there. The user can also chose the level he wants to play at, from the three available: Easy, Intermediate and Hard. The difference between levels is the speed in which the points are lost.

The user is on the reference value when the bicycle is in the same position as the Figure 12. If the user exerts more force in the left pedal, the bicycle tilts left, and if the force on the right pedal is bigger, it tilts right. If the speed is lower than the reference, the road inclines upward, and if it is greater, it inclines down.

Figure 12 - Virtual Environment

The choice between the two patient's interfaces is made based on the answers from que usability questionnaires.

Chapter 4

Ergonomics and Usability Questionnaires

The decision to opt for one of the patient's interfaces is made by measuring the ergonomics of each one, and the system as a whole. There was a debate between using a standard questionnaire and developing a new one specific to the project. And another one to decide between different standardized questionnaires, after deciding on the previous question.

In this chapter, it is made a deeper study on the ergonomics definition and how to evaluate a system usability.

4.1. Ergonomics

The philosophy of ergonomics was introduced in 1857 by the Polish scientist W.B. Jastrzebowski. The word ergonomics comes from the Greek *ergon + nomos*, which means the *study of work* [19]. The concept of ergonomics changed over time, being introduced as a discipline by Murrell in 1949, and was considered an applied junction of science and technology, promoting a human-centered holistic approach to work systems design that considers "physical, cognitive, social, organizational, environmental and other relevant factors" [19].

Human factors and ergonomics (HFE) were defined by the International Ergonomics Association, in 2003, as

> *"the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human wellbeing and overall system performance."*

An ergonomist has two roles. One as a scientist, understanding the interaction between people and artifacts and considering the capabilities, needs, desires and limitations of people in those interactions. The second as a craftspeople, contributing to the design of interacting systems, maximizing the capabilities, minimizing the limitations and trying to satisfy the needs and desires of the human race [20].

The mainly investigated domains of ergonomics are physical, cognitive and organizational. Physical ergonomics is linked to human anatomical, anthropometric, physiological and biomechanical characteristics. The concern of cognitive ergonomics is memory, perception, reasoning, information processing and motor response, this is, the way in which mental processes affect human and system interaction. Organizational ergonomics is related to socio-technical system optimization, including processes, structures and policies [19]. The various dimensions of the HFE discipline are shown in Figure 13.

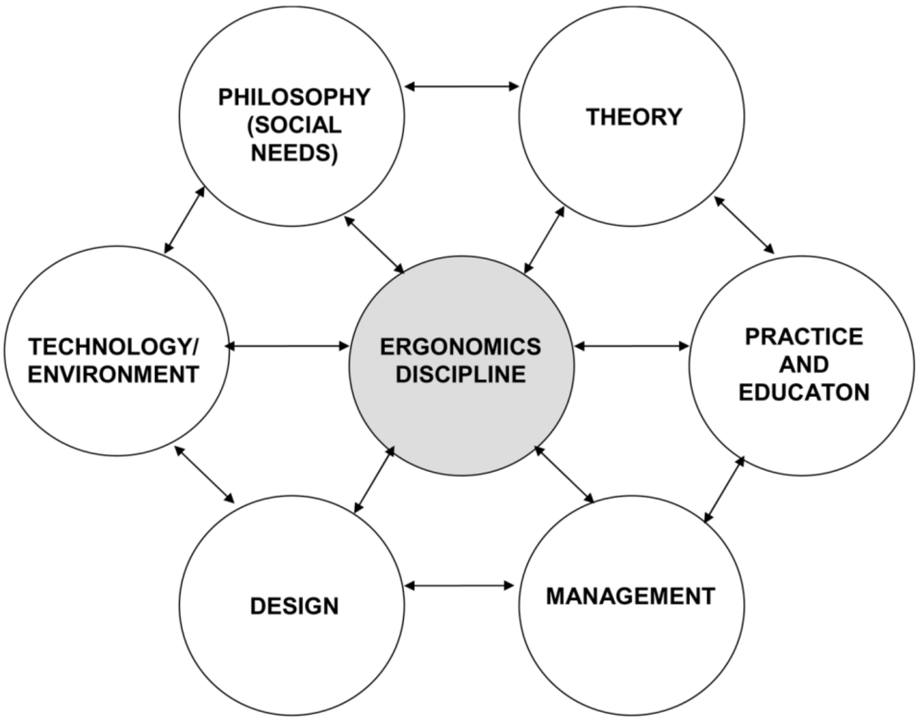

Figure 13 - The various dimensions of the Human Factors and Ergonomics [19].

The HFE discipline focuses on the understanding of interactions between people and systems, i.e. everything that surrounds people at work and outside of their working environment. HFE aims to optimize human well-being and overall system performance [19], by making human-system interactions easier, safer, more efficient and more comfortable, by studying those interactions [21].

In sum, ergonomics is about developing products with the best human interaction possible, ensuring that the design isn't forcing people to adapt, but rather complement their strengths and abilities and minimize their limitations [21].

4.2. System and Interface Usability Evaluation

After the development of the two patient's interfaces, it became necessary to evaluate if one was clearly preferred over the other, or if they were liked in a similar manner by the users. We also wanted to know if there were other improvements the patients could bring to our attention, before initializing the process of finalizing the prototype.

We wanted to evaluate the overall satisfaction, but more specifically the helpfulness of using an interface to indicate what the patient was supposed to do, with a visual appeal.

4.2.1. Usability Questionnaires

In order to select a questionnaire, to evaluate the usability of our system interfaces, we researched the types of questionnaires and surveys already existing, the parameters to watch for, the values acceptable for a system, among others.

Questionnaires and surveys allow the researcher to acquire a large amount of data, of a large group of people, for a relative low cost. The validity of the data acquired is dependent of the questions, as they must be written in a way that there is only one interpretation [22].

Evaluation Parameters

The reliability of a questionnaire is the parameter measured to determine if the questionnaire yields the same results when filled out by "like-minded people in similar circumstances" [23]. It is expressed numerically in a scale from 0.00 (very unreliable) to 1.00 (extremely reliable) [23]. Questionnaires with a reliability below 0.50 are suspect, unless they were very short (3-4 items) and there is a strong reason to use them.

Validity is the degree to which the questionnaire is in reality measuring or collecting data about what it was designed to. Validity is as issue in opinion surveys but it can also be an issue in factual questionnaires if respondents interpret the questions in different ways [23].

Types of questionnaires

There are two types of questionnaires. The closed-ended leaves no room for individual comments and the questions are replied in terms of preset responses that can be coded as numbers. And open-ended ask for answers in the respondent own words [23].

A closed-ended questionnaire is more appropriate for processing large quantities of data, or if it is scaled to produce meaningful numeric data [23].

An open ended questionnaire is better employed in initial state of research or if you are searching for a very specific comment, or even if answers can't be summed up in a numerical way [23].

Advantages and disadvantages of using usability questionnaires

Advantages

A usability questionnaire gives feedback from the users' point of view. If the questionnaire is reliable and the answers aren't bias, then the feedback will be trustworthy and a sample of what the whole population of users will think or feel. The use of questionnaires is also a quick and cost effective way to evaluate a system before taking it to the market [23].

Disadvantages

Once the questions are designed to fit a number of different situations, the answer cannot tell in detail what are the components that are working for the user and the ones that aren't. Although, through the use of well-designed questions, the issues can be thoroughly examined. In order to evaluate the overall usability of the system, the investigator should also observe the users and talk to them [23].

4.2.2. Standardized Questionnaires

Standardized questionnaires have the added benefits of: allowing the practitioners to report results with more detail than when using only personal judgment; generalizing a finding from a sample to a larger population; facility of communicating findings when referring to metrics previously standardized; and it makes it easier to compare different stages of development of a design [24].

The danger in not using a standardized and systematic metrics is that the researcher may become de-sensitized to relevant usability issues and fail to document them [24].

There are three major standardized questionnaires: the System Usability Scale (SUS), the Post-Study System Usability Questionnaire (PSSUQ) and the Software Usability Measurement Inventory (SUMI).

4.2.2.1. System Usability Scale

The SUS was developed in 1986 by John Brooke. It consists of ten statements, and half are positive and the other half are negative, and the respondent has to state the level of agreement (see Figure 14). The scale has 5-points of agreement for each statement. The result obtained doesn’t assess different features of the system [25].

The scores can be though as percentages once they are on a scale from 0 to 100, where 100 represents a perfect score [25]. The score is calculated as described in Text 1. The SUS is highly reliable (0.91) and is free [24].

	The System Usability Scale Standard Version		Strongly disagree 1	2	3	4	Strongly agree 5
1	I think that I would like to use this system.		O	O	O	O	O
2	I found the system unnecessarily complex.		O	O	O	O	O
3	I thought the system was easy to use.		O	O	O	O	O
4	I think that I would need the support of a technical person to be able to use this system.		O	O	O	O	O
5	I found the various functions in the system were well integrated.		O	O	O	O	O
6	I thought there was too much inconsistency in this system.		O	O	O	O	O
7	I would imagine that most people would learn to use this system very quickly.		O	O	O	O	O
8	I found the system very cumbersome to use.		O	O	O	O	O
9	I felt very confident using the system.		O	O	O	O	O
10	I needed to learn a lot of things before I could get going with this system.		O	O	O	O	O

Figure 14 - The SUS Questionnaire [24]

CALCULATING A SUS SCORE

To calculate a SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1, 3, 5, 7, and 9, the score contribution is the scale position minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall SUS score. Consider the sample data in Figure 6.8. The sum of the values, using these rules, is 22. Multiply that by 2.5 to get the overall SUS score of 55 percent. SUS has been made freely available for use in usability studies, for both research purposes and industry use. The only prerequisite for its use is that any published report acknowledge the source of the measure.

Text 1 - Calculating SUS scores [23]

4.2.2.2. Post-Study Usability Questionnaire

The PSSUQ is a questionnaire with 16-items that measures respondents' perceived satisfaction with the product or system (see Figure 15.) The total score is an average of the scales: System Quality (items 1-6 average), Information Quality (items 7-12 average), and Interface Quality (items 13-16 average). PSSUQ's reliability is very high (0.94) and is free [24].

	The Post-Study Usability Questionnaire Version 3	Strongly agree 1	2	3	4	5	6	Strongly disagree 7	NA
1	Overall, I am satisfied with how easy it is to use this system.	O	O	O	O	O	O	O	O
2	It was simple to use this system.	O	O	O	O	O	O	O	O
3	I was able to complete the tasks and scenarios quickly using this system.	O	O	O	O	O	O	O	O
4	I felt comfortable using this system.	O	O	O	O	O	O	O	O
5	It was easy to learn to use this system.	O	O	O	O	O	O	O	O
6	I believe I could become productive quickly using this system.	O	O	O	O	O	O	O	O
7	The system gave error messages that clearly told me how to fix problems.	O	O	O	O	O	O	O	O
8	Whenever I made a mistake using the system, I could recover easily and quickly.	O	O	O	O	O	O	O	O
9	The information (such as online help, on-screen messages and other documentation) provided with this system was clear.	O	O	O	O	O	O	O	O
10	It was easy to find the information I needed.	O	O	O	O	O	O	O	O
11	The information was effective in helping me complete the tasks and scenarios.	O	O	O	O	O	O	O	O
12	The organization of information on the system screens was clear.	O	O	O	O	O	O	O	O
13	The interface* of this system was pleasant.	O	O	O	O	O	O	O	O
14	I liked using the interface of this system.	O	O	O	O	O	O	O	O
15	This system has all the functions and capabilities I expect it to have.	O	O	O	O	O	O	O	O
16	Overall, I am satisfied with this system.	O	O	O	O	O	O	O	O

**The "interface" includes those items that you use to interact with the system. For example, some components of the interface are the keyboard, the mouse, the microphone, and the screens (including their graphics and language).*

Figure 15 - The PSSUQ Survey [24]

The variance analysis of the scores of the PSSUQ has shown that they vary with the developer, stage of development, type of product, of study, and of evaluation. They are, however, insensitive to gender, although it's still advised to include it as a variable in data analysis because different genders may react differently to a product [26].

PSSUQ's reliability is a function of the interrelatedness of scale items, the number of scale steps per item, and the number of items in a scale. Therefore, if a participant chooses not to answer an item, the reliability will decrease slightly but the remaining items should offer a reasonable estimate of the appropriate scale score [26].

PSSUQ can be confidently used to evaluate different types of products and at different times during the development process. It is particularly helpful in competitive evaluations or in tracking usability variance as a function of design changes during development, either within a version or across versions [26].

4.2.2.3. Software Usability Measurement Inventory

The last questionnaire and more complex, is the SUMI, with 50-item questions. It is used to measure respondents' perception of efficiency, affect, helpfulness, control and learnability of a system. Has high reliability (0.92), but it costs approximately $700 a month. The questions have three options, as for example: *The system responds too slowly to inputs: Agree Undecided Disagree* [24].

4.3. Selection of the Questionnaire

Selecting a questionnaire to use depends on the project stage, goals and budget.

The device doesn't have a budget for a survey like SUMI, and since what we wanted to evaluate could be accomplish by one of the other methods, automatically eliminated this questionnaire.

The SUS is appropriate to measure respondents' perceived usability of the system, and items 4 and 10 measure the perceived "learnability" [24].

PSSUQ determines users' satisfaction, but it is necessary to bear in mind that in PSSUQ all the items are positive, and that is easier to agree with a statement than disagreeing [24].

Once the goal with the questionnaire was to determine the device's ease of use, intuitiveness and overall satisfaction, the questionnaire chosen was the SUS. To the standard questions, were added three open-ended questions. Two of them were mandatory, and asked what the favorite features were and what the aspects that should be altered or improved were. The last question asked for other comments. It was delivered to the tested subjects through Google Forms, in Appendices A and B.

Chapter 5

Methods and Results

During the development of the APE, two separate phases of tests were performed. The first one had the goal of searching for patterns in cycling that could be of use for the development of better control modes or interfaces. The second one was meant to evaluate the two patient's interfaces, to select one and develop only that one in future phases of the project.

5.1. Searching for Useful Patterns

In this first trial, the goal was to test the initial control modes, and also to look for patterns in cycling that could be useful for the further improvement of the control modes.

The test subjects had to perform a total of twelve tests of one minute each. These one minute tests are described in Table 1.

Speed 600 rpm Resistance 0	*Speed 1300 rpm Resistance 0*	*Speed 2000 rpm Resistance 0*
Speed 600 rpm Resistance 0.2	*Speed 1300 rpm Resistance 0.2*	*Speed 2000 rpm Resistance 0.2*
Speed 600 rpm Resistance 0.4	*Speed 1300 rpm Resistance 0.4*	*Speed 2000 rpm Resistance 0.4*
Speed 600 rpm Resistance 0.7	*Speed 1300 rpm Resistance 0.7*	*Speed 2000 rpm Resistance 0.7*

Table 1 - Set of tests performed

The resistance was being interpreted as a normalized value, so it is the scale from 0 to 1, and does not represent physical quantity. The users were told the speed that they should cycle at, and they had to try and maintain it while guiding themselves with a graph. The speed mentioned is the motor's speed. It is related to the speed on the pedals by a factor of 53.

There were performed tests with six users. There were supposed to have been more tests, but it stopped because a sensor in one of the pedals was not working. Therefore, it could not be examined the force exerted on the pedals with the resulting speed.

The initial spikes on the speed graphs represent the initiation of the movement, till the user reached the goal speed.

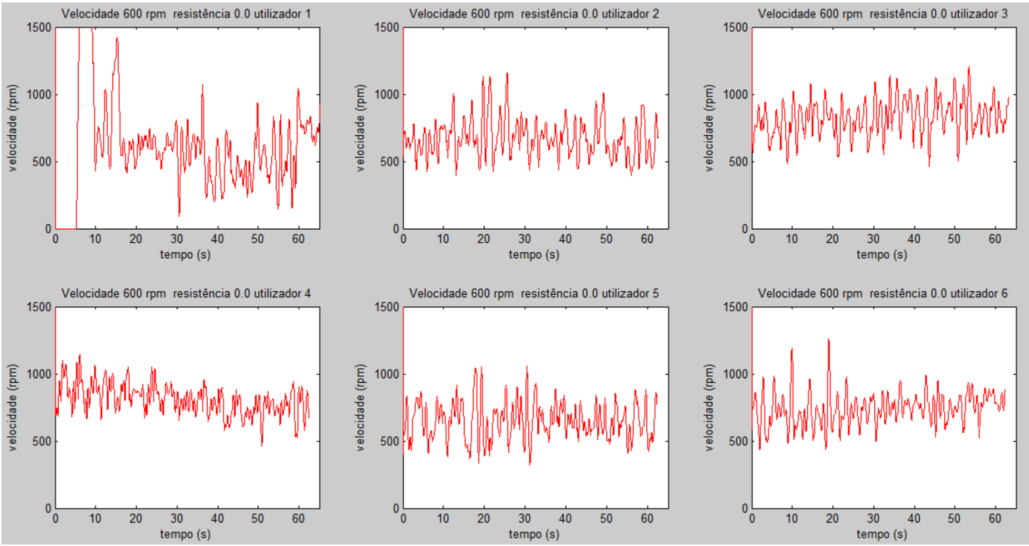

Figure 16 - Speed control by the different users aiming for 600 rpm with resistance 0.0

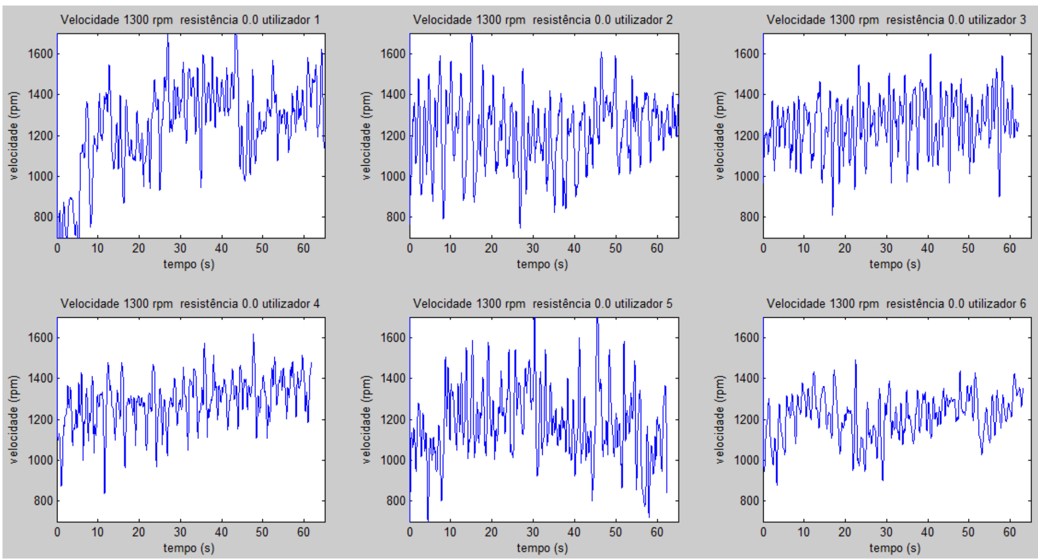

Figure 17 - Speed control by the different users aiming for 1300 rpm with resistance 0.0

The graphs for the speed of 600 rpm and 1300 rpm have the most defined cycles compared to 2000 rpm, which can be interpreted as a pattern of cycling. It can be seen in Figures 16 and 17, respectively. In Figure 18 it can be seen, the pattern for user 4, in more detail.

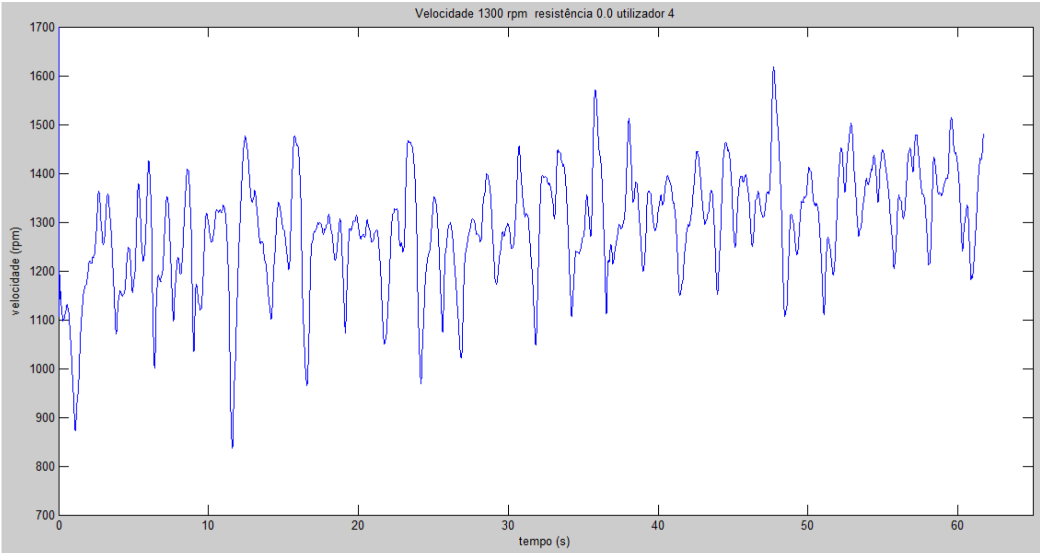

Figure 18 - Speed control by the user 4 aiming for 1300 rpm with resistance 0.0

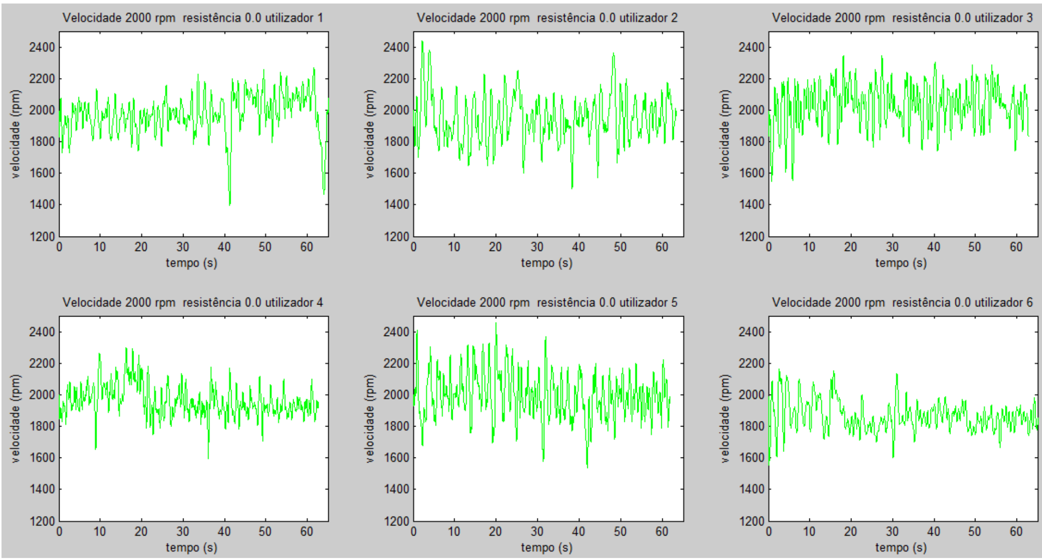

Figure 19 - Speed control by the different users aiming for 2000 rpm with resistance 0.0

For low speed (600 rpm), the users had difficulty to maintain speed (Figure 16). The speeds of 1300 rpm and 2000 rpm felt more natural to the users, so they were able to maintain those speeds more constantly (Figures 17 and 19).

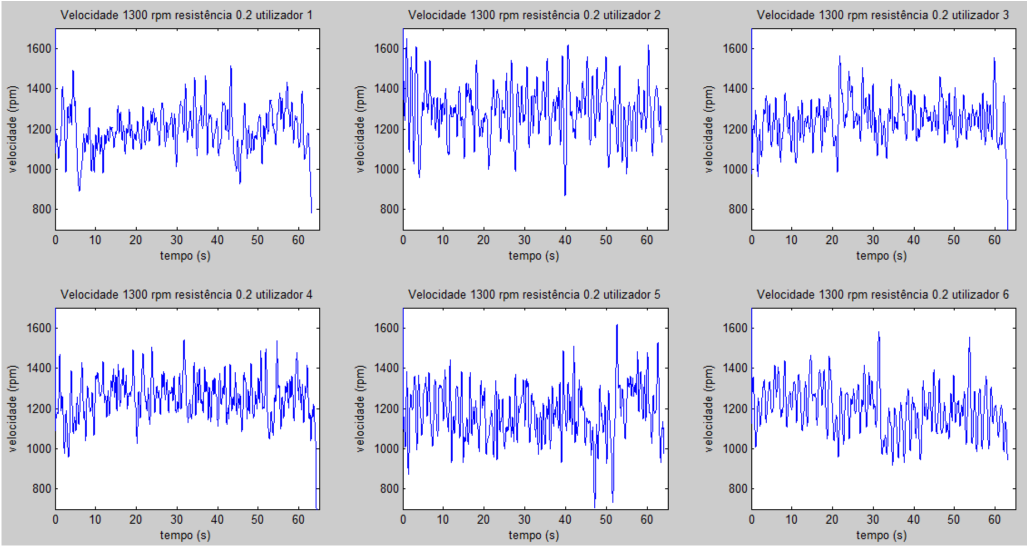

Figure 20 - Speed control by the different users aiming for 1300 rpm with resistance 0.2

When the resistance was increased, from 0.0 to 0.7, the previous pattern (see Figure 18), became more indistinct (see Figure 23). With the increase of the resistance it became more difficult to locate the pattern that before was so visible, even though it is still present (see Figures 17, 20, 21 and 22).

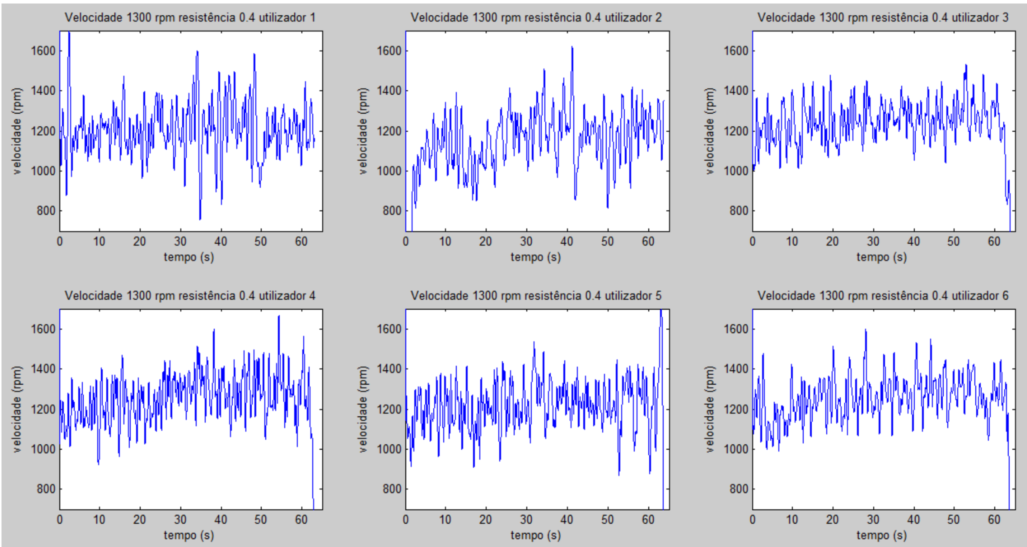

Figure 21 - Speed control by the different users aiming for 1300 rpm with resistance 0.4

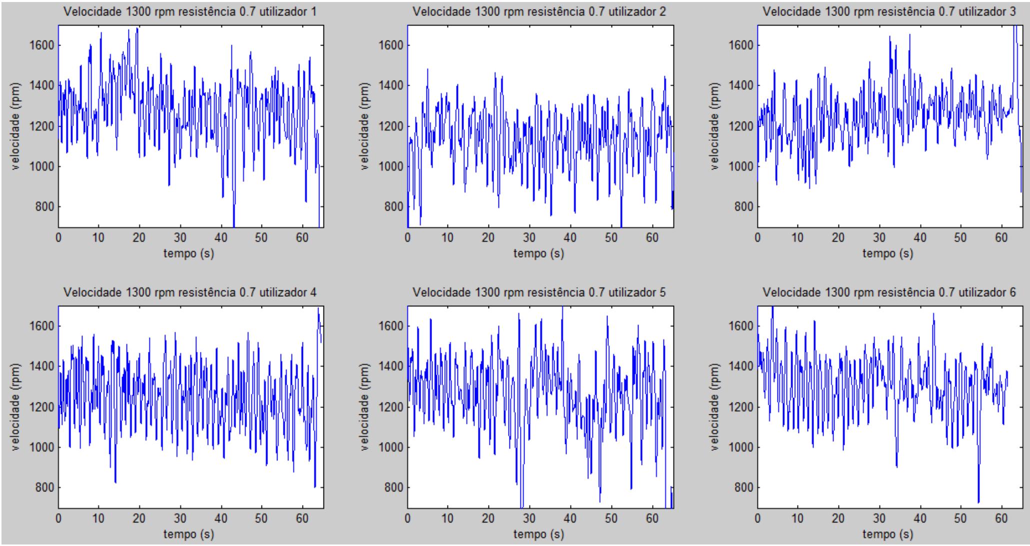

Figure 22 - Speed control by the different users aiming for 1300 rpm with resistance 0.7

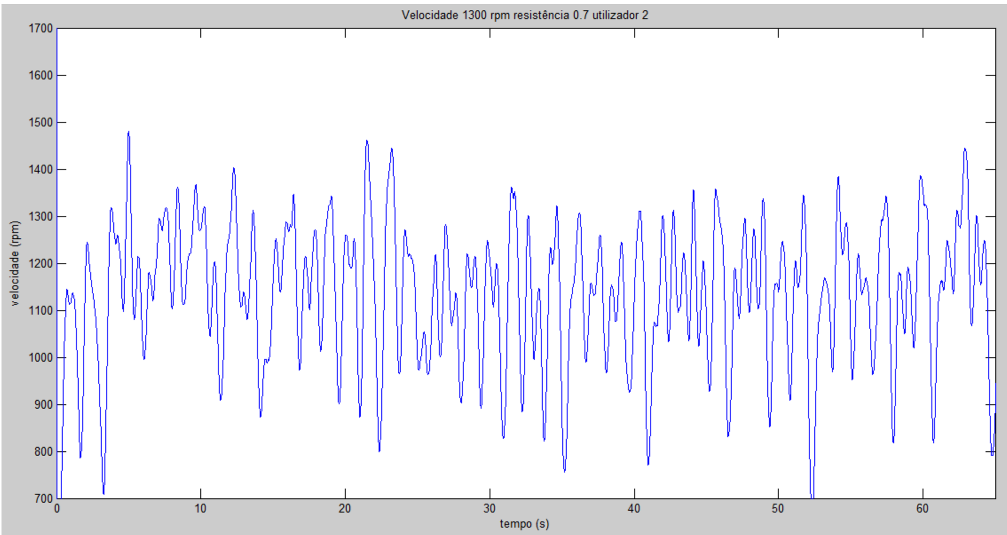

Figure 23 - Speed control by the user 2 aiming for 1300 rpm with resistance 0.7

5.2. Evaluating the Interfaces

The next phase of tests had the main purpose deciding between the two developed interfaces. The second goal was to deepen the study on the results that were sought in the first phase of tests.

At this stage, the files used were the current ones. These tests also had the duration of one minute. These tests performed were: control by force with reference force of 50 N and 70 N; control by speed with reference of 28 rpm and 40 rpm (speed on the pedals); and free mode. The free mode implemented used the default parameters of the interface. But since these values did not allow for normal cycling, they were set for 40 N and 40 rpm, so it would not interfere with the user's cycling. The tests were performed with eight users.

The initial scale for force was between 100 and 1500 N, but it was deem too difficult to achieve while seated on the bike saddle. This way, the minimum was lowered to 50 N and it was only tested till the 70 N. However, the maximum force was not lowered, so its line never appears on the patient interface, as seen in Figure 11.

The system was tested with the parameters described so far while using the patient interface. To test the virtual interface were used the force of 50 N and the speed of 40 rpm.

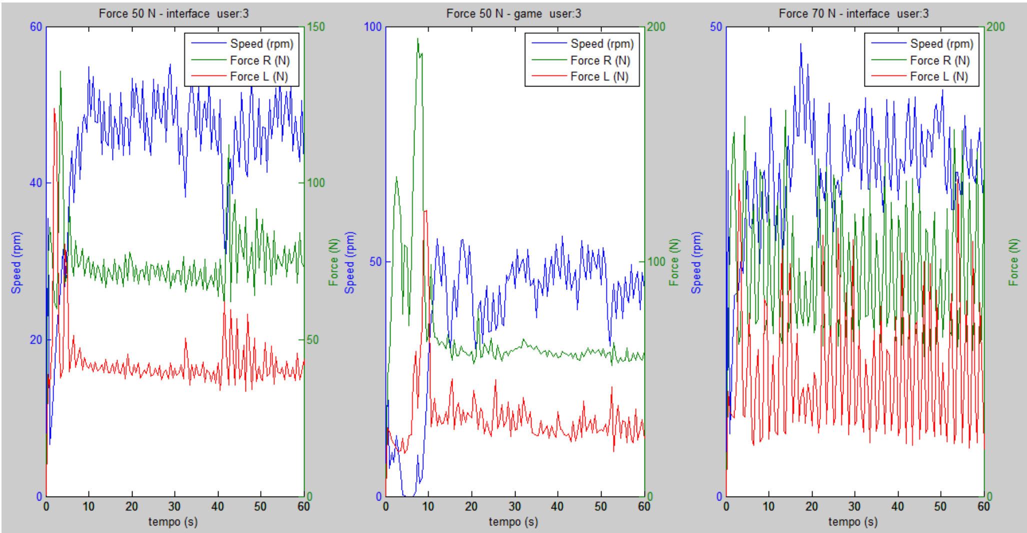

Figure 24 – Force control for user 3

There was a little difference between the forces in the pedals that caused the left one to indicate less force than the right, for the same exerted force. It affected the results because, while some people disregarded the difference, other tried to balance it. This discrepancy can be fixed by software.

In Figure 24, force control, it can be seen that the average between the forces on the pedals is the desired force. For the same force, using the patient interface the cycling pattern is not very different from the one using the virtual game. For the speed control (see Figure 25), the pattern of force had more amplitude using the patient interface than using the virtual game. Since the force of 70 N was difficult to achieve, the pattern of cycling has more amplitude than for 50 N.

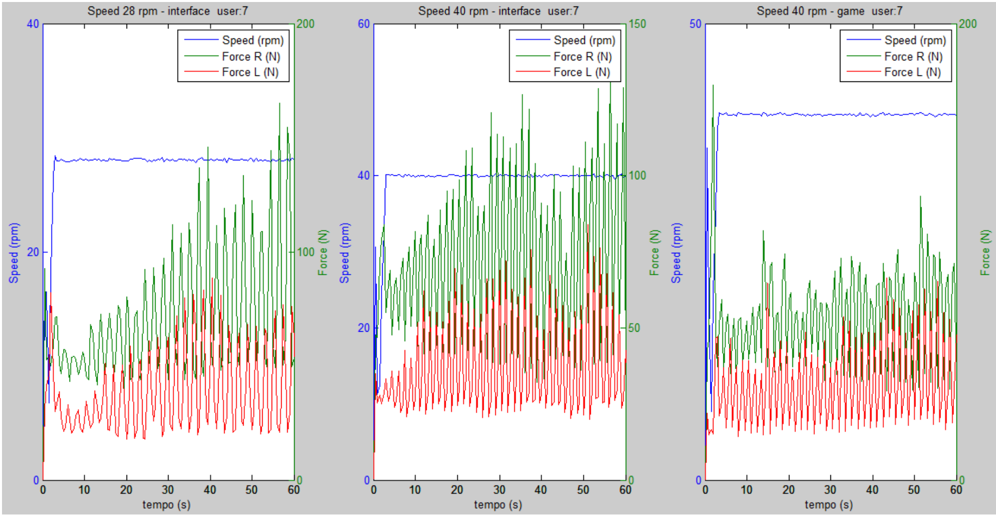

Figure 25 – Speed control for user 7

From the speed of 28 rpm to 40 rpm, the pattern of cycling did not change much but it noticeable that the period of the force waves get shorter (Figure 25). The speed in both cases is very stable due to the implemented speed mode. In the speed mode, it is injected the speed desired so that the therapeutical goal is reached.

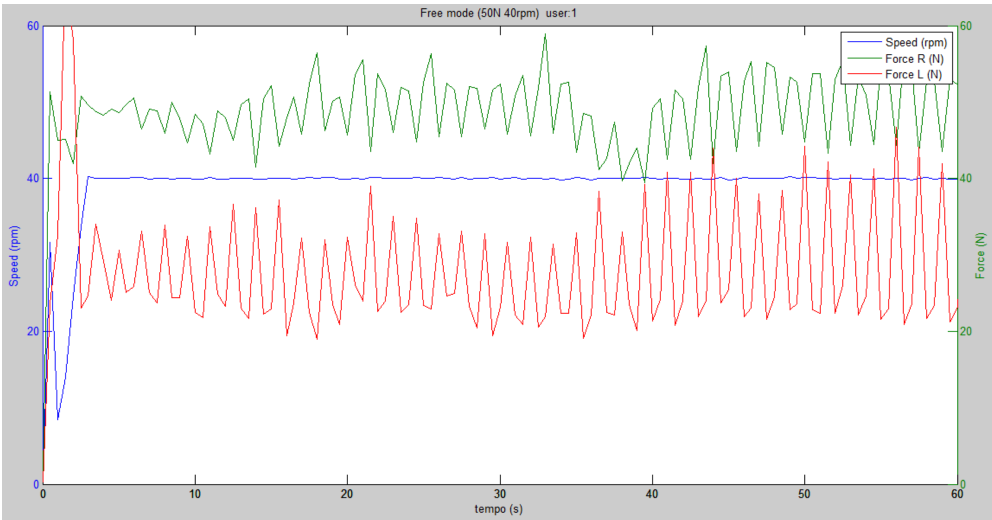

Figure 26 - Free mode, with default values of 50 N and 40 rpm, for user 1

On the free mode, we can see that the speed behavior is the same to the speed control. And since it was supposed to be a relaxed training, the cycling was very consistent and the force kept around 40/50 N.

5.3. Results of the Usability Questionnaire

Each test subject filled two forms, one SUS questionnaire for each interface.

The SUS score was calculated as instructed in Text 1. It is mathematically translated in formulae (1).

$$(1)\ SUS=100-[(\sum(x_{2n-1}-1)+\sum(5-x_{2n}))\times 2.5]$$

where *n* is the number of the question, from 1 to 10. So *2n-1* represents the odd questions and *2n* the even questions.

The entire results of the questionnaires can be found in Appendix C.

User	1	2	3	4	5	6	7	8	9	10	TOTAL
4	1	5	1	2	1	4	1	4	1	5	87,5
2	2	5	2	4	2	3	2	5	1	5	82,5
6	2	4	1	4	2	4	3	4	2	5	77,5
7	2	2	3	1	2	3	3	2	3	1	40,0
3	1	4	2	4	1	4	2	3	2	5	80,0
5	3	5	3	2	5	1	1	5	3	4	55,0
1	2	4	2	2	3	4	2	3	4	4	60,0
8	2	4	2	2	2	3	1	4	3	5	70,0
Average	1,88	4,13	2,00	2,63	2,25	3,25	1,88	3,75	2,38	4,25	69,1
%	63%	18%	60%	48%	55%	35%	63%	25%	53%	15%	**Average SUS score**

Table 2 - SUS questionnaire answers and results, for the virtual interface

The questions 4 and 10 are said to estimate the "learnability". These questions are negatively quoted. Since "learnability" is a positive parameter, the percentage was converted to calculate it, but not to interpret the answer. For the virtual interface the "learnability" is 69% = ((100%-48%) + (100%-15%))/2 and for the game is 79% = ((100%-33%) + (100%-10%))/2. So, the users felt that it was more or less needed technical assistance to use the system, but that it wasn't necessary to learn a lot to be able to use it. The most meaningful difference between the interfaces is that the users found that it was required more assistance for the use of the virtual interface, rather than the game.

The users felt that they would rather use the interface (63% to 58%), but that the game was easier to use (60% to 68%). The users did not felt the systems were complex (18% and 15%). On the other hand, they somewhat found that there was inconsistency in the systems (35% and 33%).

User	1	2	3	4	5	6	7	8	9	10	TOTAL
4	1	5	1	2	1	4	1	4	1	5	87,5
2	1	5	3	2	2	4	3	5	1	5	77,5

6	2	5	2	3	2	4	3	4	2	5	75,0
7	3	3	2	4	2	3	2	4	3	4	65,0
3	1	4	1	4	1	3	2	4	2	4	80,0
5	4	4	1	4	3	1	2	4	2	5	65,0
1	2	4	2	4	2	5	1	3	3	4	75,0
8	3	4	1	4	2	3	2	3	2	4	70,0
Average	2,13	4,25	1,63	3,38	1,88	3,38	2,00	3,88	2,00	4,50	74,4
%	58%	15%	68%	33%	63%	33%	60%	23%	60%	10%	**Average SUS score**

Table 3 - SUS questionnaire answers and results, for the game

According to the results, the functions are better integrated in the game (55% for the interface, 63% for the game), but still need refinement. The users also found that other people would probably learn to use it quickly (63% and 60%). They did not feel particularly uncomfortable, while using the systems (25% and 23%) and they felt fairly confident while using the APE (53% and 60%).

The averages for the results obtained were: 69 for the patient interface and 74 for the virtual game. A system is acceptable with a score higher than 68. This was verified in both cases.

In the questionnaire were also included open-ended questions for the users to give their opinion.

In the writing segment of the questionnaires, the users stated that the best parts of the patient interface where the visualization of the movement in real time, the variation of each parameter, the ease of use and intuitiveness, and the establishment of goals and limits. On the other hand, it was appointed that the graphic transitions were too brusque and there should be a better way to strap the feet to the pedals.

For the virtual game, the best parts were said to be: the visualization of the bicycle in the virtual environment; the score acted as a motivation; the quick response to changes and the simplicity and intuitiveness. As negative aspects mentioned were that there should be tips in the interface to indicate if the position is correct, the bicycle could be more prominent on the screen and again, better synchronization.

It was also mentioned that the bicycle is always tilted right. These facts were clarified to the test subjects and were explained in sub-chapter 5.2.

Chapter 6
Conclusions

6.1. Main Conclusions

In this dissertation, after the research of the state of the art, the physiotherapeutic interface was improved and the patient interface and the virtual game were developed. Once there was no need for two different interfaces for the patient, ergonomic tests were performed in order to decide on one of them. The SUS scores were better for the virtual game, so the suggested alterations will only be performed in this interface.

During the test phase of this dissertation, two separate sets of tests were performed. In the first phase, there was a problem with a sensor, so the conclusions were limited to finding patterns in the speed graph. The subjects had to aim for 600, 1300 and 2000 rpm (motor's speed) and resistances of 0.0, 0.2, 0.4 and 0.7. For lower speeds (600 rpm and 1300 rpm) the cycling cycles are more defined than for higher speed (2000 rpm). A pattern can be distinguished, and can be explored in the future to improve the control modes. This pattern fades with the increase of resistance.

In the second phase, the tests were performed for force of 50 N and 70 N, speed of 28 rpm and 40 rpm, and a free mode. The cycling pattern while using the patient interface and virtual game do not differ much to affect the effectiveness of the rehabilitation.

6.2. Future Developments

The project developed can still be improved in a lot of ways, to make it an even more competitive product in the market. Maybe the first thing should be implementing the tare routine to the force sensors, so that the data acquired is more reliable. To implement the suggestion the test subjects made, the engine response should be smoothed. To guide a training of a very impaired patient, it would be useful to have a pattern for normal cycling to use.

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Appendices

Appendix A

Questionário de Usabilidade - Interface Paciente

Este questionário visa aferir a ergonomia do sistema no geral, e de cada uma das interfaces em particular.
Este questionário é para avaliar a usabilidade da interface do paciente.

De 1 a 5 classifique o que achou do sistema, sendo 1 = concordo completamente e 5 = discordo completamente.

* Required

1. **1** *

Acho que gostaria de utilizar este sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

2. **2** *

Achei o sistema desnecessariamente complexo.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

3. **3** *

Achei que o sistema era fácil de ser usado.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

4. **4** *

Acho que necessitaria de ajuda técnica para ser capaz de usar este sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

5. **5** *
Achei que as várias funções do sistema estavam bem integradas.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	⬭	⬭	⬭	⬭	⬭	Discordo Completamente

6. **6** *
Achei que havia demasiada inconsistência no sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	⬭	⬭	⬭	⬭	⬭	Discordo Completamente

7. **7** *
Imagino que a maioria das pessoas aprenderiam a usar este sistema muito rapidamente.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	⬭	⬭	⬭	⬭	⬭	Discordo Completamente

8. **8** *
Achei que o sistema era muito desconfortável de usar.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	⬭	⬭	⬭	⬭	⬭	Discordo Completamente

9. **9** *
Senti-me muito confiante a usar o sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	⬭	⬭	⬭	⬭	⬭	Discordo Completamente

10. **10** *
Precisaria de aprender muitas coisas antes de conseguir começar a utilizar o sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	⬭	⬭	⬭	⬭	⬭	Discordo Completamente

11. *

Quais foram os aspectos que mais gostaste da interface?

12. *

Quais foram os aspectos que, na tua opinião, precisam de ser melhorados/alterados?

13. Outros Comentários?

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Appendix B

Questionário de Usabilidade - Jogo

Este questionário visa aferir a ergonomia do sistema no geral, e de cada uma das interfaces em particular.
Este questionário é para avaliar a usabilidade do ambiente virtual do jogo.

De 1 a 5 classifique o que achou do sistema, sendo 1 = concordo completamente e 5 = discordo completamente.

* Required

1. 1 *
Acho que gostaria de utilizar este sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

2. 2 *
Achei o sistema desnecessariamente complexo.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

3. 3 *
Achei que o sistema era fácil de ser usado.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

4. 4 *
Acho que necessitaria de ajuda técnica para ser capaz de usar este sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

5. **5** *

Achei que as várias funções do sistema estavam bem integradas.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

6. **6** *

Achei que havia demasiada inconsistência no sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

7. **7** *

Imagino que a maioria das pessoas aprenderiam a usar este sistema muito rapidamente.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

8. **8** *

Achei que o sistema era muito desconfortável de usar.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

9. **9** *

Senti-me muito confiante a usar o sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

10. **10** *

Precisaria de aprender muitas coisas antes de conseguir começar a utilizar o sistema.
Mark only one oval.

	1	2	3	4	5	
Concordo Completamente	◯	◯	◯	◯	◯	Discordo Completamente

11. *

Quais foram os aspectos que mais gostaste da Interface?

12. *

Quais foram os aspectos que, na tua opinião, precisam de ser melhorados/alterados?

13. Outros Comentários?

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Appendix C

Results of the Usability Questionnaires

<u>Results for the Patient Interface Usability Questionnaires</u>

User	1	2	3	4	5	6	7	8	9	10
4	1	5	1	2	1	4	1	4	1	5
2	2	5	2	4	2	3	2	5	1	5
6	2	4	1	4	2	4	3	4	2	5
7	2	2	3	1	2	3	3	2	3	1
3	1	4	2	4	1	4	2	3	2	5
5	3	5	3	2	5	1	1	5	3	4
1	2	4	2	2	3	4	2	3	4	4
8	2	4	2	2	2	3	1	4	3	5

Question 11

Visualização em tempo real do movimento incluindo os diferentes parâmetros (velocidade, força exercida, batimentos cardíacos).
A possibilidade de poder ver os resultados em tempo real.
O ritmo cardíaco é interessante de verificar.
O estabelecimento de metas e de limites para cada indivíduo.
Bem construída e de fácil utilização.
Quantificação da minha força
Simples e serve o propósito para que foi criada.
A interface é bastante intuitiva.

Question 12

Controlador.
Podia haver um valor numérico no topo dos gráficos como o objectivo proposto ao utilizador.
O objetivo do exercício poderia ser mais claro.

Os indicadores poderiam ter indicação com algum historial (o ritmo cardíaco está a subir?)

Estabilidade dos pedais e as transições de peso em Newton nos pedais são demasiado bruscas. Deveriam ser transições mais graduais.

Nada a mencionar.

Maior eficiência e rapidez na sincronização da bicicleta com o sistema.

Realismo do percurso a ser executado pela pessoa da bicicleta poderia melhorar

Os dados do utilizador poderiam ser guardados. Relativamente ao equipamento poderia haver uma maneira mais eficaz de prender os pés aos pedais.

No answers for Question 13

Results for the Virtual Game Usability Questionnaires

User	1	2	3	4	5	6	7	8	9	10
4	1	5	1	2	1	4	1	4	1	5
2	1	5	3	2	2	4	3	5	1	5
6	2	5	2	3	2	4	3	4	2	5
7	3	3	2	4	2	3	2	4	3	4
3	1	4	1	4	1	3	2	4	2	4
5	4	4	1	4	3	1	2	4	2	5
1	2	4	2	4	2	5	1	3	3	4
8	3	4	1	4	2	3	2	3	2	4

Question 11

Visualização em tempo real da forma com a bicicleta andaria em ambiente real.

O desenho esta bem conseguido e é claro.

Simular um ambiente de movimento em estrada é bastante positivo.

Gostei da adaptação da estrada para subida, descida e plano consoante a velocidade. O sistema e rápido a responder a essas alterações.

Gostei bastante de podermos ver a simulação do movimento e com isso corrigir o mesmo. E pelo facto de ser um jogo e ter pontuação aumenta a vontade de fazer o movimento correto.

Diferença de forças utilizadas entre o pedal direito e o esquerdo

Pareceu-me ser simples e apenas com o fundamental.

Tal como na interface anterior, pareceu-me ser uma interface intuitiva em que conseguíamos procurar o que se queria com o mínimo de esforço. A informação sobre o que se tinha de fazer estava toda disponível.

Question 12

Calibração dos sensores, pois a bicicleta ia sempre um pouco inclinada.

Podia haver "dicas" na interface: setas para indicar se a bicicleta esta a subir ou descer, ou se é preciso compensar a força a direita ou a esquerda.

A bicicleta poderia estar mais destacada.

Apesar da indicação visual da condição da bicicleta ser "realista", poderia ter um indicador extra que tornasse mais claro qual é o problema ou indicasse que está bem, principalmente no jogo vertical.

Demasiada sensibilidade no entortar da bicicleta.

Talvez as fitas adesivas que seguram os pés, deviam estar bem presas aos pedais para não haver o risco de saírem tão facilmente.

Maior sincronização e eficácia entre a força exercida na bicicleta o jogo

No teste de força do jogo penso que a bicicleta é um pouco instável

Não sei o que poderia dizer para melhorar ou alterar.

No answers for Question 13