ENHANCING POSTERIOR PELVIC TILT EXERCISE BY PROVIDING MOTIVATION INDUCING FEEDBACK TO THE PATIENT

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ABSTRACT

ENHANCING POSTERIOR PELVIC TILT EXERCISE BY MOTIVATION INDUCING FEEDBACK TO THE PATIENT

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The aim of this study is to develop a set-up that can be used by patients performing posterior pelvic tilt exercises to assess and improve the effectiveness of the exercise by visual feedbacks.

Lifetime of low back pain prevalence is between %60 and %90. In other words almost everyone encounters the problem of low back pain sometime during their life. Therapeutic and protective exercises are the most important components of treatment for the low back pain.

People who have mechanical based low back pain due to postural disorders, have weakness of abdominal and back muscles. Posterior pelvic tilt exercises are one of the effective types of exercises to solve this problem. These can be done standing against a wall or lying on a surface. These exercises are advised to patients generally as home exercise programs. However most patients cannot do their exercises effectively due to lack of training and control.

In posterior pelvic tilt exercise, the patient is asked to straighten his/her lumbar lordosis and exert as much pressure as possible to the surface he/she is lying on. It is believed that the efficiency of the exercise is correlated with the amount of this

pressure. Entertaining visual feedback may increase patient's motivation and consequently quality of the exercise.

In this experimental set-up, pressure variations were determined by three receivers which were placed under the back of the patient to provide feedback for proper posterior pelvic tilt exercises. By means of this experimental set-up training for these exercises was achieved easily and the quality of exercises was improved.

Keywords: Posterior Pelvic Tilt Exercise, Visual Feedback, Pressure, Motivation

ÖZ

POSTERİOR PELVİK TİLT EGZERSİZİNİN DAHA VERİMLİ HALE GETİRİLEBİLMESİ İÇİN GÖRSEL GERİBİLDİRİM SAĞLANMASI

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Bu çalışmanın amacı posterior pelvik tilt egzersizi yapan hastanın, egzersizin etkinliğini görsel bir geribildirim mekanizmasıyla değerlendirebileceği ve arttırabileceği bir düzenek geliştirmektir.

Bel ağrısının yaşam boyu prevalansı % 60 – 90 arasındadır. Diğer bir deyişle hemen herkes, yaşamlarının bir döneminde bel ağrısı sorunu ile karşılaşmaktadır. Özellikle bu ağrılara en sık neden olan mekanik bel sorunları için hem tedavi edici, hem de koruyucu etkinliği olan egzersizler tedavi basamakları içerisinde çok önemli bir yer tutmaktadır.

Postür bozukluğu sonucunda mekanik kökenli bel ağrısı sorunu yaşayan kişilerde en önemli sorun, karın ve bel kaslarındaki güçsüzlük olup, posterior pelvik tilt egzersizi bu sorunu gidermede başvurulan etkili egzersiz tiplerinden biridir. Ayakta ya da yatarak uygulanabilen posterior pelvik tilt egzersizi hastalara genellikle ev egzersiz programı şeklinde önerilmektedir. Ancak birçok hasta egzersiz eğitimindeki yetersizlik ve kontrol eksikliği nedeniyle egzersizlerini etkin bir şekilde uygulamamaktadırlar.

Posterior pelvik tilt egzersizinde hastanın lomber bölgesindeki lordozu düzleştirerek zemine olabildiğince basınç uygulaması istenmekte ve egzersiz etkinliğinin de bu basınçla orantılı olarak arttığı düşünülmektedir. Bu basıncın niceliğinin ölçülmesi ve bu bilginin hasta için eğlenceli olabilecek görsel bir geribildirim biçimine dönüştürülmesinin hastanın motivasyonunu, dolayısıyla egzersizin kalitesini arttıracağı düşünülmektedir.

Bu düzenekte hastanın belinin altına yerleştirilen üç adet alıcı yardımıyla basınç değişiklikleri tayin edildi ve hastaya verilen geribildirim aracıyla doğru hareket pekiştirilmiştir. Böylelikle bu düzenek sayesinde egzersiz eğitimi kolaylaşmış ve egzersizin kalitesi iyileştirilmiştir.

Anahtar Kelimeler: Posterior Pelvik Tilt Egzersizi, Görsel Geribildirim, Basınç, Motivasyon

To My Family

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Nothing is ever done alone, thus I would like to thank certain people who helped me along the way with this project.

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CHAPTER 1

INTRODUCTION

Low back pain (LBP) is a common health problem. Mostly mechanical problems are the causes of low back pain. As a remedy therapeutic and protective exercises are used. The main problem of patients with mechanical low back pain is that they have weak abdominal[1] and lumbar[2] muscles. Posterior pelvic tilt exercise is believed to be an effective exercise type. It's an isometric exercise which means that the length of the muscle does not change. In other words posterior pelvic tilt exercise (PPTE) is done in state of static contraction of muscles. These exercises can be done standing against a wall or lying on a surface.

Many people cannot perform their exercises effectively because of deficiency of exercise training and insufficiency in control of muscles. In PPTE, therapists want patients to straighten their lumbar vertebral[3] column by pressing on the surface to exert as much pressure as possible. It is thought that effectiveness of the exercise increases in proportion to this pressure. Although PPTE is an important component in the treatment of low back pain, its effectiveness is questionable when recommended verbally as part of a home program. Motivation through visual feedback is expected to produce better results. Therefore, this feedback may increase the patient's motivation and effectiveness of the exercise consequently.

[1] any of the muscles of the front and side walls of the abdominal cavity

[2] relating to the loin, esp. the lower back area

[3] each of the series of small bones forming the backbone

The aim of this study was to develop and assess the efficiency of a visual feedback setup intended to improve the efficacy of PPTE. The application includes force resistive sensors and a data acquisition card.

1.1. EXPECTED BENEFITS OF THE EXPERIMENTAL SET-UP

The experimental set-up can provide some benefits as follows:

- Patient can perform posterior pelvic tilt exercises more efficiently as part of a home program after efficient training.
- Therapists and doctors can obtain objective data on the efficiency of exercises performed by low back pain patients and monitor change of his/her muscle power.
- The exercise advices without training are generally not taken into consideration by patients; however after feedback compliance may improve.
- Patient can observe his/her muscle performance visually.
- Therapists, doctors and patients, can follow the progress in time and this can increase patient's motivation.
- Effective performance of these exercises may lessen socio-economic losses related to low back pain over the long term.

1.2. OBJECTIVES OF THE THESIS

The objective of the thesis is to show the function of developed setup which provides visual bio-feedback to low back pain patients. In this way, similar set-ups can be developed for other exercises. This set-up enables patients to perform more efficient PPTEs. In order to realize this set-up, following activities have been carried out:

- To provide a goal to perform exercise accurately.
- To monitor the change in patient's muscle power.

- To study the effects of bio-feedback on the performance of exercises.
- To increase quality of PPTEs.

For achieving these objectives, an exercise bed with proper sensors was manufactured, a computer program was developed and experiments were conducted to investigate the effectiveness of the set-up.

1.3. THESIS OUTLINE

The second chapter is an introduction to rehabilitation, goal-setting in rehabilitation, motivation and motivation in rehabilitation. The next chapter reviews literature survey of bio-feedback in rehabilitation and presents several applications about bio-feedback. Fourth chapter describes scope of thesis which includes posterior pelvic tilt exercise definition, hardware components, software architecture, experimental study and its results. Last chapter summarizes our approach and concludes future directions.

CHAPTER 2

REHABILITATION, GOAL-SETTING AND MOTIVATION

In this chapter, an introduction to rehabilitation and motivation will be discussed. Definitions about rehabilitation, goal-setting and motivation will be given. Thereafter, the importance of goal-setting and motivation will be considered.

2.1. REHABILITATION

Rehabilitation which usually involves a program at hospital or home is a recovery process of an organ or patient's psychology. The goal of rehabilitation is to return the disabled individual to his/her maximum degree of physical independence, with psychosocial adjustment and vocational productivity.

Traditionally, rehabilitation refers to methods and means aimed to recover some abilities lost due to an accident or severe illness. According to the Medical Glossary on AMA (American Medical Association) [1], *rehabilitation* is a treatment for an injury or illness which is aimed at restoring physical abilities. According to the On-line Medical Dictionary [2], *rehabilitation* is the return of function after illness or injury, and it often does with the assistance of specialized medical professionals. Webster On-Line Dictionary [3] defines '*to rehabilitate*' as 1*a*: to return to a previous condition; 2*a*: to return to a previous state (as of efficiency) *b*: to return or bring to a condition of health or useful and constructive activity.

Rehabilitation can be defined in narrow and wide perspective. The narrower one is related to regaining the function of a natural organ, and the other one is the use of

prostheses, or assistive devices which includes organ-replacing or organ function enhancing devices. According to the On-line Medical Dictionary, assistive devices are designed, made or adapted to assist a person performing a particular task. Medicine Net Dictionary [4] gave several examples to use as assistive device. Canes, crutches, walkers, wheel chairs, and shower chairs are being used to assist patients in their daily living activities. Prosthesis are commonly used as a means of rehabilitation.

Regarding the term "prosthesis," references [1], [2], [3], and [4] provide similar definitions: "Prosthesis: an artificial replacement for a missing part of the body" according to the Medical Glossary on AMA [1]; "*prosthesis:* An artificial substitute for a missing body part, such as an arm or leg, eye or tooth, used for functional or cosmetic reasons or both" according to the On-line Medical Dictionary [2]; "Prosthesis: An artificial replacement of a part of the body, such as a tooth, a facial bone, the palate, or a joint" according to the Medicine Net Dictionary [4]. Also, Webster on Line [3] defines *prosthesis* as "an artificial device to replace a missing part of the body".

Boundaries between a prosthesis and an assistive device must be clarified. Usually, a prosthesis may be seen as an assistive device and assistive device can be seen as a kind of prosthesis in many cases. Horia-Nicolai, Teodorescu and Lakhmi [5] defined that assistive devices, prostheses, and technology aimed to support the rehabilitation process are contained between the following borders as illustrated in Figure 2.1.

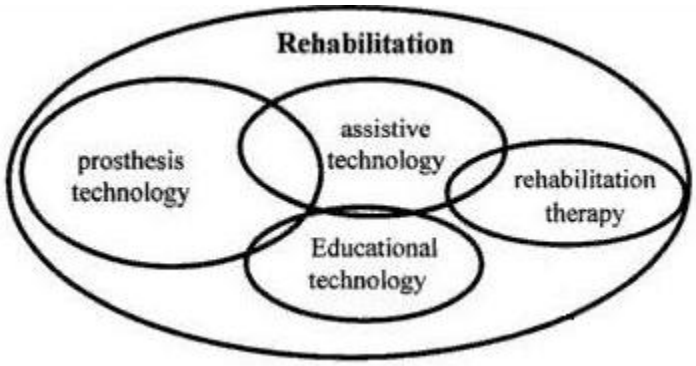


Figure 2.1 The overlapping fields with rehabilitation domain [5].

This intelligent technology field is extremely dynamic and very demanding. It's dynamic because the new technologies such as robotics, advanced materials, intelligent systems, and sensors progress at the same time in these fields. It's demanding because the designer must consider reasonable disabilities which may occur in a single subject. For this reason, the extent of requirements is frequently huge and often difficult to predict by the designer.

Horia-Nicolai et al. discussed the definition of intelligent and advanced technologies. A graphical overview of part of intelligent technologies that are used in rehabilitation and prostheses is sketched in Figure 2.3. The superposition of the domains is only partly shown in this planar representation.

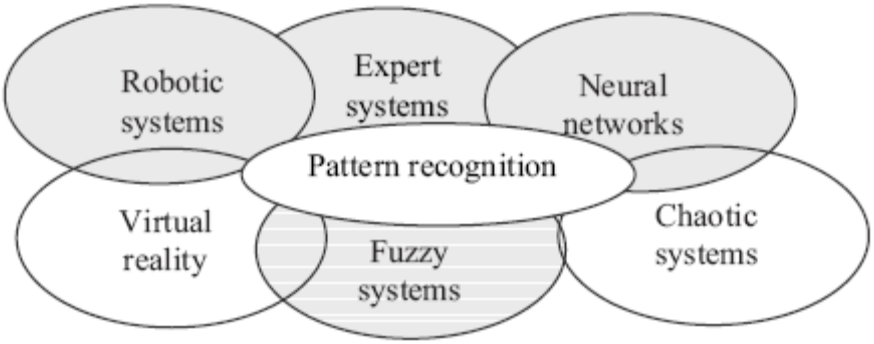


Figure 2.2 Various "intelligent" technologies and partial overlapping [5].

Cook and Hussey [6] stated that assistive technology devices are designed to enable persons with disabilities (users) to achieve utmost level of functioning in specific life roles. They described the user's resultant change in functioning in terms of quantity and quality. Quantity of functioning showed the user's participation or the consistency. The degree to which the device enables the quantitative functioning of the user reflects the effectiveness of the device. In contrast, the quality of functioning showed the ease and comfort.

Sajay et al. [7] showed (as illustrated in Figure 2.3) the relationship between the user's level of functioning and assistive technology usability. The user's satisfaction

with the device is derived on the basis of the effectiveness and efficiency of participation in activities.

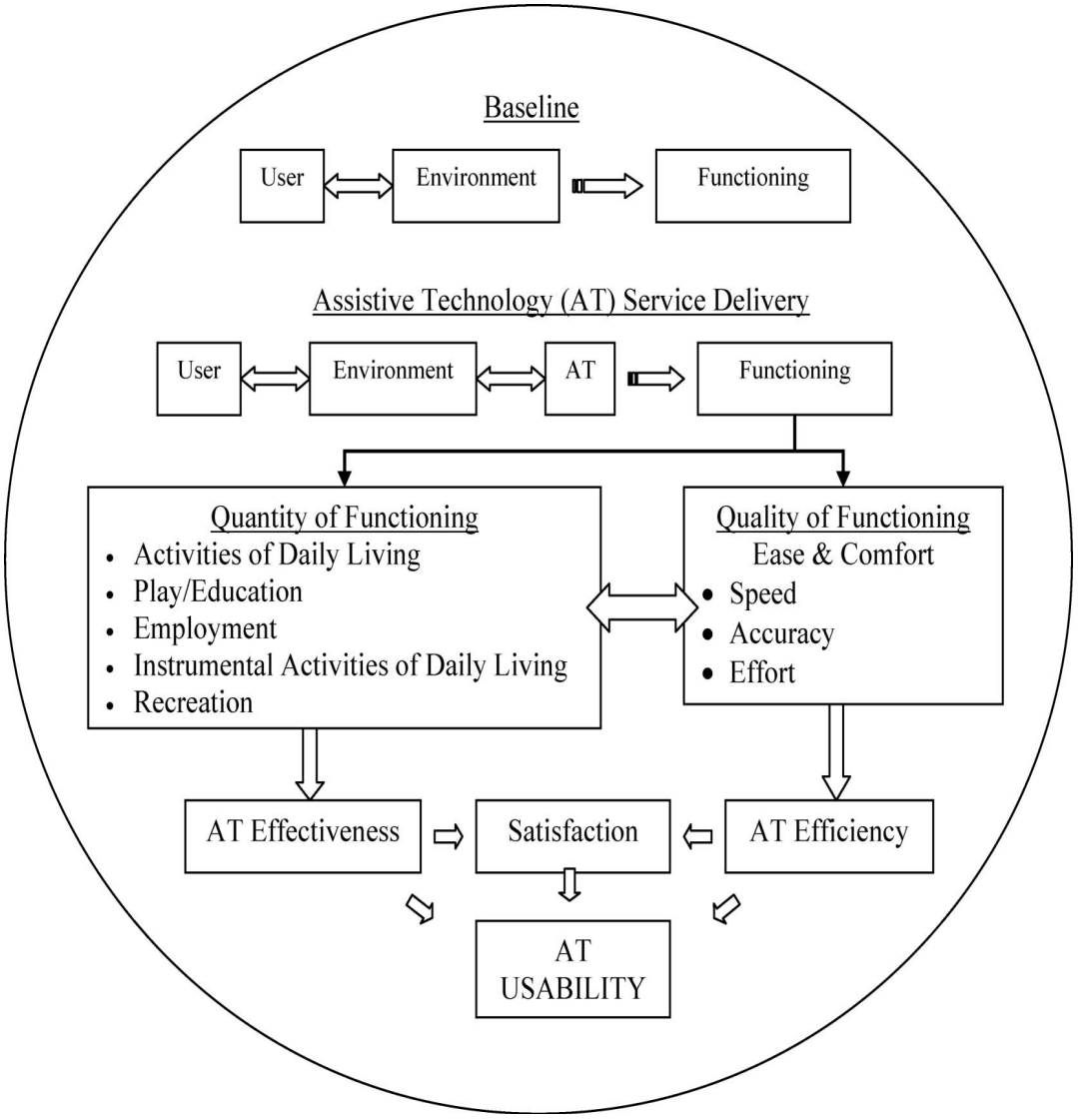


Figure 2.3 Illustration of the relationship between user's functioning and AT usability [7].

2.2. GOAL-SETTING AND REHABILITATION

Goal-setting is an effective technique in rehabilitation. When a goal-setting is set, patient's motivation will increase and patient will achieve better outcomes. Siegert, McPherson and Taylor [8] stated that increasing evidence show that goal-setting in rehabilitation may be more complicated than has been generally acknowledged.

There is sufficient empirical evidence to at least continue using goal-setting in clinical rehabilitation settings. Goal-setting has a reasonably secure place in rehabilitation practice in the future due to this evidence. Turner-Stokes et al. [9] stated that "historically, therapists formulated goals, which tended to be unidisciplinary, and then presented them to the patient with varying degrees of detail. These goals were then held as a record within the therapy notes. Currently, the guidelines for inpatient and community rehabilitation services advocate the use of collaborative goal setting, stating that patients should be involved in the goal-setting process where possible."

Holliday, Antoun, and Playford [10] stated that "the guidelines for rehabilitation exercises, however, do not specify how and when goals should be set with patients. There is little educational literature or material aimed at teaching patients about goal setting and its potential benefits. As a result, goal-setting methods vary in different settings and may tend to reflect therapists' priorities rather than patients'."

In this study, we consider that goal-setting must be our start point on the basis of above explanations and investigate the effects on motivation.

2.3. MOTIVATION

Motivation is the push of the mental forces to accomplish an action. We can separate the motivation levels into three groups.

- On the biological level: Basic human needs of food, shelter and survival are powerful motivators.
- On the psychological level: People need to be understood, affirmed, validated and appreciated.
- On the business level: Motivation occurs when people perceive a clear business reason for pursuing a transfer of knowledge or practices.

In rehabilitation, by enhancing motivation therapists can get better results from the patients. As a result of increased motivation rehabilitation can be done systematically and recovery can materialize much faster. Rehabilitation can become more entertaining when some form of a bio-feedback is provided to a patient and more productive exercises can be performed.

MacLean and Pound [11] stated that `motivated' patients are believed to perform better in rehabilitation activities, and benefit more from the exercise than those patients described as being less enthusiastic for treatment. There are several causes that motivate patients. MacLean et al. [12] categorized these causes as follows:

- Motivation is caused by personality factors
- Motivation is affected by clinical factors
- Motivation is affected by family factors
- Motivation is affected cultural factors
- Motivation is affected by the rehabilitation environment
- Motivation is affected by the professionals' behavior

Motivation level can be changed due to these causes. For example, therapists can set relevant rehabilitation goals or can access and use the patient's cultural norms. As a result, it is seen that goal-setting can be very helpful to patients to perform better in their rehabilitation process and it can create some motivation factors on patients. Hence, goal setting will be adopted within the scope of this work as well. As a part of this research a graphical user interface is developed through which the user can not only see the target but also can see his/her performance in real-time.

CHAPTER 3

LITERATURE SURVEY OF BIO-FEEDBACK IN REHABILITATION

In this chapter, bio-feedback in rehabilitation and effects of bio-feedback on motivation will be discussed. Bio-feedback applications will be introduced.

3.1. BIO-FEEDBACK IN REHABILITATION

Bio-feedback is a method that holds several physiological functions under control. These physiological functions cannot be hold under control consciously. Thanks to bio-feedback patient can control himself/herself and be self-sufficient. Electromyography (EMG), joint angle, position, pressure can be examples of bio-feedback. EMG is used for decreasing a hyperactive muscle's activity or strengthening a weak muscle. Angular or positional bio-feedback is used for improving movement of specific joints. Gravity or pressure applications are used for regaining stabilization education programs.

Palladino et al. [13] defined techniques of bio-feedback. These are "(a) appreciate the variations of a bodily function through a system that measures and converts these in acoustic and/or luminous signals; (b) modify these signals and, therefore, the function connected to them; (c) automatically control the function through practice even in the absence of the return signal."

They also mentioned that there are two types of biofeedback; direct and indirect. In direct biofeedback, patient can measure the bodily function by the help of electromyography connected to an appropriate device. In indirect biofeedback,

patient cannot evaluate the bodily function but he / she must control this by some type of monitoring.

3.2. SOME APPLICATIONS OF BIO-FEEDBACK

Mavroidis et al. [14] have developed a device which was constructed to perform a steady extension of the knee (Figure 3.1). They wanted the subject to sit on the edge of a table and attempt to extend his/her lower leg horizontally. When the subject didn't reach a point which was under him/her own force, the EMG biofeedback sensed data. If the EMG signals were above a threshold which was adjusted as a reference when the subject extended his/her lower leg, the electrical stimulation which helped the patient to achieve full extension was triggered. Once reaching his/her maximum point, EMG signals forced the muscle to complete the extension movement.

Figure 3.1 Human subjects wearing the instrumented biofeedback knee device [14].

Huang, Wolf and Jiping [15] have developed an immersive multimedia environment for biofeedback therapy (Figure 3.2). They presented an arm configuration and ideal trajectory of the hand from initial location to target. The spatial error of the endpoint was indicated by a cone shaped object. If the error was large, the transparency of the cone became reduced, and it got more visible. This told the patient to correct the error.

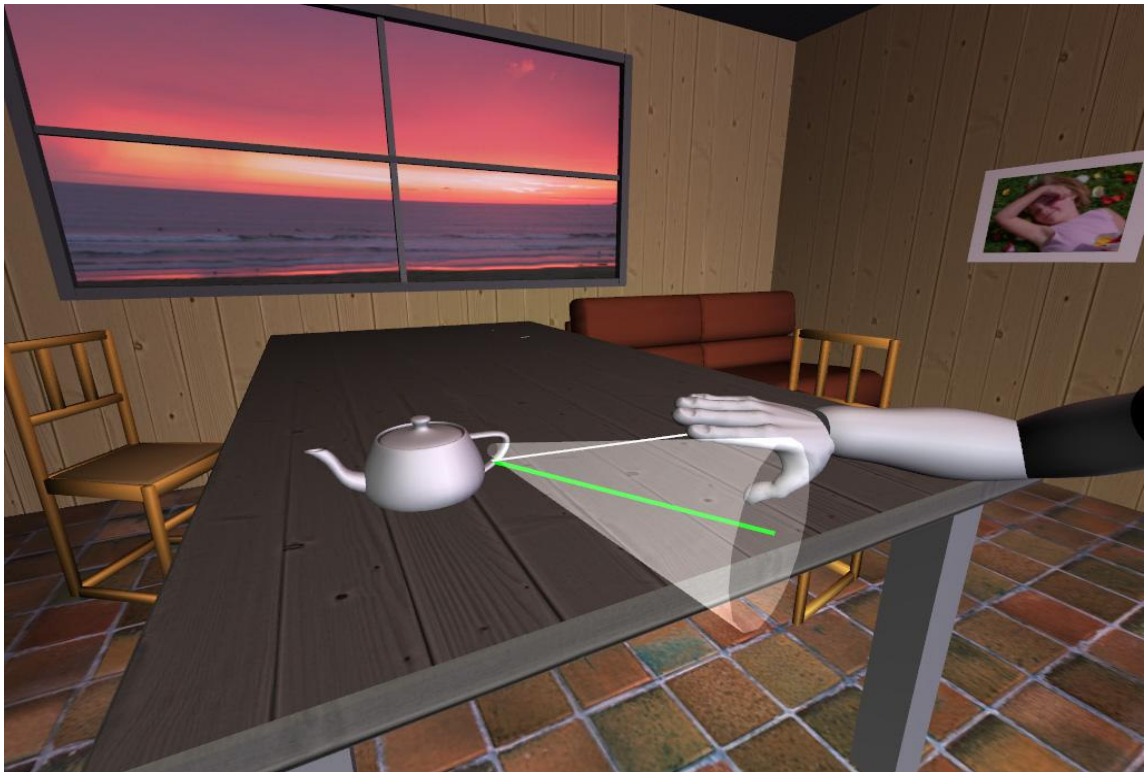


Figure 3.2 Virtual environment design: The green line indicates the ideal trajectory. The cone shape constrains the spatial error of endpoint position and provides direct knowledge of performance [15].

In addition, Huang, Wolf and Jiping provided an auditory feedback in the form of musical notes to indicate the smoothness and temporal-spatial parameters (Figure 3.3) and to map the movement quality of the participant in real-time. They indicated each note as a distance of the target that the hand must move. They stated that "When the hand reaches the target, the corresponding note starts to play. The duration of each note depends on movement speed. Therefore, patients could "compose" different melodies based on movement pattern and quality."

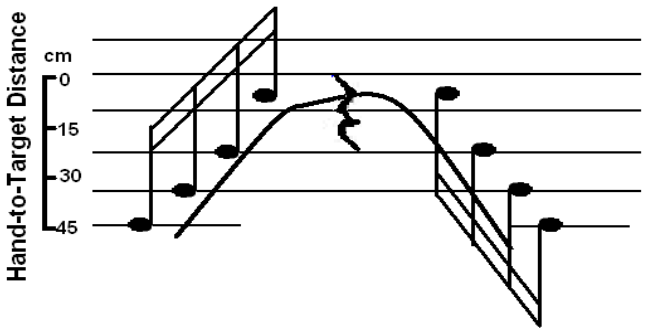


Figure 3.3 Musical feedback design: Musical notes are distributed along the hand's path from initial location to the target [15].

Lünenburger, Colombo and Riener [16] have studied about robotic gait rehabilitation. They aimed to develop a biofeedback system for a gait training robot and test its usability in subjects without neurological disorders. They developed a driven gait-orthosis DGO (Lokomat® Pro Version 4, by Hocoma AG, Volketswil, Switzerland). This system is used in conjunction with a body-weight support system to control the patient's leg movements in the sagittal plane (Figure 3.4).

Figure 3.4 The driven gait orthosis Lokomat [16].

They calculated the biofeedback values for stance and swing phase of the gait cycle as weighted averages of the torques measured in the corresponding joint drives and selected the appropriate weight functions to lead to positive biofeedback values when the patient performs therapeutically desirable activities. They provided four biofeedback values per stride and per leg after each step. They showed these 8 values in line graphs (Figure 3.5 a) and each phases are color-coded. Each point represents

the biofeedback value. They also gave therapist a choice to display a selection of biofeedback values (e.g. only one leg, only swing phase, only knee joints) to help the patient focusing on specific aspects. The selected subset of biofeedback values can also be averaged into one value that can be displayed by a smiley (Figure 3.5 b) which smiles broader for higher and frowns for lower values of the biofeedback during the most recent step. In conclusion, the smiley display allows for a goal-oriented training with feedback, i.e. the patient should focus on specific movements to reach the "goal" of a full smile.

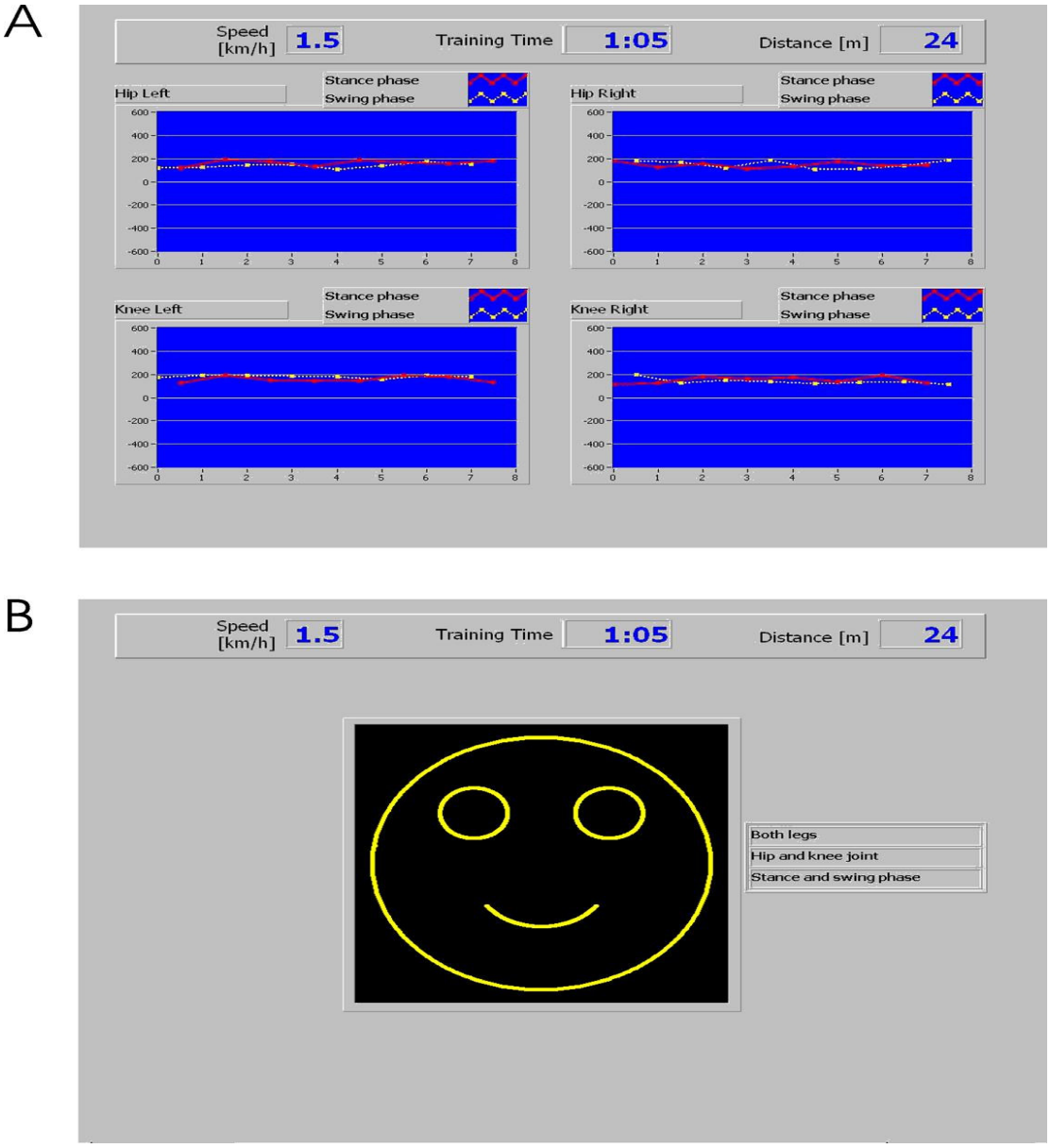
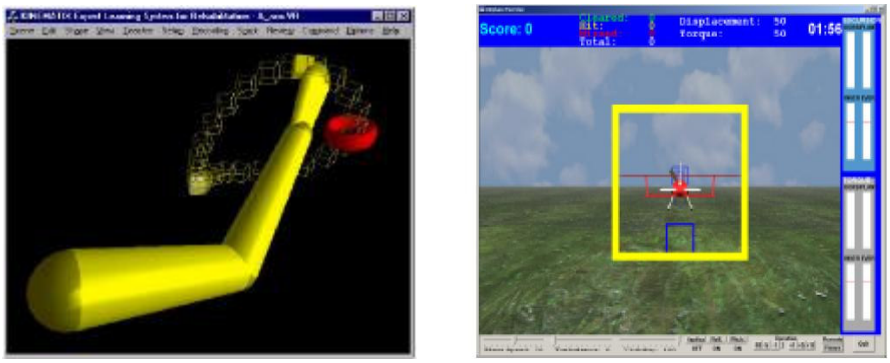


Figure 3.5 Visual displays of the biofeedback: Screen shots of two standard displays of the biofeedback implemented for gait training [16].

Holden and Todorov [17] developed an application which utilized *teaching by example* for post-stroke chronic patients at the Massachusetts Institute of Technology. As shown in Figure 3.6 a, this approach makes the patients motor training of the arm reach motion which is done with a "teacher" object (in this case a cube). The required motion trajectory is visualized to help the patients. Their arm motion is tracked and mapped to the motion of another virtual object following the teacher's example. By contrast, Boian et al. [18] made a video-game where the patient pilots an airplane through 3-D surround as shown in Figure 3.6 b. There is no teacher object in this example, and the patient has a higher cognitive load when performing the exercise.



(a) (b)

Figure 3.6 Various Virtual Rehabilitation therapeutic approaches:
a) Teaching by example [17]; b) video-game exercise simulation [18].

Burdea et al. [19] developed computerized hand diagnostic/rehabilitation system. This system uses a force feedback glove. In this application there are two physical therapy (PT) exercises. The first PT exercise models a rubber ball squeezing routine. These exercises characteristics are as follows:

- The ball stiffness is color-coded and can be selected by the patient at the beginning of the exercise.
- Ball dynamics simulate gravity and Newtonian laws.
- Once it is grasped, the ball deforms in contact with the virtual hand while force feedback is displayed to the patient
- It's recorded in the database.

They made the exercise termination either with the patient's desire or the allowed time. The second PT exercise implements a virtual version of the DigiKey [20], which is an individual finger exerciser, illustrated in Figure 3.7. Burdea stated that "After grasping the selected DigiKey, contact detection is checked between fingers and the corresponding cylinder ends; while in contact, the virtual cylinders are driven by the patient's finger movements. Forces proportional to the displacement of the DigiKey cylinders are fed back to the patient and stored transparently and simultaneously in the database."

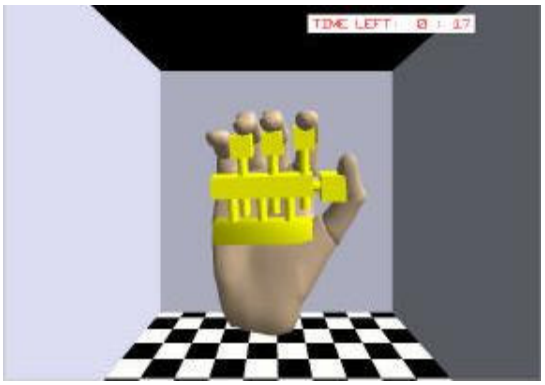


Figure 3.7 Virtual rehabilitation exercise: Virtual DigiKey [20].

Popescu et al. [21] classified the rehabilitation routines in two categories: physical therapy and functional rehabilitation. Physical therapy exercises use force bio-feedback to improve patient's motor skills which exercise his/her muscles and joints. Functional rehabilitation exercises have much greater variety. Regaining lost skills such as daily living or job activities which are related skills is the reason of this variety.

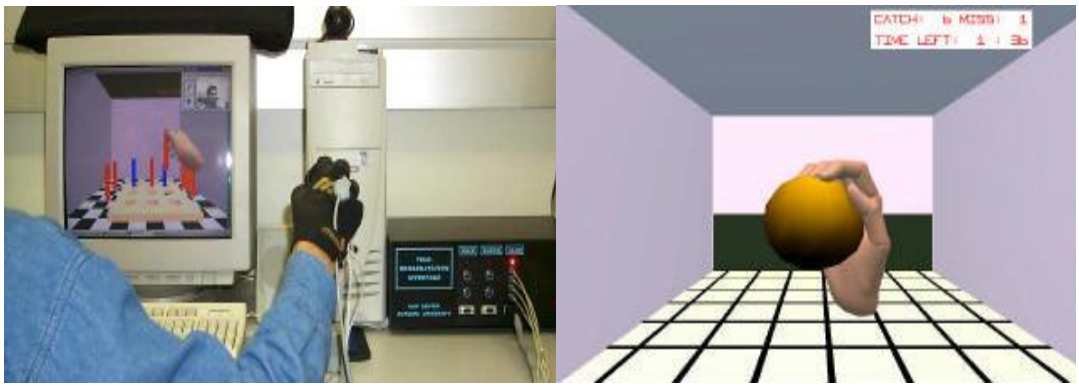
They categorized the functional rehabilitation in two applications. The first functional rehabilitation exercise is a peg board insertion task, showed in Figure 3.8 a. The simulation uses a virtual peg board with nine holes and corresponding number of pegs. Burdea explained this simulation as follows:

- The exercise has three levels of difficulty: "Novice," "Intermediate" and "Expert," each with a different clearance between the peg and hole (smallest for the "Expert" level).

- The amount of time allowed to complete the exercise is set by the therapist.
- Visual and auditory cues increase the simulation realism and help the patient overcome visual distortions.
- Pegs are grasped with a lateral pinch gesture and change color when in a correct insertion position.
- Exercise results are stored in the form of number of holes filled, time spent to perform the exercise, and number of errors made (missed hole or an attempt to put two pegs in one hole).

The second functional rehabilitation exercise is the racket Ball Game shown in Figure 3.8 b. The patient has to throw the ball through the wall which is a marked area. So he/she hits the target and after the ball bounces back to him/her. But he/she must catch the ball after one bounce off the ground. Burdea explained this simulation as follows:

- The ball speed ("fast" or "slow" ball) is selected at the beginning of the exercise.
- Any correct catch increases the patient's "catch" counter while any miss will increase the "miss" counter.
- The ball deforms when caught by the patient and loses energy while bouncing.

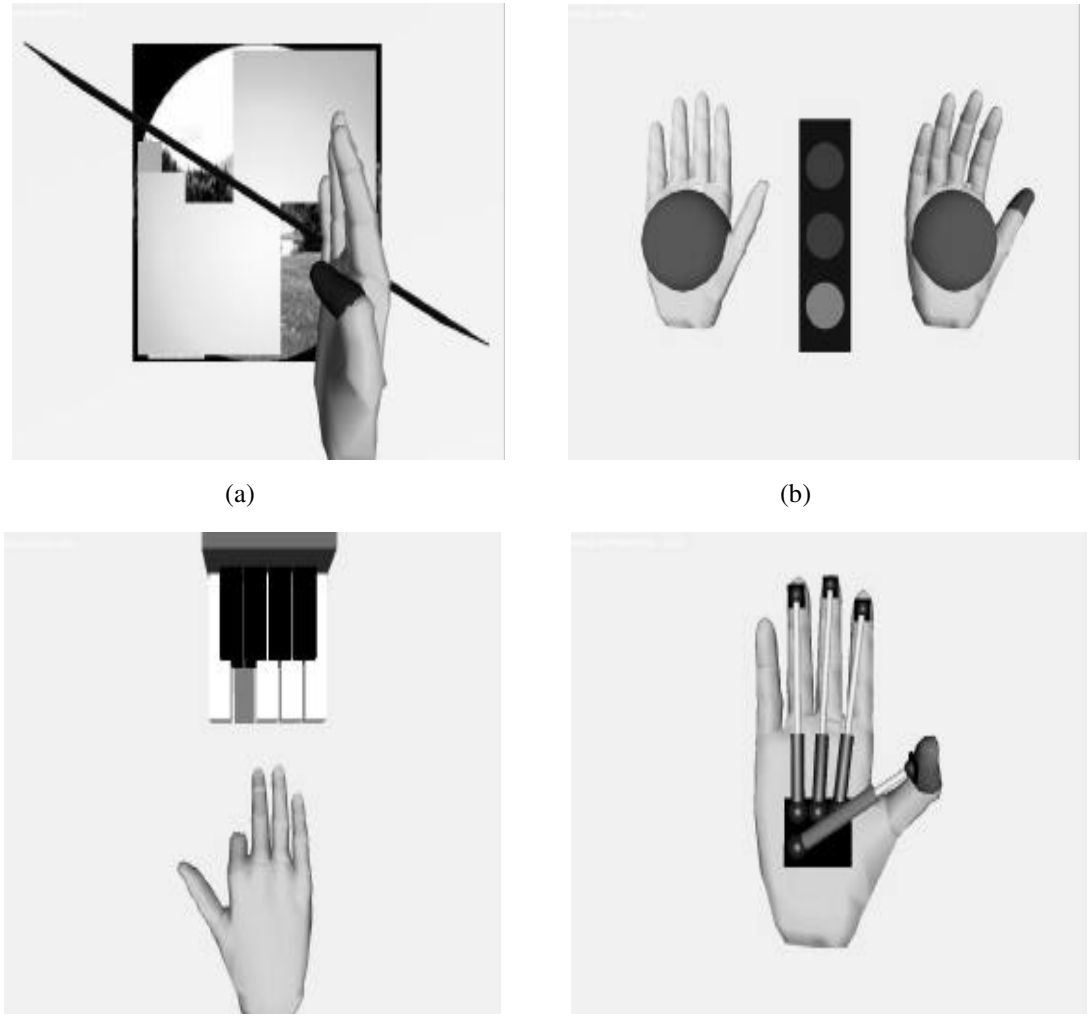


(a) (b)

Figure 3.8 a) The VR-based orthopedic rehabilitation using a haptic glove during a peg-board exercise b) Ball Game exercise [21].

This is a useful exercise to train feed-forward movements and it improves hand-eye coordination. Speed control and accuracy is improved by throwing and catching movements.

Jack et al. [22] developed an exercise program for stroke rehabilitation. The first training exercise is range of movement (Figure 3.9 a). In this exercise they made the user manipulate a “window wiper” to wipe a window clean to reveal an attractive landscape behind the window. If the angular range of movement of the fingers’ measurement is higher, the wiper rotates and clears the window more.



(a) (b)

(c) (d)

Figure 3.9 The four developed exercises (a) range of movement, (b) speed of movement, (c) finger fractionation and (d) strength of movement [22].

In the speed of movement exercise (Figure 3.9 b), they made the user achieve to target as the maximum forward angular velocity when patient does a grasping movement. On a green light, the user must close either the thumb or all the fingers together. If the user does the movement as fast as possible, the user can catch a red ball. On the left in the screen, there is an opponent hand. If the user passes the opponent's target velocity, the user beats the opponent and gets the red ball.

In the fractionation exercise which is designed around a piano keyboard (Figure 3.9 c); they made the patient move each of the four fingers. When the user moves the finger, the depressed key on the piano is shown in green. The goal of the user is to move so that only one key is depressed for every trial.

In the last exercise, they made the user's strength of movement improve. This exercise uses the RMII glove to apply forces either to the user's thumb or three fingers simultaneously. The user is presented with a graphical representation of their hand showing four pistons (Figure 3.9 d). As each actuator on the RMII is squeezed, the graphical pistons start to fill in a new color. The piston turns yellow and is completely filled if the patient manages to move the desired range at that particular force level.

Classical rehabilitation can be very boring for the patient due to its repetitive nature. This routine exercise can easily become dull and reduce patient's motivation. Another short-come of traditional rehabilitation is that a therapist (or sometimes several) has to accompany a patient. When goal-setting and bio-feedback are used together effectively, rehabilitation quality and practicability can be increased. Therefore, in our research we decided to incorporate both goal-setting and bio-feedback. At this point, we need to decide on the type of biofeedback that is to be provided to the patient. Considering factors such as, ease of implementation, ease of attracting patients' attention and keeping his/her concentration on the exercise, we decided to use visual bio-feedback in our research.

CHAPTER 4

SCOPE OF THESIS

The main objective of this thesis is to develop a complete test setup that can be used in the investigation of effects of bio-feedback on the quality of therapeutic exercised. As explained in the previous chapters, bio-feed back with goal setting will be employed in this setup. Before designing the setup, final decision that has to be made on the type of therapy for which the test setup will be designed. Since the research aims to focus mainly on the development of a test setup that provides bio-feedback along with goal-setting, the nature of the exercise is not very important. For this purpose, exercises that are not complex and that are relatively easier to measure are investigated. In order to increase the potential impact of this research on the patients, besides simplicity, a frequently prescribed exercise, namely, posterior pelvic tilt is selected.

In this chapter, posterior pelvic tilt exercise (PPTE), hardware and software components of the experimental set-up will be introduced. The structure and the flowchart of the software components of the system will be given. The user interface will be introduced and some screenshots from application will be given. At the end of the chapter case study will be mentioned.

4.1. POSTERIOR PELVIC TILT

Function, direction and position categorize the definition of the term “pelvic tilt”. Jull and Richardson [23] defined the pelvic tilt as a description of the static anterior-posterior position of the pelvis in the sagittal plane in standing posture. Waddell,

Somerville, Henderson and Newton [24] defined it as the static position of the pelvis in the frontal plane.

Feldenkrais [25], Kendall and Creary [26] presented that posterior pelvic rotation performed in the sagittal[4] plane in crook lying and then held as a static position is a common reference for pelvic tilt. Feldenkrais, Kendall and Creary, Cailliet [27] and Jull, Richardson [28] agreed that both anterior and posterior pelvic rotation in the sagittal plane in this same position is a common position in which pelvic movements are assessed and utilized in the rehabilitation setting. Jull and Richardson showed that rotation of the pelvis anteriorly and posteriorly can be performed on all fours, Cailliet referred to as pelvic tilt in standing, or sitting. Feldenkrais proved that it can be performed in many different positions and variations for motor learning and awareness.

Jull and Richardson commented that with a posterior pelvic tilt, the anterior rib cage depressed downwards. Abdominal muscles contracting to tilt the pelvis, may affect the position of the sternum[5] and ribs pulling them downwards. Similarly, motion of the pelvis may be transmitted through the lumbar and thoracic[6] vertebrae[7] to determine sternal and thorax[8] kinematics (Figure 4.1).

Feldenkrais described a corresponding matched motion of the pelvis, thorax and head with pelvic anterior and posterior tilting. Feldenkrais proposed that coordination between the head and pelvis via the length of the spine and chest is essential for efficient strain free spinal movement. Simultaneous supine pelvic rotation and corresponding thorax motion has not been previously investigated.

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[4] *of or relating to the suture between the parietal bones of the skull ** in the same plane as this, or in a parallel plane

[5] the breastbone

[6] of or related to the chest cavity

[7] each of the series of small bones forming the backbone

[8] area between the neck and abdomen

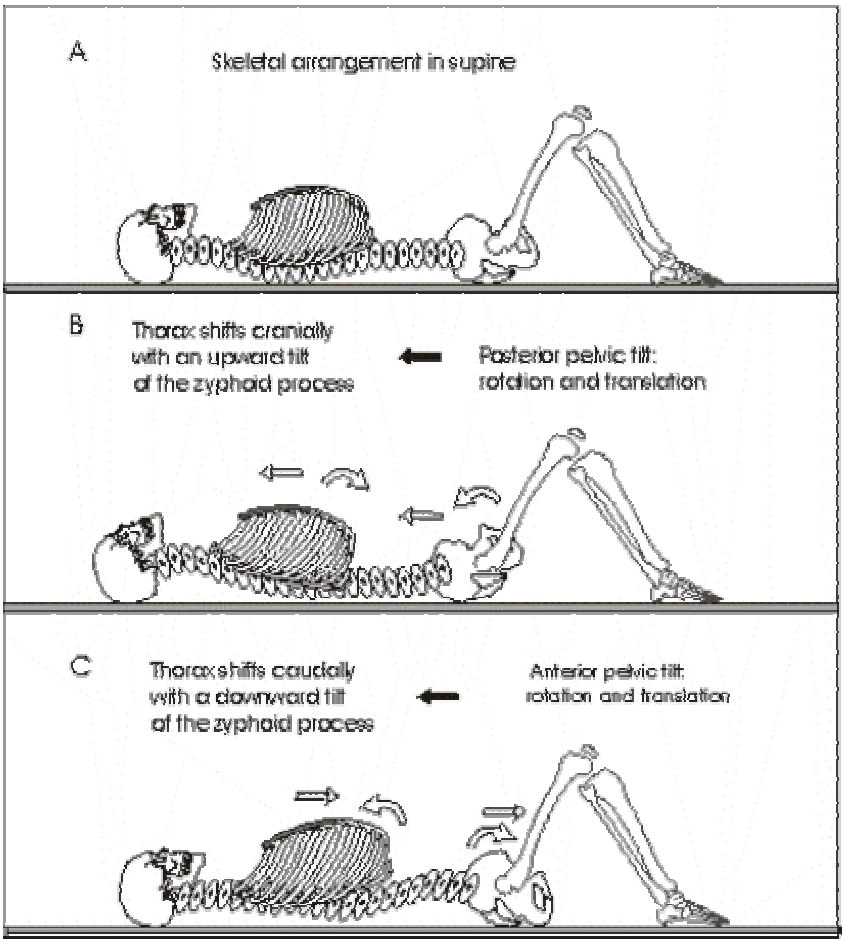

Figure 4.1 Schematic representation of posterior pelvic tilt [23].

4.2. HARDWARE COMPONENTS

The experimental set-up includes an exercise bed covered with a mat with three force resistive sensors embedded in the midway corresponding to the lumbosacral[9] region of the subject lying supine, a data acquisition card, a circuit and a desktop computer with two LCD monitors, one above the subject and one on the physician's table. Software was developed to monitor the force exerted vertically upon the force sensors during PPTE which could be followed both by the physician and by the subject on the monitors. The exercise bed was manufactured out of aluminum profiles on which the patients perform exercises (Figure 4.2).

[9] of the sacrum and the lumbar region of the back

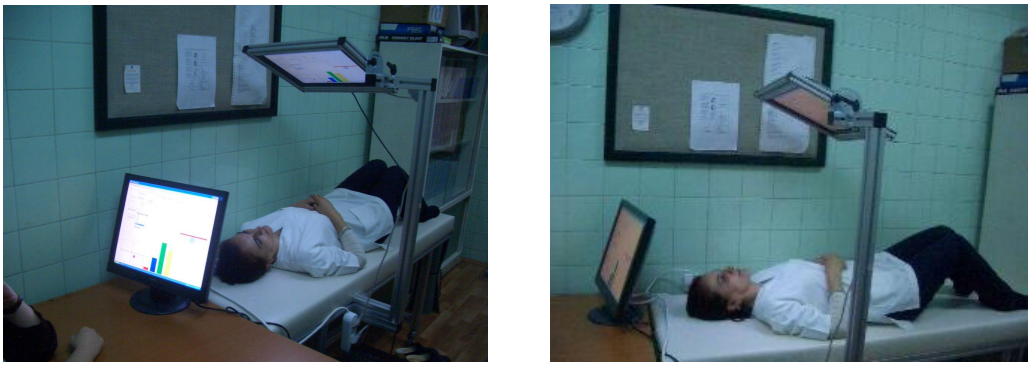

Figure 4.2 Manufactured Exercise Bed and Positions of the Monitors

Data collection process comprises sensors, circuit and data acquisition card (DAQ). First of all we placed three sensors between two rigid plates as showed in Figure 4.3. These sensors possessing 0-25 lb force range are registered trademarks of Tekscan, Inc. (Figure 4.4).

Figure 4.3 Using of Force Resistive Sensors.

Figure 4.4 Force Resistive Sensor [28].

When a patient exerts a pressure on them, sensors detect and measure relative change in force or applied load. The single element force sensor acts as a force sensing resistor in an electrical circuit. When the force sensor is unloaded, its resistance is very high. When a force is applied to the sensor, this resistance decreases. The resistance can be read by connecting a multimeter to the outer two pins, and then applying a force to the sensing area. This action sends a signal to software program through circuit and DAQ. In Figure 4.5 below, the plot shows the Force vs. Resistance distribution.

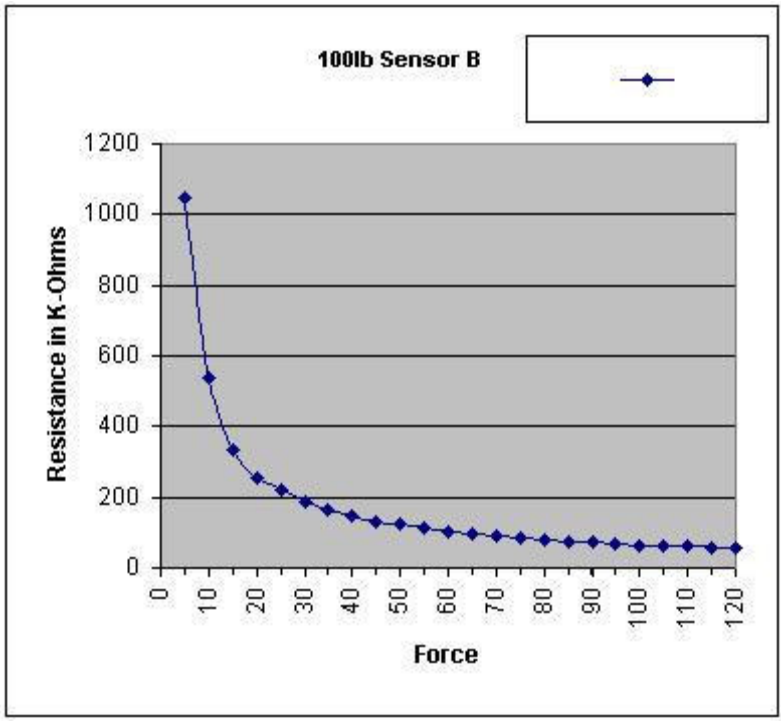

Figure 4.5 The Resistance of Force Resistive Sensor for 100 lb [48].

The sensors act as a variable resistor in an electrical circuit. When the sensor is unloaded, its resistance is very high (about 20 Meg-ohm); when a force is applied to the sensor, the resistance decreases to less than one hundred kilo-ohms. A simple voltage divider circuit is used to estimate the force applied to the sensor, the schematic of which is shown in Figure 4.6.

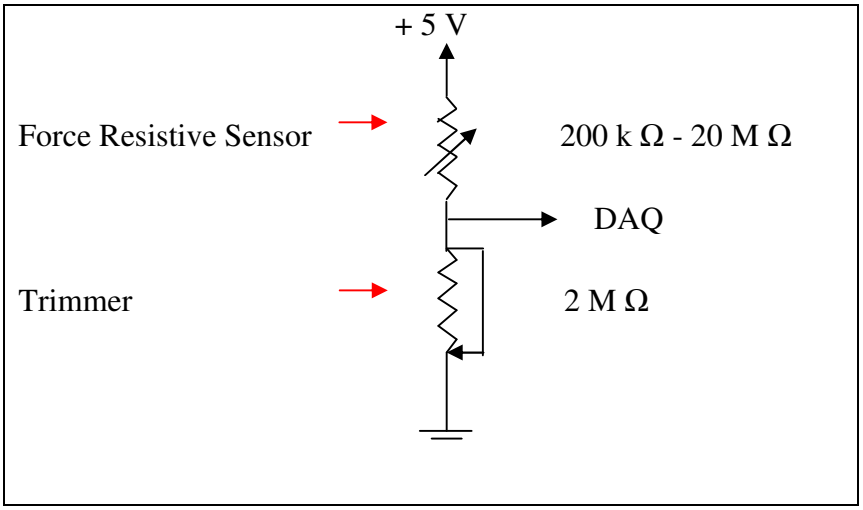

Figure 4.6 Schematic view of the circuit

In this circuit we used a trimmer pot so that sensor output can be kept within a desired range. We then established the relation between sensor's electrical output and the force applied over the sensor. Figure 4.7 illustrates this relation. Finally, we fit a 4^{th} order polynomial (Eq. 4.1.) to this curve and used the force computed by this polynomial is used in the experiments

$$F = (-1.7049 * V^4) + (19.0492 * V^3) + (-44.2502 * V^2) + (57.4024 * V) + 17.6891 \qquad (4.1)^*$$

The data acquisition card is selected as National Instruments USB – 6218 (Figure 4.8) due to its ease of use and high performance. Since it is an external piece of hardware, DAQ process becomes portable, and facilitated the development process. Available libraries for .NET environment also helped us to rapidly incorporate this card into our system. A simplified flowchart of data acquisition is shown in Figure 4.9.

* F = Force (N)
V= Voltage (V)

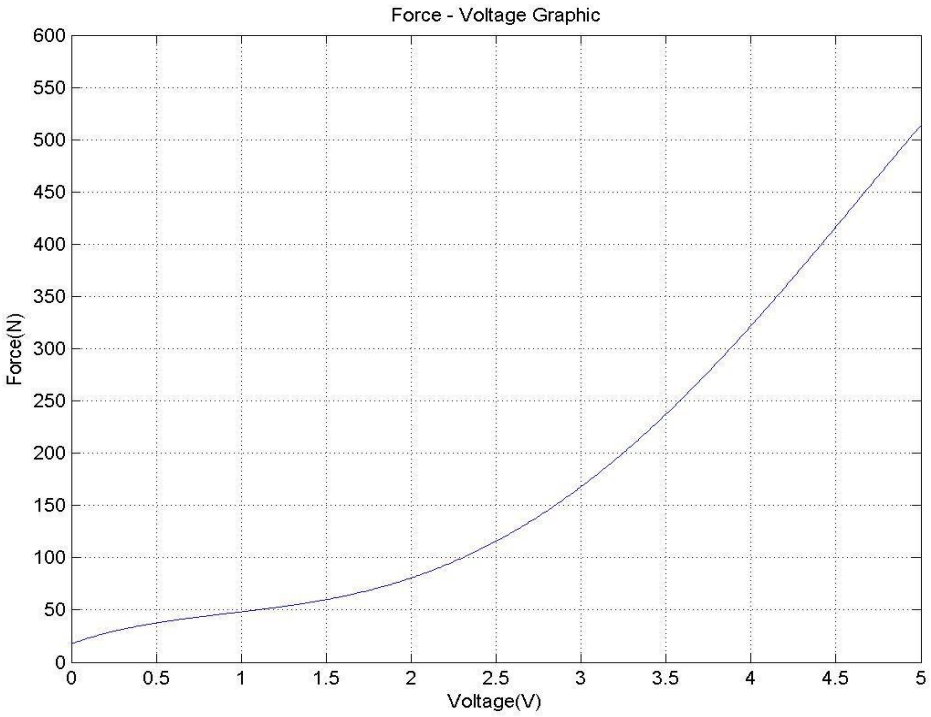

Figure 4.7 Force vs. Voltage Graphic.

Figure 4.8 National Instruments USB – 6218.

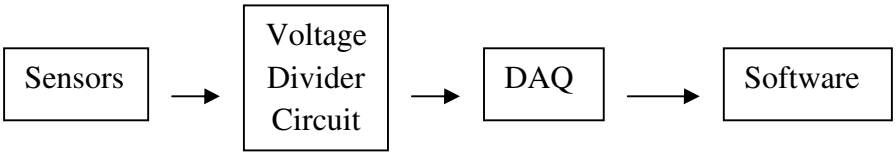

Figure 4.9 Flowchart of Data Acquisition.

4.3. STRUCTURE OF SOFTWARE

Program was created in C# language which is a part of *Microsoft .Net*. The software runs on a single computer and two monitors. One monitor is reserved for the patient, whereas, the second is for the therapist. We used *Microsoft Access* database to keep track of patient records, and records of therapy sessions. *Microsoft Access* is preferred because it is a free tool which is very well integrated with the .NET environment. Average data size for a therapy session is about 4 kbytes. The flowchart of the application is given in Figure 4.10.

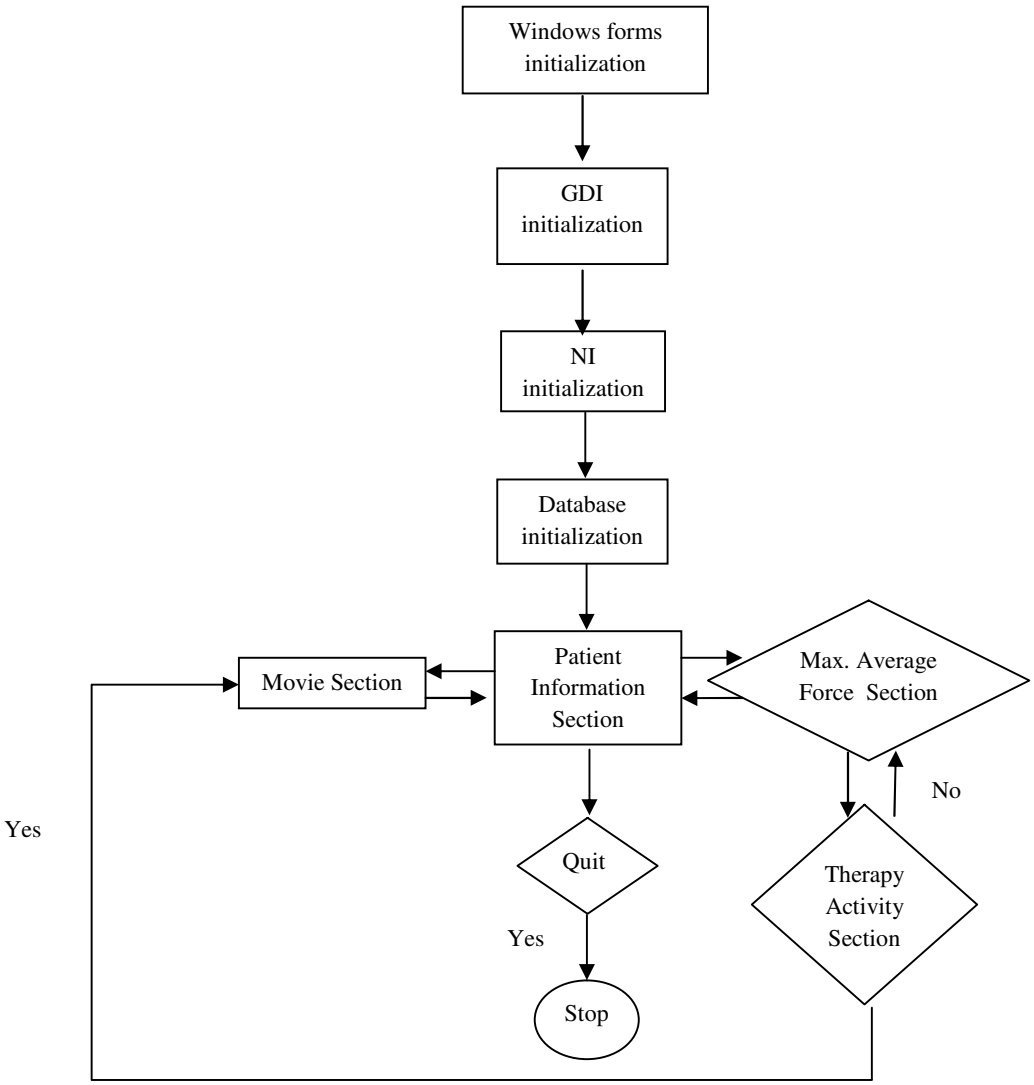

Figure 4.10 Flowchart of the Application

Windows Forms is a C# User Interface (UI) library that provides controls such as buttons, radio buttons, and list boxes. At the same time, it is used as a container to show movement of the objects which is created in GDI library and it provides us to process data. GDI library provides us to draw all graphs and to create ball and movie class dynamically. Data library holds the patient's information such as name, file number, therapy data. Finally, NI library provides us to read data from DAQ and force resistive sensors.

4.4. THE GRAPHICAL USER INTERFACE

There are three sections in the user interface. First section is the registration part (Figure 4.11). We can add new patient data or call the previous ones. Here is a screenshot of the first user interface.

Second section of the program is evaluation session part which calculates maximum force values. In this section, the program automatically detects the maximum force that can be applied by the patient within a time frame that is determined by the therapist. The force is computed as the average of the three sensors. Patient performs posterior pelvic tilt exercise about five times to calculate average maximum force value. There are two screen views one of which is the therapist screen (Figure 4.12) and the other is the patient screen (Figure 4.13). The therapist can manually start and stop this process and let the system work for a pre-determined amount of time which is to be specified in seconds. Each sensor data is shown separately in bar graph. After calculation of maximum force, therapist can enter the third section of the program.

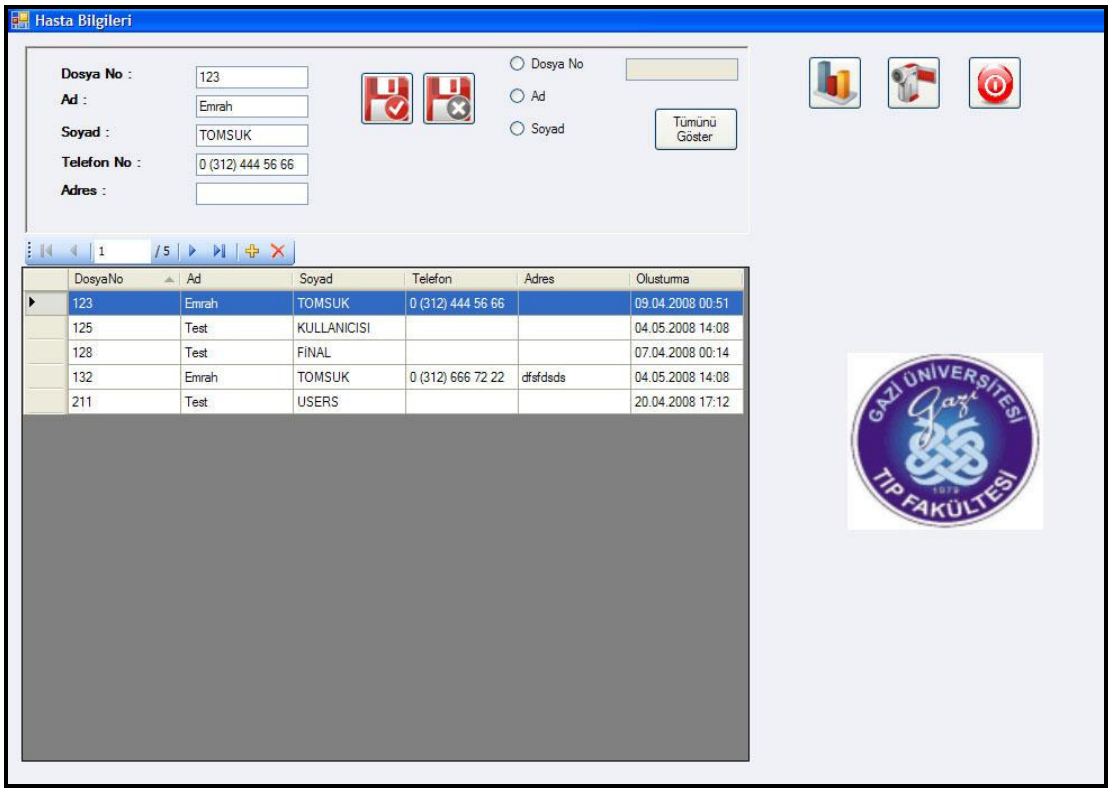

Figure 4.11 UI of Patient Information Section.

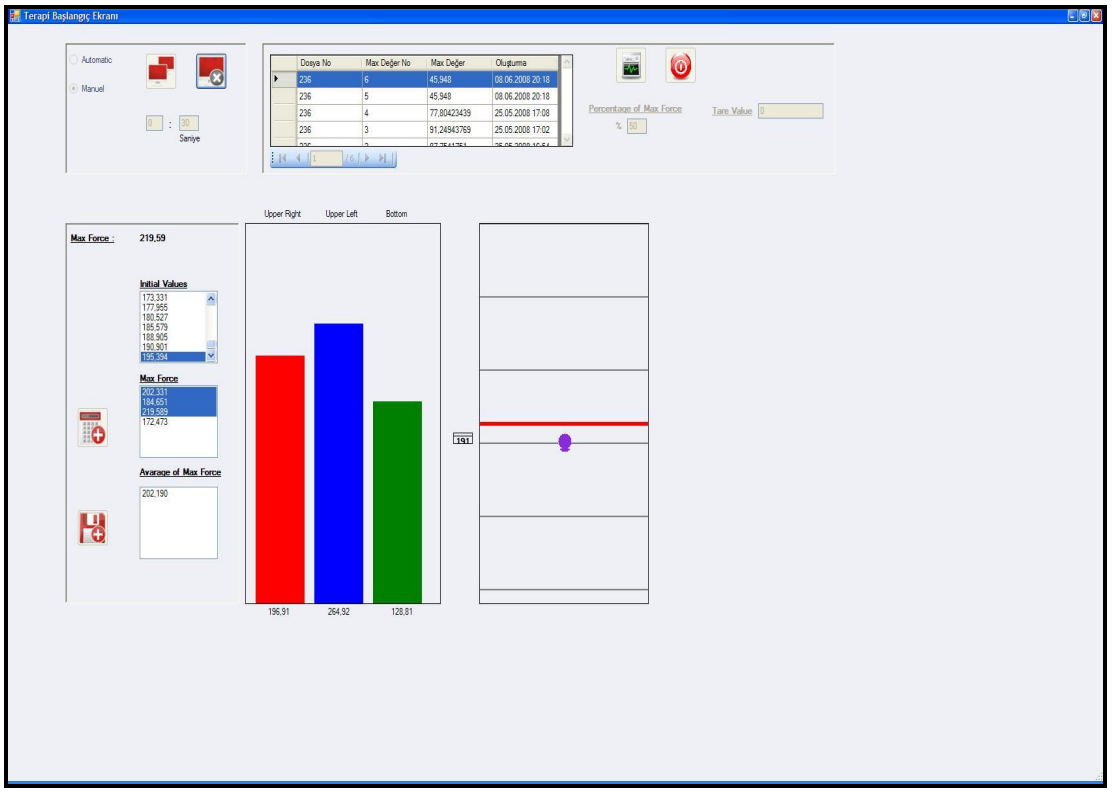

Figure 4.12 Therapist UI of Maximum Average Force Section.

Figure 4.13 Patient UI of Maximum Force Pressure Section.

The third section of the program is PPTE session part which provides visual feedback to the patient. In this section, the patient is asked to follow the path in trapezoidal graph by applying force to the sensors on the exercise bed to move the ball up and down direction while patient performs PPTE.

Each trapezoidal has rest and exercise periods which are shown in Figure 4.17. t_1, t_2, t_3 indicate muscle contraction period of therapy, t_4 indicates rest period of therapy.

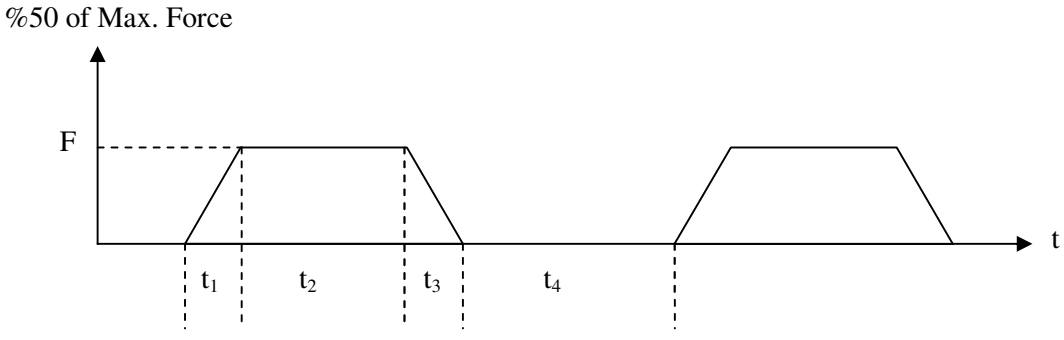

Figure 4.14: Parametric path a patient is to follow during a rehabilitation session.

On the graph abscissa shows time, and ordinate shows force. The therapist can set the time parameters before the start of rehabilitation session. There are two screen views which are the therapist screen (Figure 4.15) and the patient screen (Figure 4.16). When session is over, therapist can save all the data and review whenever he/she wants.

Recorded segments of data can be used for reviewing the former therapy activity sessions. In this section, therapist can reach all former saved sessions of every patient. Saved sessions can be controlled by play, pause and stop buttons and also the play speed can be changed to enable rapid preview, or slower analysis.

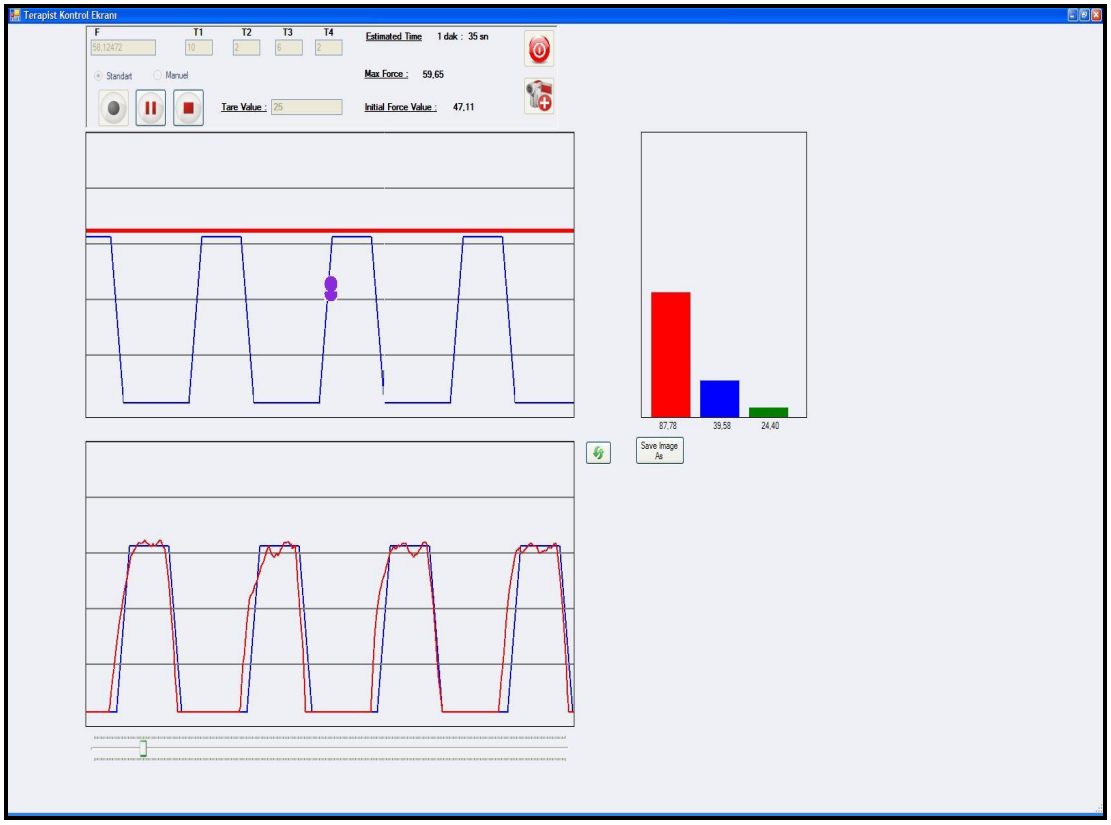

Figure 4.15 Therapist UI of Therapy Activity Section.

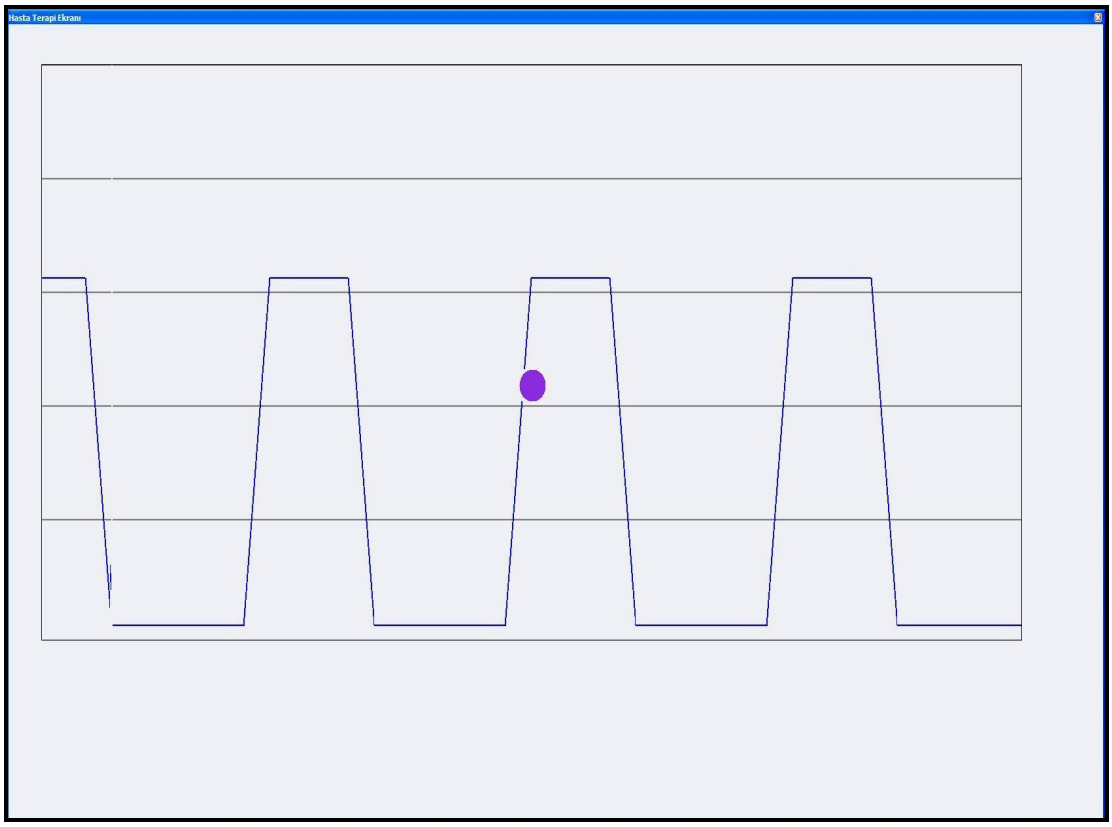

Figure 4.16 Patient UI of Therapy Activity Section.

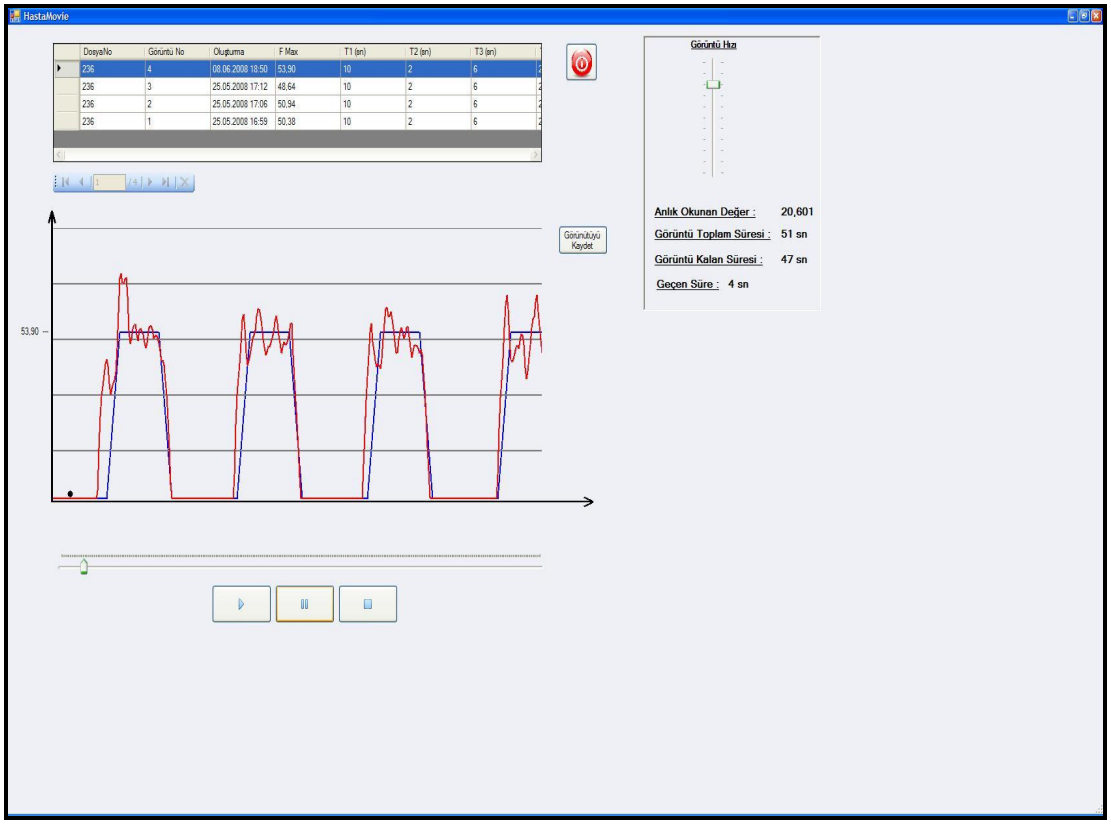

Figure 4.17 UI of Recorded segments of data.

4.5. CASE STUDY AND RESULTS

Posterior pelvic tilt exercise (PPTE) is a sort of an isometric exercise. When a patient performs this exercise his gluteal, abdominal and partly dorsal muscles are working. The main goal of this exercise is to strengthen these muscles. We can see sensors' projections in Figure 4.18.

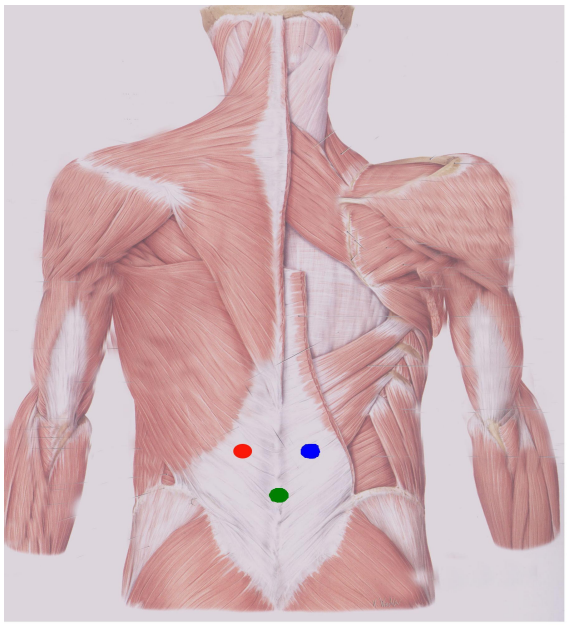

Figure 4.18 Force resistive sensors' projections which are suggested on patient's waist on thin mattress while patient lies in supine position.

Data collection was realized on twelve volunteers; seven male and five female. Their ages range was between 19 and 50. The study had two stages. First one was to perform five consecutive PPTE with maximum effort, I) without feedback, II) during feedback, III) without feedback on each subject. Subject attempts to apply the maximum possible force on the sensor. 5 attempts are performed by the subject and the mean of five forces for each situation were calculated. Second stage comprised of a series of 10 PPTE with an intensity of 50% of maximum force of each subject was designated in the form of trapezoidal with rest/exercise periods (10/6 s respectively) to provide feedback for a train of PPTE.

At the second stage of the study, we did also three experiments for each volunteer, I) without feedback, II) during feedback, III) without feedback on each subject. In the provided bio-feedback, the blue line indicates the desired path; the red line indicates the patient's performance. We recorded more than ten red trapezoidal during each therapy session. We observed that visual feedback provided a better congruency with predesignated patterns of PPTEs, qualitatively. The results per volunteers are showed as follows:

I)

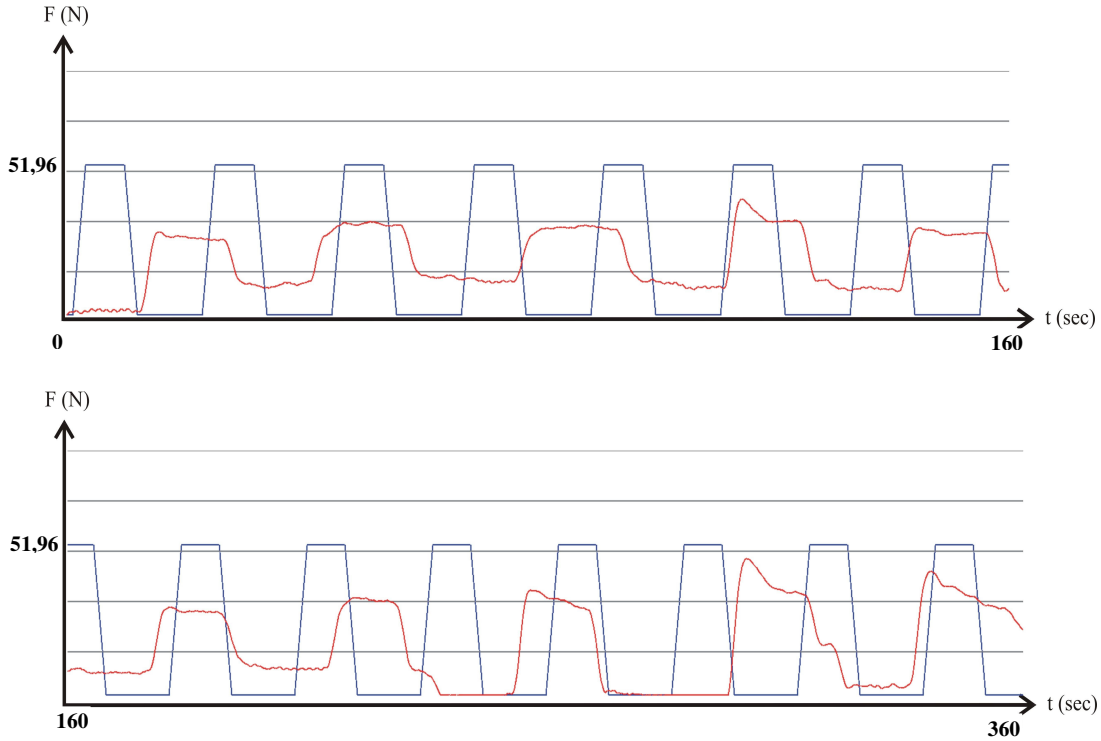

Figure 4.19 PPTE without bio-feedback in 360 sec.

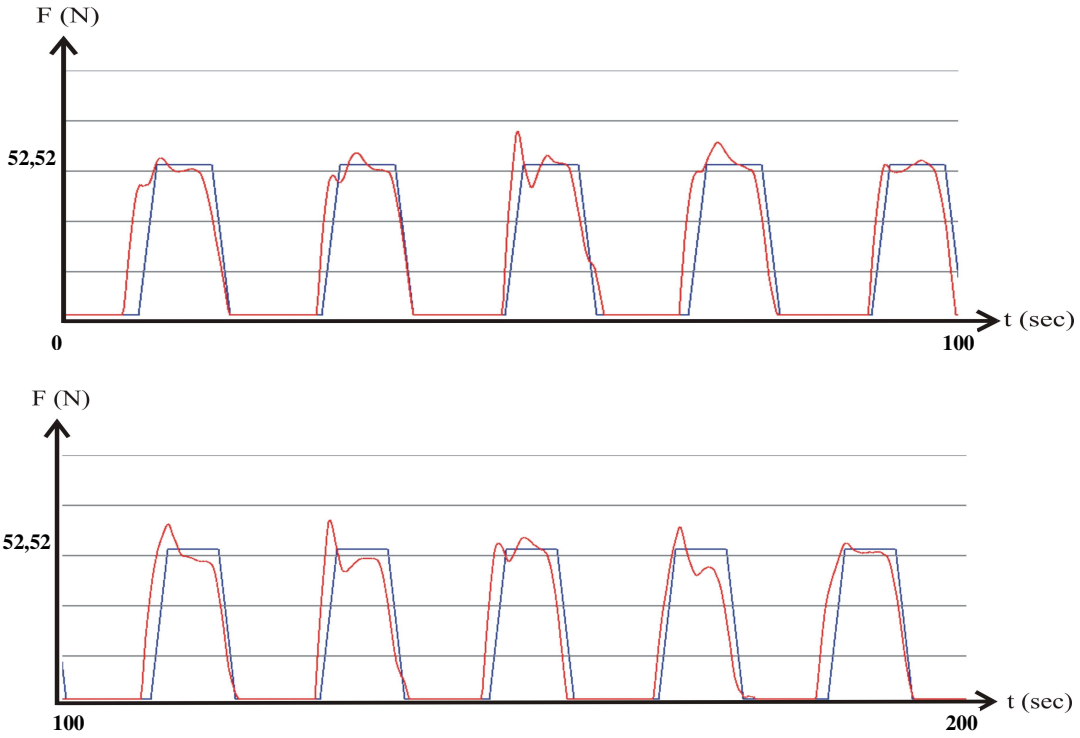

Figure 4.20 PPTE with bio-feedback in 200 sec.

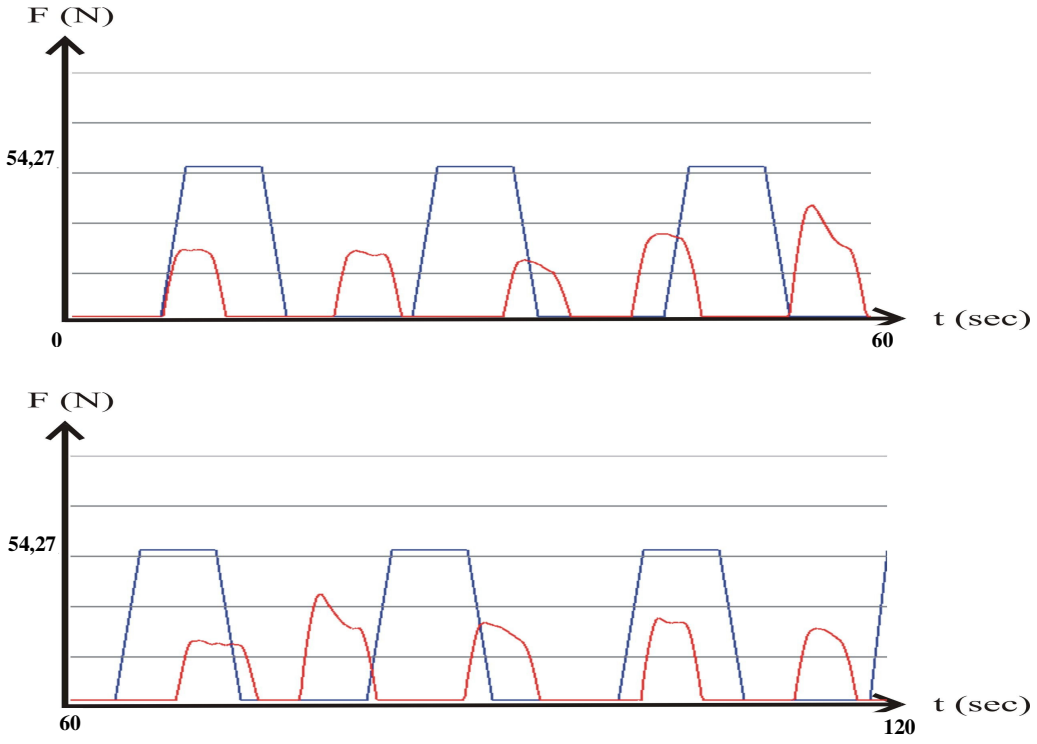

Figure 4.21 PPTE without bio-feedback in 120 sec.

II)

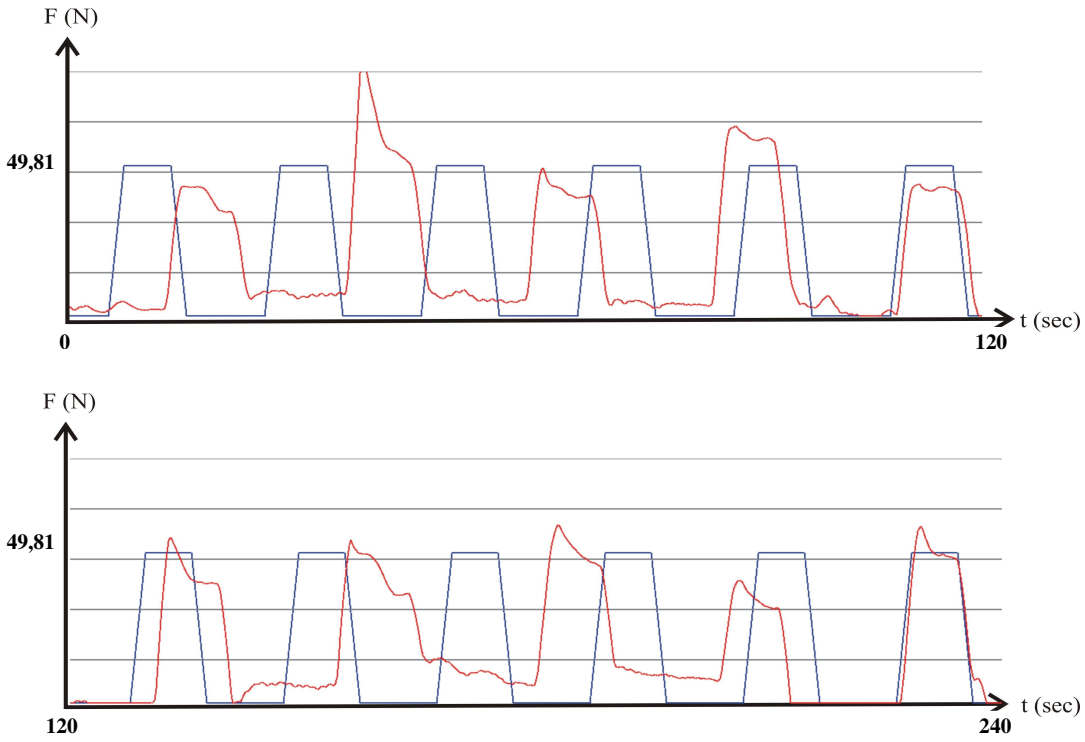

Figure 4.22 PPTE without bio-feedback in 240 sec.

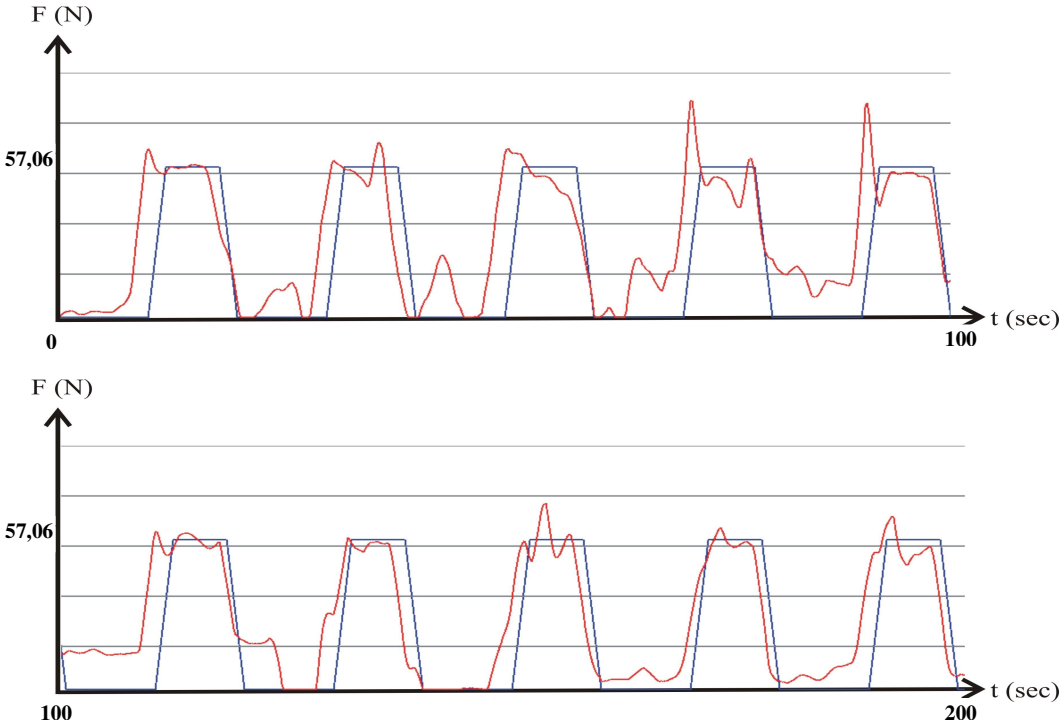

Figure 4.23 PPTE with bio-feedback in 200 sec.

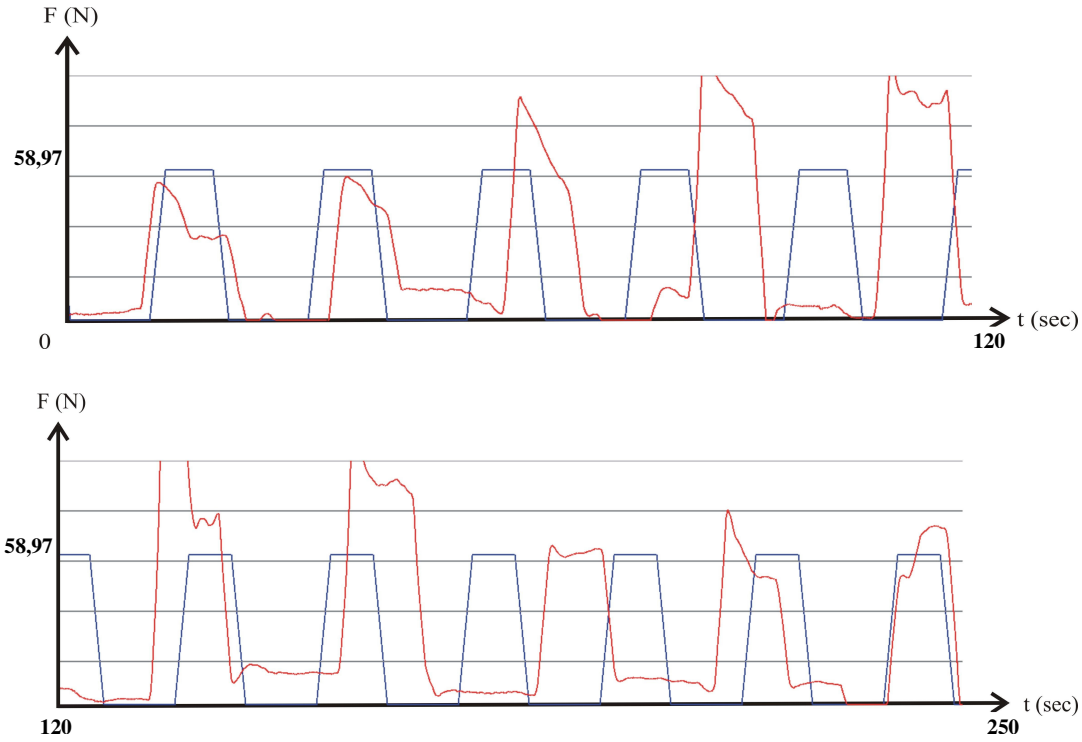

Figure 4.24 PPTE without bio-feedback in 250 sec.

III)

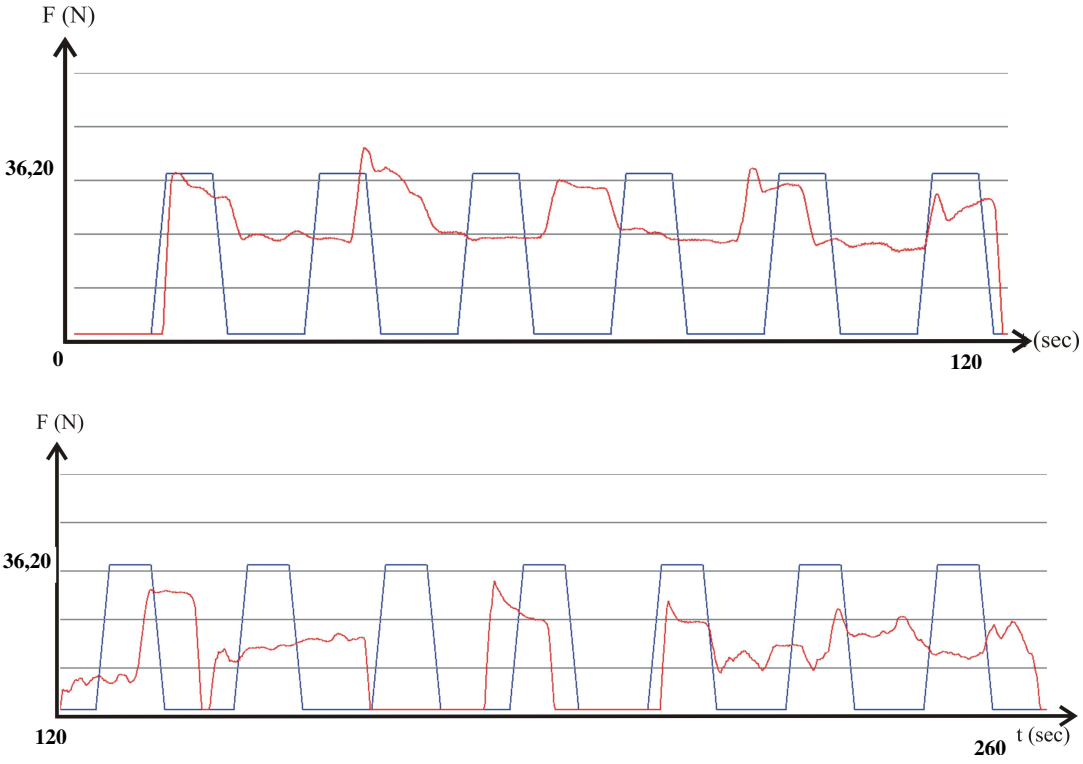

Figure 4.25 PPTE without bio-feedback in 260 sec.

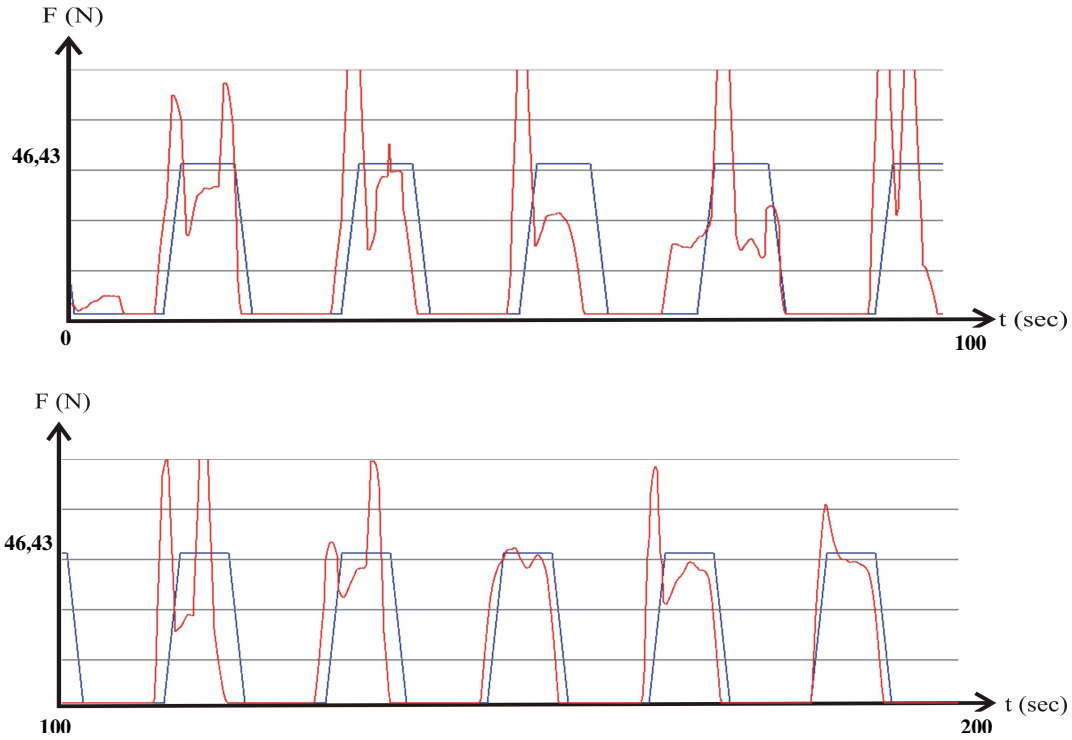

Figure 4.26 PPTE with bio-feedback in 200 sec.

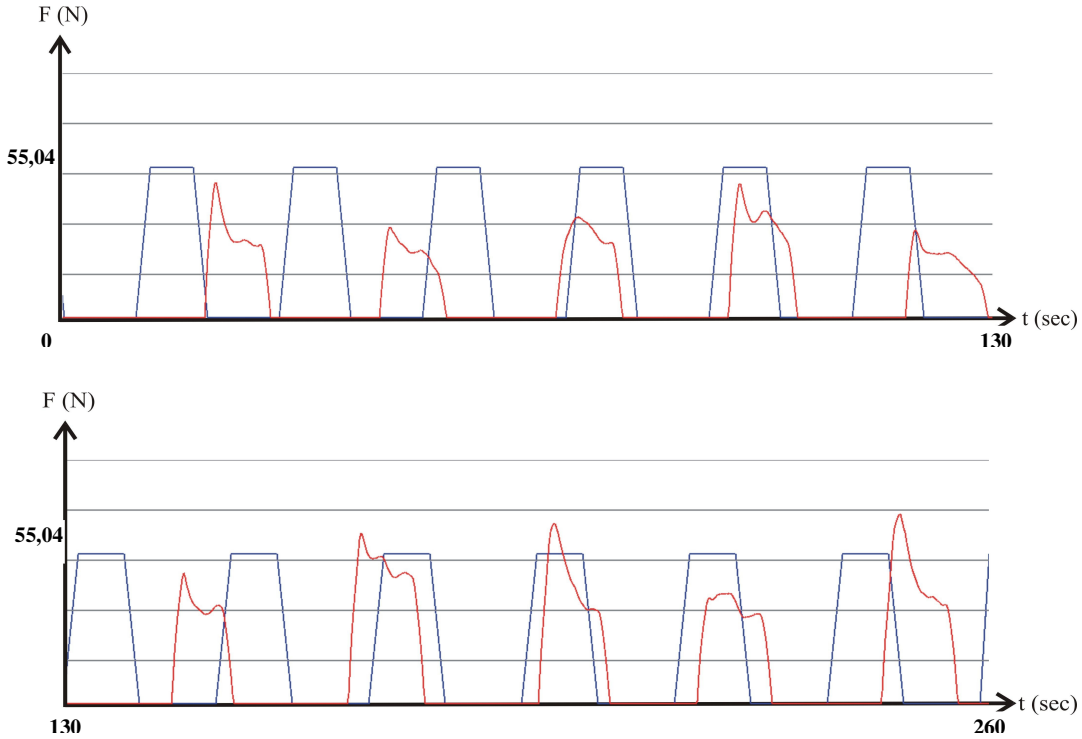

Figure 4.27 PPTE without bio-feedback in 260 sec.

IV)

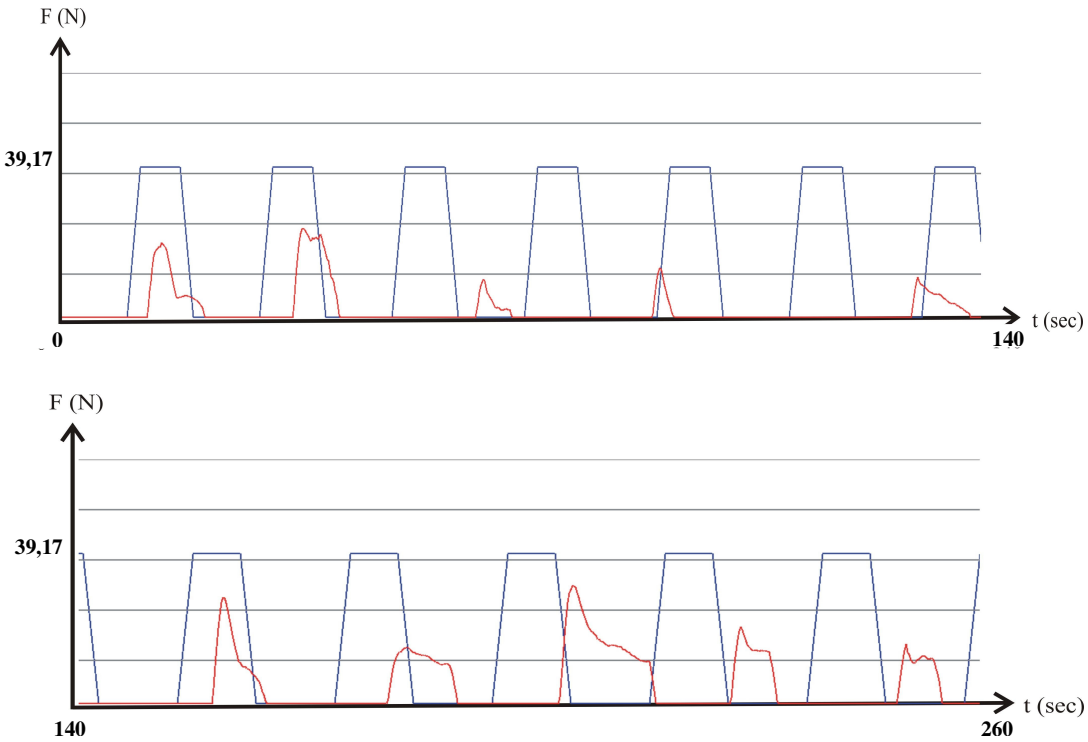

Figure 4.28 PPTE without bio-feedback in 260 sec.

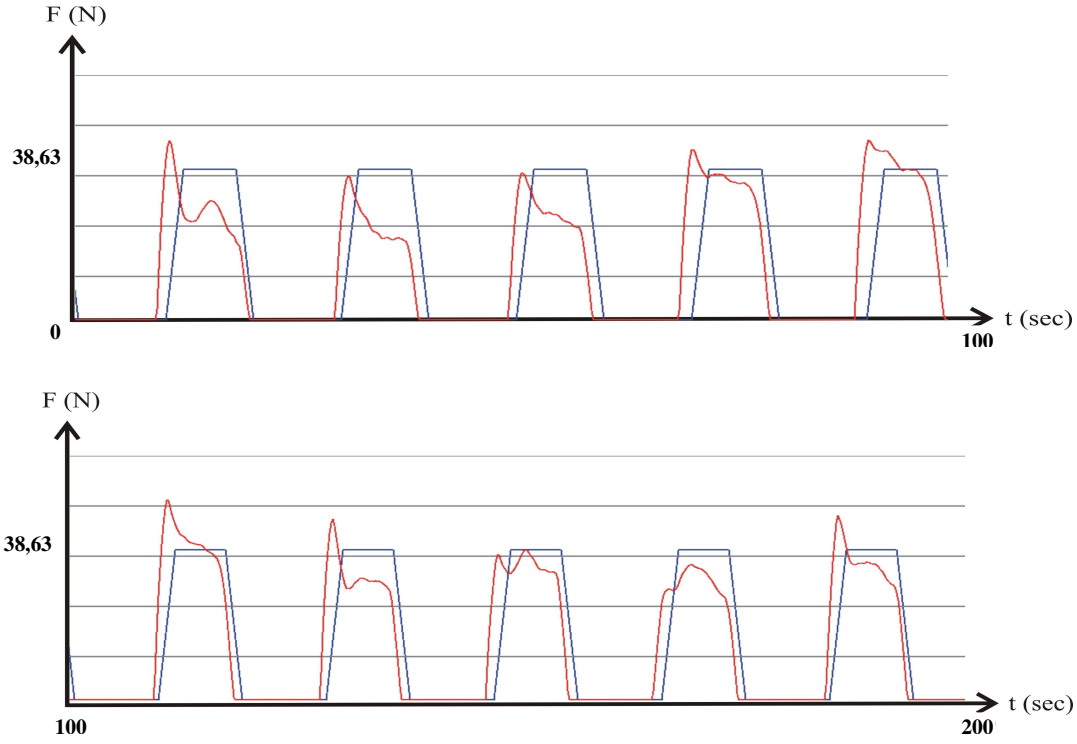

Figure 4.29 PPTE with bio-feedback in 200 sec.

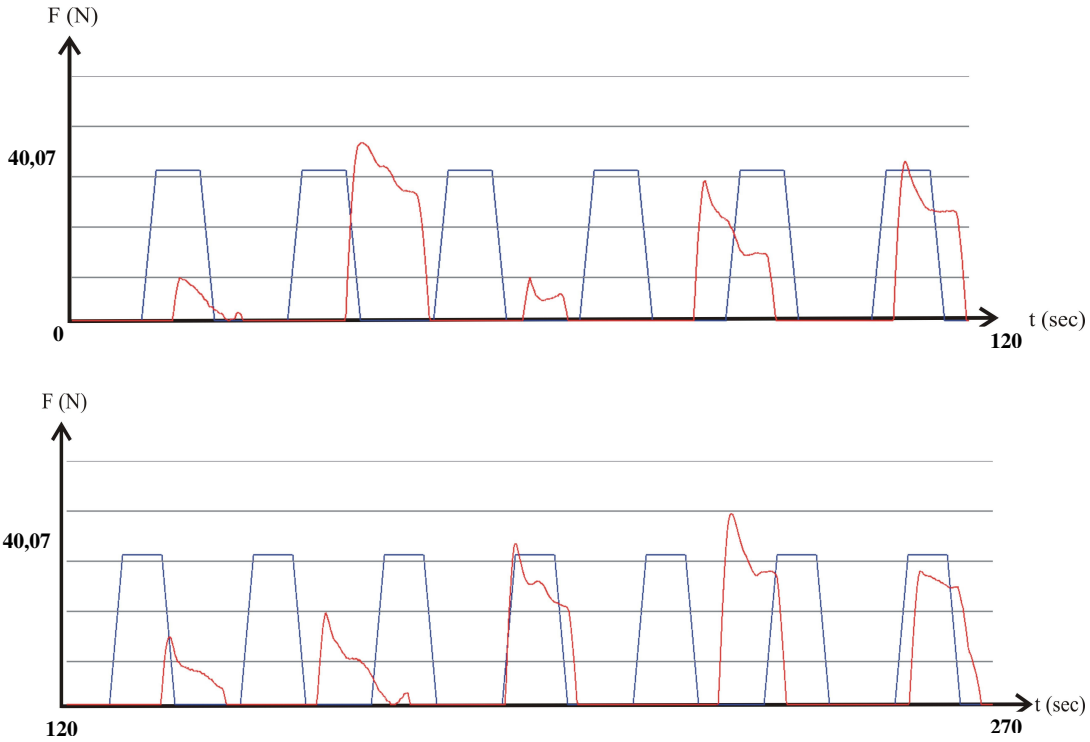

Figure 4.30 PPTE without bio-feedback in 270 sec.

V)

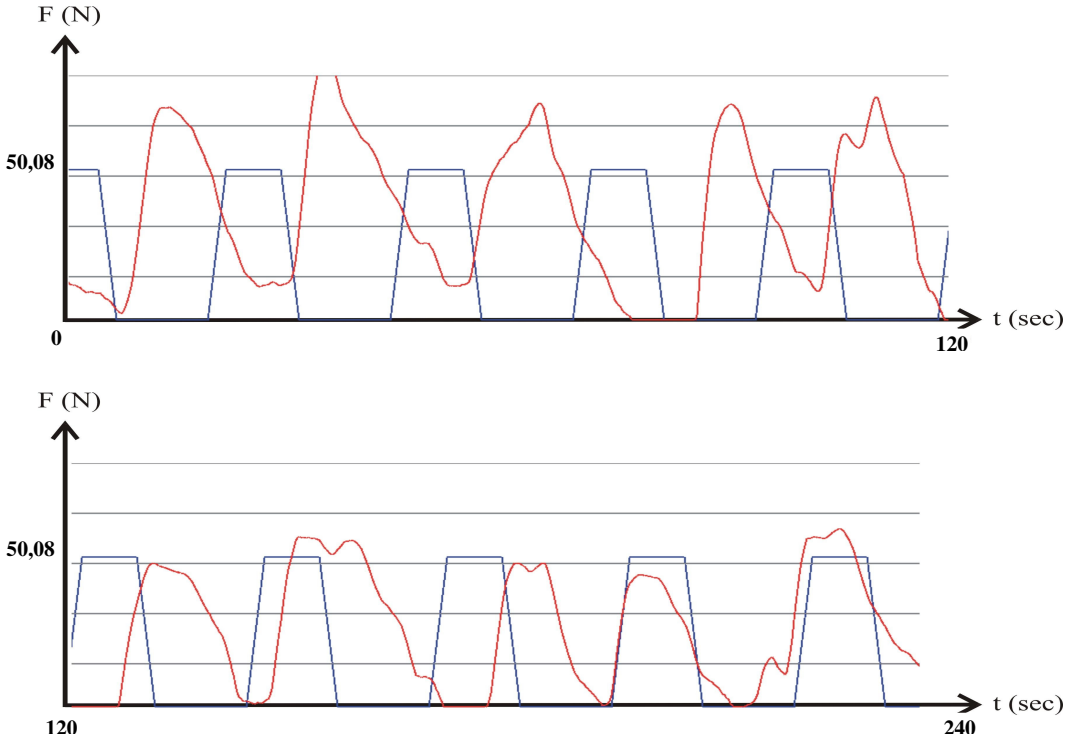

Figure 4.31 PPTE without bio-feedback in 240 sec.

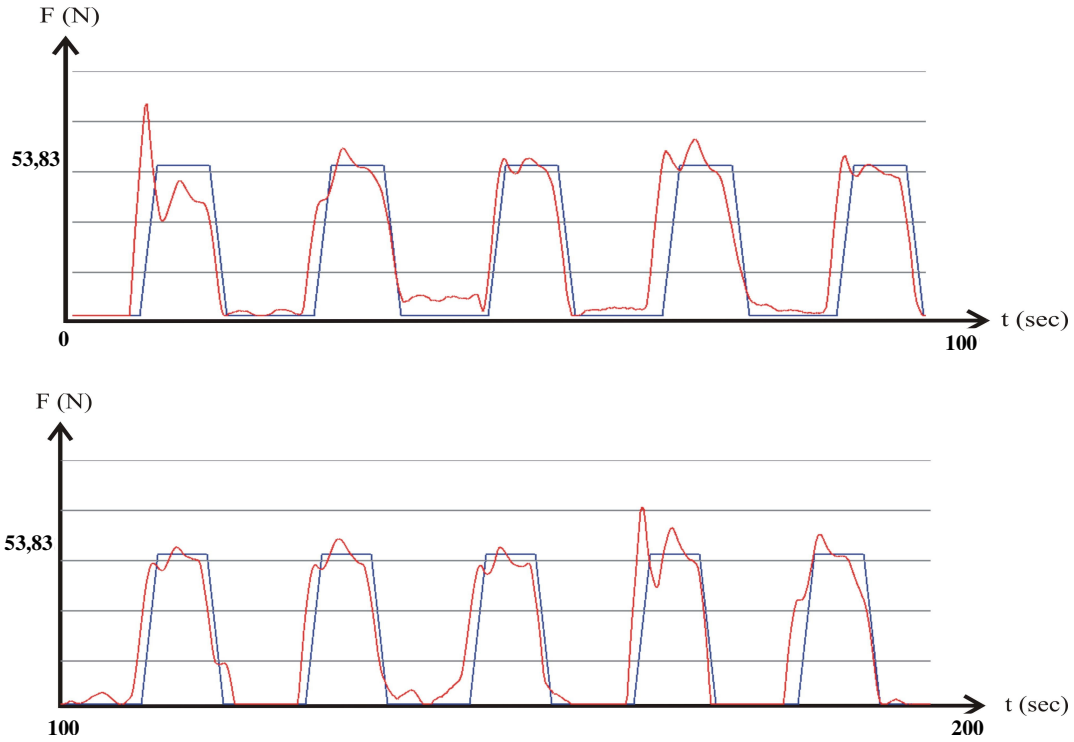

Figure 4.32 PPTE with bio-feedback in 200 sec.

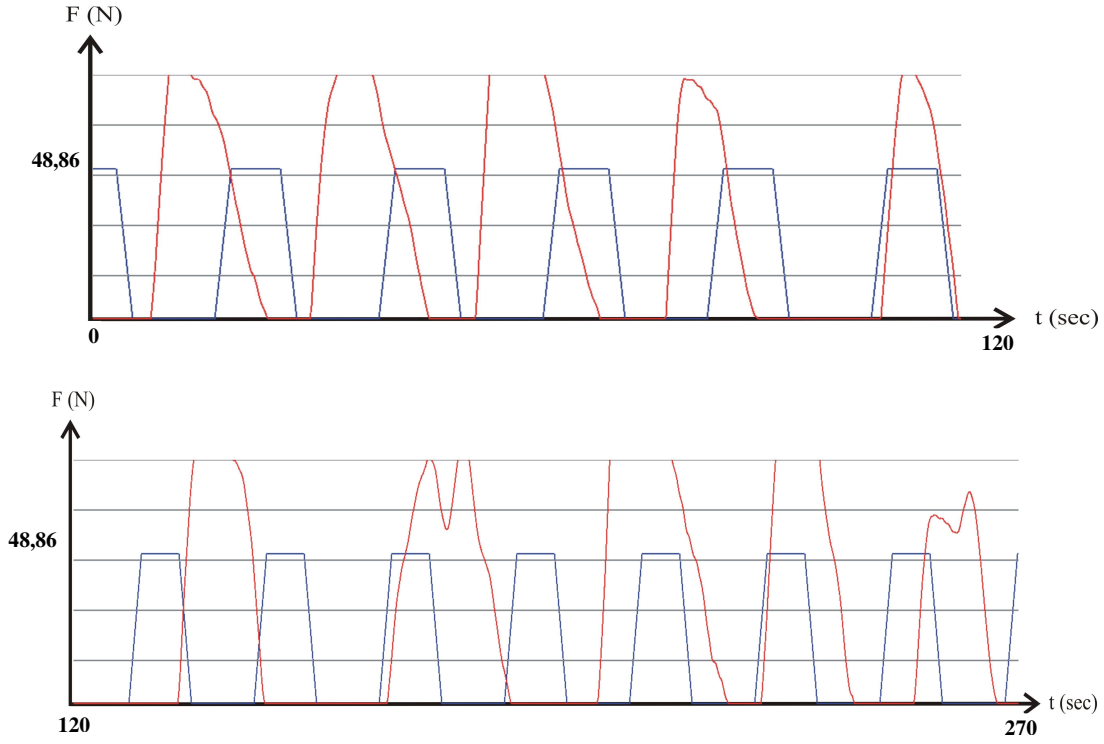

Figure 4.33 PPTE without bio-feedback in 270 sec.

VI)

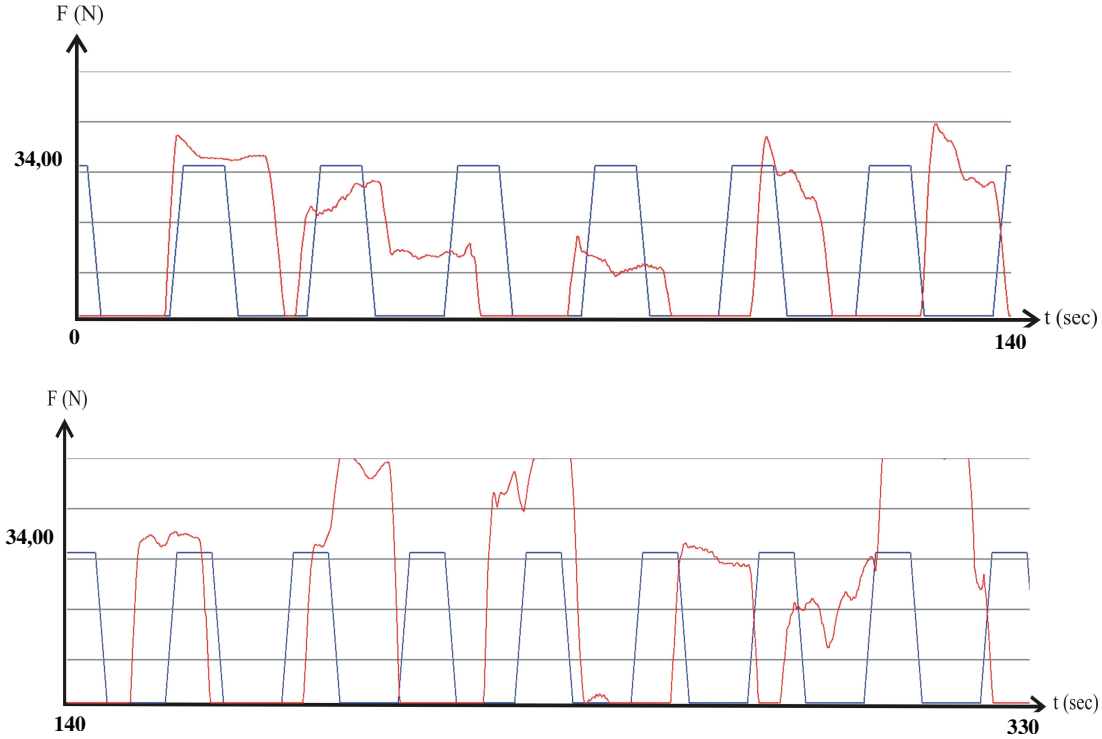

Figure 4.34 PPTE without bio-feedback in 330 sec.

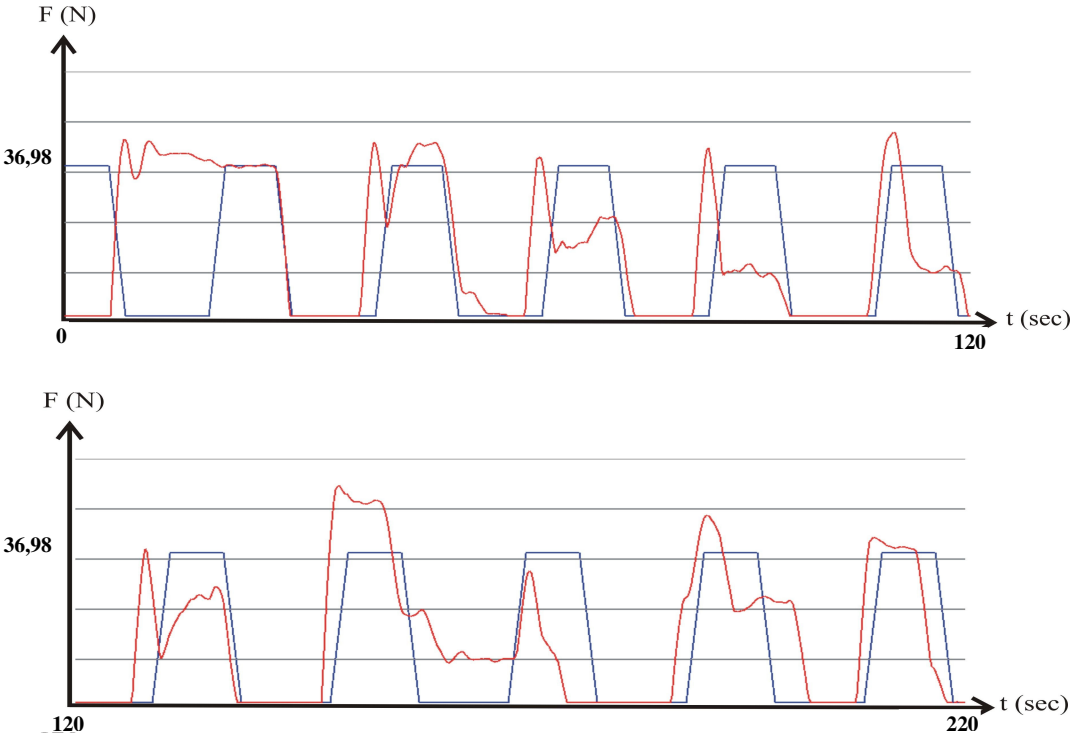

Figure 4.35 PPTE with bio-feedback in 220 sec.

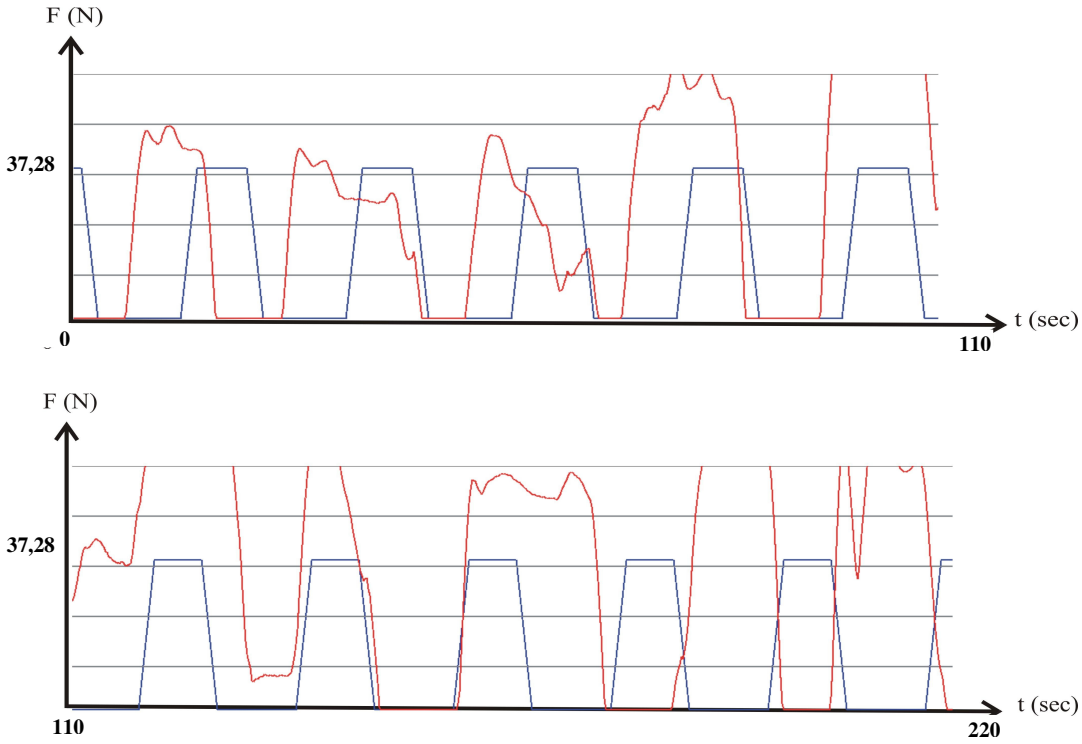

Figure 4.36 PPTE without bio-feedback in 220 sec.

VII)

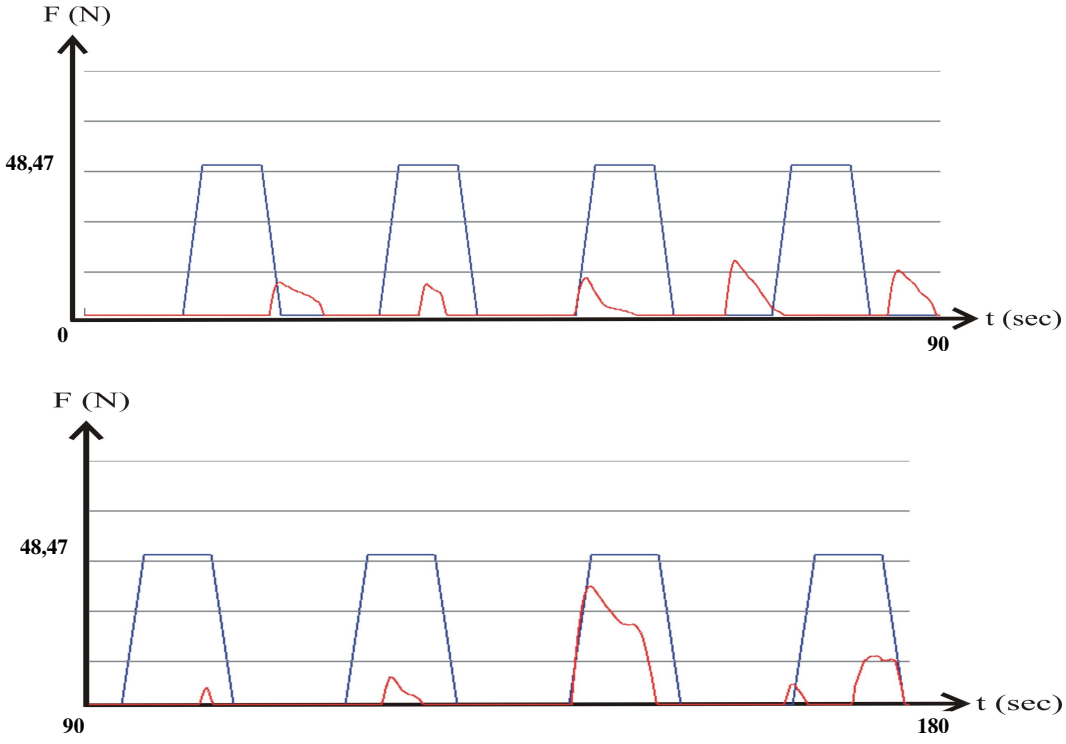

Figure 4.37 PPTE without bio-feedback in 180 sec.

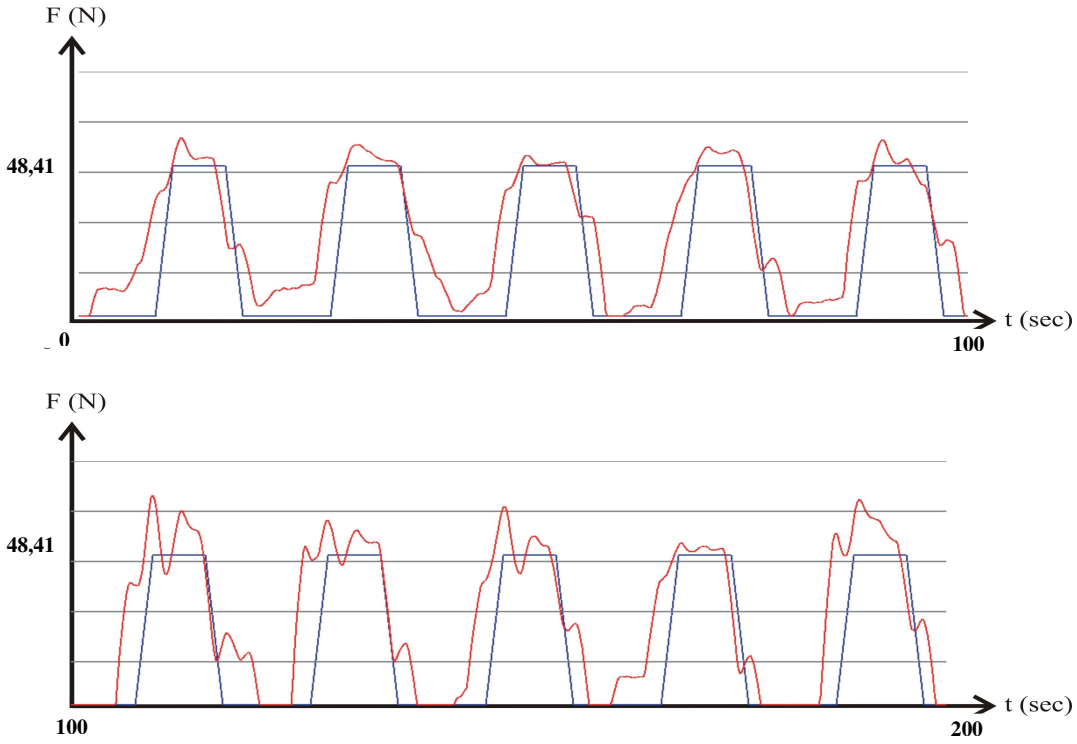

Figure 4.38 PPTE with bio-feedback in 200 sec.

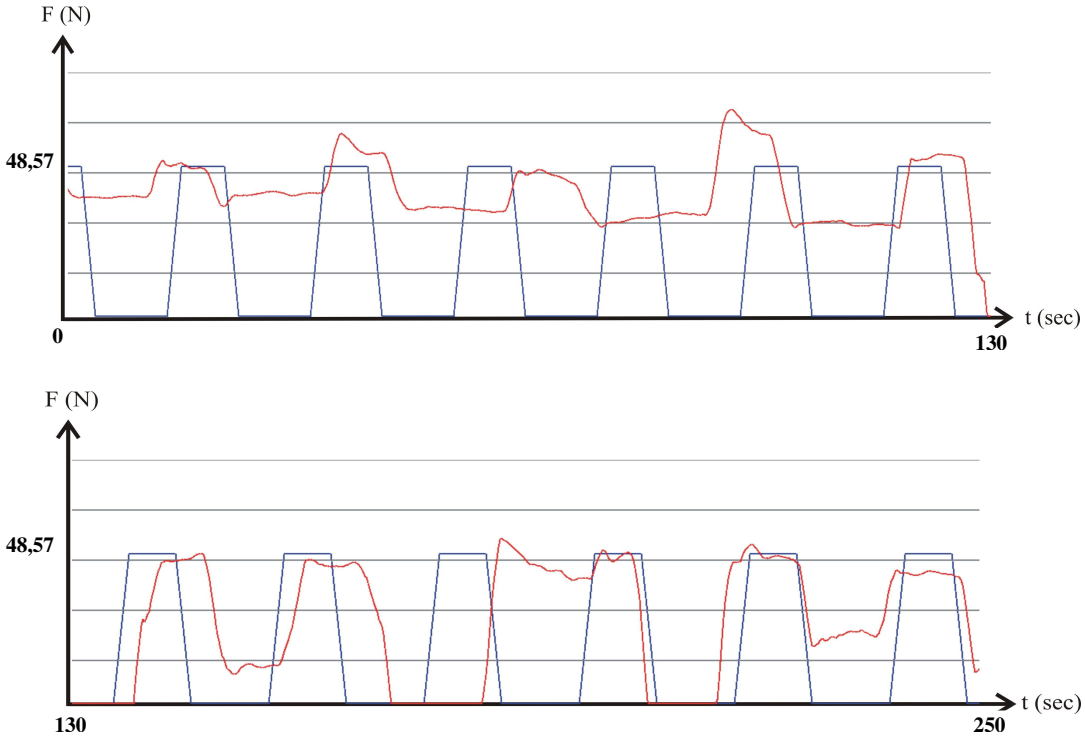

Figure 4.39 PPTE without bio-feedback in 250 sec.

VIII)

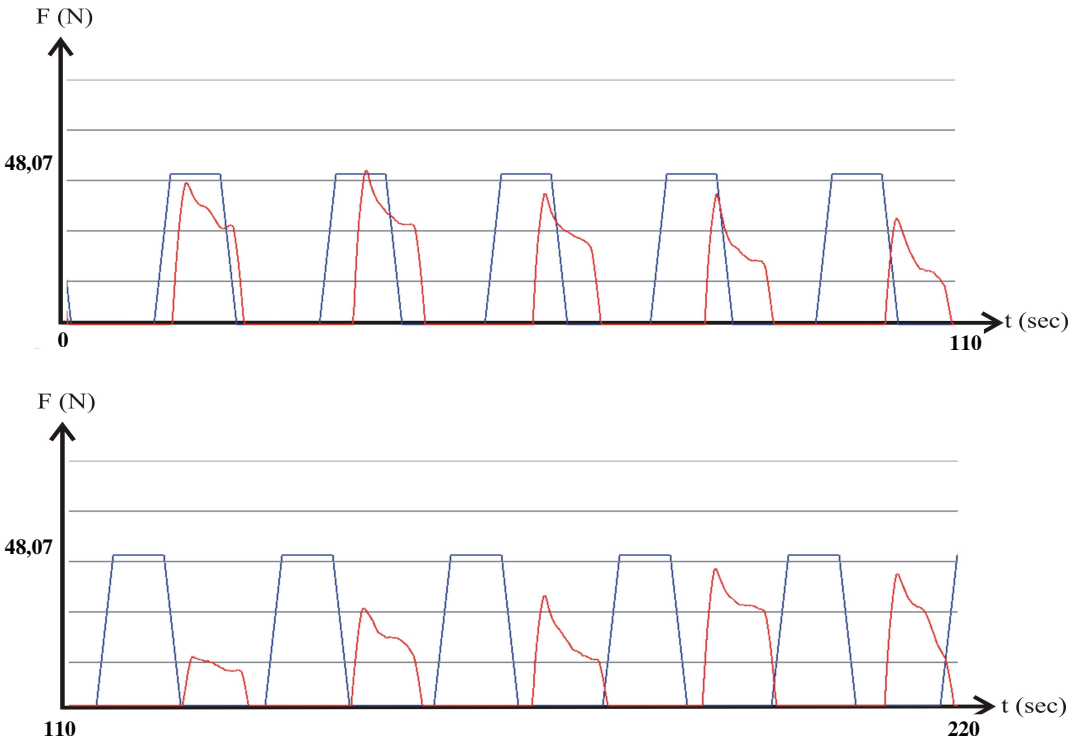

Figure 4.40 PPTE without bio-feedback in 220 sec.

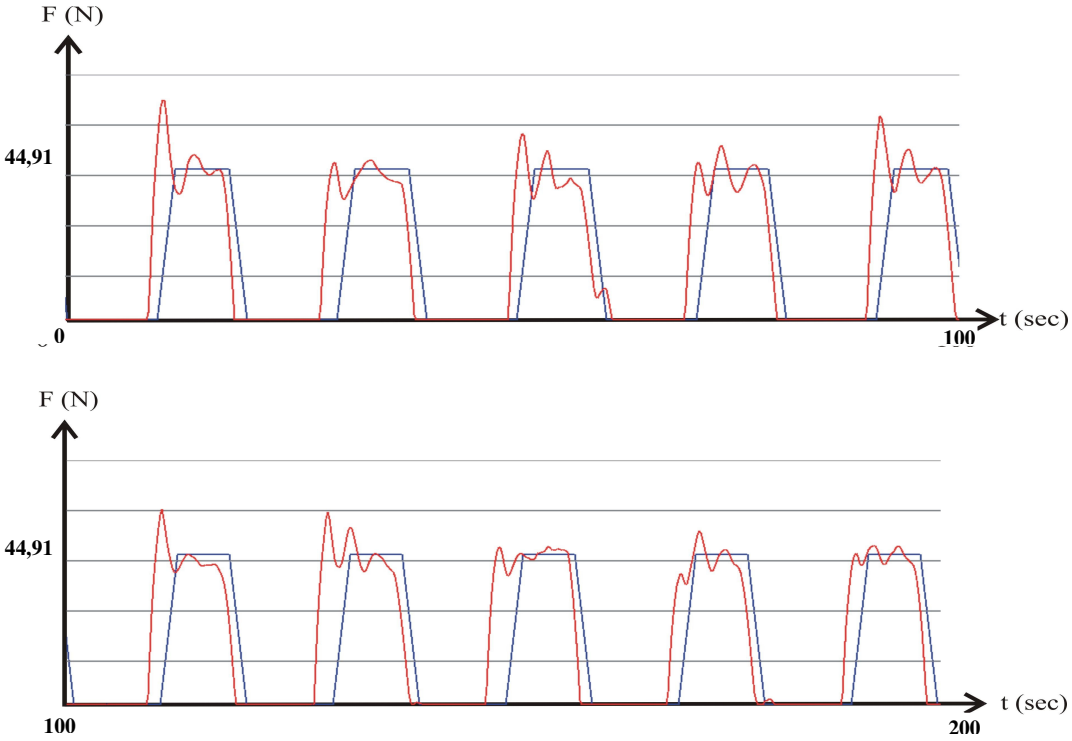

Figure 4.41 PPTE with bio-feedback in 200 sec.

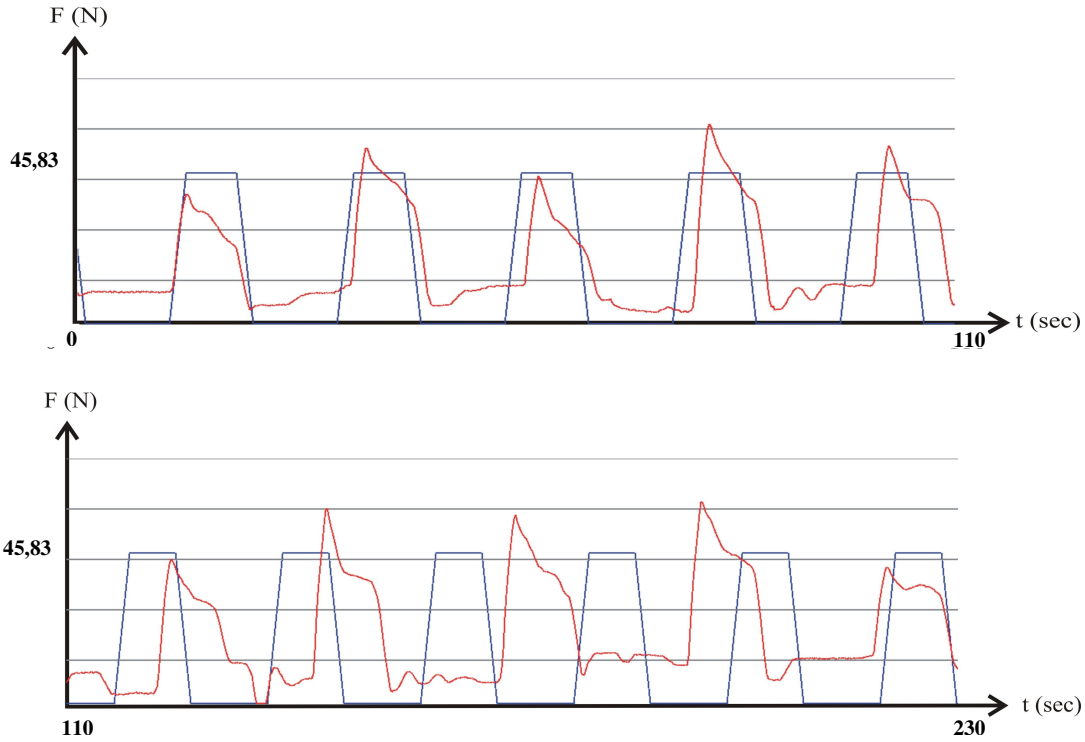

Figure 4.42 PPTE without bio-feedback in 230 sec.

IX)

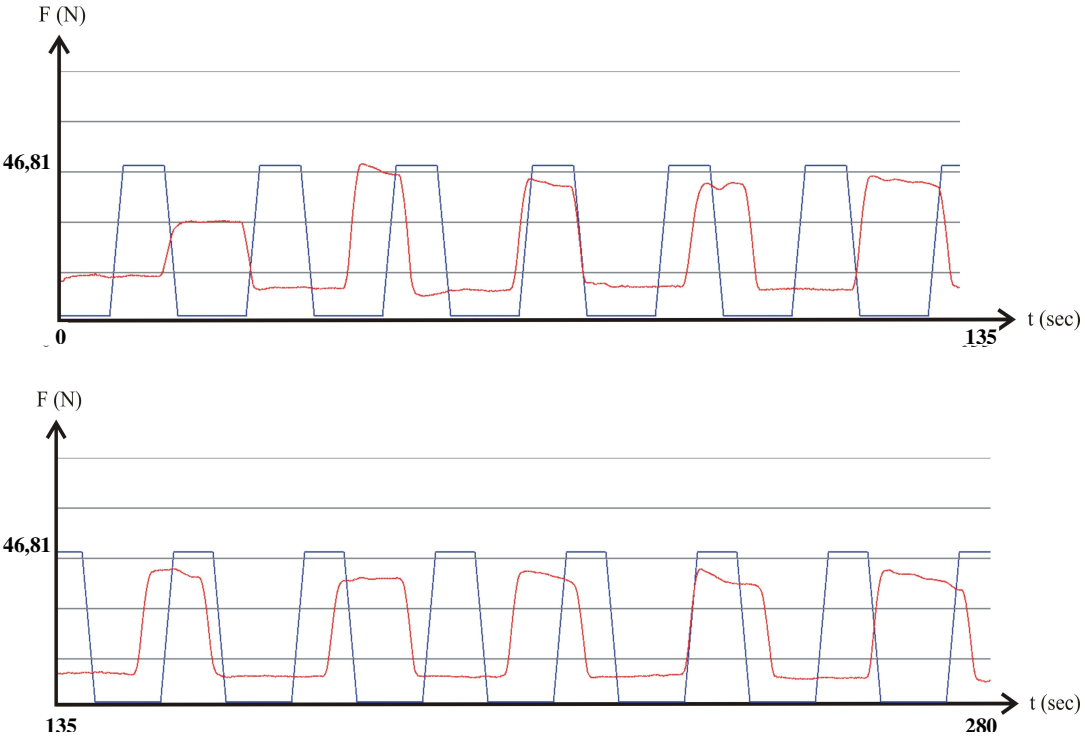

Figure 4.43 PPTE without bio-feedback in 280 sec.

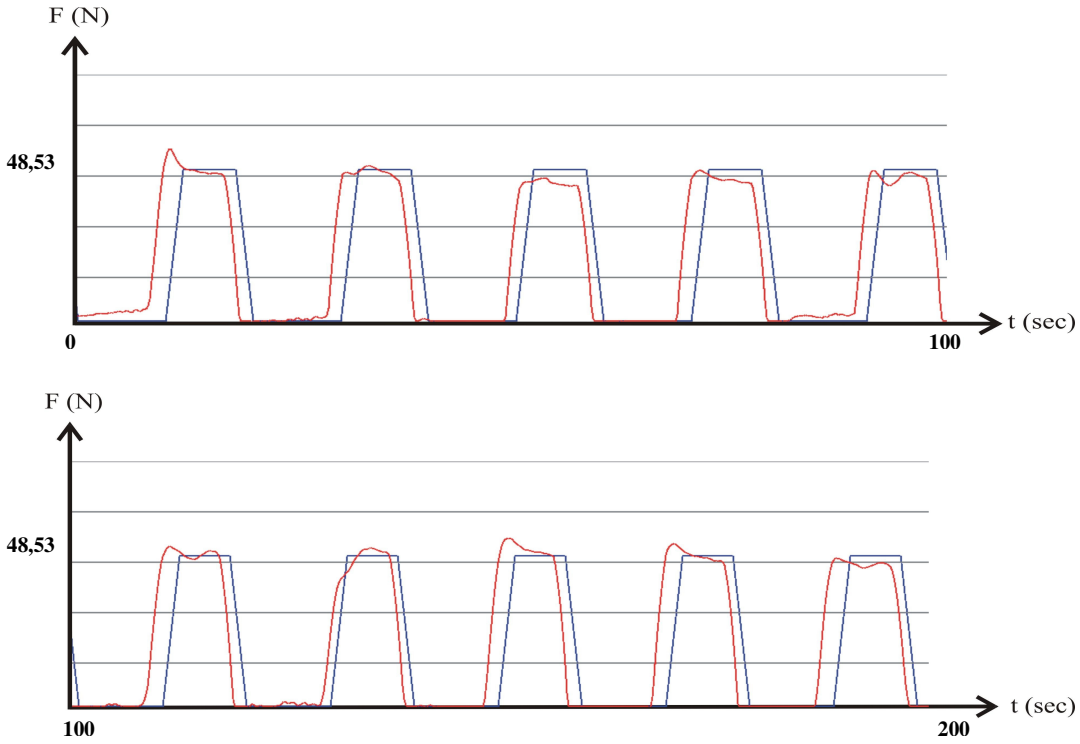

Figure 4.44 PPTE with bio-feedback in 200 sec.

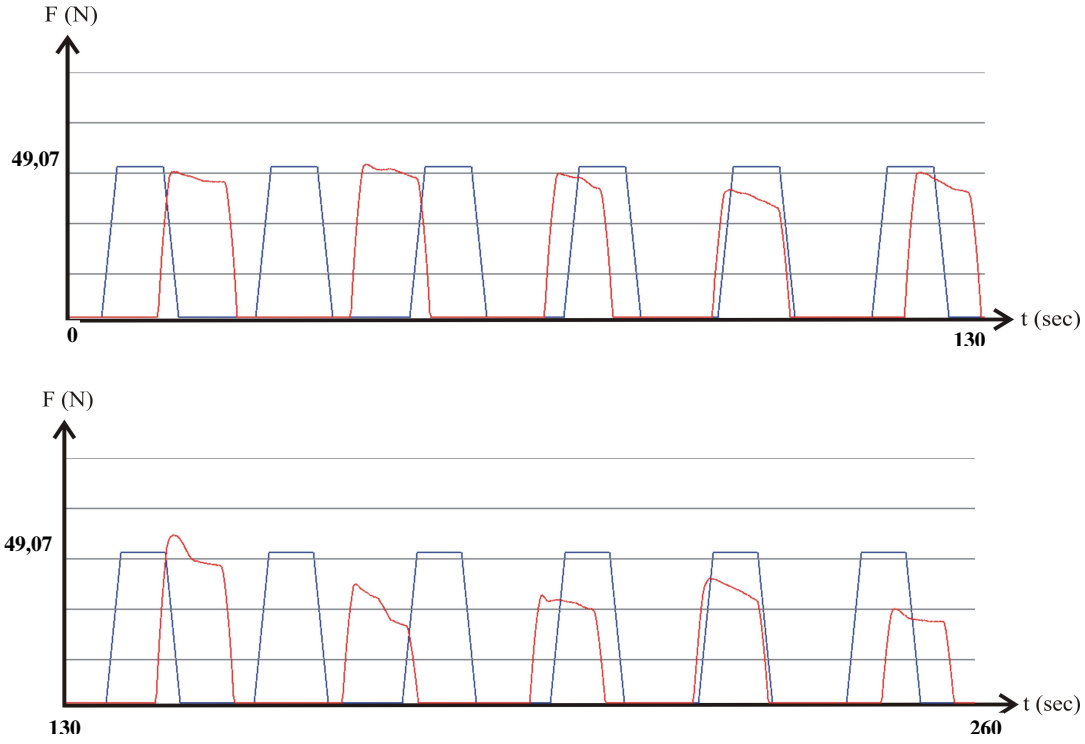

Figure 4.45 PPTE without bio-feedback in 260 sec.

X)

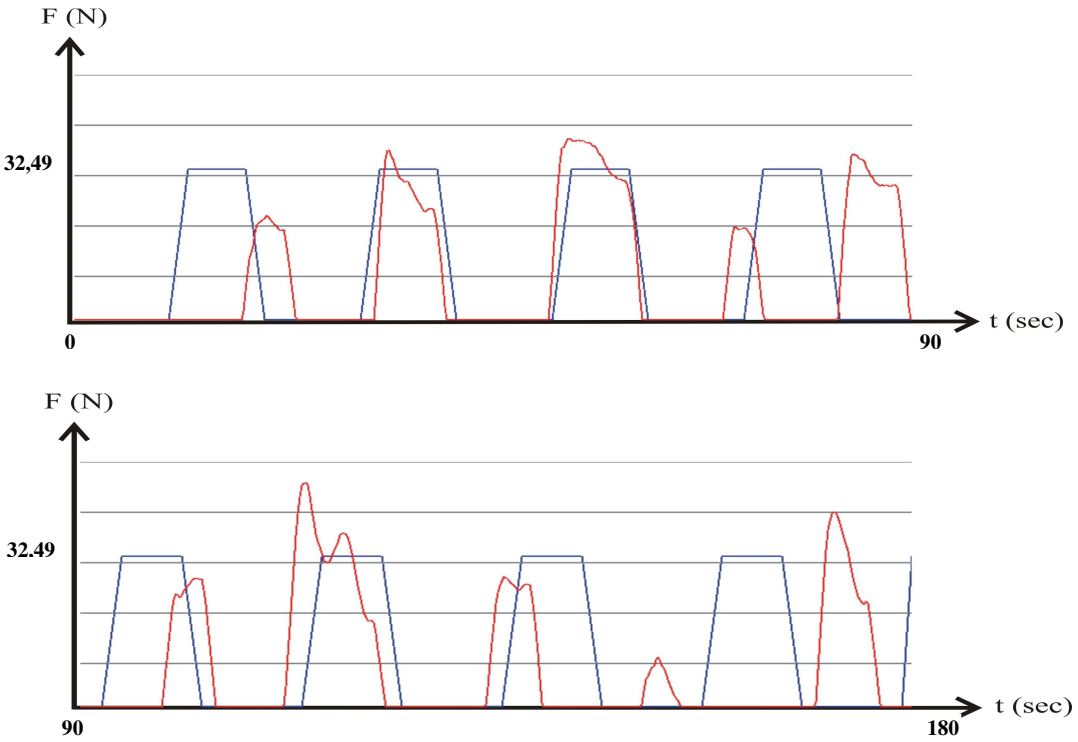

Figure 4.46 PPTE without bio-feedback in 180 sec.

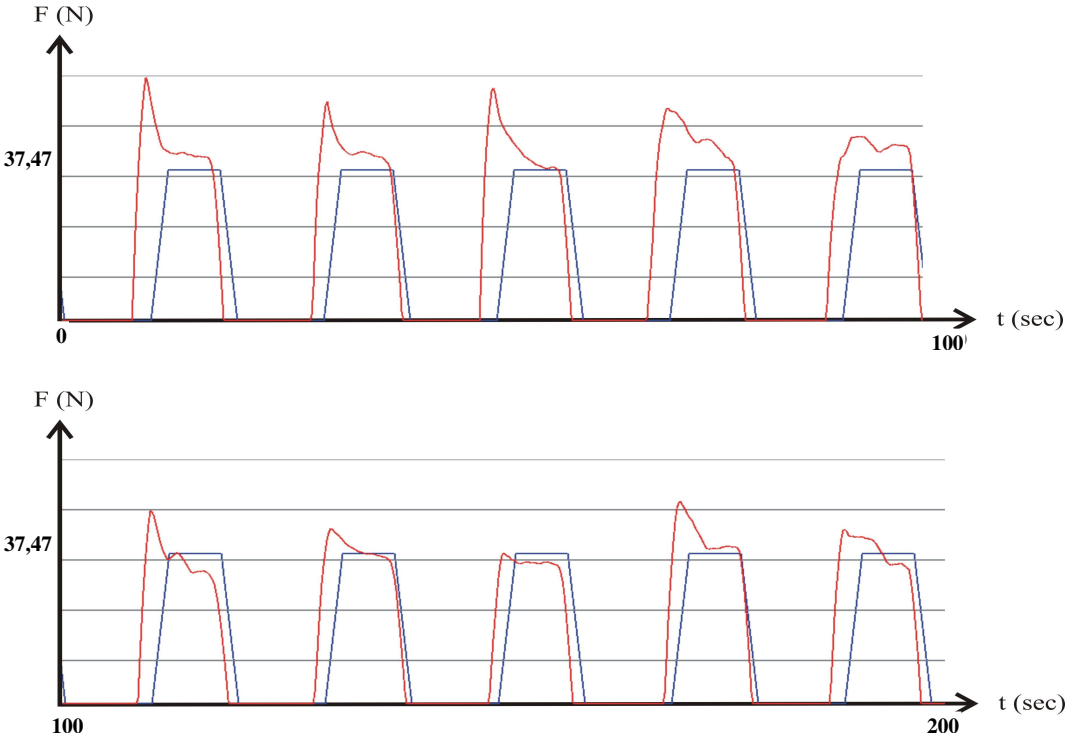

Figure 4.47 PPTE with bio-feedback in 200 sec.

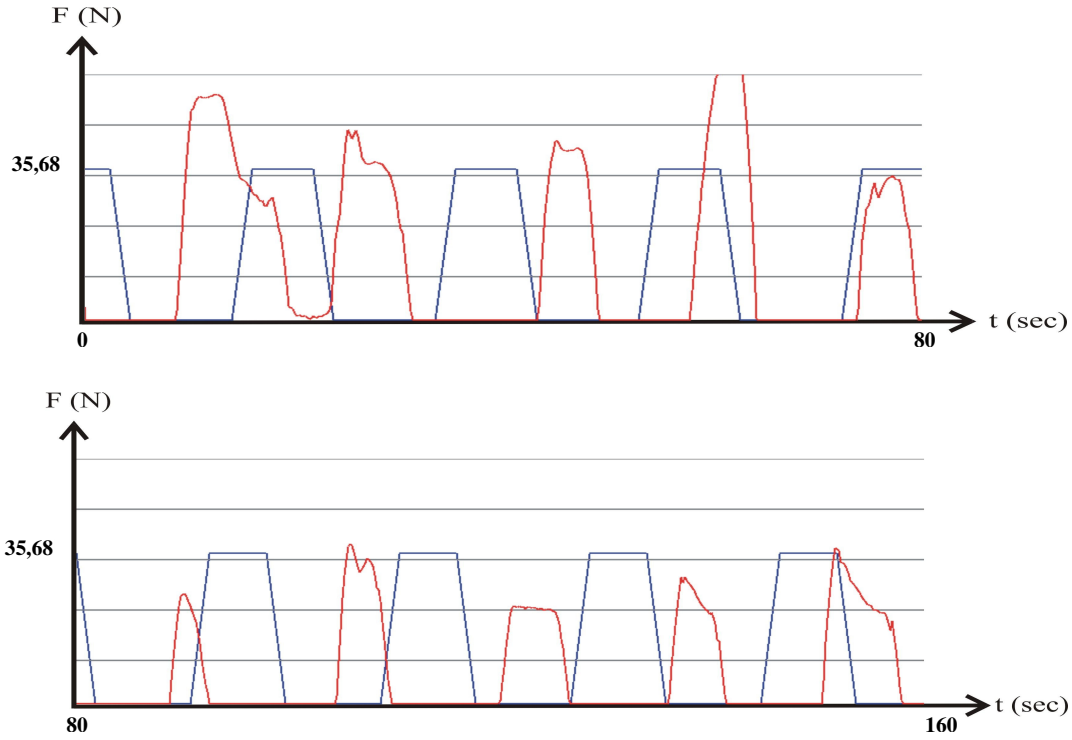

Figure 4.48 PPTE without bio-feedback in 160 sec.

XI)

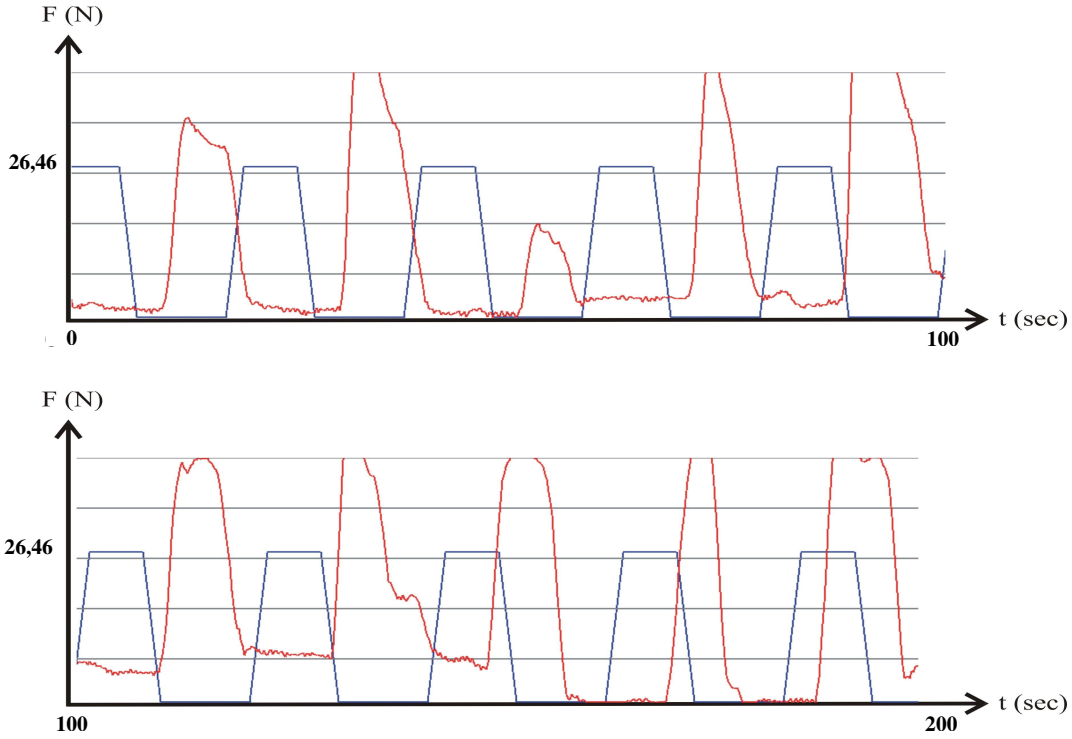

Figure 4.49 PPTE without bio-feedback in 200 sec.

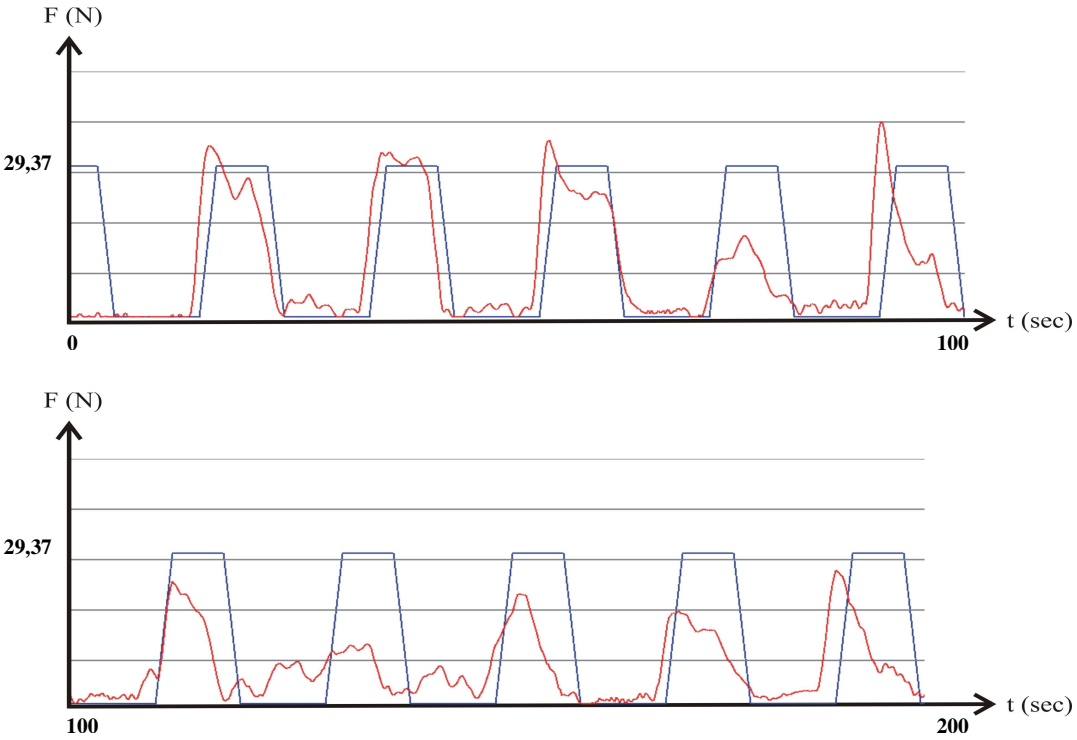

Figure 4.50 PPTE with bio-feedback in 200 sec.

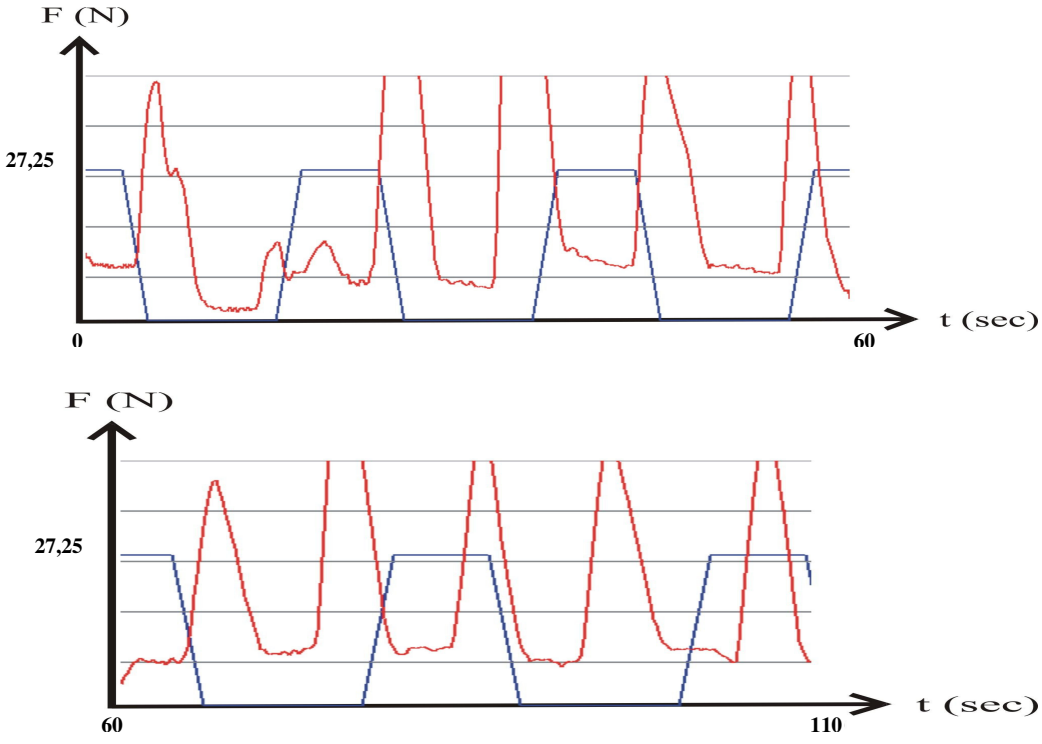

Figure 4.51 PPTE without bio-feedback in 110 sec.

XII)

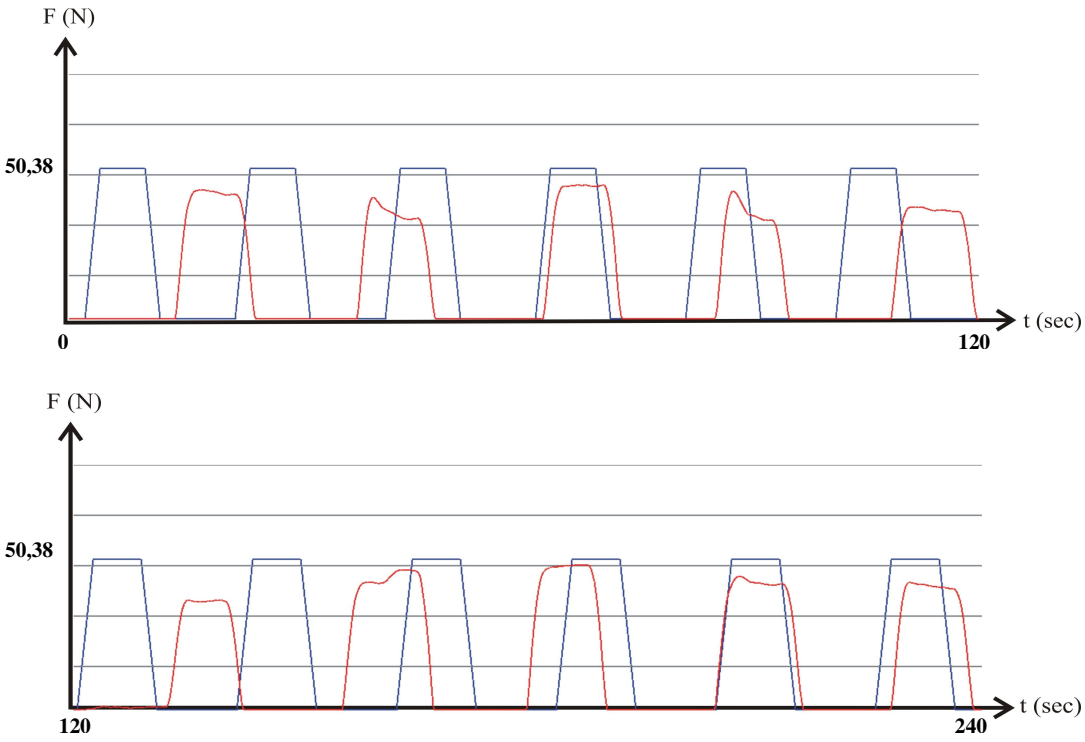

Figure 4.52 PPTE without bio-feedback in 240 sec.

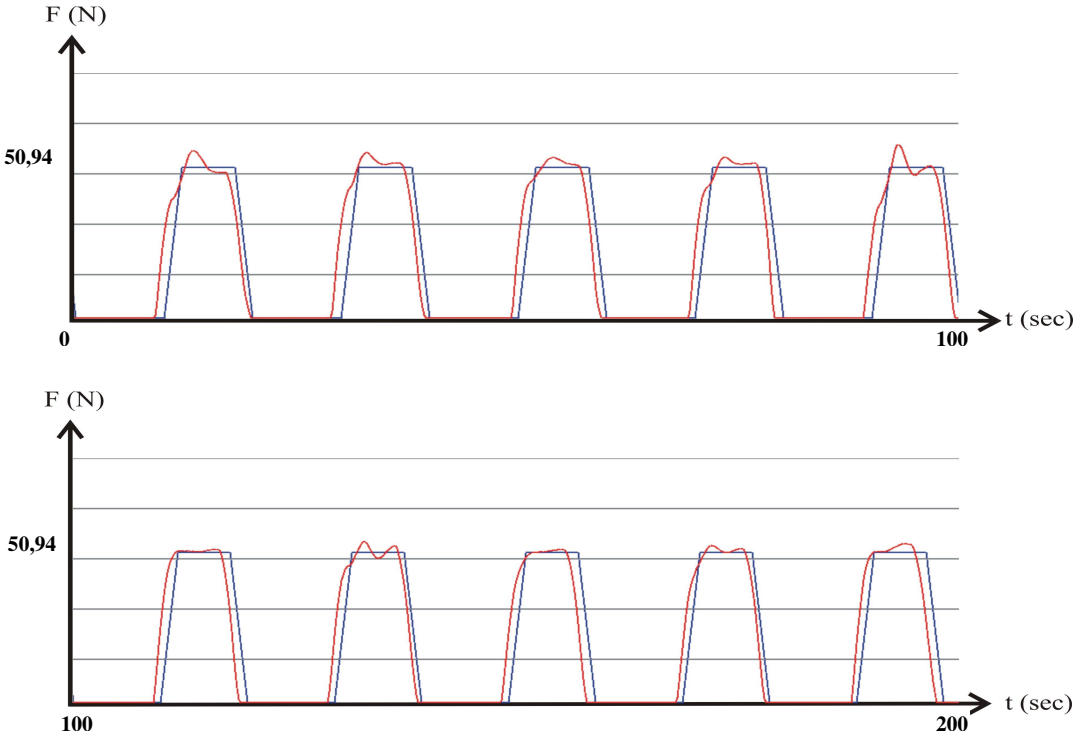

Figure 4.53 PPTE with bio-feedback in 200 sec.

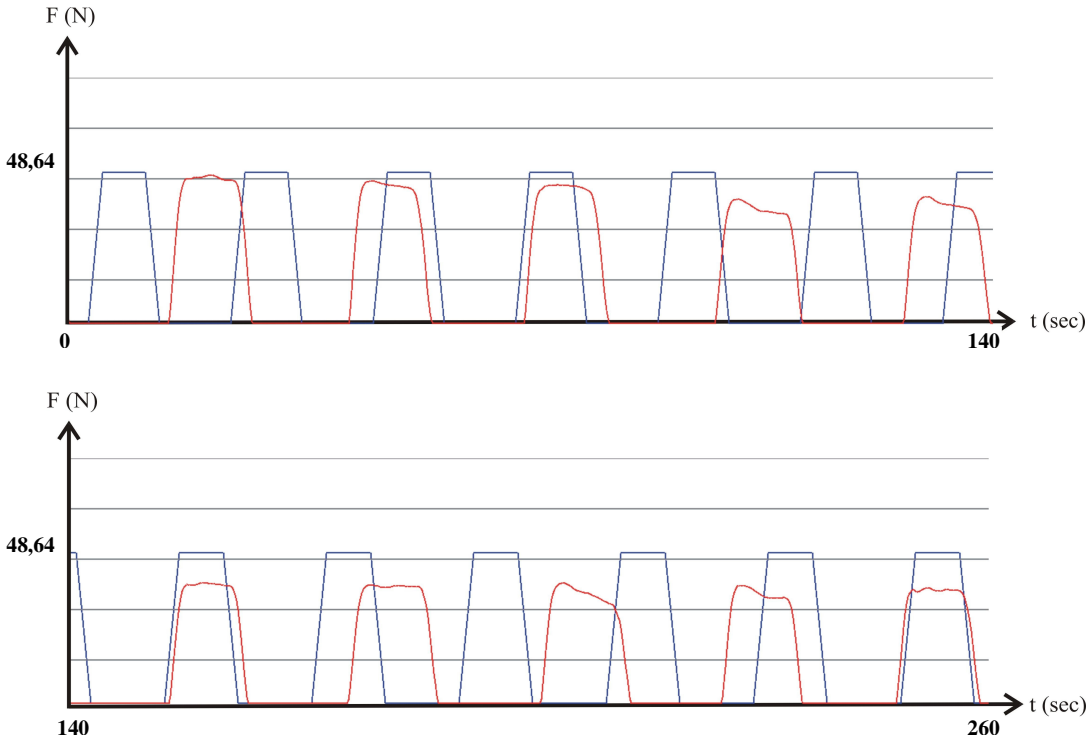

Figure 4.54 PPTE without bio-feedback in 260 sec.

During our study, we observed that PPTEs characteristic is difficult to understand at first time by patients. Since our experimental set-up provides real-time data, we can encourage the patient to perform better by explaining the relation between patients' activity and response plotted on the screen. When the characteristic is well-understood, subjects performed the exercise more accurately. It becomes more evident that the bio-feedback is very helpful in training how to do the exercise. The desired path stimulates the subject to follow the path and hence perform more accurate PPTEs. When we look at the figures during bio-feedback, subjects' accommodation are increased by the help of bio-feedback.

Friedman and Wilcoxon Signed Rank tests are used for statistical evaluations. The Friedman test is a non-parametric statistical test developed by the U.S. economist Milton Friedman. It is used to detect differences in treatments across multiple test attempts. The procedure involves ranking each row (or *block*) together, then considering the values of ranks by columns. The Friedman test is used for two-way repeated measures analysis of variance by ranks. In Friedman test there is a p value.

If the p value is small (typically $p<0.05$), we can reject the idea that all of the differences between columns are coincidences of random sampling and conclude instead that at least one of the treatments (columns) differs from the rest. If the p value is large (typically $p>0.05$), the data do not give any reason to conclude that the overall medians differ. This is not the same as saying that the medians are the same. The results of a Friedman test only make sense when the subjects are independent.

The Wilcoxon signed-rank test is a non-parametric test developed by Frank Wilcoxon. The Wilcoxon test involves comparisons of differences between measurements, so it requires that the data are measured at an interval level of measurement. However it does not require assumptions about the form of the distribution of the measurements. In Wilcoxon signed-rank test there is a p value, too. If the p value is smaller than 0.05, we can reject the idea that the difference is a due to chance and conclude instead that the population has a median distinct from the hypothetical value we entered. If the p value is larger than 0.05, the data do not give us any reason to conclude that the population median differs from hypothetical median. Like all statistical tests, Wilcoxon signed-rank test assumes that the errors are independent.

In Table 4.1, we can see their mean of five forces for each situation in first study. As we see in Table 4.1, maximum forces of all volunteers increased from 62,515 N to 71,641 N with feedback and stayed steady showing a slight increase (73,057N) after feedback.

Table 4.1 Maximum Average Force Values of Each Volunteers

Volunteer	Sex	Age	MFBF*	MFDF**	MFAF***
I	M	19	91,054	94,456	105,761
II	M	19	78,791	124,797	133,227
III	M	19	43,509	63,657	110,927
IV	M	27	48,629	47,783	50,107
V	M	31	80,229	102,825	69,558
VI	F	50	40,830	45,010	44,659
VII	F	37	65,939	71,854	66,356
VIII	M	27	72,530	60,133	63,207
IX	F	32	68,976	74,773	77,497
X	F	28	39,160	46,086	43,590
XI	F	30	32,783	37,063	33,995
XII	M	32	87,754	91,249	77,804
Average	-	-	62,515	71,641	73,057

* All Force Values are in Newton

In statistical evaluation, we determined 50% of maximum force in every ten peaks of each session. While they performed PPTEs, we can see all 50% of maximum force's data of each volunteer in every session (Table 4.2. a, b, c).

* Maximum Force Before Feedback

** Maximum Force During Feedback

*** Maximum Force After Feedback

Table 4.2.a. 50% of maximum forces of each volunteer before bio-feedback

Volunteer	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1st peak	42,03	59,50	83,43	64,01	85,17	80,90	54,77	57,36	55,37	75,48	104,01	55,96
2nd peak	45,12	84,80	87,43	67,25	75,34	71,81	54,79	45,39	68,57	86,22	89,21	53,27
3rd peak	47,09	63,10	82,35	55,17	75,06	88,34	56,10	55,40	65,07	88,22	107,55	51,69
4th peak	46,32	70,77	84,14	58,27	76,45	90,43	58,28	58,02	64,27	73,94	71,29	54,25
5th peak	51,20	59,52	80,12	55,42	61,17	86,94	57,40	63,81	65,62	85,73	101,08	52,98
6th peak	45,91	66,24	78,65	70,12	66,58	100,64	52,29	62,72	64,00	79,69	133,55	49,69
7th peak	46,00	65,92	70,84	59,76	61,08	103,07	54,67	55,15	62,28	95,22	96,91	49,20
8th peak	47,80	63,98	79,60	73,68	59,35	92,47	68,76	61,67	63,54	79,93	108,38	55,53
9th peak	49,15	57,68	76,88	63,72	68,14	109,69	53,50	59,91	64,31	66,85	98,67	56,58
10th peak	54,83	68,60	75,42	60,74	71,18	85,41	57,89	57,25	63,74	90,46	101,01	54,17

* All Force Values are in Newton

Table 4.2.b. 50% of maximum forces of each volunteer during bio-feedback

Volunteer	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1st peak	57,01	56,47	89,41	86,77	63,22	86,56	72,63	90,06	69,53	101,08	83,66	59,62
2nd peak	57,89	56,18	141,87	79,70	55,53	87,41	71,81	77,03	66,09	96,00	94,77	59,27
3rd peak	61,91	47,18	123,02	80,26	53,61	86,75	69,74	82,79	63,53	98,81	84,72	58,26
4th peak	59,37	46,01	136,80	85,49	57,13	83,95	71,37	80,20	65,05	94,62	65,70	58,20
5th peak	56,67	51,72	147,13	87,68	54,34	85,62	71,81	86,08	64,03	88,70	88,58	60,79
6th peak	60,35	47,91	106,74	92,20	53,84	88,93	79,36	84,88	67,24	90,70	73,92	56,78
7th peak	61,06	47,43	91,64	87,91	55,14	83,23	74,51	84,33	66,66	86,89	67,81	58,52
8th peak	57,94	49,35	74,01	80,95	53,78	95,33	77,21	76,80	68,79	81,78	76,17	56,77
9th peak	59,74	50,50	90,55	77,86	59,96	89,56	70,02	80,15	67,66	92,70	74,31	57,58
10th peak	56,91	45,69	83,03	88,79	55,98	85,47	78,57	76,80	64,77	86,66	84,91	57,96

* All Force Values in Newton

Table 4.2.c. 50% of maximum forces of each volunteer after bio-feedback

Volunteer	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1st peak	37,46	42,65	47,20	43,71	89,80	108,62	74,20	63,86	62,35	96,61	115,57	62,25
2nd peak	37,29	43,29	40,04	86,51	93,16	90,99	78,18	78,16	63,77	89,80	121,31	60,96
3rd peak	35,71	54,65	41,46	55,78	96,65	87,22	72,98	72,22	62,29	87,61	124,02	60,12
4th peak	40,20	64,48	47,07	77,99	85,50	89,53	82,31	83,41	58,97	102,17	116,17	56,96
5th peak	44,56	61,28	39,11	82,40	88,71	101,67	75,31	77,68	62,53	80,84	135,75	57,51
6th peak	36,19	85,79	46,73	61,27	91,28	110,99	73,49	71,44	67,13	74,28	96,22	56,23
7th peak	44,05	63,88	53,38	67,12	89,79	103,40	72,57	82,54	57,12	83,98	137,00	55,76
8th peak	39,30	49,62	54,93	82,98	112,72	98,59	75,92	79,77	55,00	71,89	109,05	56,19
9th peak	40,05	51,18	42,92	89,47	102,24	107,71	74,85	83,77	58,25	77,52	110,11	55,66
10th peak	38,17	48,77	56,45	76,57	81,08	109,06	70,35	69,81	51,74	83,18	93,69	55,11

* All Force Values in Newton

Friedman test, which was done at first step, showed a meaningful difference between three therapy sessions ($p = 0.046$). Wilcoxon Signed Rank test showed us that performance before and during bio-feedback a meaningful difference ($p = 0.023$).

There was no difference between performance with bio-feedback and performance after bio-feedback for maximum average contractions ($p > 0.05$) (Table 4.3).

Table 4.3 Statistical Evaluation of Average Maximum Force Values

before, during and after Bio-feedback.

	MFBF - MFDF	**MFDF - MFAF**	**MFAF - MFBF**
p value	0,023	0,875	0,239

Volunteers' accommodations were poor in contraction–relaxation time before bio-feedback. But we observed that volunteers' accommodations were improved with bio-feedback. In Figure 4.55 a, b, c, we can see force data of subjects during PPTE with 50% of maximum in a scatter plot. As we see in graphs, 50% of maximum force could not be estimated even during bio-feedback.

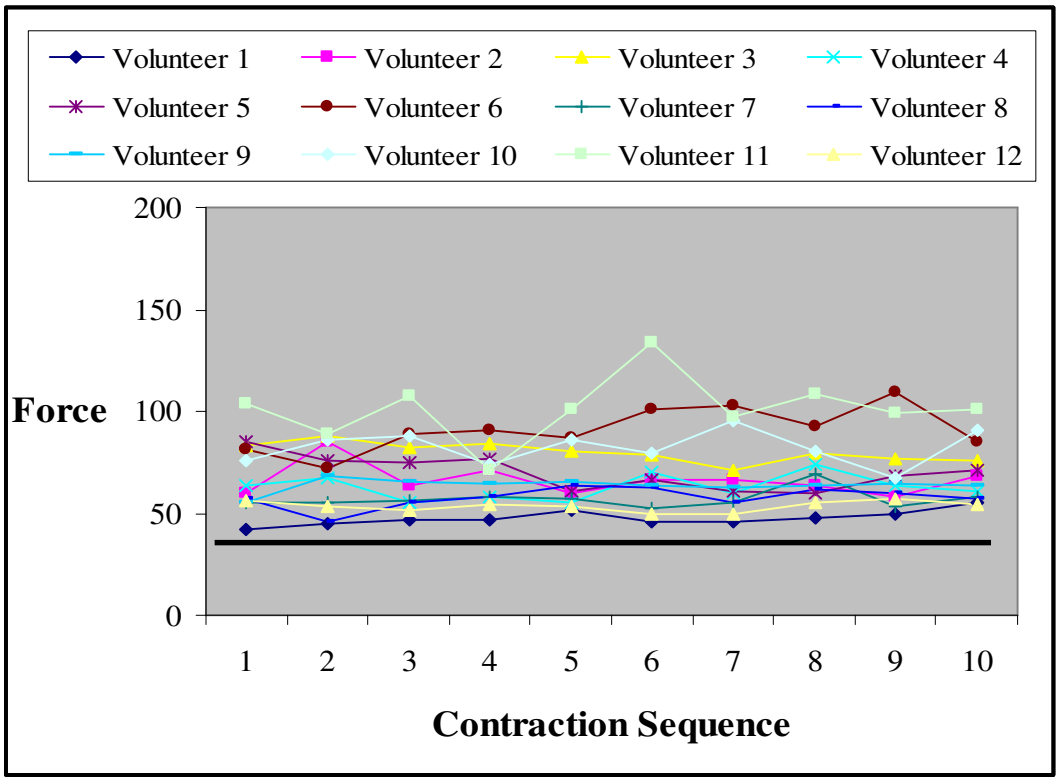

Figure 4.55a Accommodation to 50% of Max. Force

Before Bio-Feedback.

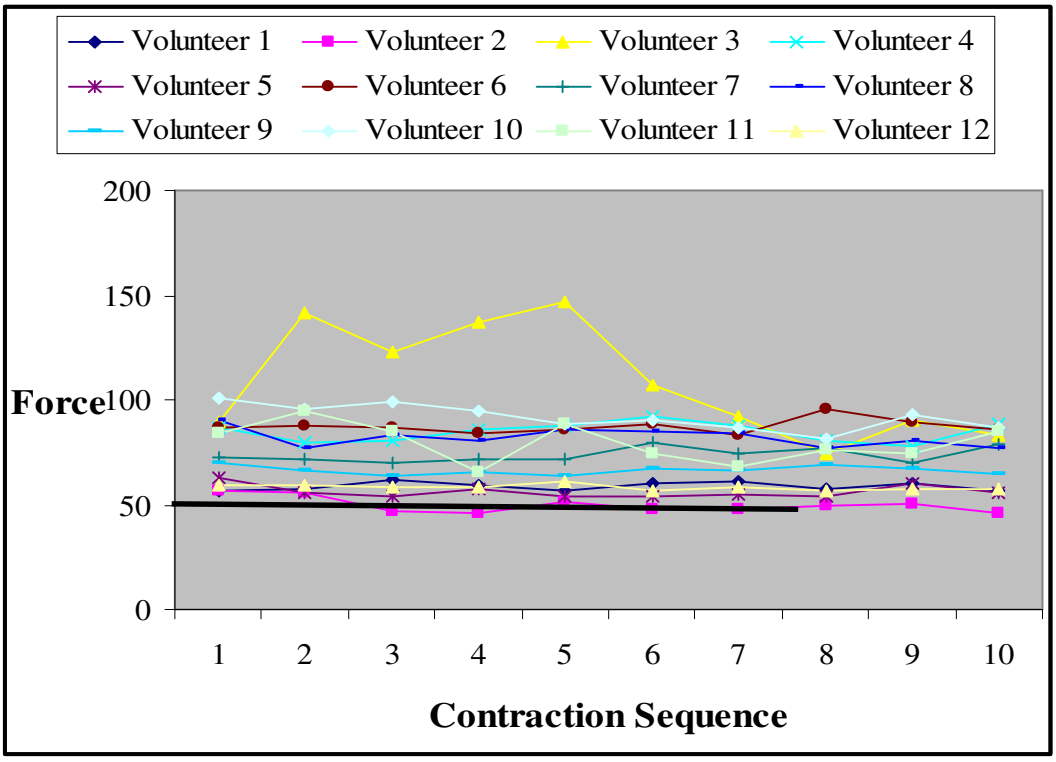

Figure 4.55b Accommodation to 50% of Max. Force

During Bio-Feedback.

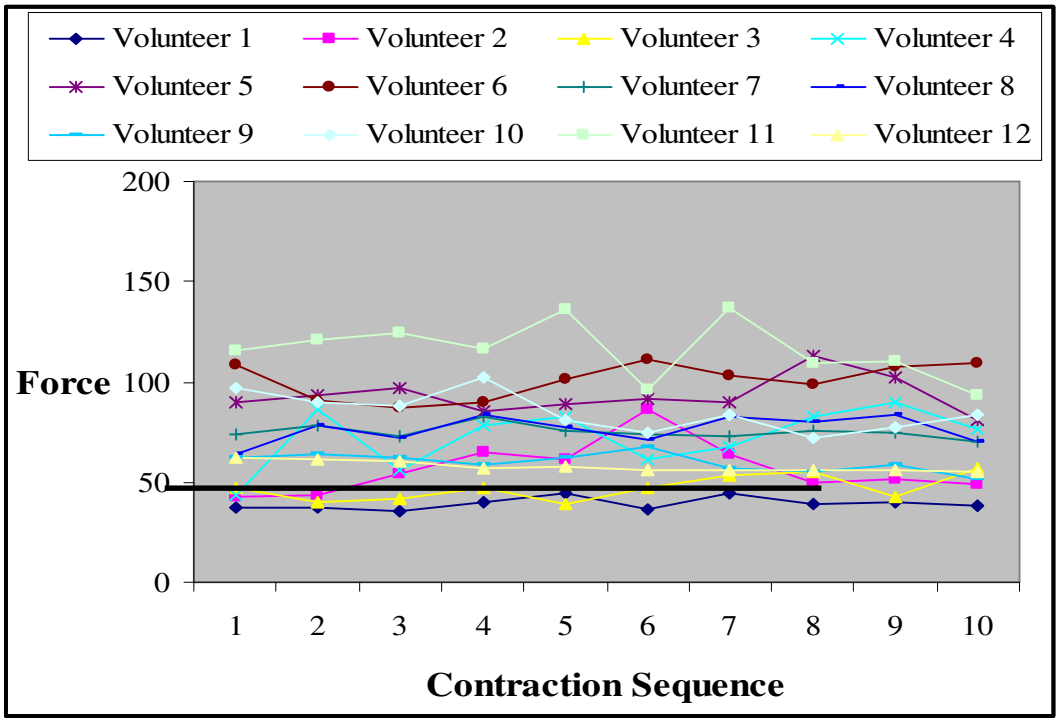

Figure 4.55c Accommodation to 50% of Max. Force

After Bio-Feedback.

Even though statistical analysis does not provide a clear conclusive result, visual inspection of the plots given in figures 4.19-4.54 suggests that at least some of the subjects have accomplished significant improvement with the aid of bio-feedback. To illustrate this fact, the data obtained during the tests evaluated based in a different manner. Considering the fact that one of the major improvements expected at the end of PPT exercises is the patient's ability to apply proper amount of steady state pressure during each episode, we isolated the steady state regions of the trapezoid exercise patterns and analyzed them separately. Hence, only the time sliced where 50% of maximum force is to be applied is isolated from the whole data. Then we calculated the difference between the target force with the measured ones throughout these time slices. Mean errors are computed for each session, namely, before, during and after the introduction of bio-feedback, and these values are tabulated in Tables 4.4, 4.5 for each test subject.

First analysis is done based on the change between *before* and *during using bio-feedback* is given in Table 4.4. As marked on the table, 7 out of 12 volunteers have improved their performances significantly. This observation suggests that, use of such a setup has the potential of significantly increasing the effectiveness of an exercise for some patients.

Table 4.4 Statistical Evaluation of 50% of Max. Force

Before and During Bio-Feedback.

patient	Before Bio-Feedback	During Bio-Feedback
Volunteer 1	11,0	1,2
Volunteer 2	2,7	3,3
Volunteer 3	5,6	-1,0
Volunteer 4	16,6	3,3
Volunteer 5	2,4	2,8
Volunteer 6	-2,1	4,9
Volunteer 7	14,1	1,1
Volunteer 8	12,0	0,5
Volunteer 9	5,1	0,2
Volunteer 10	2,2	-2,4
Volunteer 11	-6,5	9,3
Volunteer 12	6,1	-0,4

Second analysis is based on the change between *before* and *after bio-feedback* the result of which is presented in Table 4.5. Again 7 subjects out of 12 exhibited relative improvement when they performed the exercised without bio-feedback. Out of these 7 subjects, 3 of them have shown significant performance improvement. This analysis suggests that, use of bio-feedback may enhance unguided exercise performance of some patients.

Table 4.5 Statistical Evaluation of 50% of Max. Force Before and After Bio-Feedback.

patient	Before Bio-Feedback	After Bio-Feedback
Volunteer 1	11,0	14,7
Volunteer 2	2,7	-3,9
Volunteer 3	5,6	9,9
Volunteer 4	16,6	9,7
Volunteer 5	2,4	-11,3
Volunteer 6	-2,1	-8,6
Volunteer 7	14,1	0,1
Volunteer 8	12,0	4,4
Volunteer 9	5,1	5,1
Volunteer 10	2,2	1,8
Volunteer 11	-6,5	-5,5
Volunteer 12	6,1	5,6

As a result, based on the data obtained from test subjects we cannot conclude that, exercises with goal-setting and bio-feedback improves learning of the PPTE for all patients. However, there is a clear indication that developed setup enhances exercise performance for some of the test subjects significantly. Even though the results cannot be generalized, the test setup we have developed can potentially be used to identify the patients who have the potential to learn PPTE and hence can perform the exercise effectively on their own outside of the hospital. The results also suggest that further research has to be conducted whether wider range of people can benefit from this setup by using different modes of visual feedback.

CHAPTER 5

CONCLUSION

5.1. SUMMARY

Low back pain is of non-specific origin in 85% of cases. These low back pain cases exhibit movement and motor control impairment. Musculoskeletal injuries and low back pain may follow if imbalanced paraspinal muscle activity causes undue loads to vertebrae. Furthermore, in people who have chronic low back pain, decrease in maximum isometric contraction of low back muscles is reported. PPTE has an important role to improve low back extensors. Surface paraspinal electromyography (EMG) and dynamometers have been used in low back analysis systems. Thanks to these systems, both bio-feedback is provided and also low back extensor activity is evaluated.

In this study a bio-feedback system for posterior pelvic tilt rehabilitation system was implemented. Same system has the potential to be modified for any other muscle group.

There are several bio-feedback systems which are marketed with high prices in western countries. These systems are specially listed under the topics of decreasing muscle spasm, heart rate – blood pressure control, galvanic skin response control, voiding control and muscle strengthening.

Our experience at the end of this study can be listed as follows:

1. Force resistive sensors' quality that was selected may not be optimum; other sensing mechanisms can be built by using different sensors such as strain gage.

2. After a lot of trials with force resistive sensors we had decided to construct a sensor plate that has three separate force sensors. For developing more advanced techniques, further trials needs to be done.

3. Calibration sensitivity of this work is not very high. But fundamental aim of this study was to provide feedback so this calibration may be adequate.

4. Because of the inadequacy of oral description of the PPTE before the bio-feedback to patients, it was observed that patients failed to fulfill the exercise. During bio-feedback with the monitor, the maximum force that they could exert increased significantly. This shows that our main aim is satisfied. Some increase in force continued after bio-feedback session. This showed us that the positive effect of bio-feedback is acquired and maintained. The observed improvement with only a single practice indicates that better results can be achieved after multiple sessions. These results must be confirmed with longitudinal studies.

5. Ability to apply 50% of maximum force didn't show significant progress with only one session. After multiple sessions this ability could improve. To prove this probability a prospective study is necessary first in a group of normal volunteers, then in a group of patient population in need of PPTEs.

6. Isolated analysis of constant force section of the exercise suggests that most of the subjects (7 out of 12) have significantly improved their performance during bio feedback. This suggests that if possible, patients should use this setup for more effective therapies

7. Isolated analysis of constant force section of the exercise also suggests that, some of the patients (3 out of 12) have significantly improved their performance after being exposed to bio-feedback with goal-setting.

8. Based on improved performance for some of the patients, it can be concluded that, the developed setup can be used to identify patients that can learn PPTE, and home exercises can safely be assigned to these patients.

5.2. FUTURE WORK

The future tasks of the system are focused on increasing the usefulness and improving the different UI's and bio-feedback systems. One way of improving the usefulness could be partially combining with other complex virtual environments. Different UI's may be much more attractive for patients. As mentioned before, some patients have shown significant performance improvement on the existing setup. Effects of different feedback methods on unsuccessful subjects might improve the effectiveness of the developed setup; hence, this issue should be investigated.

Moreover, this bio-feedback system can be applied to various rehabilitation exercises and different UI's can be developed for each specific rehabilitation exercise. Updating hardware components may be concentrated on obtaining more powerful workstations and improving virtual environment. It is clear that as the increase in performance of computers continues, also the data acquisition capabilities of the implemented bio-feedback system will improve.

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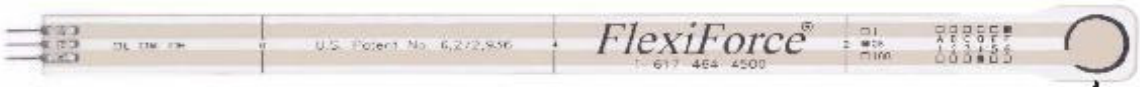
APPENDIX A

HARDWARES

FlexiForce®

A201 Standard Force & Load Sensors



Actual size of sensor

Sensing area

Physical Properties

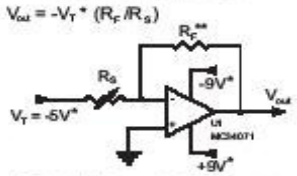
Thickness	0.008" (0.208 mm)
Length	7.75" (197 mm), *optional trimmed lengths*: 6" (152 mm), 4" (102 mm), or 2" (51mm)
Width	0.55" (14 mm)
Sensing Area	0.375" diameter (9.53 mm)
Connector	3-pin Male Square Pin (center pin is inactive)
Substrate	Polyester (ex: Mylar)

Standard Force Ranges (as tested with circuit shown below)

0 - 1 lb. (4.4 N)
0 - 25 lb. (110 N)
0 - 100 lb. (440 N)*

In order to measure forces above 100 lb (up to 1000 lb), apply a lower drive voltage and reduce the resistance of the feedback resistor (1kΩ min.)

Recommended Circuit



- * Supply Voltages should be constant
- ** Reference Resistance R_F is 1kΩ to 100kΩ
- Sensor Resistance R_S at no load is > 5MΩ
- Max recommended current: 2.5 mA

Typical Performance

		Evaluation Conditions
Linearity (Error)	< ±5%	Line drawn from 0 to 50% load
Repeatability	< ±2.5% of full scale	Conditioned sensor, 80% of full force applied
Hysteresis	< 4.5 % of full scale	Conditioned sensor, 80% of full force applied
Drift	< 5% per logarithmic time scale	Constant load of 25 lb (111 N)
Response Time	< 5 µsec	Impact load, output recorded on oscilloscope
		Time required for the sensor to respond to an input force
Operating Temperature	15°F - 140°F (-9°C - 60°C)*	

*Force reading change per degree of temperature change – ±0.2%/°F (0.36%/°C)
*For loads less than 10 lbs., the operating temperature can be increased to 165°F (74°C)

Tekscan, Inc. 307 West First Street South Boston, MA 02127-1309 USA tel: 617.464.4500/800.248.3669 fax: 617.464.4266
e-mail: marketing@tekscan.com URL: www.tekscan.com

Rev E_022806

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Figure A.1 Force Resistive Sensor Datasheet

Bus-Powered M Series Multifunction DAQ for USB — 16-Bit, up to 400 kS/s, up to 32 Analog Inputs, Isolation

NI USB-6210, NI USB-6211, NI USB-6212, NI USB-6215, NI USB-6216, NI USB-6218

- Up to 32 analog inputs at 16 bits, up to 400 kS/s (250 kS/s scanning)
- Up to 2 analog outputs at 16 bits
- Up to 32 TTL/CMOS digital I/O lines
- Two 32-bit, 80 MHz counter/timers
- Digital triggering
- NI-PGIA 2 and NI-MCal calibration technology for improved measurement accuracy
- NI signal streaming for 4 high-speed data streams on USB
- Bus-powered
- Available with CAT I isolation
- 1-year warranty
- Additional warranty and calibration services available

Operating Systems

- Windows Vista (32- and 64-bit)/XP/2000
- Mac OS X[1]
- Linux®[1]

Recommended Software

- LabVIEW
- LabVIEW SignalExpress
- LabWindows™/CVI
- Measurement Studio

Other Compatible Software

- C#, Visual Basic .NET
- ANSI C/C++

Measurement Services Software (included)

- NI-DAQmx or NI-DAQmx Base driver software
- Measurement & Automation Explorer configuration utility[2]
- LabVIEW SignalExpress LE[2]

[1]Mac OS X and Linux kits are not available for USB-6212 and USB-6216
[2]Windows kits only

Family	Bus	Connector	Analog Inputs	Resolution (bits)	Max Rate (S/s)	Analog Outputs	Analog Input Resolution (bits)	Max Rate (S/s)	Range (V)	Digital I/O	32-Bit Counter	Isolation
USB-6210	USB	Screw	16	16	250 kS/s	0	16	250 k	±10	4 DI/4 DO	2	–
USB-6211	USB	Screw	16	16	250 kS/s	2	16	250 k	±10	4 DI/4 DO	2	–
USB-6212	USB	Screw/68-pin SCSI	16	16	400 kS/s	2	16	250 k	±10	32 DIO[1]	2	–
USB-6215	USB	Screw	16	16	250 kS/s	2	16	250 k	±10	4 DI/4 DO	2	60 V CAT I
USB-6216	USB	Screw/68-pin SCSI	16	16	400 kS/s	2	16	250 k	±10	32 DIO[1]	2	60 V CAT I
USB-6218	USB	Screw	32	16	250 kS/s	2	16	250 k	±10	8 DI/8 DO	2	60 V CAT I

[1] 24 digital I/O for 68-pin SCSI mass terminal versions.

Table 1. NI USB-621x Selection Guide

Overview and Applications

With recent bandwidth improvements and new innovations from National Instruments, USB has evolved into a core bus of choice for measurement and automation applications. NI M Series devices for USB deliver high-performance data acquisition in an easy-to-use and portable form factor through USB ports on laptop computers and other portable computing platforms. NI designed a new and innovative patent-pending NI signal streaming technology that enables sustained bidirectional high-speed data streams on USB. The new technology, combined with advanced external synchronization and isolation, helps engineers and scientists achieve high-performance applications on USB.

NI M Series bus-powered multifunction data acquisition (DAQ) devices for USB are optimized for superior accuracy in a small form factor. They provide an onboard NI-PGIA 2 amplifier designed for fast settling times at high scanning rates, ensuring 16-bit accuracy even when measuring all available channels at maximum speed.

All bus-powered devices have a minimum of 16 analog inputs, digital triggering, and two counter/timers. USB M Series devices are ideal for test, control, and design applications including:

- Portable data logging – log environmental or voltage data quickly and easily
- Field-monitoring applications
- Embedded OEM applications
- In-vehicle data acquisition
- Academic lab use – academic discounts available

NI Signal Streaming

To optimize the use of the Universal Serial Bus (USB) and deliver high-performance data acquisition, National Instruments created several key technologies to push the limits of USB throughput and latency. NI signal streaming combines three innovative hardware- and software-level design elements to enable sustained high-speed and bidirectional data streams over USB. For more information, visit ni.com/usb.

NATIONAL INSTRUMENTS

Figure A.2 Data Acquisition Card Datasheet

APPENDIX B
SOFTWARE

The program is initializing the “HastaBilgileri” form class and loading “HastaInfTableAdapter” component class. At this point, program splits into two parts which are Maximum Average P UI and Movie User UI. If we choose the Maximum Average Pressure UI, the program is initializing the “HastaMaxPressure” form class and loading “HastaMaxValues” component class, “DrawBar, DrawLine and Ball” classes. When we press the start button, DrawBar, DrawLine and Ball classes are called and “HastaMax” form class is loading. Channels which read data from DAQ are created in an array in “HastaMax Pressure” form class and timer starts to work at 100ms. When the activity is saved, “HastaMaxValues” component class is called and program creates the activity session data in database.

After saving data procedure, program can either enter the Therapy Activity UI or return the Patient Information UI. When we enter the Therapy Activity UI, program is initializing the “HastaAktivite” form class and loading “DrawBar, DrawLine and DrawMovie” class. In this UI, start button recalls “DrawBar, DrawLine and DrawMovie” classes and loads “HastaAkt” form class. Channels array is created in the same way in “HastaAktivite” form class. When user press refresh button which creates an instant view from starting of therapy session’s time, program recalls the “DrawMovie” class. Finally end of the activity, pressing save button calls “HastaMovieInfTableAdapter” component class (holds patient’s personal information, tare and maximum pressure values) and “HastaMovieValuesTableAdapter” component class (holds all data which came from DAQ).

“HastaMovie” form class is the other part in the “Hasta Bilgileri” form class. In this UI, firstly program is initializing the “HastaMovie” form class and loading the “HastaMovieInfTableAdapter” component class and “DrawMovie” class. When we play the movie, program calls the “HastaMovieValuesTableAdapter” component class. The single thread of this application continues until the user exits the program.

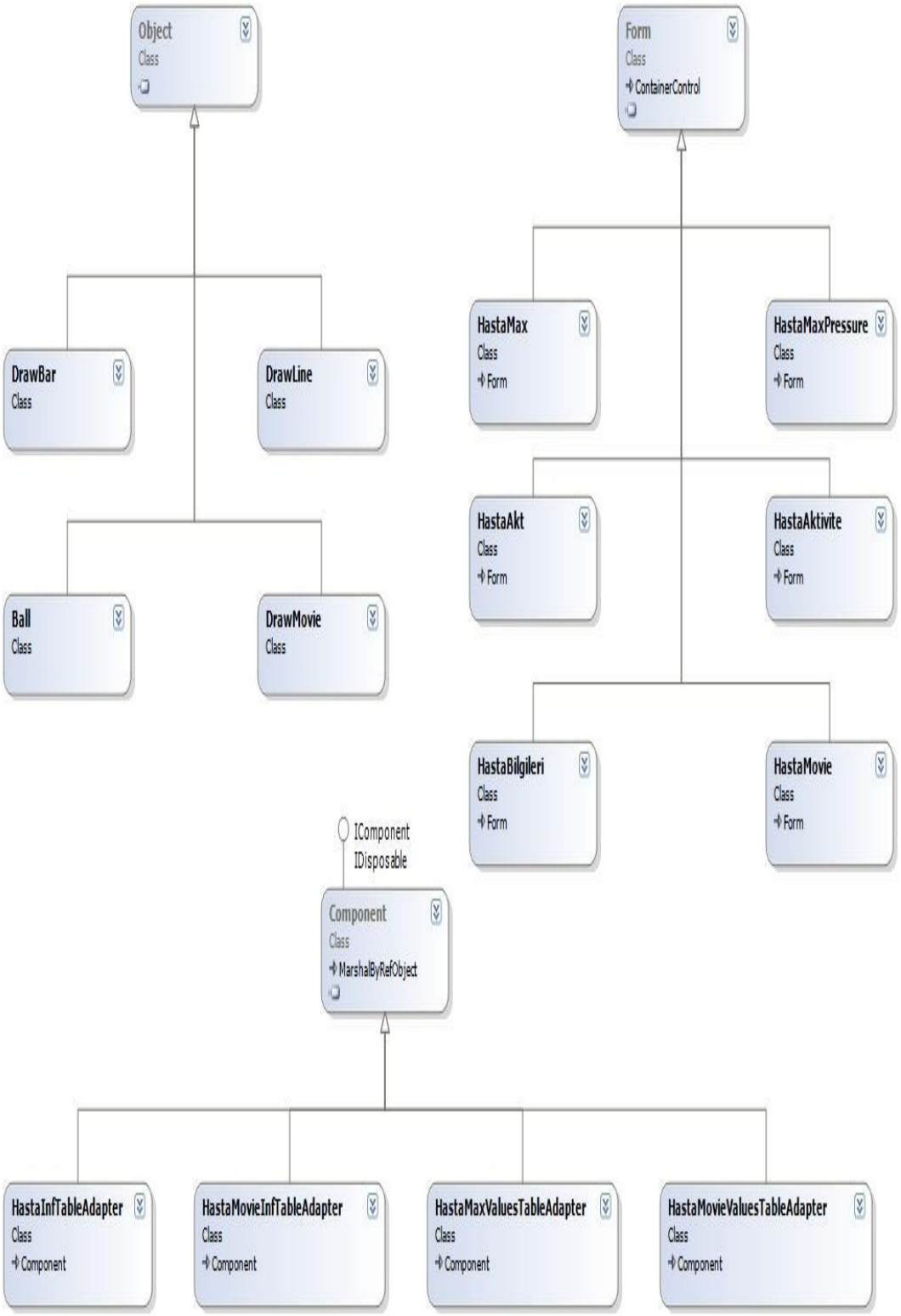


Figure B.1 The Class Diagram of the Application

Table B.1 Patient Information UI Menu

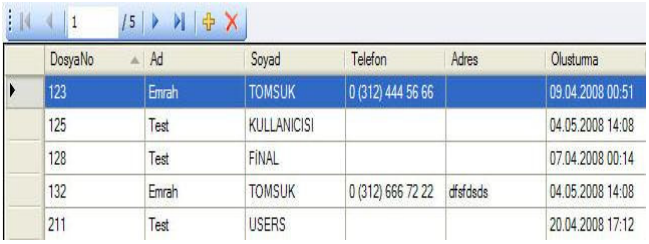
	Patient registration panel is used for registration or reaching older patient's information.
	Database panel includes patient's file folder number, name, telephone, address.
	Add button
	Abandon button
	Enter the second user interface section
	Enter the movie section
	Exit the program

Table B.2 Maximum Average Force Value UI Menu

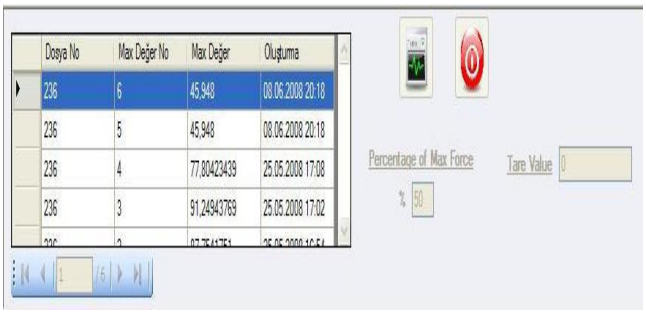
	Therapy start or stop panel includes two alternatives. Therapist can set the session manual or automatic.
	Maximum average pressure panel includes three list boxes. First one has instant values, second one has maximum force values which are calculated in every session one by one, and third one has maximum average force value.
	Database panel includes all maximum average force values. In this panel, therapist can decide the value by entering the percentage value which can be set top level of trapezoidal graphic and also can set the tare value of the patient.

Table B.2 Cont'd

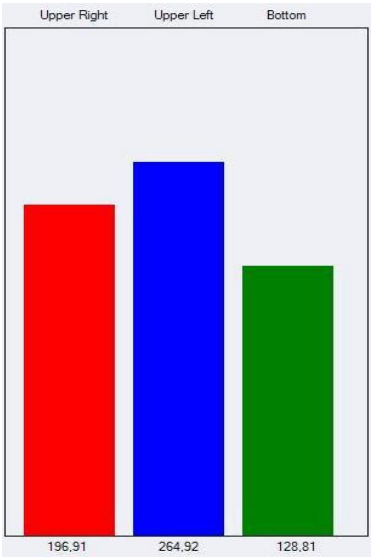
	Bar panel includes three bars which are represented by each sensor. This panel can show us how much force on each sensor.
	Start the session
	Stop the session
	Calculate the maximum average pressure value
	Add the maximum average pressure value to the database
	Enter the third user interface section
	Return the first user interface section

Table B.3 Therapy Activity UI Menu

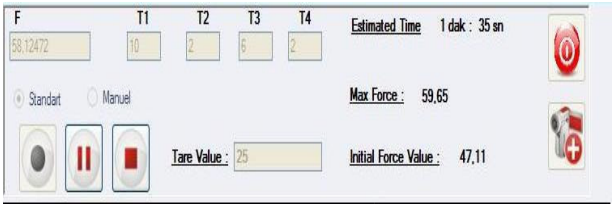
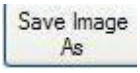
	Therapy start or stop panel includes two alternatives. Therapist can set time values and session can be controlled by start, pause and stop buttons.
	Instant data panel includes two list boxes. Left one has instant voltage values, right one has instant force values.
	Therapist can watch the session in this panel. The red line represents the maximum pressure value in whole session.
	Refresh panel is used for viewing the session motionless from starting time to moment that we press the refresh button. We can also move this panel by helping of track bar.

Table B.3 Cont'd

	Start the session
	Stop the session
	Pause the session
	Refresh the session
	Save the refresh view as a TIF file
	Save the whole session.
	Return the second user interface section