Hochschule
Bonn-Rhein-Sieg
University of Applied Sciences

Fachbereich Informatik
Department of Computer Science

Master Thesis

A Computer Game based Motivation System for Human Muscle Strength Testing

Tintu Mathew

A thesis submitted to the
University of Applied Sciences Bonn-Rhein-Sieg
for the degree of
Master of Science in Autonomous Systems

Referee and Tutor: Prof.Dr-Ing.Rainer Herpers
external Referee: Prof.Dr.Joern Rittweger

Submitted: March 14 2012

I, the undersigned below, declare that this work has not previously been submitted to this or any other university, and that unless otherwise stated, it is entirely my own work.

DATE

Tintu Mathew

ABSTRACT

The objective of this thesis is to implement a computer game based motivation system for maximal strength testing on the Biodex System 3 Isokinetic Dynamometer. The prototype game has been designed to improve the peak torque produced in an isometric knee extensor strength test. An extensive analysis is performed on a torque data set from a previous study. The torque responses for five second long maximal voluntary contractions of the knee extensor are analyzed to understand torque response characteristics of different subjects. The parameters identified in the data analysis are used in the implementation of the 'Shark and School of Fish' game. The behavior of the game for different torque responses is analyzed on a different torque data set from the previous study. The evaluation shows that the game rewards and motivates continuously over a repetition to reach the peak torque value. The evaluation also shows that the game rewards the user more if he overcomes a baseline torque value within the first second and then gradually increase the torque to reach peak torque.

ACKNOWLEDGMENTS

I would like to thank my supervisors, Prof.Rainer Herpers and Prof.Joern Rittweger, for giving me the opportunity to work on this project.I thank Jochen Zange and Uwe Mittag at DLR for all their support and valuable feedback.
My thanks to Sandra Felsner for all the valuable suggestions.I would also like to thank David Scherfgen and Timur Saitov for all the support during the implementation of this project.
Finally, many thanks to my friends and family for all the love and support during my study.

CONTENTS

ABSTRACT . . . v

ACKNOWLEDGMENTS . . . vii

LIST OF FIGURES . . . xiii

1. INTRODUCTION . . . 1
   - 1.1 Objective . . . 1
   - 1.2 Motivation . . . 1
   - 1.3 Background . . . 1
   - 1.4 Thesis Outline . . . 4

2. STATE OF THE ART . . . 7
   - 2.1 Verbal Encouragement and Visual Feedback . . . 7
   - 2.2 Computer Game and Virtual Reality based Encouragement . . . 9

3. PROBLEM STATEMENT . . . 11

4. SYSTEM OVERVIEW . . . 13

5. DATA ANALYSIS . . . 17
   - 5.1 Characteristics of Torque Data . . . 19
   - 5.2 Identification of Control Parameters . . . 21
   - 5.3 Classification of Test Subjects . . . 27
   - 5.4 Description of Control Parameters . . . 27

6. GAME DESIGN . . . 31
   - 6.1 Game Overview . . . 32
     - 6.1.1 Game Concept . . . 33
     - 6.1.2 Target Audience . . . 33
   - 6.2 Game Play and Mechanics . . . 33
     - 6.2.1 Levels . . . 33
     - 6.2.2 Game Play . . . 33
     - 6.2.3 Game World . . . 33
     - 6.2.4 Characters . . . 34

6.2.5 Mechanics . . . 34
6.3 Interface . . . 35
6.3.1 Visual System . . . 35
6.3.2 Control System . . . 36
6.4 Game Implementation . . . 36
6.4.1 Game Algorithm . . . 39
6.4.2 Reward Algorithm . . . 41
7. EVALUATION . . . 45
7.1 Time Analysis of Rewards . . . 45
7.1.1 Analysis of total fish caught in each second by all users . . . 45
7.1.2 Analysis of relation between rewards and time taken to reach initial threshold . . . 46
7.1.3 Analysis of relation between rewards and time taken to reach peak torque . . . 46
7.1.4 Latency in Rewards . . . 49
7.2 Analysis of game events for different torque curves . . . 49
8. CONCLUSION AND FUTURE WORK . . . 55
8.1 Summary . . . 55
8.2 Future Work . . . 55
BIBLIOGRAPHY . . . 57
APPENDICES
A. Analysis of Torque Data in Matlab for Derivation of the Game Algorithm Case 1- θ is decreased . . . 61
B. Analysis of Torque Data in Matlab for Derivation of the Game Algorithm Case 2- θ not decreased . . . 65

LIST OF FIGURES

1.1 Biodex System 3 [htt12] . . . 2

1.2 Knee adapters and range of movement . . . 3

4.1 Top Level System Architecture . . . 13

4.2 Torque Data Processing . . . 14

5.1 Torque response for subject A visit 1. Positive peaks are extensions and negative peaks are flexions . . . 17

5.2 Torque response for Subject A Trial 1 After Removing Negative Peaks(Flexions) 18

5.3 Torque Response for a Single Repetition : A Closer View . . . 18

5.4 Time taken by test subjects to reach 80% of peak torque in each repetition . . 19

5.5 Time taken by test subjects to reach peak torque in each repetition . . . 20

5.6 Comparing repetition for which user reaches maximum peak torque across different visits . . . 21

5.7 A repetition in which subject crosses initial threshold in the last second . . . 22

5.8 A repetition in which subject goes above threshold and sustains it to reach peak . . . 23

5.9 A repetition in which the subject goes above the threshold but does not sustain it to reach peak . . . 23

5.10 Subject crosses initial threshold and reaches peak torque in the first two seconds 24

5.11 A repetition in which subject does not go above initial threshold . . . 25

5.12 A repetition with a lot of peaks and valleys in the torque curve . . . 26

6.1 Game Environment . . . 34

6.2 Game Characters . . . 34

6.3 Visual Interface during game play . . . 35

6.4 Main Menu of the Game . . . 37

6.5 Game Logic Overview . . . 40

6.6 Reward Algorithm . . . 42
7.1 Total fish caught in each second by all users across all repetitions in all visits 45
7.2 Fish caught against time to reach initial threshold . . . 47
7.3 Fish caught against time to reach initial threshold . . . 48
7.4 Latency in rewards . . . 49
7.5 A repetition in which subject crosses initial threshold in the last second . . . 50
7.6 A repetition in which subject goes above initial threshold and sustains it to reach peak . . . 51
7.7 A repetition in which subject goes above initial threshold and sustains it to reach peak . . . 52
7.8 Subject goes above the initial threshold but does not sustain it to reach peak 53
7.9 Subject crosses threshold and reaches peak torque within the first two seconds 53
7.10 Repetitions where the subject never went above threshold . . . 54
7.11 A repetition with peaks and valleys in the torque curve . . . 54
A.1 A repetition in which subject crosses initial threshold in the last second . . . 61
A.2 A repetition in which subject goes above initial threshold and sustains it to reach peak . . . 62
A.3 A repetition in which subject goes above the threshold but does not sustain it to reach peak . . . 62
A.4 A repetition in which subject crosses threshold and reaches peak torque in the first two seconds . . . 63
A.5 A repetition in which subject does not cross initial threshold . . . 63
A.6 A repetition with peaks and valleys in the torque curve . . . 64
B.1 A repetition in which subject crossed initial threshold in the last second . . . 65
B.2 A repetition in which subject went above threshold and sustained it to reach peak . . . 66
B.3 Went above the threshold but did not sustain it to reach peak . . . 66
B.4 Subject crossed threshold and reached peak torque in the first two seconds . . 67
B.5 A repetition in which subject never crossed initial threshold . . . 67
B.6 A repetition with a lot of peaks and valleys in the torque curve . . . 68

Chapter 1

INTRODUCTION

1.1 Objective

The physiology laboratory at the Institute of Aerospace Medicine,DLR conducts different human physiological experiments. This particular project targets the Biodex System3 Isokinetic Dynamometer [Bio12] at this laboratory . The Biodex System3 is used for force and power diagnostics in different human muscle groups [GAC12] . The different force and power diagnostic experiments conducted requires the human subjects to exert maximum force voluntarily. The investigator uses verbal encouragement to motivate the subject to exert maximum force. But the experiment heavily relies on the subject's voluntary effort. The goal of this project is to develop a computer game for the biodex machine to motivate the subject.

1.2 Motivation

The trend of combining computer games with exercising or rehabilitation equipments to provide motivation and customized training has been around for some time. Computer games are able to engage people in game play for long durations and make it an enjoyable experience. The games that combine play and exercise are called exergames [Bog05]. Gaming or virtual reality systems can make rehabilitation interesting and can provide customized training for different patients [BMC$^+$09]. It is possible to create new and interesting tasks using gaming or virtual reality based systems. The user interacts with a virtual environment using body movements or using specific rehabilitation equipments or machines. Taking a cue from these , this project builds a prototype computer game based motivation system for Biodex System 3. A tailor made game for the system can motivate the subject and also standardize the process. It will reduce the dependency on the investigator for encouragement as well as guide the subjects through the experiment.

1.3 Background

The Biodex System 3 (figure 1.1 is used in neuromuscular testing and rehabilitation. It also provides comprehensive data to assess isolated muscle strength. In DLR, it is used for research studies. The Biodex System 3 has six different modes of operation which include

- Setup mode

Figure 1.1: Biodex System 3 [htt12]

The system is setup for testing in this mode. The subject is properly stabilized and positioned for actual testing. The range of motion and adapters required for testing are also adjusted in this mode.

- Isokinetic mode

  In this mode the biodex machine controls velocity. The subject is allowed to accelerate up to a maximum speed value selected for each direction. The subject can also freely decelerate. The subject can change direction at any point within the preset range of motion. This mode can be used to simulate functional or sport activities.

- Passive mode

  In the passive mode active participation by the subject is not required since the dynamometer initiates motion. In this mode dynamometer provides continuous motion within the preset range at a constant velocity. The subject changes direction only when the limits of the preset range of motion is reached.

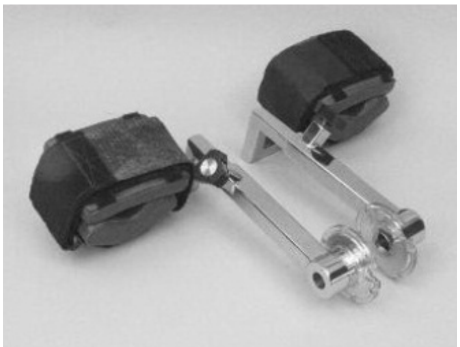
- Isometric mode

  In this mode dynamometer maintains the velocity at zero. The subject does not move. The subject can exert force at any selected point within the range of motion with zero velocity.

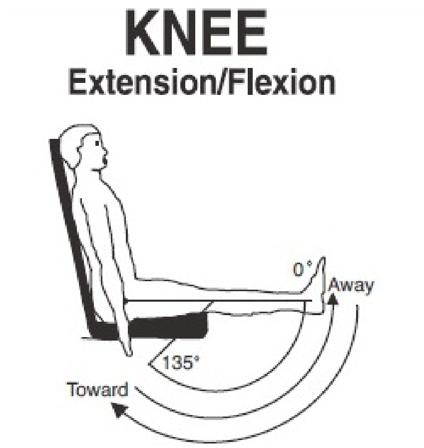
- Isotonic mode In this mode speed of motion can be varied but the torque remains constant. There is a minimum torque limit to be surpassed by the subject. This mode can be used to selectively train a muscle group.

- Reactive eccentric mode In this mode the subject has to reach a selected torque value to start moving and has to stay under a torque value to continue the motion. The biodex system moves in a direction opposite to the direction of torque exerted by the test subject.

The different standard test and exercise patterns on Biodex include Knee Extension/Flexion, Ankle Plantar/Dorsi flexion, Ankle Inversion/Eversion, Hip Abduction/Adduction, Hip Extension/Flexion, Shoulder Extension/Flexion, Shoulder Abduction/Adduction, Elbow Extension/Flexion, Forearm Pronation/Supination, Wrist Extension/Flexion, Wrist Radial/Ulnar Deviation etc.For a detailed explanation on the workings of the Biodex isokinetic dynamometer refer to the manuals on the manufacturer's website [Bio12].



(a) Knee adapters for left and right knee



(b) Knee extension(away) and flexion (toward)

Figure 1.2: Knee adapters and range of movement, [Bio12]

The studies on the Biodex System 3 in DLR uses isokinetic, isotonic or isometric modes. For building the game prototype, the knee extension exercise pattern in isometric mode was chosen. For a knee extension test, the subject is secured to the dynamometer as shown in figure 1.1. For the knee extension test, a knee adapter as shown in figure 1.2(a) is used. There are two different adapters for the left and right leg.The knee adapter for the leg tested is fixed to the dynamometer shaft. The range of motion of the leg is from 0^{deg} to 135^{deg} as shown in figure 1.2(b). In the isometric mode, the adapter will be fixed at 70^{deg}, 80^{deg} or 90^{deg} angle. The adapter will not move. The subject will push hard against the adapter. In an extension, the subject exerts force in a direction away from the dynamometer.

Each study will have a test protocol associated with it, which specifies the details of the exercise patterns used for the study and the setup of the Biodex machine for the specific exercise. The details and terms in the test protocol which is of interest to the game are explained below

- Number of Visits - the number of times the subject is tested at the Biodex. The gaps between visits are determined by the nature of the study. Usually this is at least a week or more.
- Number of Repetitions - the number of times an exercise pattern is repeated. In a single visit the user is tested for a set of exercise patterns. Each exercise pattern has to be repeated a few times to obtain data for the study.
- Rest interval - time between repetitions for a single exercise pattern
- Peak torque - the maximum torque reached by a subject in a maximal strength test.
- Mean peak torque - the mean of maximum peak torque in different repetitions for a single visit.
- Familiarization - repetitions done by the subject to become familiar with the exercise pattern and the Biodex system

1.4 Thesis Outline

This master thesis is organized as follows.

- Chapter 2 gives an overview of previous studies on the effect of verbal and visual feedback in field of strength testing in physiology experiments. It also gives an insight into the field of exergaming and the use of virtual reality in the field of physical rehabilitation.
- Chapter 3 explains the objective of this work and specifies the scientific problem.
- Chapter 4 gives an overview of the system implementation. It explains the components in the game system and how they are connected to each other.
- Chapter 6 explains the game concept and game design. It also explains the game world, characters, game play, mechanics and the visual interface in detail
- Chapter 5 explains the data analysis done to identify the control parameters required to implement the game. The data from a previous study conducted on the Biodex System 3 was used. Data from eight subjects for isometric knee extension was used for the analysis. Different torque responses were identified and classified here. Control parameters are identified and described. The overall game logic is also explained here.

- Chapter 7 provides an evaluation of the game implementation. A retrospective evaluation of the system using data from an existing study is done. The behaviour of the game is analysed. It evaluates how time and torque values influences the reward system in the game. It also gives a detailed analysis of game events for different torque responses.
- Chapter 8 explains the results of the thesis and discusses open issues and future work.

Chapter 2

STATE OF THE ART

Maximal strength testing is a standard procedure in physiology studies. The subject has to exert maximum force voluntarily. The subject could be encouraged by external factors to exert force rather than just relying on his intrinsic motivation alone. The popular motivation strategies in physiology studies include

- Verbal encouragement
- Visual feedback

Some studies use verbal encouragement alone while others combined verbal encouragement and visual feedback. Verbal encouragement is provided by the investigator using motivating statements like "Push harder..", "You can do it...", "Good job.." etc. Visual feed back is usually a real time display of the torque exerted as a graph. Different works which studied the effects of verbal encouragement and visual feedback on torque exerted by subjects are discussed in section 2.1.

Computer games have been combined with exercise equipments and rehabilitation equipments in order to motivate users to exercise. Games which promote physical activity include [FTSC10]

- Exergames
- Therapeutic Exergames or Virtual Rehabilitation

Exergames are used to promote physical fitness and tackle obesity [Bog05], [GHW+10], [WBH+07], [LML+06], [MVHV03]. Since computer games are able to engage people in game play for long, interesting exergames can provide physical fitness along with fun. Therapeutic exergames or virtual rehabilitation is used to encourage users with physical disabilities and make rehabilitation tasks interesting [BMC+09], [YT11]. Rehabilitation also makes use of virtual environments which are increasingly being used in stroke rehabilitation [MJB+02], [Hei]. Different studies in the field of exergames and virtual rehabilitation is discussed in section 2.2.

2.1 Verbal Encouragement and Visual Feedback

In the course of maximal strength testing, the subject can be influenced by factors like verbal encouragement, competition etc to improve his performance. Verbal encouragement has been traditionally used to motivate the subject. In some experiments visual feedback is also used. Few works exploring the effects of verbal encouragement and visual feedback on maximal strength testing are discussed here.

Jung and Hallbeck [JH04] studied the effect of instruction type, visual feedback and verbal encouragement on static and peak hand grip strength. They found that verbal encouragement and visual feedback improved the static grip strength or maximal force exerted. They also compared the time to build up maximum strength. Verbal encouragement improved build up times while visual feedback did not always improve build up time.

The study by Campanella et.al [CMK00] tested the effect of verbal encouragement and visual feedback on concentric hamstring and quadriceps force production. Using a Biodex-200 Isokinetic Dynamometer, the peak torque values for knee extensions and flexions at an isokinetic velocity of $60^{\deg}/sec$ was recorded. The torque curve graph display on the dynamometer was used as visual feedback and the investigator gave positive verbal encouragement. The study found out that visual feedback generated greater concentric peak torque than verbal encouragement. Also combined verbal encouragement and visual feedback had a significant effect in generating greater peak torques than no feedback.

Hald and Bottjen [HB87] also found that visual feedback improved peak torque responses of quadriceps and hamstring muscles. The visual feedback was the torque graph display. Figoni and Morris [FM84] also used the torque curve on the visual display of the Cybex-II dynamometer as visual feedback for testing knee extensor and flexor strength at slow and fast speeds. The visual feedback had a significant effect in generating higher peak torque values at slow speeds. The not so significant effect in fast speeds was attributed to the time needed to process and use visual feedback.

The study by Andreacci et.al [ALC$^+$02] tried to determine the effect of frequency of verbal encouragement on exercise testing. They hypothesized that verbal encouragement increases the likelihood of maximal effort and that there is a direct relationship between verbal encouragement and a subject's performance. The study gave importance to the rate, duration and temporal distribution of encouragement. The subjects were divided into 4 groups, one control group and 3 experimental groups. The experimental groups were given encouragement at an interval of 20s, 60s and 180s. The verbal encouragement was found to have a significant effect when it was given at 20s and 60s. When it was 180s, the encouragement was too far apart to provide any effect. They suggest that the encouraging statements will distract the subject from the discomfort of maximal effort. Some of the verbal statements used were encouraging statements while others were instructional. The encouraging statements acted as positive reinforcers. Instructional statements took advantage of the human tendency to follow commands or instructions.They also note that a maximal effort can be positively reinforced by achieving a competitive goal or by looking good to the experimenters and negatively reinforced by avoiding appearance or weakness and of being out of shape.

The study by McNair et.al [MDBS96] also found that verbal encouragement has significant effect on peak torque generated. The peak torque was increased by 5 percent during isometric muscle test of elbow flexors. They suggested that the strength and the nature of verbal encouragement is an important factor.

2.2 Computer Game and Virtual Reality based Encouragement

In the field of exergaming, therapeutic exergaming and virtual rehabilitation people are motivated to be physically active through games or virtual environments. People are encouraged to be physically active without them being too aware of the fact that they are exercising. In rehabilitation systems people with movement disabilities are motivated to do repetitive exercises by manipulating objects in a virtual environment .

Different usability studies were conducted to identify design and evaluation principles for different exergaming and rehabilitation systems [CNF08], [YG07]. The factors which have to be taken into account while designing an exergaming system are different from a regular game. The primary goal of a computer game is player enjoyment. But for an exergame the physical activity and energy expenditure are also important. An exergaming or rehabilitation system should be effective in terms of exercise requirements and also attractive enough to compel the player to come back and play it frequently for the required duration [WBH+07] [SHM07]. The user should be able to achieve short term goals in the game and improve over time. Exergames can also reinforce long term behavioural changes by reinforcing desirable behaviours through positive or negative reinforcements through the game [AMD+09], [LML+06].

According to Sweester et.al[SW05], for a computer game to be enjoyable, it should provide a sufficient level of challenge and ease of use for the player to be totally concentrated on the game. The challenges in the game must match a players skill level and it should not be too overwhelming or too easy. The player should be able to progress to different levels according to his skill levels. The player should be able to learn the game easily and should not have to rely on extensive tutorials to learn how to play. It would also be an advantage if the player could learn by playing the game. The player should feel a sense of control over the game. They should feel that their actions are making an impact on the game world and that they are making the decisions that are changing the game world. The player should have a clear goal at all times and given appropriate feedback for all his actions. The player should be able to immerse himself in the game that he becomes less aware of the real world and forgets that he is participating in a game. Games should also support social interactions and allow the player to communicate, compete and cooperate.

In their work [SW05], Sweetser et.al explore important factors for design of games.

They adopt Csikszentmihalyi's concept of flow to explain enjoyment in games. The elements of the game flow model developed by them are concentration, challenge, player skills, control, clear goals, feedback, immersion and social interaction. All these factors should also be taken into consideration while designing an exergame or a game for a rehabilitation equipment. The type of input device used is also an important factor. When the player has to pay attention to both input device and the game, the experience will not be enjoyable since he will not be able to concentrate on the game. But in the case of a game like Dance Dance Revolution which is extremely popular, the focus was more on the input device than the visual interface which just gave scores [SHM07]. So the player should either focus on the device or the game.

Burke et.al [BMC+09] explored the use of games in stroke rehabilitation. Gaming or virtual reality systems can make rehabilitation interesting and can provide customizable training for different patients. Rewards and incentives increases motivation to complete a game. Wrong choices should be faced by failure or a setback in the game. But in the case of rehabilitation it is better that the feedback be generally positive since people should not attribute the failure to their disabilities due to the stroke. There should be different difficulty levels according to the users ability, which is also important as the user progresses through his rehabilitation. There are games which can adapt their difficulty depending on the player's game play.

In the work by Dimovska et.al [YT11], a nintendo wii game is modified for rehabilitation. The wii board is used to control the game for patients with leg injuries. The patient is motivated to work with the injured leg. In the work by Widman et.al [WMA06], the efficiency of a game cycle as an aerobic equipment is tested. Eight adolescent subjects were surveyed in the study. The game cycle combines Nintendo's GameCube with a hand cycle for people with mobility impairments. They found that subjects were able to reach an intensity level equivalent to aerobic training with the game cycle. They also found that the game cycle was not of much help to subjects with well developed upper bodies.

In the fitness game developed by Mokka et.al [MVHV03], the subject uses an exercise bike to ride through a virtual environment. The evaluation of the system showed that people felt that they were exercising instead of playing a game. This is because of the use of an exercise bike as control. Nevertheless game was still enjoyable to the users considering the fact that biking in a gym could be more boring than having a virtual environment to explore.People also felt like they were immersed in the environment. People who were in the real location displayed in the virtual environment were eager to find familiar spots.

Chapter 3

PROBLEM STATEMENT

Maximal strength testing is a standard procedure in exercise physiology. Peak torque is an important parameter used for analysis in these studies. The peak torque exerted by a subject could be affected by verbal encouragement as well as visual feed back. It can also be influenced by other factors like resting intervals, intrinsic motivation, competition etc. Previous studies ([JH04], [CMK00], [HB87], [FM84], [ALC+02], [MDBS96]) show that verbal encouragement given at specific intervals and visual feedback can improve torque exerted by subjects. The experiments which used visual feedback as encouragement used a graph of the torque exerted by the subject as a visual display. The subject could perceive his effort through the display and try to improve his torque output.To the best of our knowledge, an approach of using a game or virtual reality has not been tested before. The goal of this project is to develop a prototype game for maximal isometric knee extension testing to see whether it can influence the torque output.

In the studies conducted on the Biodex system, an investigator guides a subject through the study by following the test protocol. Verbal encouragement is used to motivate the subject to produce higher torque values. Since the studies are long and monotonous, it is up to the investigator to keep the subject motivated.The effect of the verbal encouragement is dependent on the expertise of the investigator. The nature of statements or instructions used can affect different subjects in different ways. The frequency of verbal encouragement [ALC+02] is also an important factor influencing the torque output. The rate or the kind of verbal encouragement provided is usually not known or documented. This project aims to replace verbal encouragement by a computer game based motivation system. The subject will be controlling a game using the Biodex machine. The following hypotheses are defined.

The system is expected to

- Generate higher mean values for peak torque than verbal motivation
- Produce smaller standard deviation between peak torque values
- Motivate the subject in a standardized and reproducible way

An interactive game environment will replace verbal motivation and encourage the subject in the same or improved manner. The test subject is encouraged to work harder and reach the expected level of performance throughout the game. The subject is expected to perceive and improve his performance through events in the game. With the game, the subject should be more focused on the task at hand. The subjects will be motivated in the same way using the game across all trials in a study. So, unlike verbal encouragement, the motivation process is standardized and reproducible.

Chapter 4

SYSTEM OVERVIEW

The top level system architecture of the computer game based motivation system prototype for Biodex System 3 is shown in figure 4.1. The prototype system consists of

- Biodex System 3
- Game System
  - Unity Engine
  - Game Logic
- SQLite Database
- Visual interface

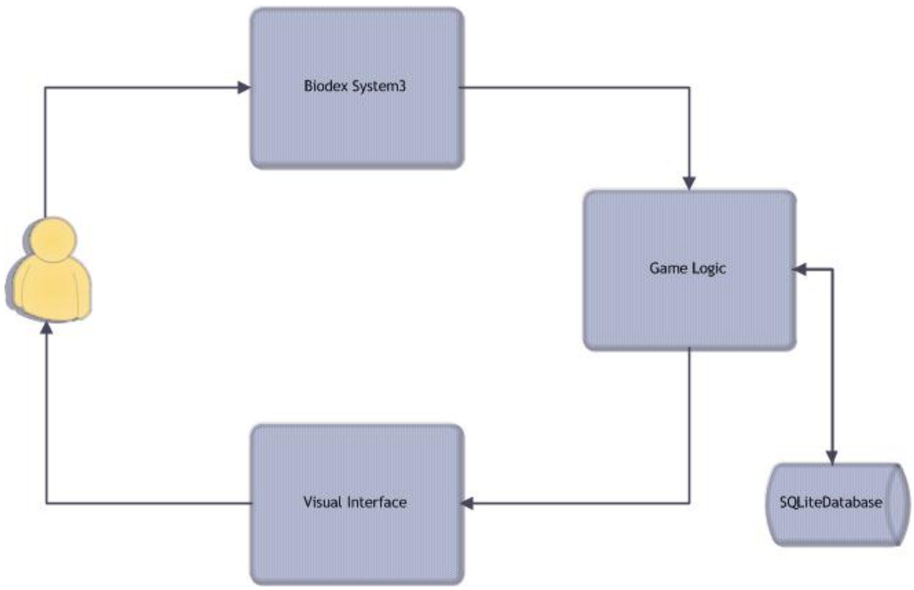


Figure 4.1: Top Level System Architecture

The game based motivation system augments the Biodex System. When a test protocol is activated on the Biodex system, the game has to be in sync with the protocol. The Biodex System acts as the game controller. It has an EMG/Analog Signal Access Interface [Bio12]. Analog signals for velocity, torque and position is available in real time

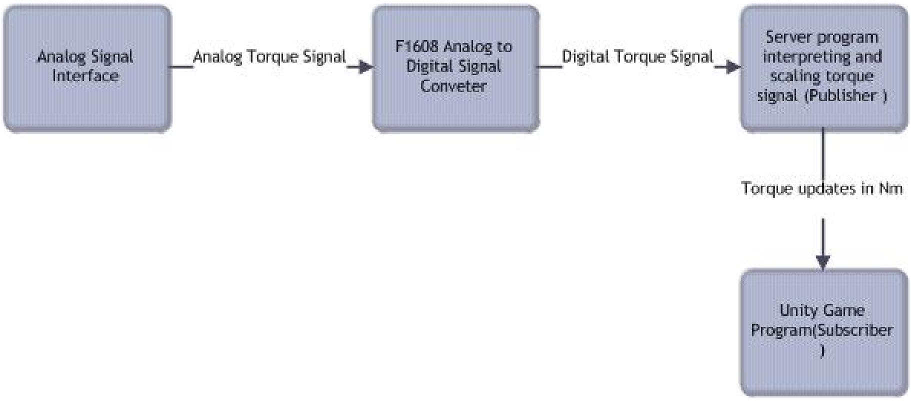


Figure 4.2: Torque Data Processing

from this interface. The signals are output in real-time directly from the motor control digital signal processor. A synchronization signal is also provided. The game system uses only the torque analog signal.The voltage range of the torque signal is within -5V to +5V . This translates to a torque value of -694.18 Nm to +694.18 Nm. The system defaults to a full range of torque from -694.18 Nm to +694.18 Nm. The analog signal has three different output modes - On Always, On Timed and Off(disabled). In the On Always mode the signal is output regardless of the operational stage of the machine. In the On Timed mode analog signal is output only for fixed time intervals. In Off mode no signal is output. The Biodex System 3 here is set to On Always mode.

The analog torque signal has to be converted to digital signal before it could be sent to the game system.An analog to digital converter([ME12]) is used for this. The AD converter gave output as voltages. This had to be converted to torque in Newton meter to relate it to the data displayed in the computer on Biodex. The voltage is multiplied by a scaling factor to get torque,

$$\begin{aligned} \eta &= \frac{T_{max}}{V_{max}} = 138.8 \\ where& \\ \eta &= Scaling factor \\ T_{max} &= Maximum\ value\ of\ torque\ in\ full\ range (694.18 Nm) \\ V_{max} &= Maximum\ voltage\ corresponding\ to\ the\ maximum\ value\ of\ torque (5V) \end{aligned} \tag{4.1}$$

$$
\begin{aligned}
&\quad T = (V * \eta)\, Nm \\
&where \\
&\quad T = Torque \\
&\quad V = Voltage\, output\, from\, the\, AD\, converter
\end{aligned}
\tag{4.2}
$$

Unity3D is used to develop the game. Torque is the only control signal for the game. Torque data is transferred to the game system over asynchronous sockets. A publisher subscriber architecture is used for the communication.A server reading and interpreting data from the Biodex acts as the publisher. The game system subscribes to the torque data. SQLite database is used to store details about the subjects in the study.The torque data and events during the game are also logged for further exploration. This would aid in improving the algorithm and analyzing user behavior.

A user receives feedback for his actions through the visual interface. The user interacts with the game interface by applying torque on the adapter fixed to the Biodex System. The torque exerted by him is transferred into actions in the game. The visual interface displays the results to the player in real time. So the user could assess his performance and react accordingly. The game also provides a menu at the beginning of the game to enter user details to retrieve useful information required to play the game.

Chapter 5

DATA ANALYSIS

The analogue torque output from the biodex machine is the only control signal for the game prototype. It is important to understand the characteristics of the torque data to implement a system which should motivate the test subject effectively. The prototype system was developed for one test- the isometric knee extension testing. The game is designed to increase the peak torque. The improvement of torque development time was not taken into account while designing the game. The different control parameters for implementing the game will solely depend on torque data.

Data from the SAG study was used for analyzing data characteristics. The torque data from eight subjects labeled A - H is used for analysis. Data for the isometric knee extension at 70^{deg} angle setting for the knee adapter was analyzed. Every test subject performed six contractions which last for around five seconds with thirty second long rest intervals. The six contractions alternated between extensions and flexions (figure 5.1). Only extensions were considered for developing the prototype. So data for flexions were removed (figure fig:SAG Study Subject A Trial 1(Only extensions)).

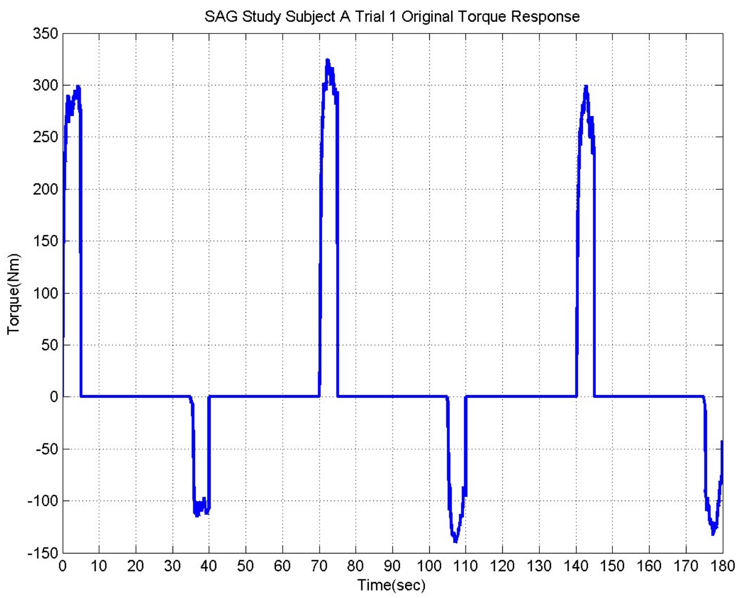


Figure 5.1: Torque response for subject A visit 1. Positive peaks are extensions and negative peaks are flexions

Study Subject A Trial 1(Only Extensions).jpg

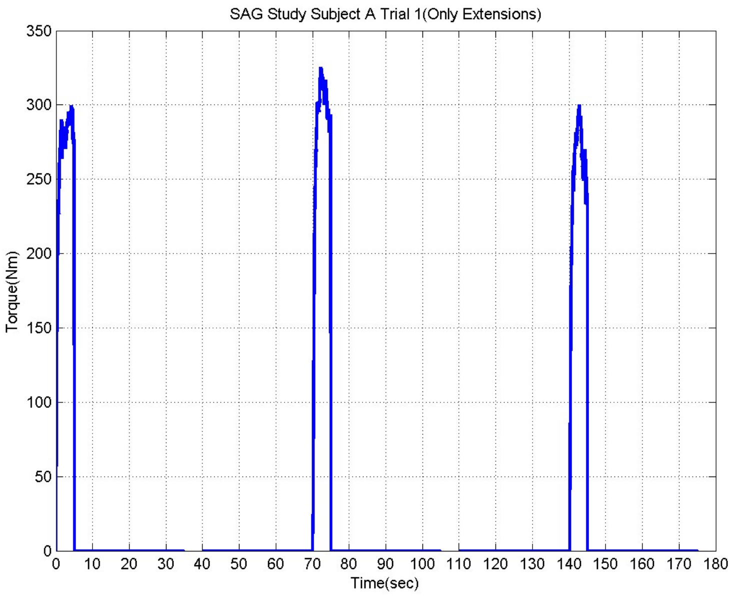


Figure 5.2: Torque response for Subject A Trial 1 After Removing Negative Peaks(Flexions)

Study Subject A Trial 1 Repetition 1(Extension).jpg

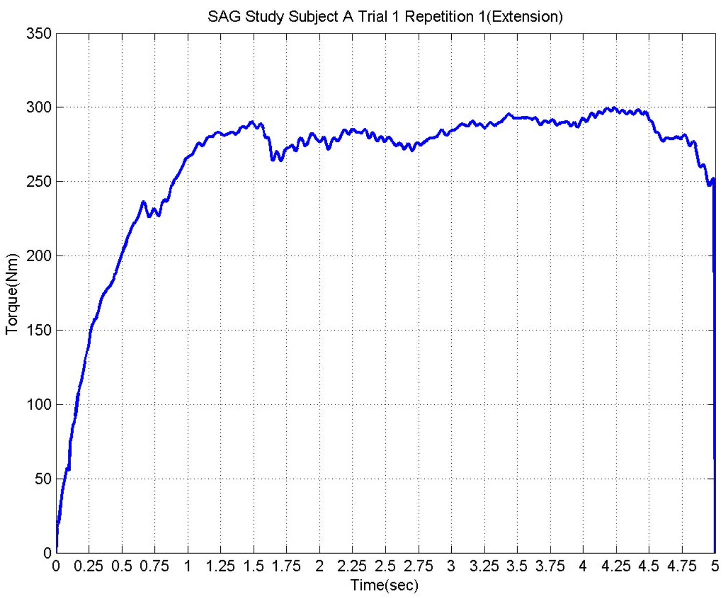


Figure 5.3: Torque Response for a Single Repetition : A Closer View

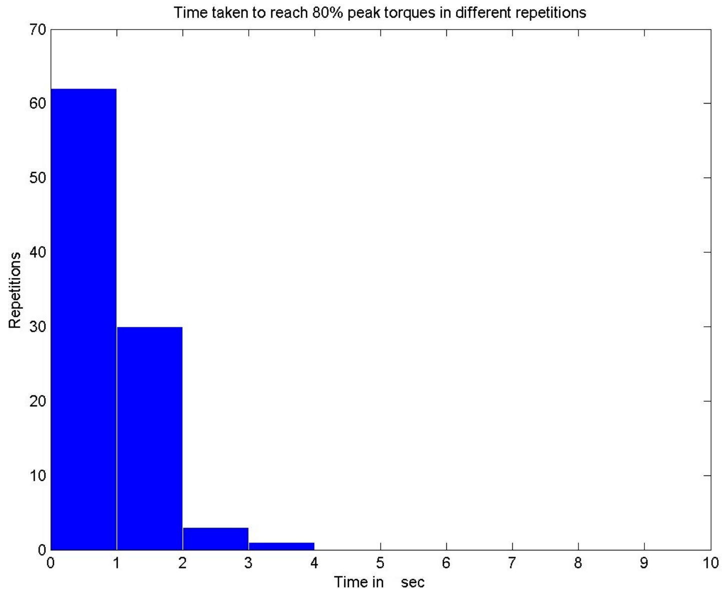


Figure 5.4: Time taken by test subjects to reach 80% of peak torque in each repetition

5.1 Characteristics of Torque Data

The torque data was analyzed to find how rapidly the torque rose by observing the time taken to reach 80% of the peak torque. A histogram was plotted for the time taken by all subjects all repetitions to reach 80% of peak torque (figure 5.4). Of the total number of 96 repetitions for all eight users in four visits,

- In 62 repetitions, subjects reached 80% of the peak torque within zero to one seconds
- In 30 repetitions, subjects reached 80% of the peak torque within one to two seconds
- In 3 repetitions, subjects reached 80% of the peak torque within two to three seconds
- In 1 repetition, a subject reached 80% of the peak torque within three to four seconds.

In most repetitions, subjects reached 80% of the peak torque within the first two seconds. Only four took more than two seconds to reach 80% of the peak torque the peak torque.Reaching 80% of the peak torque after two seconds is not a desired behavior since the peak torque reached after this will not be his personal best. When looking at the torque curve it can be seen that after the steep slope during torque build up in the first second, torque varied only slightly up or down to reach the peak torque. The torque response closely resembled a square curve (figure 5.8).

The time required to reach peak torques was compared next. Peak torques were plotted against the time required to reach them (fig:PeakHistogram). Of the total number of 96 repetitions for all eight users in four visits,

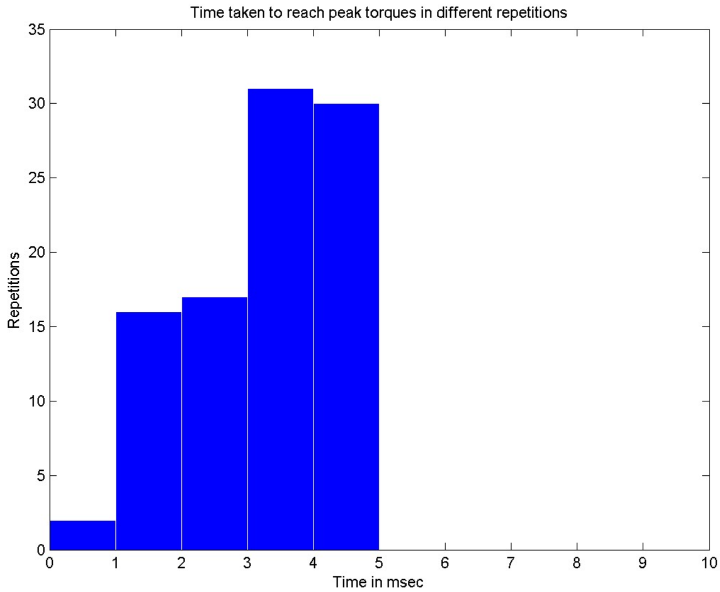


Figure 5.5: Time taken by test subjects to reach peak torque in each repetition

- In 2 repetitions, subjects reached peak torque within one second
- In 16 repetitions, subjects reached peak torque within two seconds
- In 17 repetitions, subjects reached peak torque within three seconds
- In 31 repetitions, subjects reached peak torque within four seconds
- In 30 repetitions, subjects reached peak torque within five seconds

In most cases the subjects reached peak torque within two to four seconds. There were comparatively few repetitions in which subject's reached peak torque in the first second or in the last second.

A histogram was plotted to find out in which repetition(first, second or third), the user attained the highest peak torque in a visit (figure 5.6). Of the total number of 32 visits

- In 7 visits, the subject attained highest peak torque in the first second
- In 10 visits, the subject attained highest peak torque in the first second
- In 15 visits, the subject attained highest peak torque in the first second

The highest peak torque in a visit was attained mostly in the second and third repetition. The relatively small number of maximum peak torques in the first second can be because of the fact that the subject is getting used to the test (exertion of torque) in the first repetition.

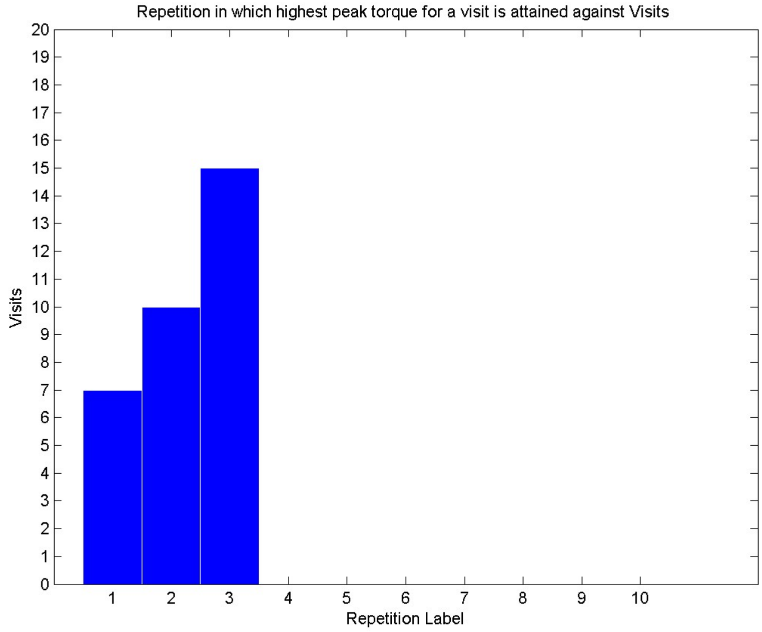


Figure 5.6: Comparing repetition for which user reaches maximum peak torque across different visits

5.2 Identification of Control Parameters

Control parameters had to be identified based on the characteristics of the torque data to control events in the game to build the game's reward system. It was decided that the subject will be rewarded for the first time if he crosses a baseline torque value called initial threshold. This initial threshold value was established by running a familiarization repetition. The initial threshold value was taken as 80 percent of the peak torque achieved in the familiarization repetition. Since the data used for the analysis is from a previous study, the first repetition in the first trial of every subject was considered as the familiarization repetition. The torque data was then analyzed based on this value as initial threshold. The repetitions were classified into the following cases or generalizations.

1. Repetitions in which the subject goes above the initial threshold

   (a) Repetitions in which the user goes above the initial threshold very late.

   In the repetition shown in figure 5.7 , the subject B crosses the threshold after the fourth second and the peak torque attained by the user is 268.9Nm. But the subject B's highest peak torque in all visits combined was 348 Nm. This is far above the peak torque in this repetition. The question is how to implement a reward system that motivates the test subject to cross the threshold sooner and makes him attain higher peak torques.

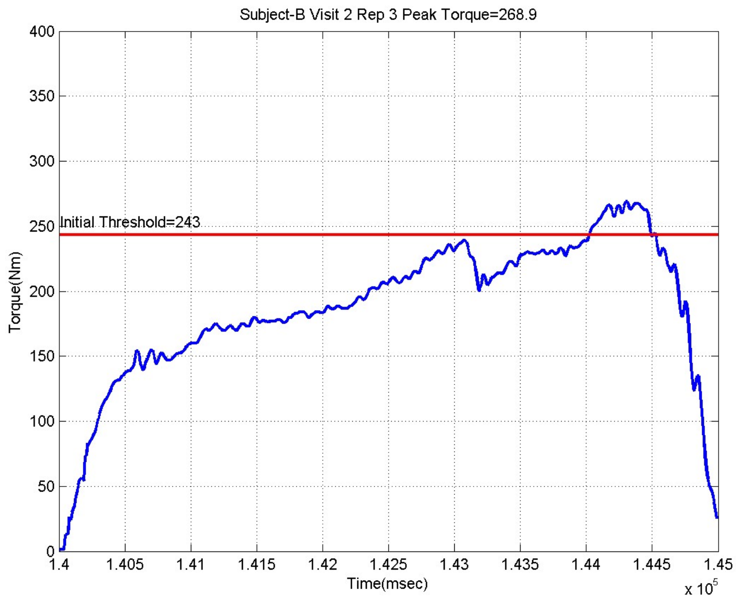


Figure 5.7: A repetition in which subject crosses initial threshold in the last second

(b) A repetition in which subject goes above the initial threshold and sustains it to reach the peak

In the repetition shown in figure 5.8, the subject B crosses threshold almost at the end of the first second which is a desirable response. The subject then pushes harder and reaches a peak torque of 341Nm in this repetition. This is very close to this subject's highest peak torque(348Nm) in all visits. In a torque curve like this the subject should be kept motivated and rewarded for the desired response

(c) Repetitions where the user goes above the initial threshold early in the repetition but did not sustain it for long

In the repetition shown in fig 5.9, the subject C crosses threshold in 500ms, well within the first second, but then goes below it after around 250ms. The subject never reaches the initial threshold again.The peak torque attained by the subject in this repetition is 201Nm whereas the peak torque of the subject in all visits is 288Nm. The subject should be motivated to keep pushing harder without giving up.

(d) Repetition in which the subject crosses the initial threshold and reaches peak torque within the first two seconds

In the repetition depicted in figure 5.10 the subject crosses initial threshold of 241Nm within 500ms and reaches peak torque 1500ms. The peak torque

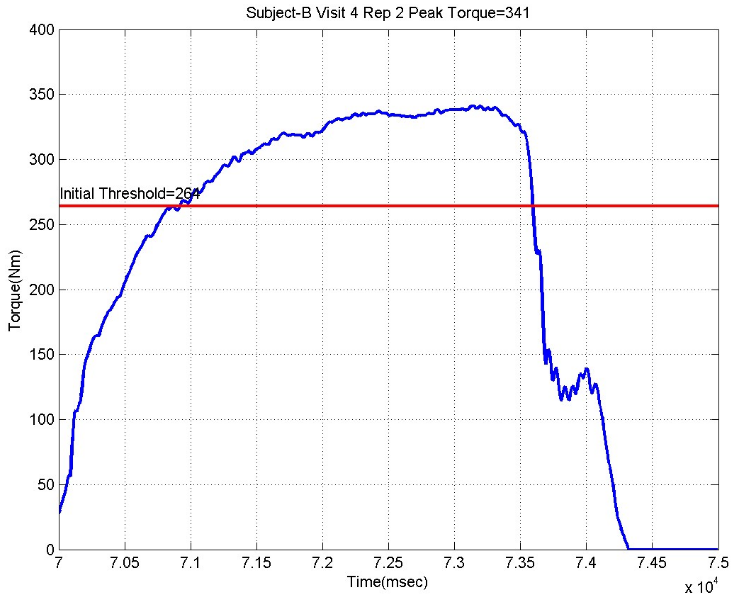


Figure 5.8: A repetition in which subject goes above threshold and sustains it to reach peak

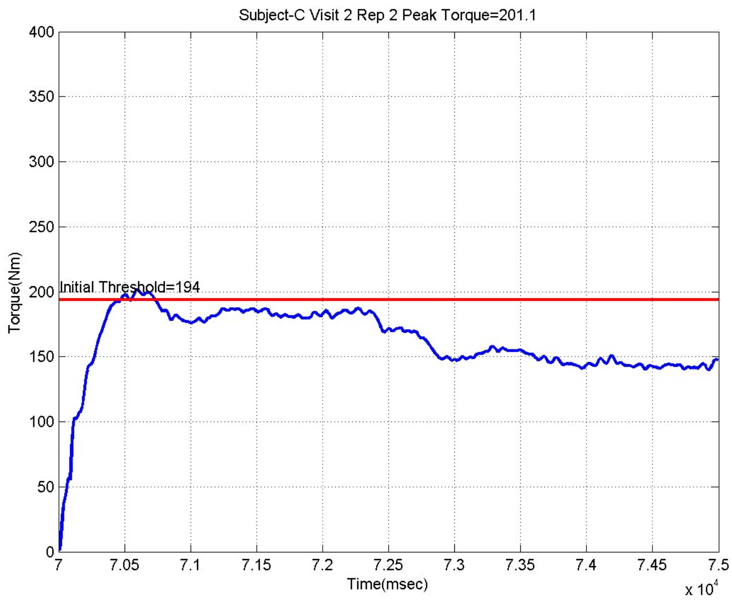


Figure 5.9: A repetition in which the subject goes above the threshold but does not sustain it to reach peak

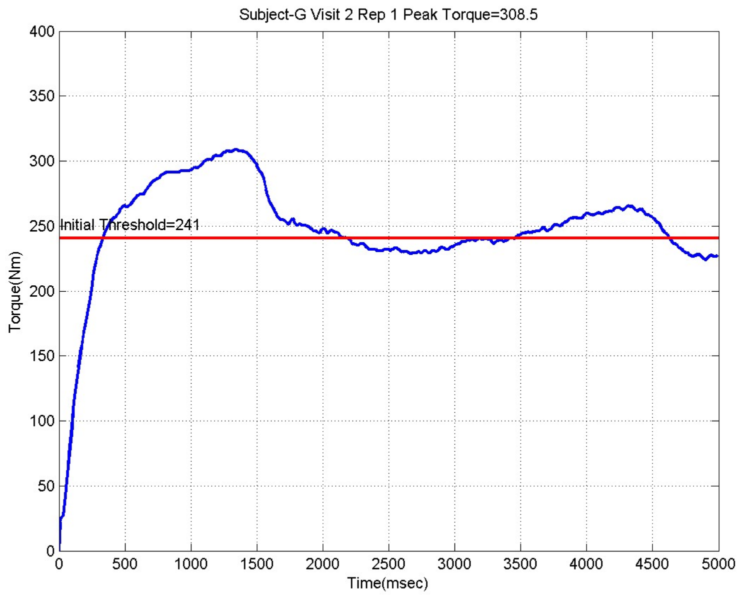


Figure 5.10: Subject crosses initial threshold and reaches peak torque in the first two seconds

308.5Nm attained in this repetition is the highest peak torque value reached by this subject in all repetitions. Here even though the torque exerted went down after two seconds, it is a desired behaviour. Here the subject's intrinsic motivation would have contributed more to the high peak torque. It will be challenging for the game to motivate the subject to reach peak within such a short interval.

2. Repetitions in which the subject does not go above threshold

   In the repetition shown in figure 5.11 , the subject B never crosses the threshold. The peak torque attained by the subject is 221.8Nm whereas the threshold was 243Nm. But the subject B's highest peak torque in all visits combined was 348 Nm. This is a lot higher than the subject's maximal effort in this repetition. So it is obvious that the subject is capable of exerting more force. The game has to motivate the subject to go above the threshold. For example if the subject is not given any reward when he is exerting torque below the intial threshold, it will act as negative reinforcement which in turn encourages the subject.

3. Repetitions in which the subject goes above threshold but keeps varying the torque up and down frequently

   In the repetition depicted in figure 5.12 the subject crosses the threshold but the torque response has too many ups and downs. The user keeps pushing harder and

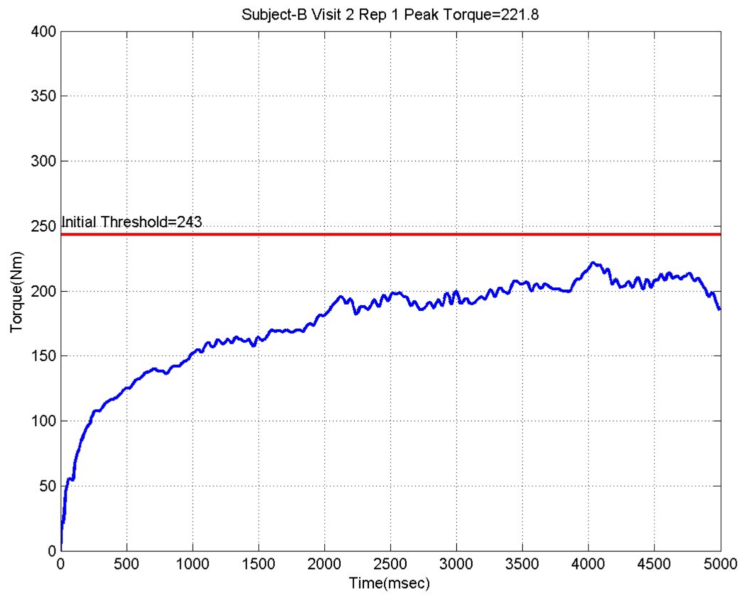


Figure 5.11: A repetition in which subject does not go above initial threshold

then drops and then tries again. It is not a focused continuous effort. The maximum torque attained by the user is 303.9Nm and the initial threshold is 225Nm. The subject came close to the maximum peak torque in all repetitions,348Nm, though it has to be debated whether this torque response is a desired one.In a case like this the game should motivate the user to continuously increase the effort without giving up in between.

The game algorithm has been tested and improved over time using the sample data set. The first parameter identified as discussed before has been the initial threshold. There should be a baseline torque value against which the subject's performance can be asessed. The initial threshold can be calculated from a familiarization repetition. The subject usually builds up the torque from zero to this initial threshold well within the first second as discussed above. But the same subject may not reach the initial threshold in some repetitions. The question is whether this threshold has to be reduced to encourage him to get to the previously established initial threshold.

Two choices for calculating intial threshold have been

- Mean value of the entire torque curve in the familiarization repetition.
- 80% of the peak torque in the familiarization repetition.

For a torque curve which closely resembles a square curve as in 5.8 mean value can be considered as intial threshold. But for a torque which has many peaks and valleys as in

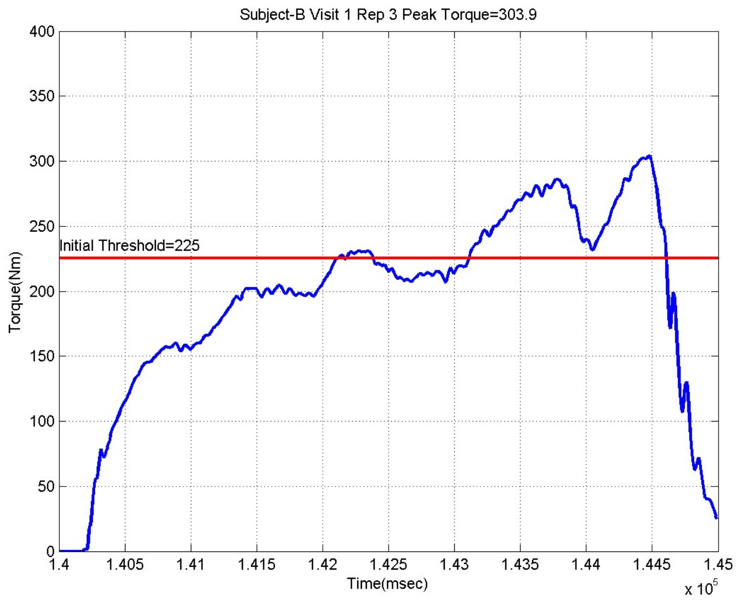


Figure 5.12: A repetition with a lot of peaks and valleys in the torque curve

5.12 , the mean value will be too low even though the user is able to reach considerably high peak torques. So 80% of the peak torque has been considered a better choice.

To understand the changes in the torque curve, the curve should be analyzed over small sampling intervals. The subject's torque response for a sampling interval will be analyzed and he will be encouraged to modify the response the next interval.The sampling interval was assumed to be 200 msec(equivalent to 20 samples) for the analysis. To understand the nature of the torque curve in this interval a new parameter has to be introduced.

Two choices for this have been

- Maximum torque reached in the sampling interval
- Mean value of the torque samples in the sampling interval

The torque values can have changing behaviors in an interval. It can have a positive gradient, a negative gradient or a mixture of both. If the subject increases torque in the beginning of the interval and then brings it down, the maximum torque in the interval will not reflect his behavior appropriately. The mean of the torque samples in the interval will reflect the torque response more appropriately in this case. The mean torque value will also work for a positive or negative slope.

The initial threshold has to be adapted to keep the subject motivated. The current threshold was compared to the mean torque computed in the sampling intervals. The difference in mean of the current interval and previous interval is determined. The threshold can be adapted to a fraction of this value. If the mean value has increased over the intervals, the threshold can be increased to motivate the user to push harder. If the mean value has decreased, the threshold can be decreased. This decision has been changed later after the analysis of the data. The threshold has not been reduced since it is never beyond his capability as the user is able to reach it once. Also when the threshold is reduced the user is getting more rewards. Eventhough getting rewards could encourage the user, it reduces the value of the rewards.

The frequency of rewards has been based on the user performance meaning that the more he crosses the thresholds set by the program the more he is rewarded. The latency in rewards is the time difference between rewards. After a reward there has to be a small gap of of 200 msec until the next reward, since humans need atleast 135 msec respond to visual feedback [Car81].

5.3 Classification of Test Subjects

The test subjects in a study are divided into two categories.

- Subjects with no previous history

  In this case a subject will have no subject history stored in the Biodex database. So for a new subject intial threshold has to be determined using a familiarization repetition. The investigator will be able to give an estimate of the torque based on his experience as well as the physical characterestics such as weight and height of the subject. The estimated value given by the investigator is used as the intial threshold for the familiarization repetition. 80 % of the peak torque exerted in the familiarization repetition is considered as the initial threshold for the first real trial.

- Subjects with previous history

  In this case, the user will have subject history stored in the database. Since the subject was already studied before, the initial threshold will be determined from the history. The user can proceed directly to the study without a familiarization repetition.

5.4 Description of Control Parameters

The following is the description of parameters identified in the data analysis.

1. Peak torque

   Peak torque, T_p is the maximum torque exerted by the subject in a repetition.

$$
\begin{aligned}
&T_p = Max_{i=1}^{n}\{T_i\} \\
&where \qquad\qquad (5.1) \\
&n \;=\; total\ number\ of\ torque\ samples\ in\ a\ repetition
\end{aligned}
$$

Parameter	Notation	Unit
Initial Threshold	θ_0	Newton meter
Mean Torque	T_{mean}	Newton meter
Threshold	θ	Newton meter
Peak Torque	T_p	Newton meter
Repetition Time	t_{rep}	milliseconds
Rest Interval	t_{rest}	milliseconds
Number of Repetitions	N_{rep}	—
Number of Visits	N_{visit}	—

Table 5.1: Control Parameters- Notation and Units

2. Initial Threshold

   Initial threshold θ_0 is the torque value the subject has to overcome to begin getting rewarded.

$$
\begin{aligned}
&For\,an\,existing\,user,\ \theta_0 = 0.8 * Max\{T_{p_{i=1,j=1}}, ..., T_{p_{i=1,j=n}}, ...T_{p_{i=m,j=n}}\}\\
&\qquad where\\
&\qquad T_{p_{i,j}} = Peak\,torque\,in\,visit\,i\,repetition\,j\\
&\qquad n = No:\ of\,completed\,visits\\
&\qquad m = No:\ of\,completed\,repetitions
\end{aligned}
\tag{5.2}
$$

$$
\begin{aligned}
&For\,a\,new\,user,\ \theta_0 = 0.8 * Max\{T_{p0}\}\\
&\qquad where\\
&\qquad T_{p0} = Peak\,torque\,in\,a\,familiarization\,repetition
\end{aligned}
\tag{5.3}
$$

3. Mean Torque

   The mean torque, T_{mean}, is the average of all samples in a sampling interval

$$
\begin{aligned}
&T_{mean} = \frac{\sum_{i=1}^{n} T_i}{n}\\
&where\\
&\qquad n = \ Sample\ size
\end{aligned}
\tag{5.4}
$$

4. Threshold

   After crossing the initial threshold, θ_0 , the threshold has to be adapted to motivate the subject to push harder. The threshold is only increased and never decreased.

The threshold,θ, is adapted using the following equation.

$$
\begin{aligned}
&if \theta > T_{mean} \\
&\quad \theta = \theta + (T_{mean} - \theta) \qquad (5.5)\\
where\, T_{mean} \;&=\; Mean\, torque\, in\, the\, current\, sampling\, interval.
\end{aligned}
$$

5. Repetition time

   The total repetition time , $t_{rep} \;=\; length\, of\; a\; single\, repetition$

6. Rest Interval

   The rest interval , $t_{rest} \;=\; length\, of\; a\, rest\; interval$

Chapter 6

GAME DESIGN

The proposed system will employ biodex system as a controller for a game. The user uses the biodex system to interact with the graphical interface for the game. A computer game suitable for the test protocols run on the biodex system should be implemented. The game should be

- Motivating the user to exert maximum torque
- An enjoyable experience for the player
- Interesting to play for the entire duration of the study
- Challenging enough to keep the player engaged in the game

One of the important factors influencing choice and design of the game is the fact that Biodex System3 is the game controller. The biodex system is very different from conventional game controllers. The torque output from the machine is the only factor controlling the game. The player should be able to control the game effectively using the system and get immediate feedback for his actions using the controller. Also the system is operated in a pattern fixed by the test protocol. A test protocol specifies details of the muscle strength tests, pose of the subject on the biodex, the number of repetitions, the time of repetitions and rest intervals. The amount of time the player plays is lesser than conventional computer games since the studies used to estimate peak torques usually wont last more than five seconds. A number of games were discussed for the biodex. Following is a summary of them.

- High Striker

  In this game a mallet is used to hit a lever at the bottom of a tower. If enough force is applied, the bell at the top of the tower rings. There are markers on the tower for the amount of force applied. For the biodex system, the force output can be used to charge up the mallet and then hit the lever.

- Greyhound racing

  A version of the popular greyhound racing was considered. A greyhound is chasing a rabbit. A cage comes over the rabbit after every repetition to protect it during the break/until next repetition. The cage could be opened slowly at the start of a repetition. This is to give time to come closer to maximum force. The greyhound cannot reach the rabbit now. When the cage is lifted, maximum force is used to accelerate the rabbit.If one repetition is 3 seconds, then the probability that the rabbit is caught in the first 2.9 seconds should be very small. This is because the subject will stop trying to push if the rabbit is caught too early. Only if the subject does not exert enough force, the rabbit is caught earlier.The subject can be the rabbit or the hound. This way you will get two different scenarios to test

- Shark and school of fish

  A shark is following a school of fish.The player has to apply force on the biodex system to move the shark closer to the swimming fish. For the player to catch the fish, he has to push really hard to get closer to the fish and swallow it. The number of fish caught indicates how well the player performed. Also the fish caught at different intervals indicate good performances within a repetition.

- Motorbike ramp jump

  The force exerted on the biodex machine is used to accelerate a motorbike on a ramp and jump above a wall. Maximum force can be used for the jump. The bike jump will closely resemble the force applied.

- Car racing

  The force applied on the biodex machine is used to accelerate the car and overtake a single opponent in a race. The issue is the small time duration of a repetition or set. It is too short a time for a racing game and the subject will not enjoy the game.

- Airplane over a hilly terrain.

  The subject should apply enough force to gain altitude and fly above a hill. Force can also be used to maintain the altitude. If the subject doest not apply enough force, he might crash much before the repetition ends.

6.1 Game Overview

The game chosen for implementation after the preliminary discussion was the shark and the school of fish. Since the shark can gain rewards over the entire repetition it is easier to motivate the user continuously during a repetition.The greyhound racing game was similar,but the shark was thought to be more interesting than a dog. In the high striker and motorbike ramp jump, a positive behavior from the user cannot be reinforced effectively since the user is rewarded only at the end of a repetition. The other two games, car racing and airplane over a hilly terrain, are not interesting to play within a duration of five to ten seconds. The specifics of "the shark and the school of fish" game are detailed below.

6.1.1 Game Concept

Shark and school of fish is a predator prey chase game. The shark chases a school of fish in 3D deep sea environment. The shark has to move fast and get closer to the fish using torque applied on the biodex system. The shark must aim to catch the maximum number of fish. The number of fish caught reflects how well the player performed in the repetition and also in the complete visit.

6.1.2 Target Audience

The game is meant for study subjects using the biodex machine. It is expected to motivate them to put maximal effort into generating peak torque in an isometric knee extensor strength test. At present the subjects are verbally encouraged by the investigator to perform their best. Using this game the subjects will be continuously motivated with positive reinforcements (rewards) to encourage delivery of maximum torque. The game is expected to help the player to be better focused on the activity.

6.2 Game Play and Mechanics

6.2.1 Levels

The game has only a single level. There is a familiarization step for getting used to the game system. But this is not considered as a separate level.

6.2.2 Game Play

The game will only have one mode of play in which the shark has to chase the fish and catch them. The shark starts at a fixed position behind the school of fish. The fish are positioned in a long row in front of the shark. The user will press harder to increase the torque to help the shark get closer to the fish. The objective is to catch as many fish as possible. The reward system in the game functions in a way that when the player goes above an expected level of torque, he is given an extra boost with an increase in speed. With this boost the shark will accelerate more and catch the last fish. After this catch the rest of the fish will move away and the shark again follows them. Every instant the user generates a desired level of torque, the action is reinforced by giving a speed boost to the shark thereby enabling it to catch another fish.

6.2.3 Game World

The game is played in a 3D deep sea environment closer to the sea bed. The environment consists of a sandy sea bed, rocks, plants, a shipwreck, a cannon and a treasure chest. The environment does not have any animations,in contrast to the animated characters,the shark and school of fish. The environment is made big enough so that the

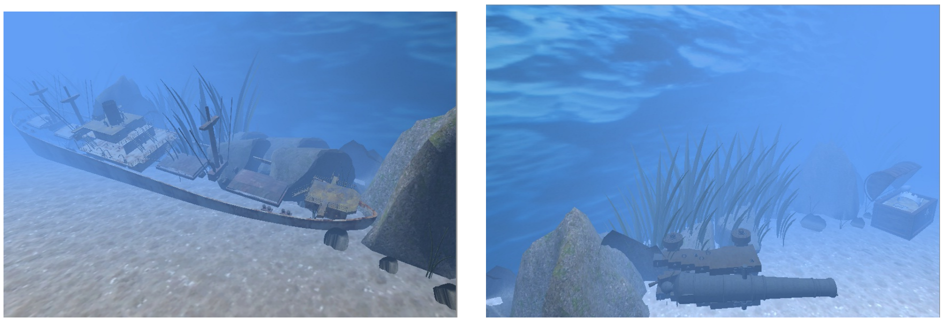


Figure 6.1: Game Environment

user can be tested for repetitions which last a maximum of 20 seconds. repet The game has only one level.

6.2.4 Characters

The characters in the game is the school of fish and shark. The player controls the shark while fish are controlled by the game logic. The fish are modeled after a clown fish. The school of fish is modeled by replicating the fish model multiple times. Both fish and shark have wagging tail and fin animation attached to them. The shark and the fish swim in a single direction.

(a) Game character - Shark

(b) Game character - Clown fish

Figure 6.2: Game Characters

6.2.5 Mechanics

The shark and fish are modeled as rigid bodies. The shark has a capsule collider attached to it and the fish has spherical collider attached to it. The movement of the shark and fish is controlled by torque exerted by the subject. Whenever the torque goes above an expected level shark receives a speed boost and is able to catch a fish. The parameters for the control of the movement of shark and fish is derived by analyzing torque data from a previous study. The reward system (fish caught) is also derived by analyzing torque data from a previous study.

Figure 6.3: Visual Interface during game play

6.3 Interface

6.3.1 Visual System

The models used in the game are from the google 3D warehouse [GDW12]. The unity engine is used for rendering graphics. The game has one camera and it gives a single perpective of the game environment. It closely follows the shark. The game interface during a play would look as shown in figure 6.3. The game updates regarding the score are given by a progress bar and a score display overlayed on the interface. The game has a main menu where the user has to enterh his user name and study name. If he is a new user he has to enter details about the test protocol. If it is an existing user, the details are retrieved from the database. The interface includes

- User Name text field

  Enter the test subject's name here.

- Study Name text field

  Enter study name here.

- Biodex Play Button

  Click this button to play game in real time using Biodex System 3.

- Replay Button

  Click this button to play game with the torque data stored in database.

- Start Button

  Click this button to start the first repetition. This button becomes active after the familiarization repetition for a new user. For an existing user once the user name and study name is entered, this button becomes active.

- Trial Button

  Click this button to start the familiarization repetition. This button becomes active if the subject is a new user.

- Quit Button

  Click this button to quit the game.

- Number of visits

  Enter the number of times the subject will come in for the study.

- Number of repetitions

  Enter the number of repetitions in one visit.

- Duration of a single repetition

  Enter the total time required for a single repetition in seconds here.

- Rest Interval

  Enter the time given as rest between repetitions in seconds here.

- Initial Threshold torque

  Enter the initial threshold torque to be used for the familiarization repetition in Newton meters here.

- Submit Details Button

  Click this button to submit user details to the database.

6.3.2 Control System

Biodex system 3 is the control for the game. There are no other commands or inputs like conventional computer games. The player controls the game by pushing on the knee adapter attached to the biodex system. When the user pushes the knee adapter the torque exerted is obtained as a voltage signal. This signal is retrieved from the analog signal interface of the biodex machine and is transmitted to the game engine. The game engine uses this to control the movement of the charachters in the game.

6.4 Game Implementation

The game is implemented using the control parameters identified from the data analysis(section 5). The user details are gathered through the menu at the beginning of the game. The investigator has to enter the subject's name and the study name. Using this information it is determined whether it is a new user or whether the user is already

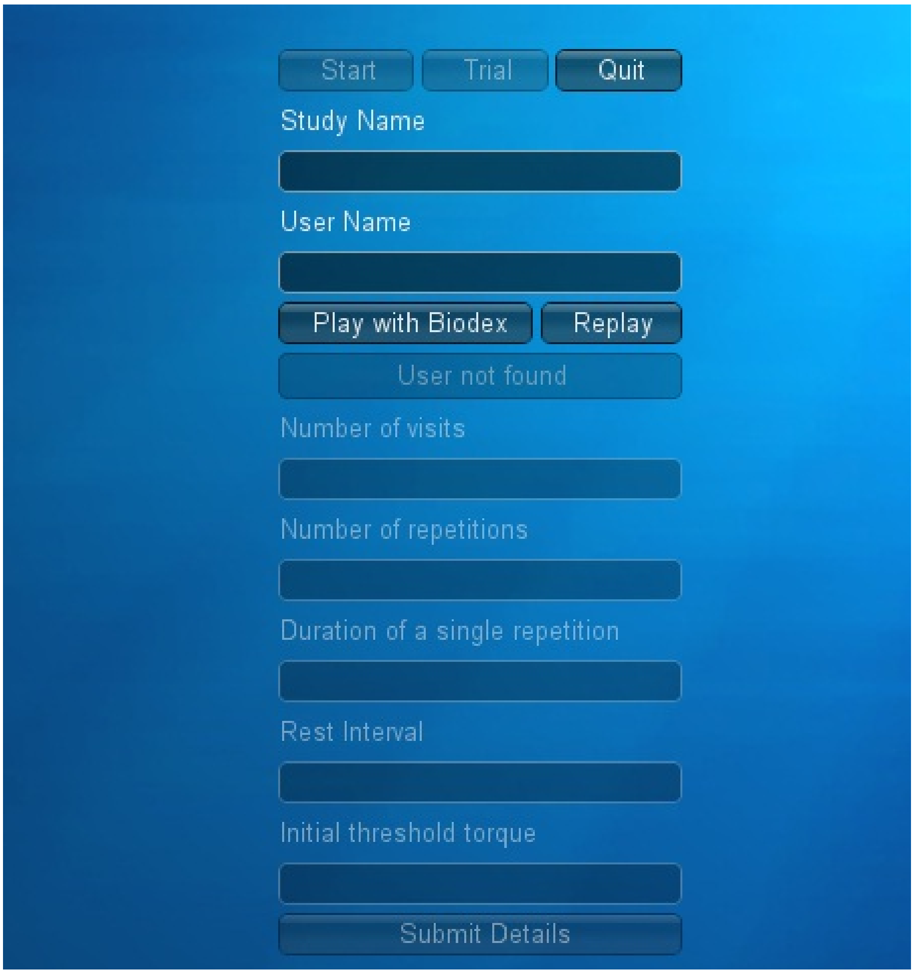


Figure 6.4: Main Menu of the Game

in the database. In case of a new user, details regarding the test protocol such as number of visits, number of repetitions, duration of a repetition and duration of a rest interval are gathered. The investigator will also have to enter an initial threshold for the user based on his knowledge and assumptions.

For a new user a familiarization repetition is conducted to find the initial threshold to be used in the study. For the familiarization repetition the threshold entered by the investigator in the main menu is used as the baseline. After the familiarization repetition, the initial threshold, θ_0, is calculated using the equation 5.3. The threshold entered by the investigator is discarded after this.

For an existing user, the initial threshold is calculated from the history available in the database using the equation 5.2. The initial threshold for all further repetitions in this visit will be the same. The initial threshold will not be updated within a visit. This is because during one of the real evaluations it was noticed that the user found it really demotivating that he could not catch the same amount of fish as in the earlier repetition eventhough he was performance remained more or less similar. It was becoming too hard.

The game works as follows. The torque values from the Biodex machine are read. The school of fish moves between two way points. The shark follows the school. The mean of every twenty samples is calculated. The threshold is compared against this mean torque. If the mean torque is greater than the current threshold the threshold is updated and a catch flag is set to indicate that the user deserves a reward. Once the catch flag is set the reward algorithm is initiated. These steps are continued until the repetition time is over. Once the repetition time is over, the user can relax over a rest interval. A countdown is displayed during the rest interval. After the rest interval the threshold is re-initialized and the repetition continues as above until all the repetitions for the current visit are over. The equations of motion for the fish and shark are discussed below.

- Speed of fish

  Every fish in the school has the same speed. The speed of a fish is directly proportional to torque.

$$\begin{aligned} fish_{vel} &\propto T_i \\ &= \frac{1}{100} T_i \end{aligned} \tag{6.1}$$

- Direction of motion of fish

  The school of fish moves between two way points, $waypoint_1$ and $waypoint_2$, in the environment. It starts at the first way point and moves in the direction of the way point at the end of the environment.

$$Direction_{fish} = \frac{\boldsymbol{Pose_{fish} - Posewaypoint_2}}{|\boldsymbol{Pose_{fish} - Posewaypoint_2}|} \tag{6.2}$$

- Speed of shark The speed of the shark is directly proportional to the current torque

$$\begin{gathered} speed_{fish} = \frac{1}{100} * T_t \\ where\, T_t\, denotes\, the\, torque\, at\, current\, instant\, t \end{gathered} \tag{6.3}$$

- Direction of motion of the shark

  The shark follows the school of fish. So the direction of shark's motion is calculated by finding the position of the last fish in the school.

$$
\begin{aligned}
\boldsymbol{Pose_{shark}} &= 3D\, position\, of\, the\, shark \\
\boldsymbol{Pose_{lastfish}} &= 3D\, position\, of\, the\, fish\, closest\, to\, the\, shark \\
Direction_{shark} &= \frac{\boldsymbol{Pose_{lastfish}} - \boldsymbol{Pose_{shark}}}{|\boldsymbol{Pose_{lastfish}} - \boldsymbol{Pose_{shark}}|}
\end{aligned}
\tag{6.4}
$$

6.4.1 Game Algorithm

The flow chart of the algorithm is depicted in figure 6.5. The game algorithm is explained here.

1. Begin
2. Get the user name and study name.
3. Check whether the user details exist in the database to determine whether it is an existing user. If yes, go to step 6(existing user) else continue,
4. For the new user get details in the test protocol. These are
   (a) Number of visits, N_{visit}
   (b) Number of repetitions, N_{rep}
   (c) Duration of a repetition, T_{rep}
   (d) Duration of a rest interval, T_{rest}
   (e) Initial threshold for familiarization repetition
5. Run familiarization repetition and find initial threshold, θ_0, for the first repetition using the equation 5.3. Go to step 7.
6. Find the initial threshold, θ_0, from database using the equation 5.2.
7. Initialize threshold, $\theta = \theta_0$.
8. Check whether time elapsed in the current repetition is greater than total repetition time, t_{rep}. If yes go to step 17 else continue.
9. Read torque values from the Biodex System.
10. Move the shark by calculating the speed using the equation 6.3 and direction using the equation 6.4.
11. Move the school of fish by calculating the speed using the equation 6.1 and direction using the 6.2.

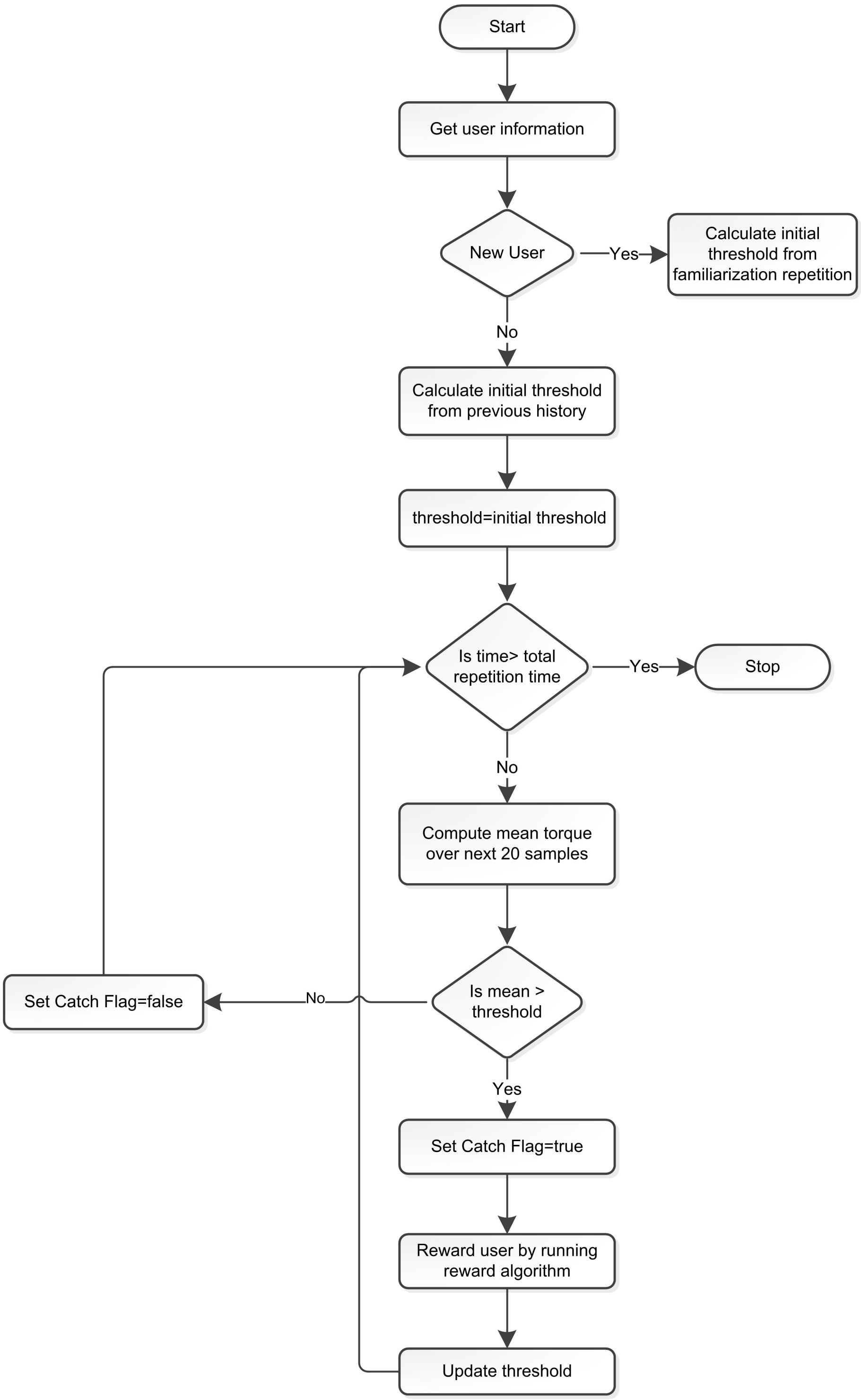


Figure 6.5: Game Logic Overview

12. Calculate mean torque, T_{mean}, for every twenty samples
13. If $T_{mean} > \theta$, $\theta = T_{mean}$ else go to step 8
14. Set $CatchFlag = true$
15. Run Reward Algorithm
16. Go to step 8
17. End

6.4.2 Reward Algorithm

When the user crosses the threshold, the main game algorithm indicates that the user deserves a reward by setting the Catch flag. After the catch flag is set the reward algorithm is called to calculate the speed boost for the shark. The flowchart for this algorithm is depicted in 6.6. The algorithm is explained below.

1. Begin
2. Check whether EnableCatch flag is set to true. If $EnableCatchFlag = true$ go to end
3. Intialize the speed of every fish in the school. The initial speed of each fish in the school is directly proportional to the current torque value.

$$fish_{initspeed} = \frac{1}{100} * T_t \tag{6.5}$$

4. Calculate the speed of shark using the following equation

$$\begin{aligned} \boldsymbol{Pose_{shark}} &= 3D\, position\, of\, the\, shark \\ \boldsymbol{Pose_{lastfish}} &= 3D\, position\, of\, the\, fish\, closest\, to\, the\, shark \\ Distance_{shark,school} &= |\boldsymbol{Pose_{shark}} - \boldsymbol{Pose_{fish}}| \\ Shark_{initspeed} &= \frac{Distance_{shark,school} + fish_{initspeed} * 10}{10} \end{aligned} \tag{6.6}$$

5. Update the speed of every fish in the school in every frame using the following equation

$$speed_{fish} = fish_{initspeed} * 0.90 \tag{6.7}$$

6. Update the speed of the shark in every frame using the equation 6.6
7. Check for collision between shark and fish. If they collide continue else go to step 5

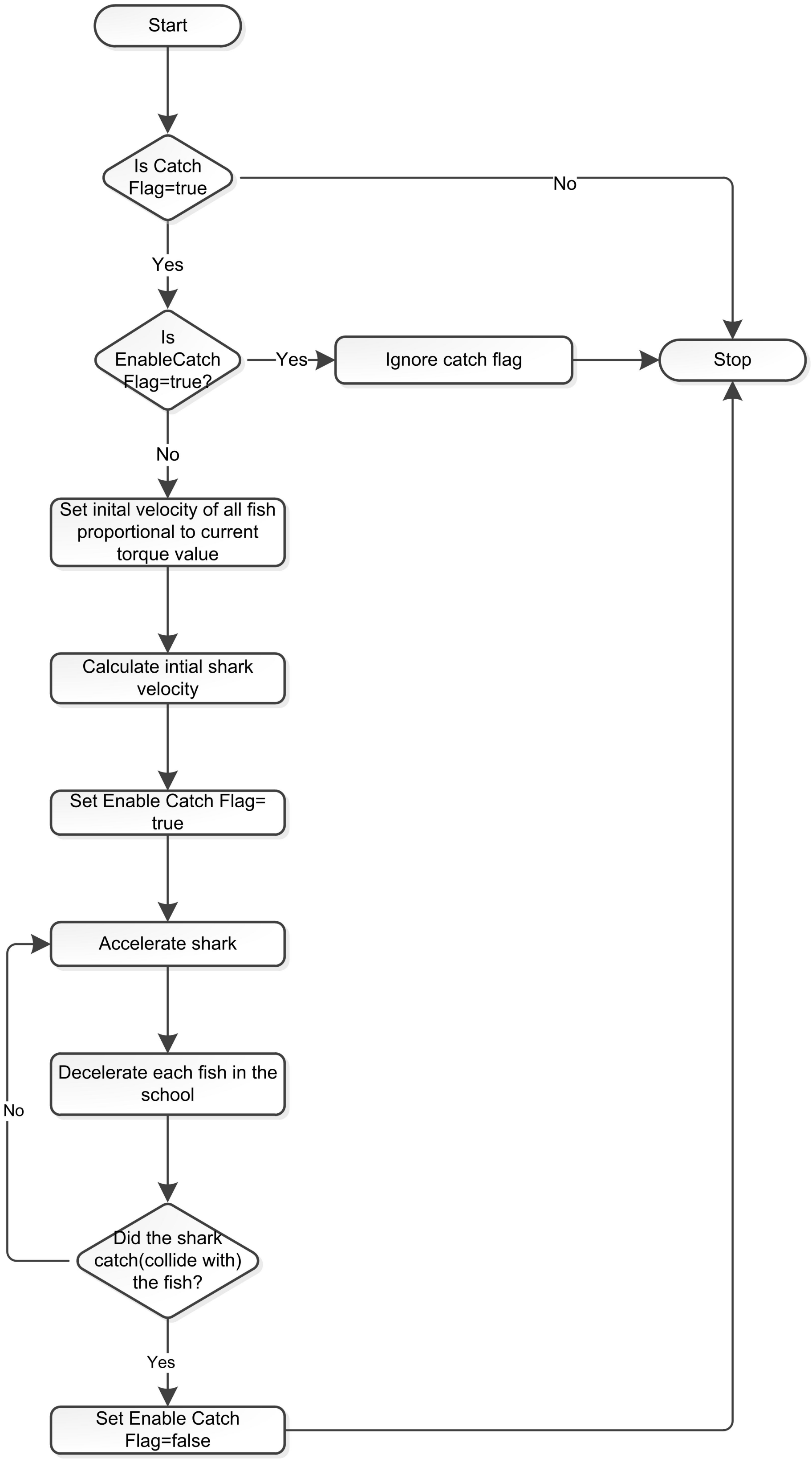


Figure 6.6: Reward Algorithm

8. Set EnableCatch Flag to zero

9. End

Chapter 7

EVALUATION

An evaluation was conducted to analyze the behavior of the program with existing data. This is a retrospective analysis. A different data set from the SAG study is used for evaluation. The torque data for isometric knee testing at 80^{deg} angle setting for the biodex adapter was used. The reward system was analyzed for different torque curves. Different parameters in the reward system are explored.

7.1 Time Analysis of Rewards

.

7.1.1 Analysis of total fish caught in each second by all users

The histogram in figure 7.1 shows the fish caught in each second by all users across all repetitions in all visits. The histogram shows that,

- 36 fish are caught in the zero to one second
- 138 fish are caught in the one to two seconds

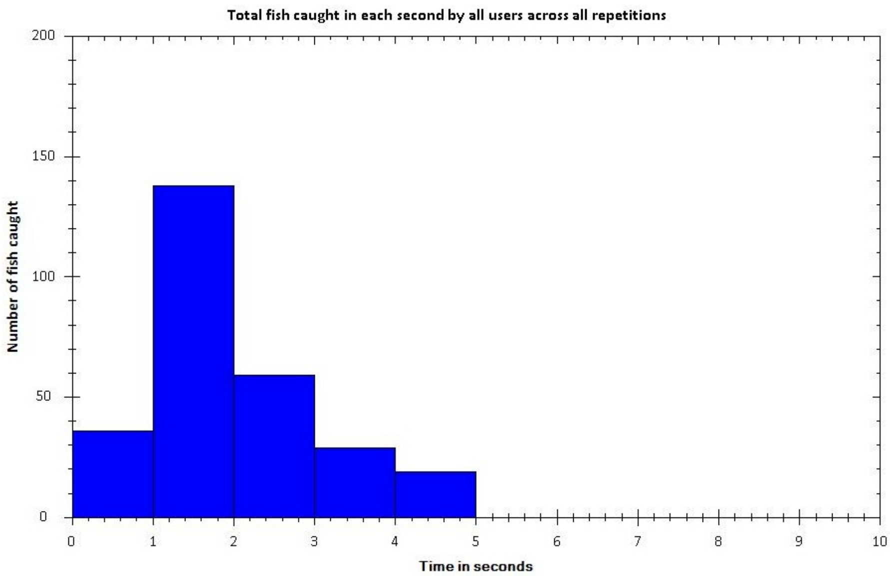


Figure 7.1: Total fish caught in each second by all users across all repetitions in all visits

- 59 fish are caught in the two to three seconds
- 29 fish are caught in the three to four seconds
- 19 fish are caught in the four to five seconds

The relatively low number of fish caught within the first one second is due to the fact that the first 200 to 300ms is the torque development time. The user crosses the threshold and increases the torque after this. Because of the latency in reward, most of the catches in the latter half of first second happens in the next second. The lower number of fish caught in the last two seconds is because of the fact that the subject is reducing the torque exerted after reaching his maximum.

7.1.2 Analysis of relation between rewards and time taken to reach initial threshold

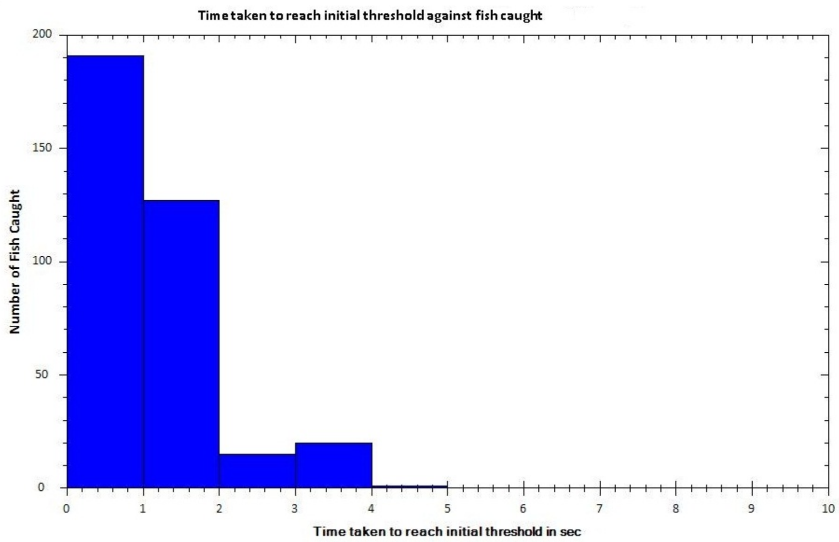
The influence of time taken to reach initial threshold on the total number of rewards is analyzed. A histogram is plotted with the time taken for a subject to reach the threshold against the number of fish caught(figure 7.2(a)). A scatter plot is also displayed in figure 7.2(b). The histogram shows that,

- 175 fish are caught when the subject crosses initial threshold within zero to one seconds
- 90 fish are caught when the subject crosses initial threshold within one to two seconds
- 8 fish are caught when the subject crosses initial threshold within two to three seconds
- 7 fish are caught when the subject crosses initial threshold within three to four seconds
- 1 fish is caught when the subject crosses initial threshold in the fifth second

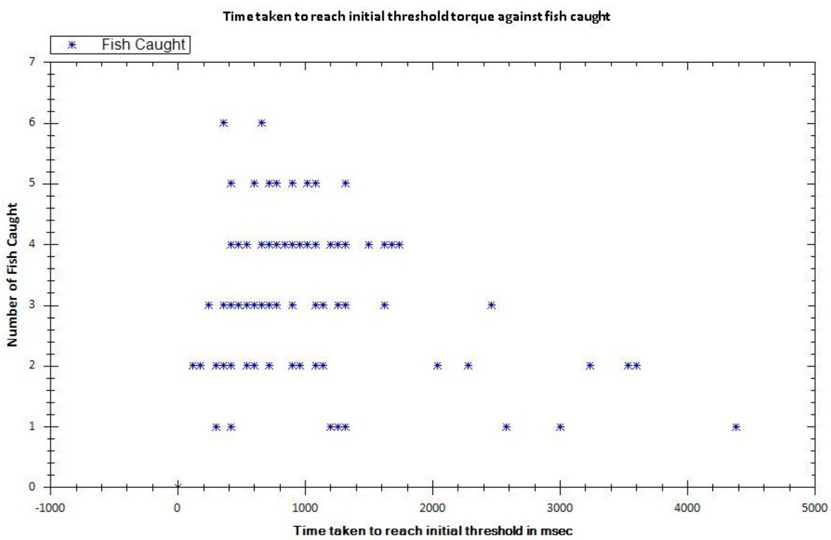
The plot shows that the subject is rewarded more if he crosses the initial threshold in the first one second. The scatter plot in figure 7.2(b) shows that when the intial threshold is crossed after the second second,the rewards are smaller since the subject will not have much time to push harder and gain more rewards.

7.1.3 Analysis of relation between rewards and time taken to reach peak torque

The influence of time taken to reach peak torque on the total number of rewards is analyzed. A histogram is plotted with the time taken for a subject to reach the threshold against the number of fish caught. A scatter plot for this is shown if figure 7.3(b). The histogram shows that,



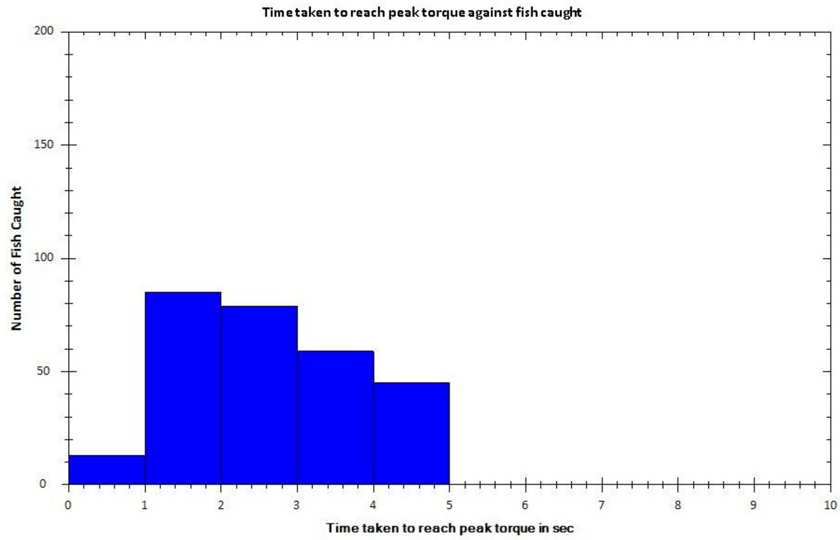
(a) Histogram for fish caught against time taken to reach initial threshold



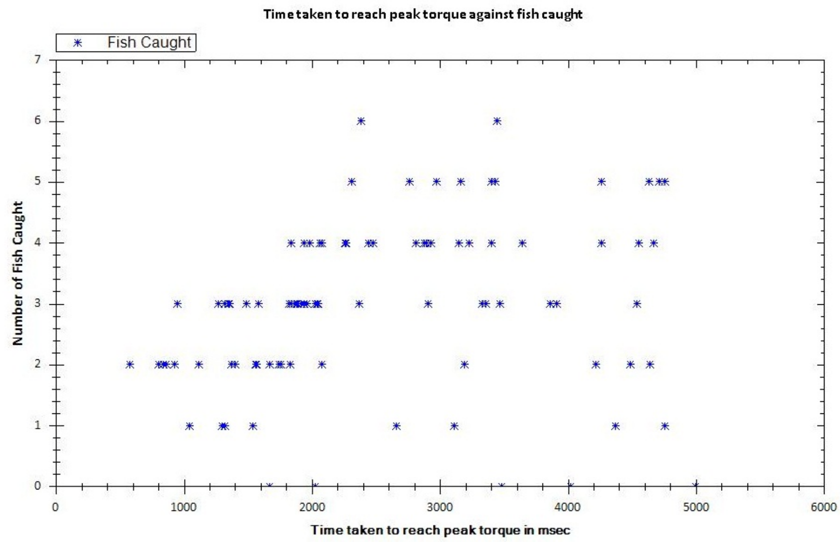
(b) Scatter plot for fish caught against time taken to reach initial threshold

Figure 7.2: Fish caught against time to reach initial threshold

- 13 fish were caught when the subject reached peak torque within zero to one seconds
- 85 fish were caught when the subject reached peak torque within one to two seconds
- 79 fish were caught when the subject reached peak torque within two to three seconds
- 59 fish were caught when the subject reached peak torque within three to four seconds
- 45 fish were caught when the subject reached peak torque within four to five seconds



(a) Histogram for fish caught against time taken to reach peak torque



(b) Scatter plot for fish caught against time taken to reach initial threshold

Figure 7.3: Fish caught against time to reach initial threshold

In this case, the scatter plot shows that relatively small number of fish is caught when the user reaches peak torque within the first second. This is because the threshold gets adapted to the high peak torque and the user is not able to go higher than this. The scatter plot also shows an increase in number of fish caught when the peak torque is attained after the 2 seconds, although the influence is not very pronounced. This is because of the fact that the user increases the torque from initial threshold to peak torque gradually over few seconds collecting rewards continuously.

7.1.4 Latency in Rewards

The time difference between when the user should be rewarded and when he actually gets a reward is analysed here. A histogram was plotted to show the latency across rewards in all repetitions. For a user to get rewarded the user had to overcome the gap between the shark and fish after he was marked for a reward. This resulted in a latency in rewards. In most repetitions, the latency is between 100 to 400msec. There are four events in which the user was marked for a reward but did not get it. This was because the user is marked for the reward towards the end of a repetition and repetition ended before the user could be rewarded. The average latency for rewards is 288msec.

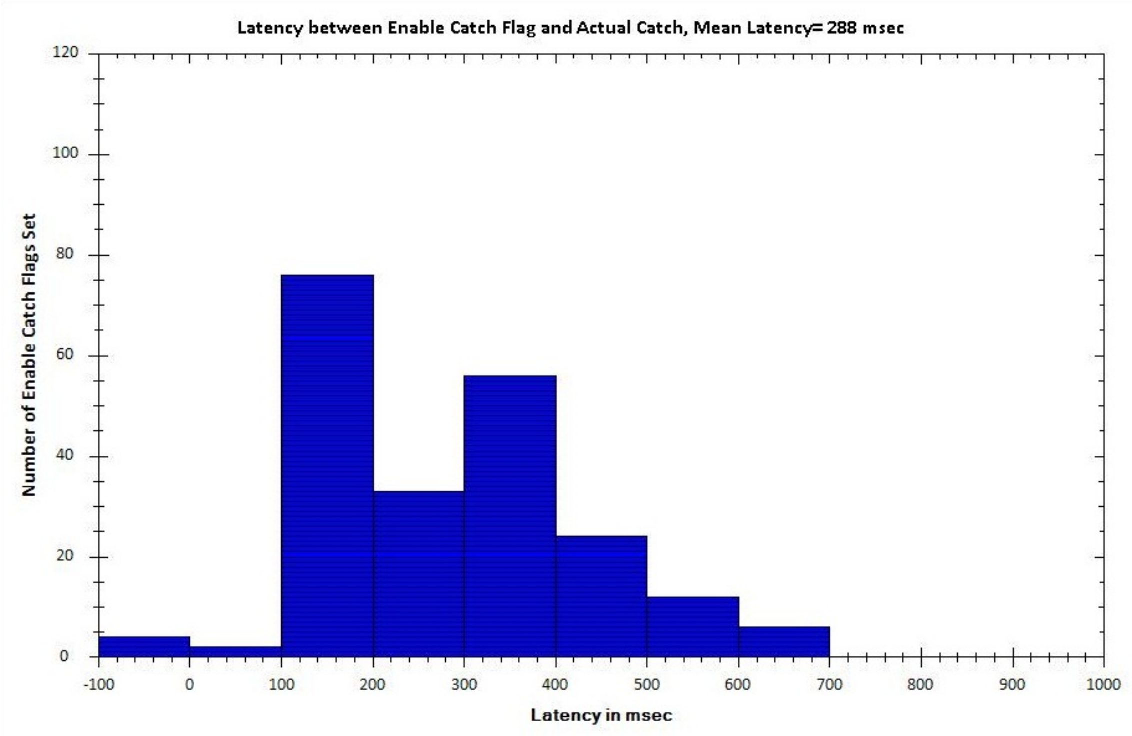


Figure 7.4: Latency in rewards

7.2 Analysis of game events for different torque curves

The game was analyzed for different torque curves.

- Subject crosses initial threshold in the last second

  In the repetition depicted in 7.5, the user crosses the intial threshold of 186Nm only in the last second at 4380 ms.The catch flag is set instantly. The speeds of shark and fish are calculated and the enable catch flag is set in 40ms. The user is rewarded right before the repetition ends. The subject reaches a maximum peak torque of 193Nm in this repetition where as his peak torque in all repetitions is 233Nm. In this case the user is never rewarded before he crossed threshold. This is expected to act as negative reinforcement.

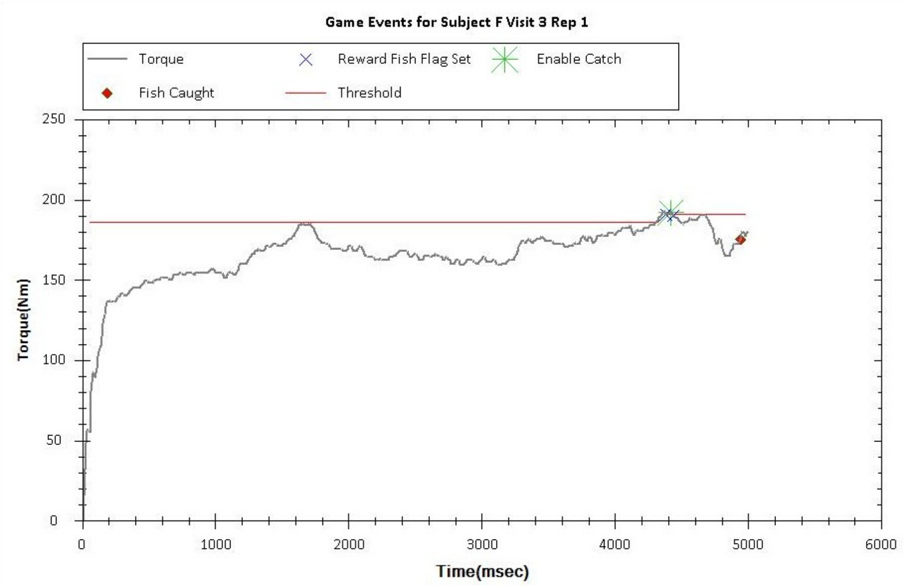


Figure 7.5: A repetition in which subject crosses initial threshold in the last second

- Subject goes above initial threshold and sustains it to reach peak

  The torque response for first and third repetitions of a subject in the same visit is depicted in 7.6 and 7.7. In the first repetition the user is rewarded five times and for the third one the user is rewarded six times. Since both the repetitions are within the same visit, they both had an initial threshold of 197Nm. The subject reaches a peak torque of 276 Nm in the first repetition and 279Nm in the second repetition. The user crosses the initial threshold a little before first second.The user increases the torque gradually after crossing the initial threshold to reach the peak torque. So the number of fish caught is high in these two repetitions(7 is the maximum number of fish caught by any subject in all repetitions across all visits).There is a mean latency of 324msec in rewards for the first repetition and 261.67msec for the third repetition.

- Subject goes above the initial threshold but does not sustain it to reach peak

  In the repetition depicted in figure 7.8, the subject goes above the threshold a little after one second (1200ms). The user is rewarded with a latency of 350msec for this. After this, since the user goes below the threshold, there are no more rewards. The subject should push hard to get rewarded again. Since this is a retrospective analysis the reaction of the user to not getting a reward and the corresponding torque

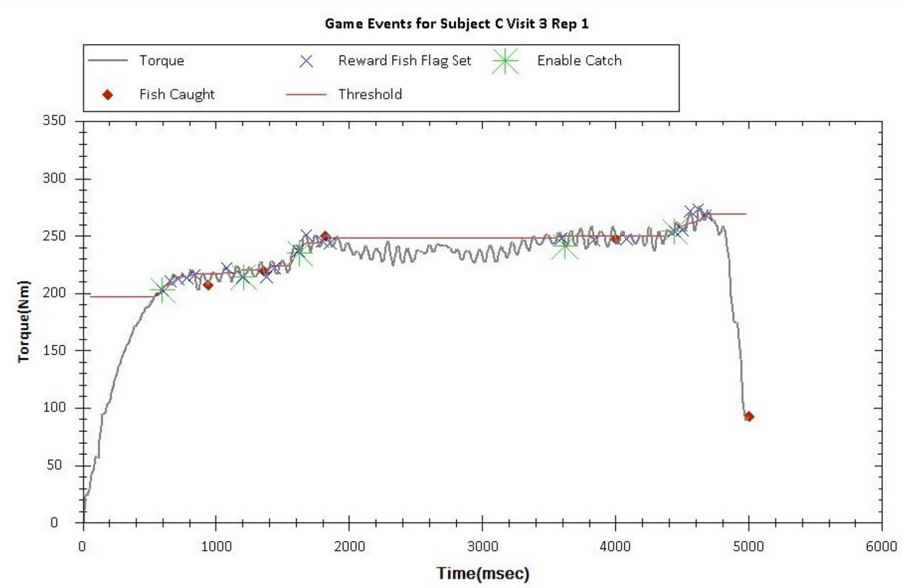


Figure 7.6: A repetition in which subject goes above initial threshold and sustains it to reach peak

response could not be analyzed. But it is expected that the user would try harder to get a reward and the torque response will change.

- Subject crosses threshold and reaches peak torque early in the repetition

  In the repetition depicted in figure 7.9, the subject crosses threshold at around 1 second (1080 msec) and reaches peak torque of 288Nm within two seconds. He is rewarded twice for that upward climb in torque. But the number of fish he got did not increase since torque exerted goes down after it. But the peak torque he reached is close to his maximum in all visits(301Nm). In this game rewards are not directly proportional to the peak torque. User is rewarded more if the he gradually increases torque over time.

- Repetitions where the subject never went above threshold

  In the repetition depicted in figure 7.10, the user does not go above the initial threshold of 225 Nm. The peak torque reached in this repetition is 210 Nm which is much below his peak torque in all repetitions (303 Nm). The user is never rewarded. The user has to push hard to get the reward and threshold is never reduced. A few undocumented trials on the Biodex showed that getting rewarded too frequently is not motivating. The subject is more motivated to work hard when he could not get the fish.

- A repetition with peaks and valleys in the torque curve

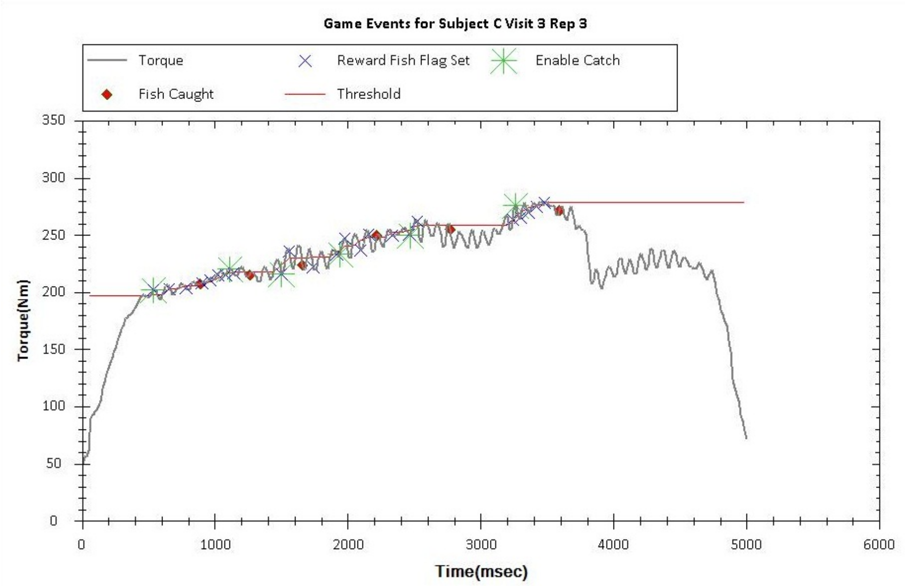


Figure 7.7: A repetition in which subject goes above initial threshold and sustains it to reach peak

In a repetition as shown in figure 7.11 where the user goes above an initial threshold of 237 Nm within 1620 msec , but the torque exerted goes up an down frequently after it.The user was rewarded for the upward climbs three times.

The evaluation of the game shows that the game encourages the user to improve his torque output by continuously rewarding him for any increase in torque exerted. The game also encourages a user to cross the initial threshold faster to gain more rewards. The analysis of game events for the torque curves shows that the game provides appropriate motivation for different kinds of torque curves, although the latency in rewards delayed the encouragement at the right time.

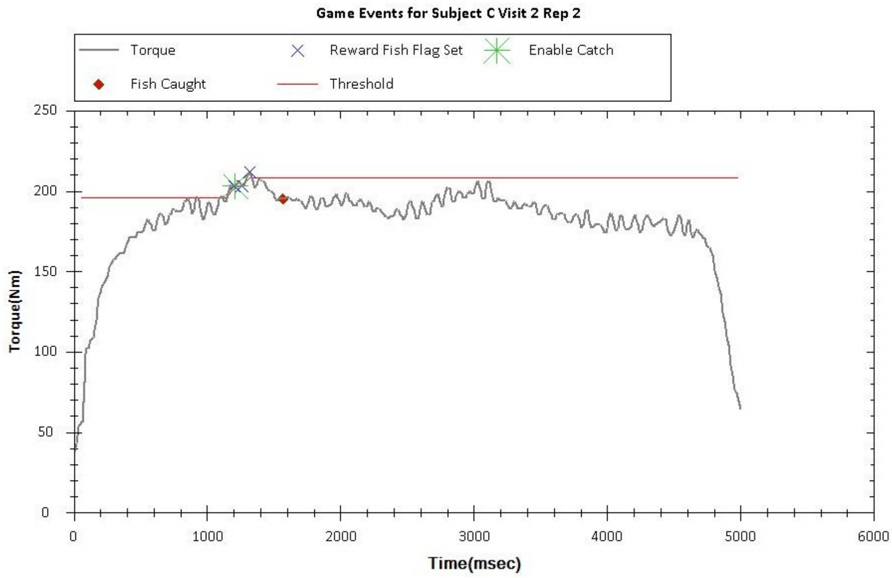


Figure 7.8: Subject goes above the initial threshold but does not sustain it to reach peak

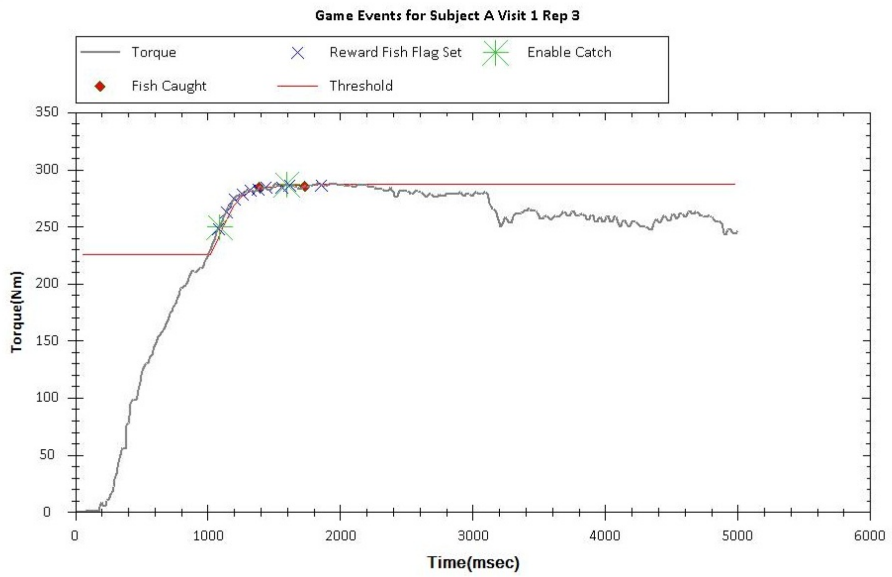


Figure 7.9: Subject crosses threshold and reaches peak torque within the first two seconds

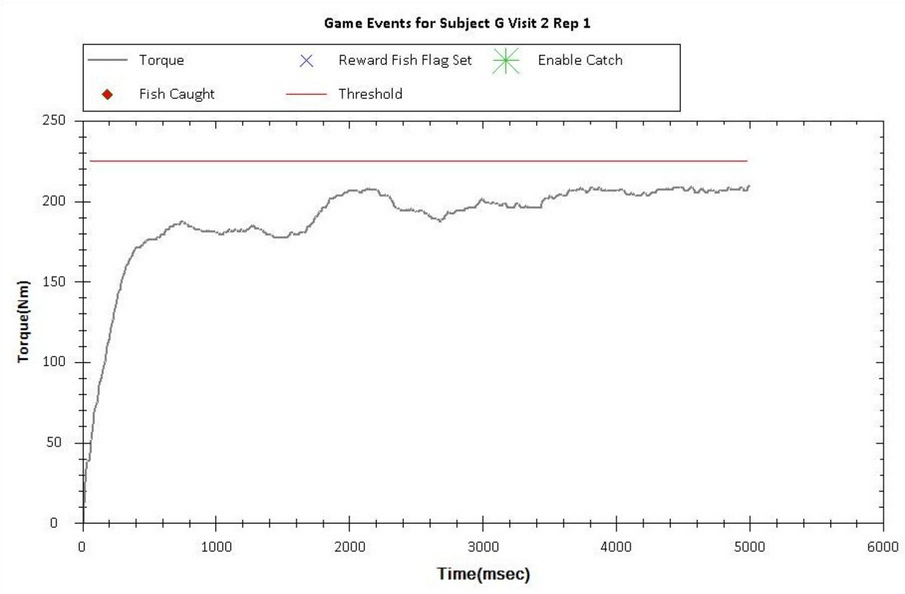


Figure 7.10: Repetitions where the subject never went above threshold

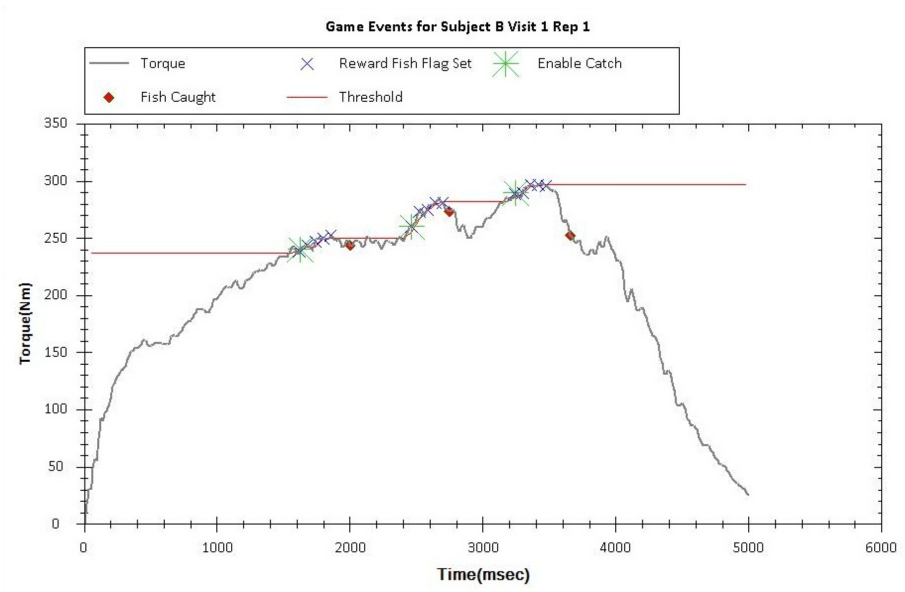


Figure 7.11: A repetition with peaks and valleys in the torque curve

Chapter 8

CONCLUSION AND FUTURE WORK

8.1 Summary

A game based motivation system is implemented to motivate subjects in a maximal strength test for the knee extensor muscle under isometric conditions. The data from a previous study is used to understand the torque characterestics. The data for isometric knee extension tests of eight subjects is used for the analysis. It is observed that most subjects reached eighty percent of the maximum torque they exerted in a repetition within the first two seconds and peak torques are usually achieved within two to four seconds.

The nature of torque response is analysed in different repetitions based on an initial threshold torque.To analyze the real time torque data in the game, more parameters are identified. The torque curve was analyzed over small sampling intervals. The mean of the samples in an interval is used to understand user's torque response in that interval. Depending on the value of the mean torque the threshold is updated and the user is rewarded. The game and reward algorithm are derived from the data analysis.

The shark and school of fish game was used to motivate and reward the user continuously during a repetition . In the game , the speed of the shark and fish reflects the torque exerted by the user. But once the user goes above the threshold, it gets a speed boost to catch the last fish. After this the shark will decelerate and return to a speed proportional to the current torque value. The user can perceive his performance through the number of fish caught.

An evaluation is performed using existing data to understand the behaviour of the game for different torque curves. It is observed that the game gives the maximum number of rewards when the fish crosses intial threshold early in the repetition. The game also gives more rewards when the user crosses the threshold within the first second and gradually increse peak torque. When peak torque is attained faster(within 2 sec), the user gets rewarded for that rise but after that he will not get any rewards since the threshold is already adapted to a higher torque value. So a bigger gap between intial threshold and peak torque does not necessarily mean more number of rewards.

8.2 Future Work

Some open issues and suggestions for improvement are addressed here for future work.

The evaluation of the prototype game system is performed using existing data. The game has to be tested with new subjects to assess how the program influences the torque response. The system has to be evaluated to test the following hypothesis

- Game based motivation generates higher mean values than verbal motivation.
- Game based motivation will result in smaller standard deviation

The visual interface of the game can also be improved. In the current implementation, when a fish is caught ,the shark comes very close to the fish the fish disappears . The animation of the shark eating the fish should be implemented for a better understanding of what is happening in the game. The game can also benefit from more interesting visual prompts in the interface to keep the user interested across multiple visits.

BIBLIOGRAPHY

[ALC+02] J.L. Andreacci, L.M. Lemura, S.L. Cohen, E.A. Urbansky, S.A. Chelland, and S.P. von Duvillard. The effects of frequency of encouragement on performance during maximal exercise testing. *Journal of sports sciences*, 20(4):345–352, 2002.

[AMD+09] M.A. Adams, S.J. Marshall, L. Dillon, S. Caparosa, E. Ramirez, J. Phillips, and G.J. Norman. A theory-based framework for evaluating exergames as persuasive technology. In *Proceedings of the 4th International Conference on Persuasive Technology*, page 45. ACM, 2009.

[Bio12] Biodex. Dynamometers, March 2012.

[BMC+09] J.W. Burke, MDJ McNeill, DK Charles, PJ Morrow, JH Crosbie, and SM McDonough. Serious games for upper limb rehabilitation following stroke. In *Games and Virtual Worlds for Serious Applications, 2009. VS-GAMES'09. Conference in*, pages 103–110. IEEE, 2009.

[Bog05] I. Bogost. The rhetoric of exergaming. In *Digital Arts and Cultures (DAC) Conference (December 2005), IT University Copenhagen*, 2005.

[Car81] L.G. Carlton. Processing visual feedback information for movement control. *Journal of Experimental Psychology: Human Perception and Performance*, 7(5):1019, 1981.

[CMK00] B. Campenella, C.G. Mattacola, and I.F. Kimura. Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females. *Isokinetics and exercise science*, 8(1):1–6, 2000.

[CNF08] T. Campbell, B. Ngo, and J. Fogarty. Game design principles in everyday fitness applications. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, pages 249–252. ACM, 2008.

[FM84] SF Figoni and AF Morris. Effects of knowledge of results on reciprocal, lsokinefk strength and fatigue. *The Journal of orthopaedic and sports physical therapy*, 6(3):190, 1984.

[FTSC10] D.D. FitzgeralD, N. Trakarnratanakul, B. Smyth, and B. Caulfield. Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. *journal of orthopaedic & sports physical therapy*, 40(1):11–19, 2010.

[GAC12] http://www.dlr.de/me German Aerospace Center. Physiology laboratory at the institute of aerospace medicine, March 2012.

[GDW12] http://sketchup.google.com/3dwarehouse Google 3D Warehouse. 3d models, March 2012.

[GHW+10] S. Goebel, S. Hardy, V. Wendel, F. Mehm, and R. Steinmetz. Serious games for health: personalized exergames. In *Proceedings of the international conference on Multimedia*, pages 1663–1666. ACM, 2010.

[HB87] RD Hald and EJ Bottjen. Effect of visual feedback on maximal and submaximal lsokinetic test measurements of normal quadricem-and hamstrings. *The Journal of orthopaedic and sports physical therapy*, 9(3):86, 1987.

[Hei] S. Heidi. Motor rehabilitation using virtual reality. *Journal of NeuroEngineering and Rehabilitation*, 1.

[htt12] http://www.semisportmed.com. Sports and exercise medicine institute, biodex system 3, March 2012.

[JH04] M.C. Jung and M.S. Hallbeck. Quantification of the effects of instruction type, verbal encouragement,and visual feedback on static and peak handgrip strength. *International Journal of Industrial Ergonomics*, 34(5):367–374, 2004.

[LML+06] J. Lin, L. Mamykina, S. Lindtner, G. Delajoux, and H. Strub. Fishnsteps: Encouraging physical activity with an interactive computer game. *UbiComp 2006: Ubiquitous Computing*, pages 261–278, 2006.

[MDBS96] P.J. McNair, J. Depledge, M. Brettkelly, and S.N. Stanley. Verbal encouragement: effects on maximum effort voluntary muscle: action. *British journal of sports medicine*, 30(3):243–245, 1996.

[ME12] http://www.meilhaus.de Meilhaus Electronic. Fs1608 usb module, March 2012.

[MJB+02] A.S. Merians, D. Jack, R. Boian, M. Tremaine, G.C. Burdea, S.V. Adamovich, M. Recce, and H. Poizner. Virtual reality–augmented rehabilitation for patients following stroke. *Physical therapy*, 82(9):898–915, 2002.

[MVHV03] S. Mokka, A. Väätänen, J. Heinilä, and P. Välkkynen. Fitness computer game with a bodily user interface. In *Proceedings of the second international conference on Entertainment computing*, pages 1–3. Carnegie Mellon University, 2003.

[SHM07] J. Sinclair, P. Hingston, and M. Masek. Considerations for the design of exergames. In *Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia*, pages 289–295. ACM, 2007.

[SW05] P. Sweetser and P. Wyeth. Gameflow: a model for evaluating player enjoyment in games. *Computers in Entertainment (CIE)*, 3(3):3–3, 2005.

[WBH+07] D.E.R.W.D.E.R. Warburton, S.S.D.B.S.S.D. Bredin, L.T.L.H.L.T.L. Horita, D.Z.D. Zbogar, J.M.S.J.M. Scott, B.T.A.E.B.T.A. Esch, and R.E.R.R.E.

Rhodes. The health benefits of interactive video game exercise. *Applied Physiology, Nutrition, and Metabolism*, 32(4):655–663, 2007.

[WMA06] L.M. Widman, C.M. McDonald, and R.T. Abresch. Effectiveness of an upper extremity exercise device integrated with computer gaming for aerobic training in adolescents with spinal cord dysfunction. *The journal of spinal cord medicine*, 29(4):363, 2006.

[YG07] J. Yim and TC Graham. Using games to increase exercise motivation. In *Proceedings of the 2007 conference on Future Play*, pages 166–173. ACM, 2007.

[YT11] G.N. Yannakakis and J. Togelius. Experience-driven procedural content generation. *Affective Computing, IEEE Transactions on*, 2(3):147–161, 2011.

Appendix A

Analysis of Torque Data in Matlab for Derivation of the Game Algorithm Case 1- θ is decreased

The analysis of the torque curves discussed in the section 5 in matlab is shown in the figures below. The analysis follows the algorithm in the figure 6.5 to some extent. The difference is that the threshold is reduced when the user does not cross the initial threshold. The threshold is also reduced by fifty percent of the mean torque when the user is not crossing the current threshold.

In the following graphs

- Thresholds are displayed as numbers next to green dots on the curve
- f=1 denotes that the user deserves a reward for the past interval
- f=0 denotes that the user does not deserve a reward for the past interval

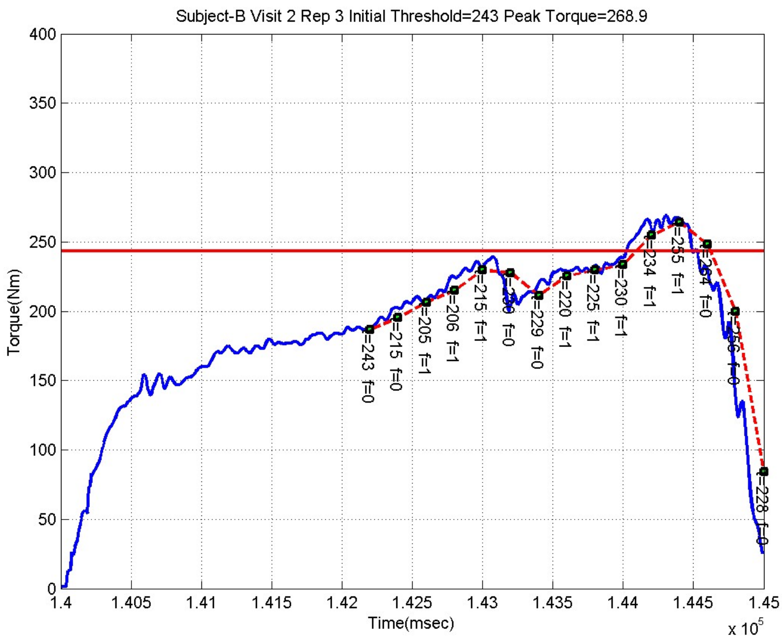


Figure A.1: A repetition in which subject crosses initial threshold in the last second

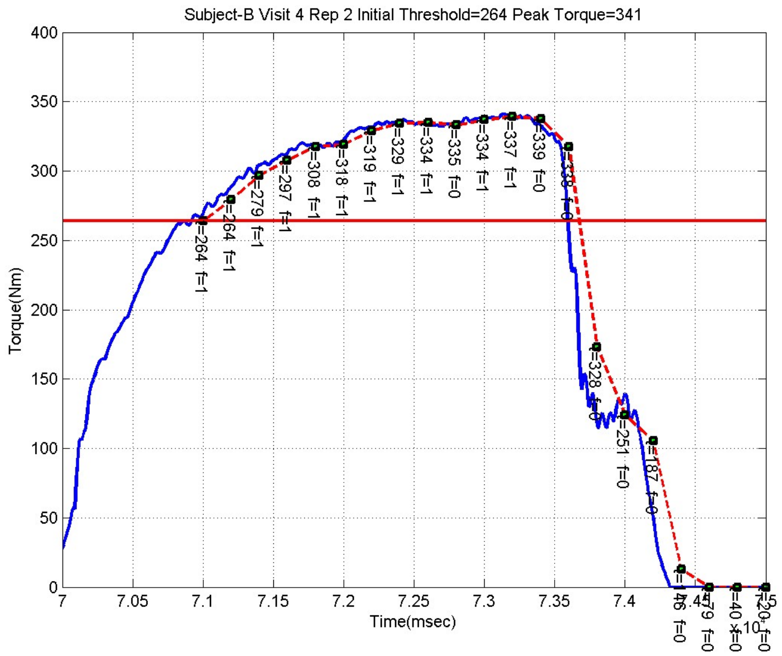


Figure A.2: A repetition in which subject goes above initial threshold and sustains it to reach peak

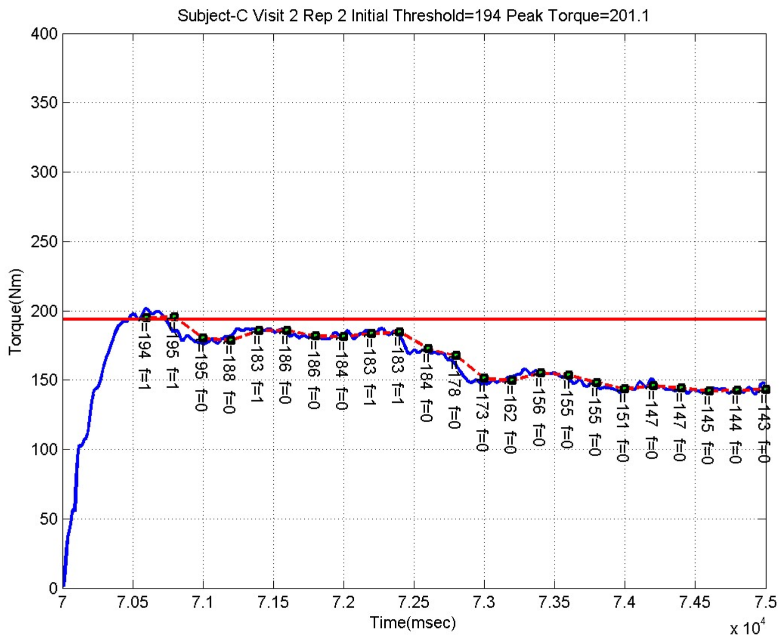


Figure A.3: A repetition in which subject goes above the threshold but does not sustain it to reach peak

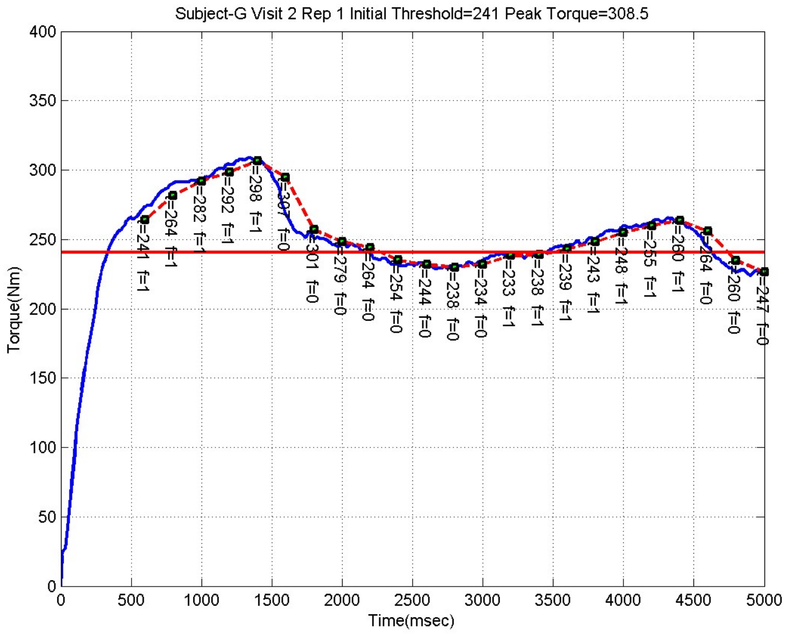


Figure A.4: A repetition in which subject crosses threshold and reaches peak torque in the first two seconds

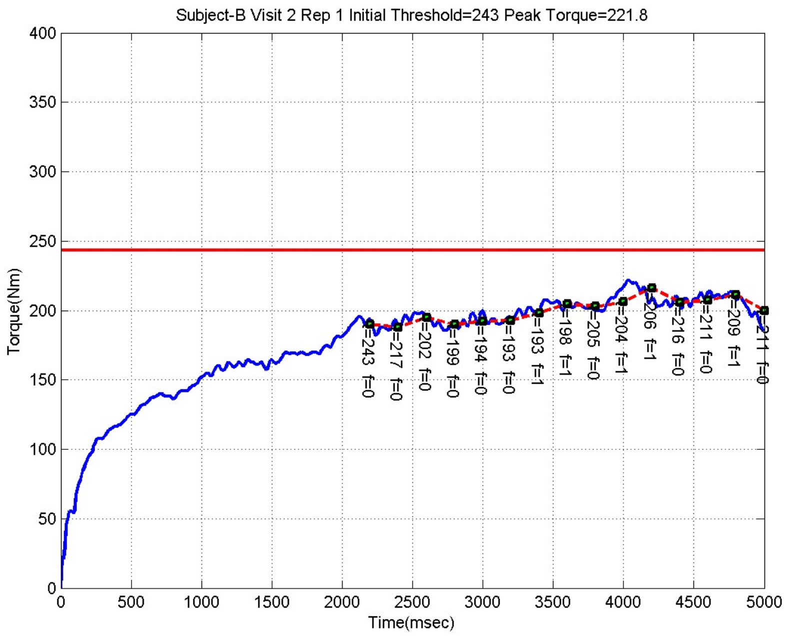


Figure A.5: A repetition in which subject does not cross initial threshold

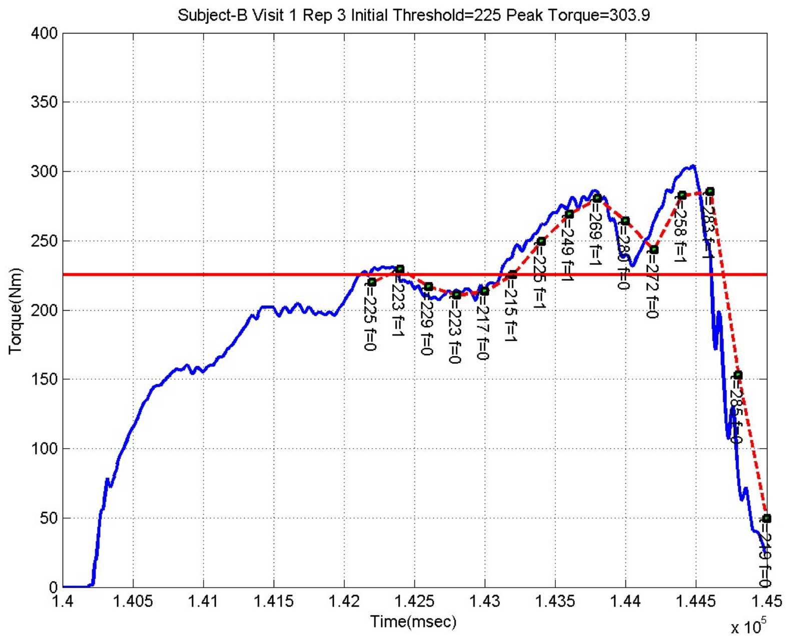


Figure A.6: A repetition with peaks and valleys in the torque curve

Appendix B

Analysis of Torque Data in Matlab for Derivation of the Game Algorithm Case 2- θ not decreased

The analysis of the torque curves discussed in the section 5 in matlab is shown in the figures below.The analysis follows the algorithm in the figure 6.5, the implemented algorithm.

In the following graphs

- Thresholds are displayed as numbers next to green dots on the curve
- f=1 denotes that the user deserves a reward for the past interval
- f=0 denotes that the user does not deserve a reward for the past interval

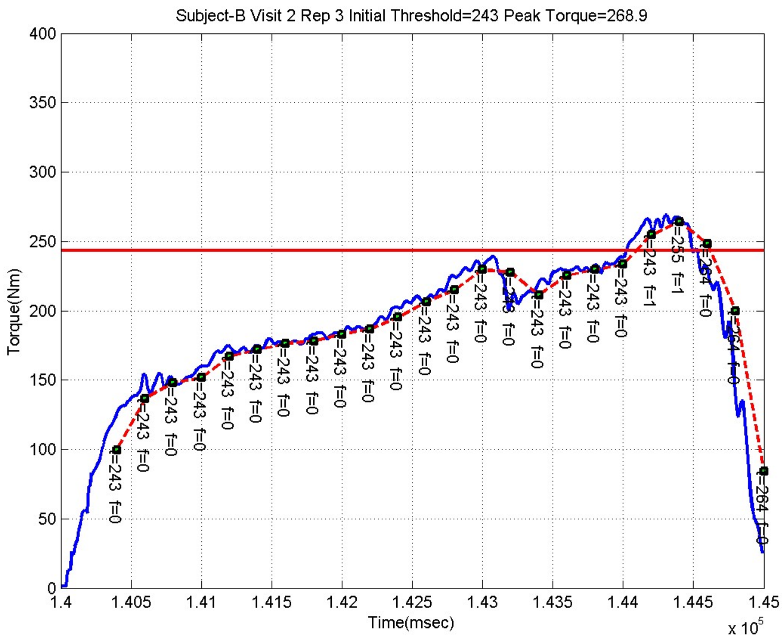


Figure B.1: A repetition in which subject crossed initial threshold in the last second

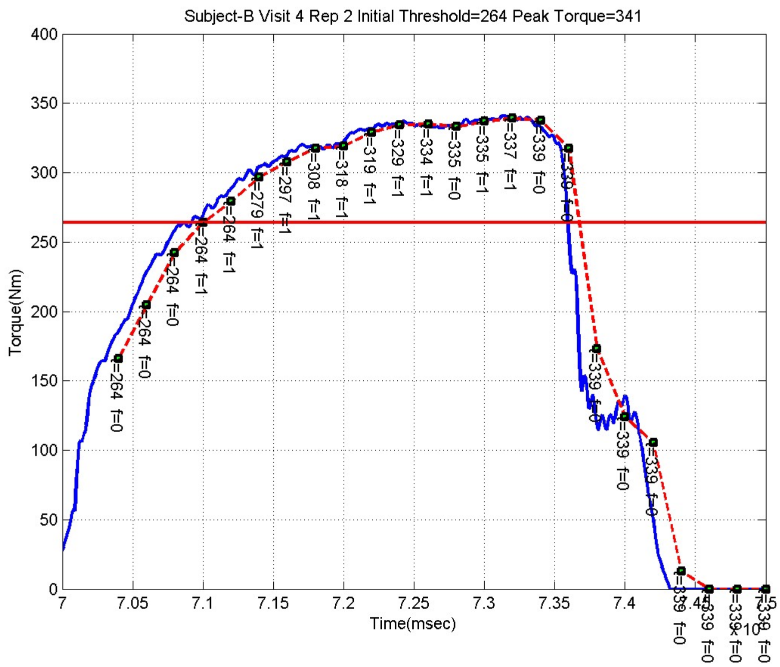


Figure B.2: A repetition in which subject went above threshold and sustained it to reach peak

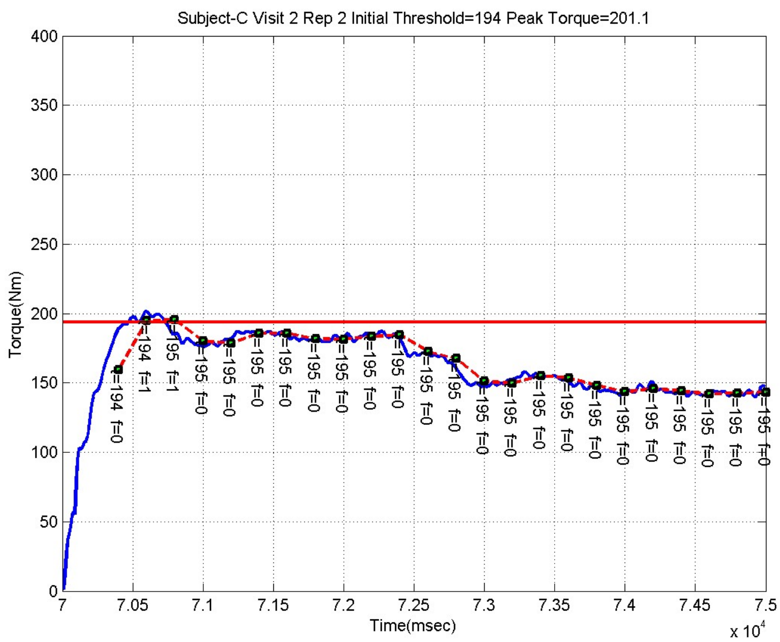


Figure B.3: Went above the threshold but did not sustain it to reach peak

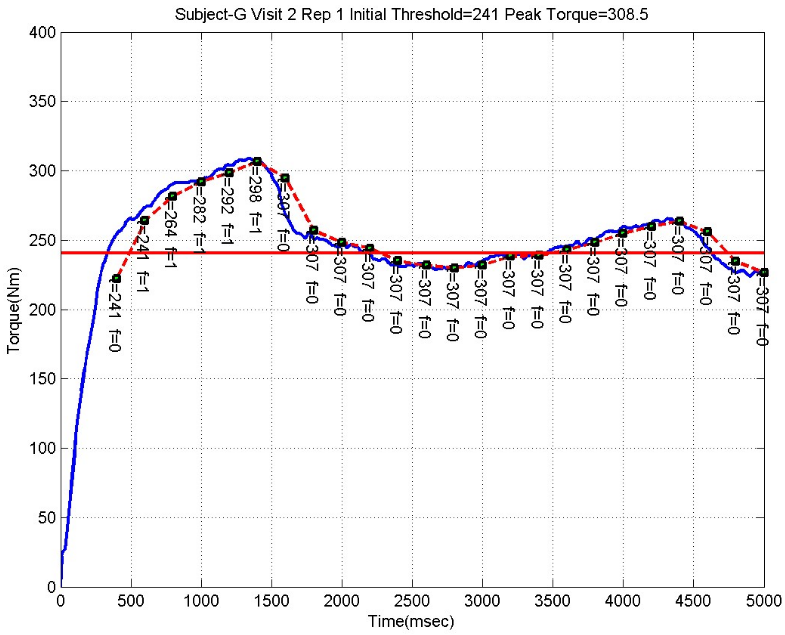


Figure B.4: Subject crossed threshold and reached peak torque in the first two seconds

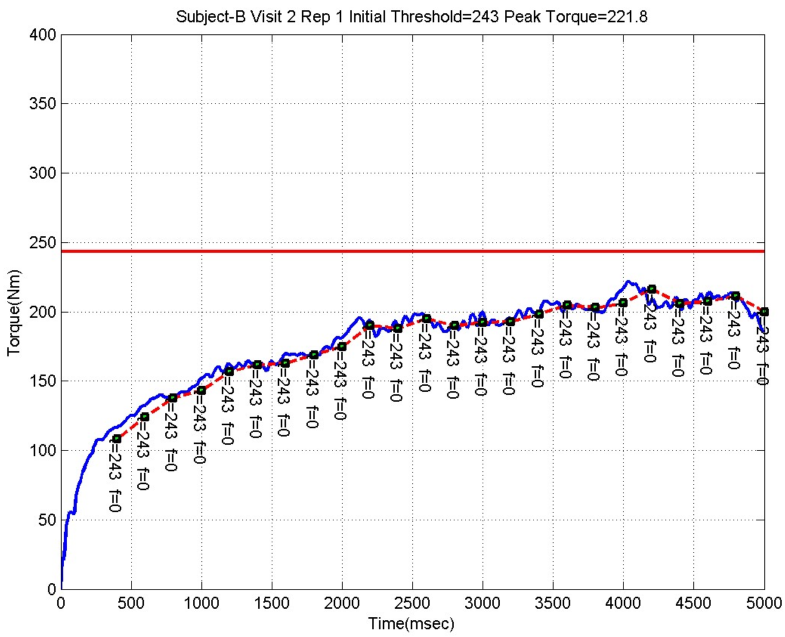


Figure B.5: A repetition in which subject never crossed initial threshold

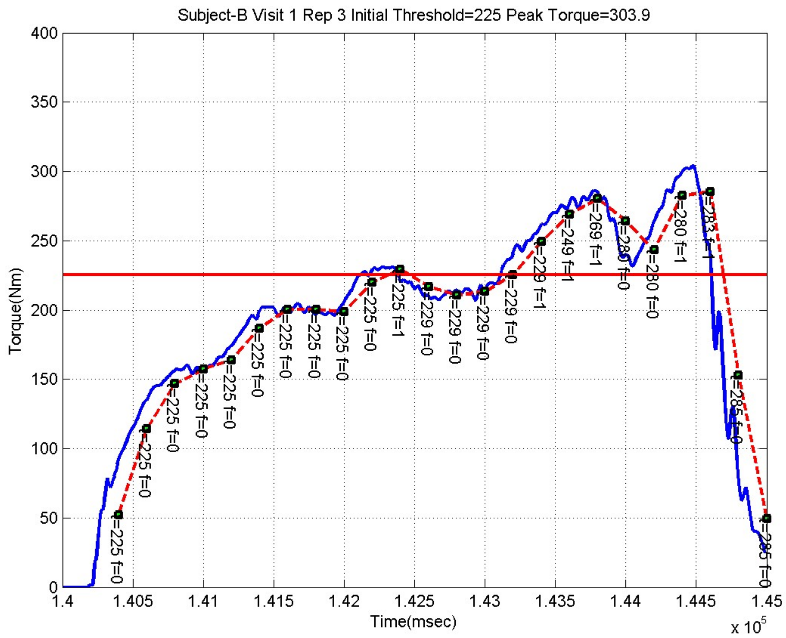


Figure B.6: A repetition with a lot of peaks and valleys in the torque curve