Course Number: ME-GY 99662

MS Project Report

Upper Extremities Rehabilitation Monitoring using Wearable Sensor

Submitted in partial fulfillment for the degree of

Master of Science (MS) in Mechatronics and Robotics.

by

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Mechanical and Aerospace Engineering

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Abstract

Rehabilitation is crucial for recovery of the lost motor function for individuals after neurological events such as stroke. This project aims to develop a user interface for visualizing, monitoring, and data acquisition for a Myo armband. Additionally, a game-based rehabilitation interface for stroke patients, which utilize acceleration and orientation data from Myo armband for practicing therapeutic exercises. The key purpose of this system is to motivate stroke patients for performing rehabilitation exercise specifically for fine motor skills such as hands. Additionally, therapists and physicians can gauge the progress of the patient by capturing the motion and muscle activities of the forearm using electromyography sensors and inertial measurement unit of Myo Armband. The developed applications will enable the user to pursue exergames in home-based setting and allow therapist/physicians to monitor the progress of outpatients remotely, than have them to come to the clinic. The developed gaming application is tested with ten neurologically tact subjects for usability and cognitive workload evaluations. The results show project the developed interfaces are appealing to users and do not pose any cognitive burden to the users.

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1. Introduction

This report describes the development of rehabilitation monitoring and gaming interfaces for recovery of hand motor skills in stroke patients. The system integrates a wearable armband, Myo armband with two distinct interfaces for 1.) Measurement and Monitoring and 2) Gaming and therapy. The measurement and monitoring interface is used by both the patients as well as therapists to see the progress made in their range of motion of upper arms.

The Myo armband is equipped with 8 EMG sensors in the form of pods which acquires the muscle activities in the patient's forearm. One of pod also contains an IMU sensor which can capture the accelerometer, gyroscope and magnetometer data in 3 principal axes. These data are sent to a computer via a Bluetooth adapter after making sure that Myo armband is connected to Myo Connect software.

For the first interface, a modular approach is chosen involving three levels of motions. In the first level, the patient does supination/pronation of forearm in 3 principal axes. In the second level, the patient does gestures like extension/flexion of the wrist and opening/closing of the fist. The third and final levels involve lifting of an instrumented object. While doing all these activities, the patient can choose to view the acceleration, orientation or EMG data involved with a specific movement. All these data are also saved in a directory to measure the improvements in subsequent practices.

The second interface is a gaming interface, where the patient while wearing the Myo armband on their forearm, moves his hand in 3D space to move a ball on a computer screen and finished the desired task. The game developed here requires the user to move a ball forward so that it falls into a hole at the end of a rectangular surface. The movement of the hand and the corresponding direction of the ball is also clearly mentioned in this interface. To further increase the level of engagement and motivation of the patients, a number of collectibles are placed on the surface which when collected increases their score level.

After developing the interfaces, a number of trials were conducted to evaluate the reliability and efficiency of the system. Factors like the weight and comfort of the system, system stability, level of engagement, potential fatigue and the statistics of the game (score, time, win/defeat) were considered during the evaluation process. A number of subjective as well as objective tests were conducted to gather data about each aspect involved in this project.

2. Hardware

To develop the prototype, a number of essential hardware devices and modules were used in this project. Following are the hardware components used in this project followed by a detailed description of each of the devices:

- **Armband:** 1 x Myo Armband by Thalmic Labs
- **Standard Micro-USB Cable** by Thalmic Labs
- **Bluetooth adapter:** 1 x USB Bluetooth adapter by Thalmic Labs
- **Sizing clips:** 10 x Myo sizing clips

Figure 1: Myo armband setup (Source: www.myo.com)

1. *Myo Armband*

The Myo armband manufactured by Thalmic Labs is a gesture control device that enables the user to control virtual interfaces such as video games, presentations, media center navigation, etc. wirelessly using different hand gestures. It uses 8 stainless steel electromyography (EMG) sensors that sense electrical activity in the forearm muscles, along with a 9-axis Inertial measurement unit (IMU) to recognize gestures. It also encompasses an ARM Cortex M4 processor compatible with many platforms.

It differs from the Leap Motion device as it is worn rather than a 3D array of cameras that sense motion in the environment. It is a promising option in terms of facility, convenience, and cost for signal acquiring, conditioning, preprocessing and transmission. It has an electrically safe setup with low voltage battery and Bluetooth LE protocol, eight sEMG sensors working at a frequency of 200 Hz and a three-axis gyroscope, accelerometer, and magnetometer, working at 50 Hz. EMG signals are already filtered through notch filters at frequencies of 50 Hz and 60 Hz in order to take out any powerline interference. Moreover, the device comes with an SDK, which is very suitable for the development of standalone applications.

The following image illustrates the main components of the Myo armband:

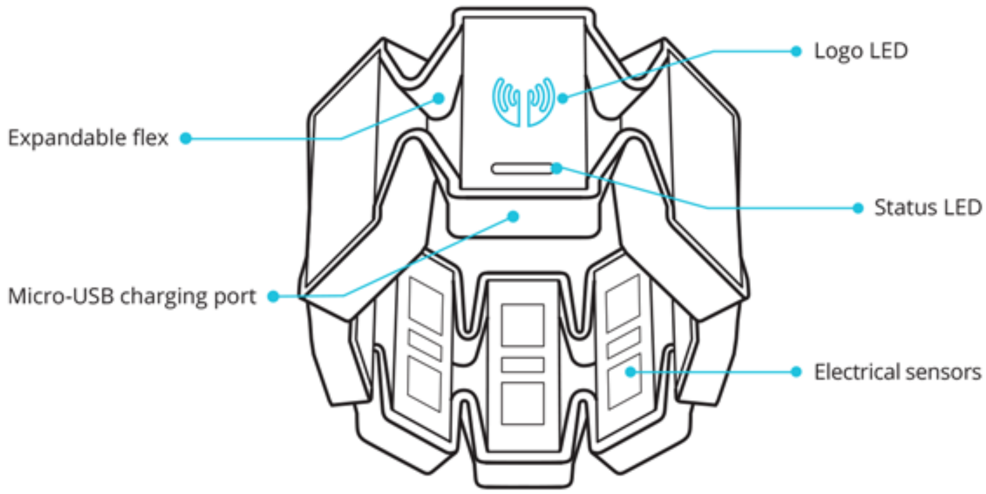


Figure 2: Myo Armband
(Source: www.myo.com)

The eight segments of expandable casing house the Myo armband's components and are connected using stretchable material that allows them to expand and contract relative to each other so that the Myo armband can comfortably fit each user's unique physiology. The electrical sensors measure electrical signals traveling across the user's arm, which the Myo armband translates into poses and gestures.

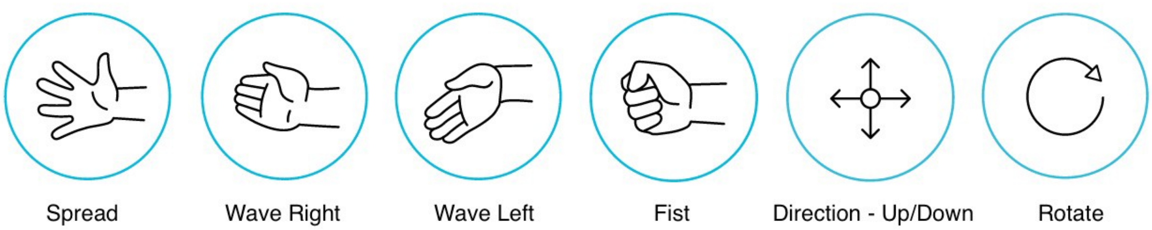


Figure 3: Gestures detected by Myo armband
(Source: www.myo.com)

The logo LED shows the sync state of the Myo armband. It pulses when the Myo armband is not synced. The LED becomes solid when you perform the Sync Gesture successfully and the Myo armband is synced to your arm.

The status LED shows the current state of the Myo armband. It lights up in blue once the Myo armband is connected to a device. The technical specifications of myo armband from its webpage are summarised in table 1.

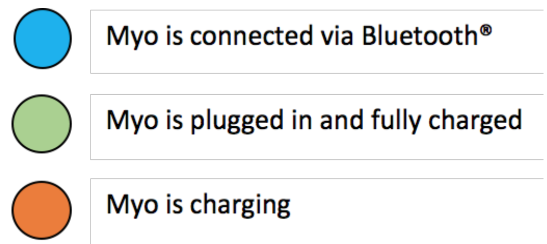


Figure 4: Myo LED and its meaning

2. *Micro-USB Cable*

The USB charging port allows you to charge the Myo armband's internal battery using a USB power adapter or a conventional USB port on a computer. The standard micro-USB cable is used to set up initial connection between the armband and Myo Connect software.

3. *Bluetooth adapter*

The Myo armband is connected to a device (e.g. a computer, tablet, or smartphone) using Bluetooth 4.0 Low Energy. It has a Bluetooth adapter for wireless communication, which stands as an interesting alternative to high-cost wireless sEMG sensors, despite its lack of flexibility in terms of sensor positioning. The SDK takes care of all of the low-level details related to Bluetooth connections and data transmission.

4. *Sizing clips*

The sizing clips allow Myo armband to be one fit for all product. When all of them are connected the Myo armband becomes 7.5 inches in diameter from 13.4 inches when not connected.

Colors	Black White
Arm size	Expandable between 7.5 - 13 inches (19 - 34 cm) forearm circumference
Weight	93 grams
Thickness	0.45 inches
Compatible devices	Windows, Mac, iOS, Android
Sensors	Medical Grade Stainless Steel EMG sensors, Highly sensitive nine-axis IMU containing three-axis gyroscope, three-axis accelerometer, three-axis magnetometer
LEDs	Dual Indicator LEDs
Processor	ARM Cortex M4 Processor

Haptic feedback	Short, Medium, Long Vibrations
Communication	Bluetooth® Smart Wireless Technology
Power & Battery	Micro-USB Charging, built-in rechargeable lithium-ion battery, one full day use out of single charge

Table 1: Myo armband technical specifications

5. Anatomy

The forearm counts on many muscles with two main functions: flexion/extension of fingers and flexion/extension of the hand. All the flexors are located anteriorly, while the extensors are in the posterior compartment of the arm. For the rehabilitation exercises, the most important information is related to the activation level of fingers' extensors and flexors. However, a single finger movement doesn't depend on only one muscle: sometimes the functions of two muscles are overlapped and the resulting effect is achieved by muscles synergies. Moreover, those designated to flexion of fingers are deep muscles and their area of contact with the surface of the arm is very narrow. Therefore, particular care must be used in correctly placing the EMG sensor, designated to collect the signal from the finger flexor.

According to standard anatomical guidelines, we define a standard position of the Myo armband on the patient's arm. If the Myo armband is located as described in Fig. 6, the expected signal detected by each sensor will be as follow.

1) Palmaris longus (Flexor of hand)

2) Flexor carpi ulnaris (Flexor of hand)

3) Extensor carpi ulnaris (Extensor of hand)

4) Extensor digiti minimi (Extensor of little finger)

5) Extensor digitorum (Extensor of finger)

6) Extensor carpi radialis longus or brevis (Extensor of hand)

7) Brachioradialis (Extensor of arm)

8) Flexor carpi radialis (Flexor of hand)

Figure 5: Cross-section showing muscles of forearm
(Source: basicmedicalkey.com/anterior-forearm/)

Figure 6: Placement of Myo on forearm

3. Software

In the development of this prototype, a number of open-source software and libraries were used. Below listed are all the software:

- **Myo Connect**
- **Processing**
- **Unity**

1. *Myo Connect*

The Myo experience begins with Myo Connect. In addition to mediating software access to the Myo armband and providing basic control over some applications, Myo Connect helps you set up and explore the Myo armband capabilities. Myo Connect provides a menu with some options and commands.

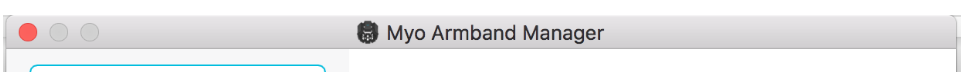


Figure 7: Screenshot of Myo Connect

2. *Processing*

Processing is a flexible software sketchbook and a language for learning how to code within the context of the visual arts. Since 2001, Processing has promoted software literacy within the visual arts and visual literacy within technology. There are tens of thousands of students, artists, designers, researchers, and hobbyists who use Processing for learning and prototyping. Processing 3 (version 3.3.6) was used for developing the interface on macbook pro.

3. *Unity*

Unity is a cross-platform game engine developed by Unity Technologies, which is primarily used to develop both three-dimensional and two-dimensional video games and simulations for computers, consoles, and mobile devices. It has been extended to work on 27 platforms. Unity 2017.3 was used for gaming-interface development on windows 10 OS.

4. Overall Process

1. *Processing interface*

The interface allows the user to visualize data captured by the 8 EMG sensors and 1 nine-axis IMU. The data is sent to the processing interface via the Bluetooth module once the connection is set up between Myo armband and Myo Connect. The user can click on the button “EMG”, “Acceleration” or “Orientation” to see the corresponding data. The “EMG” page will show the activation level of respective muscles under each pod. The “Acceleration” and “Orientation” page shows the acceleration and orientation respectively in X, Y and Z direction of middle pod “4” which encompasses the IMU. The acceleration data is in g units and the orientation data is in degrees.

Figure 8: Front page of Processing interface

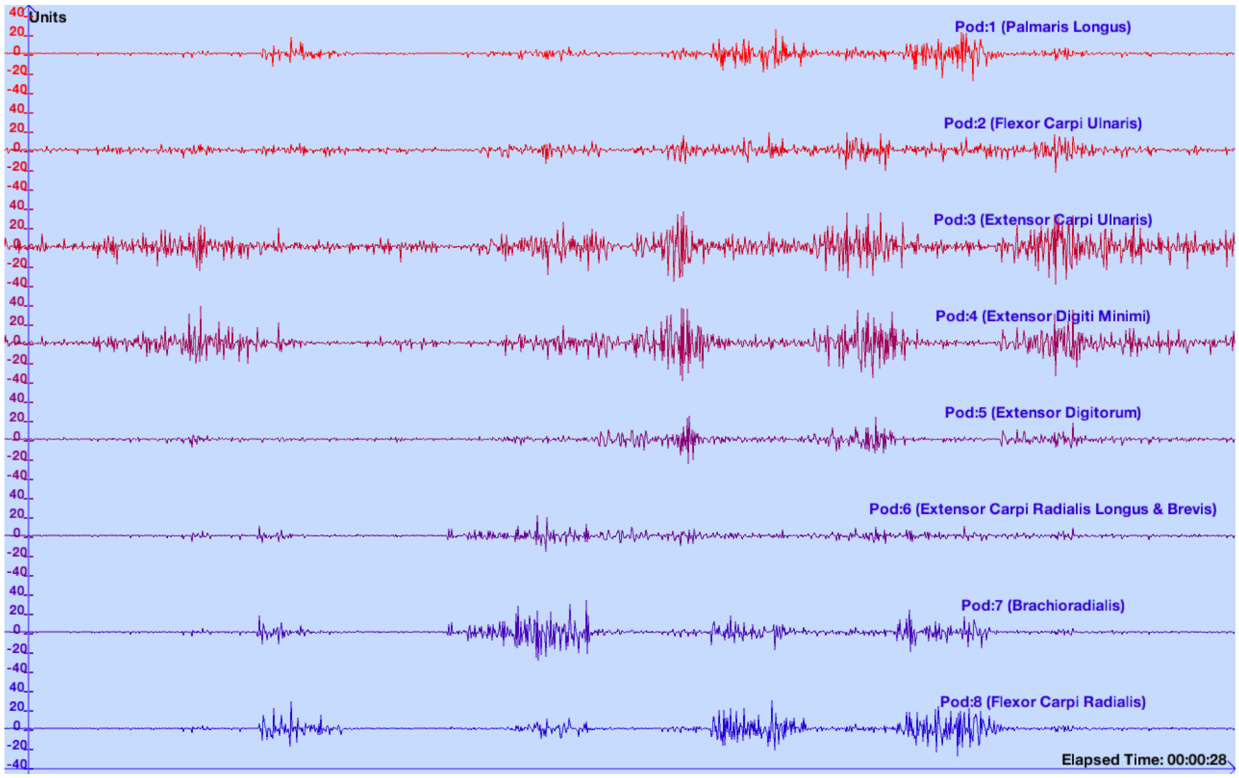


Figure 9: EMG values in processing interface

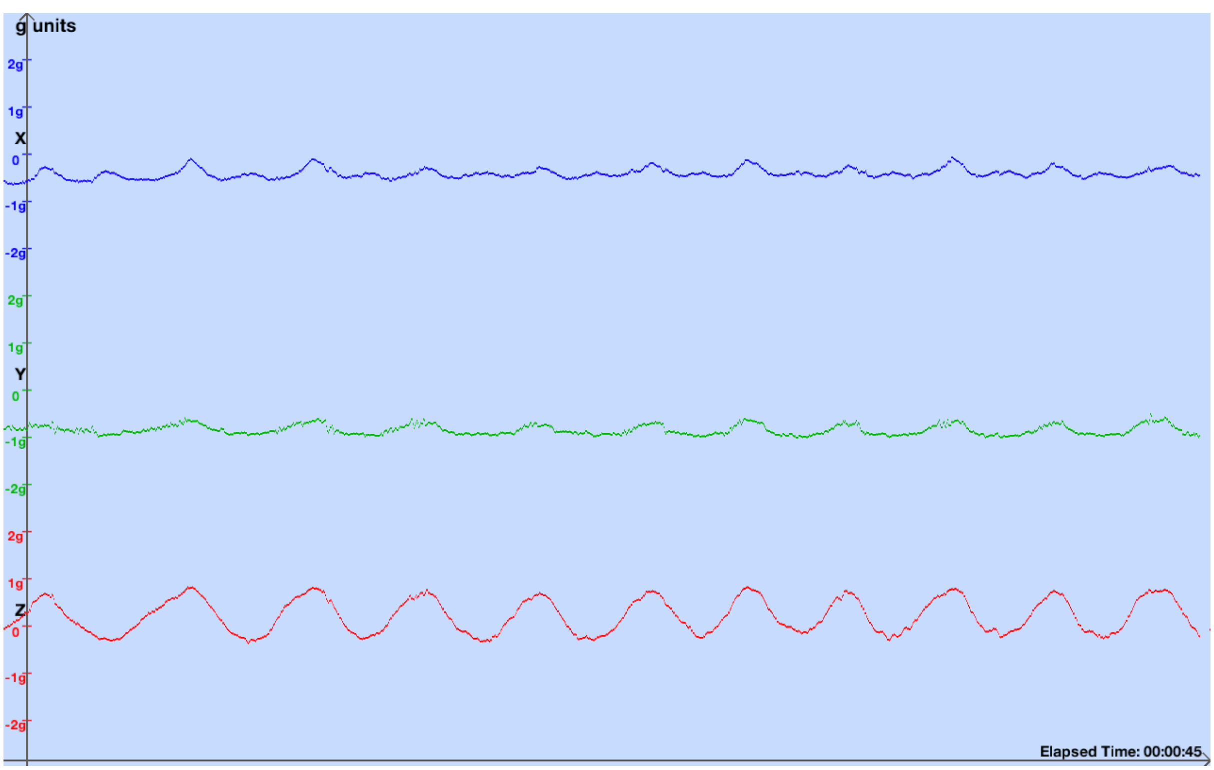


Figure 10: Acceleration values in processing interface

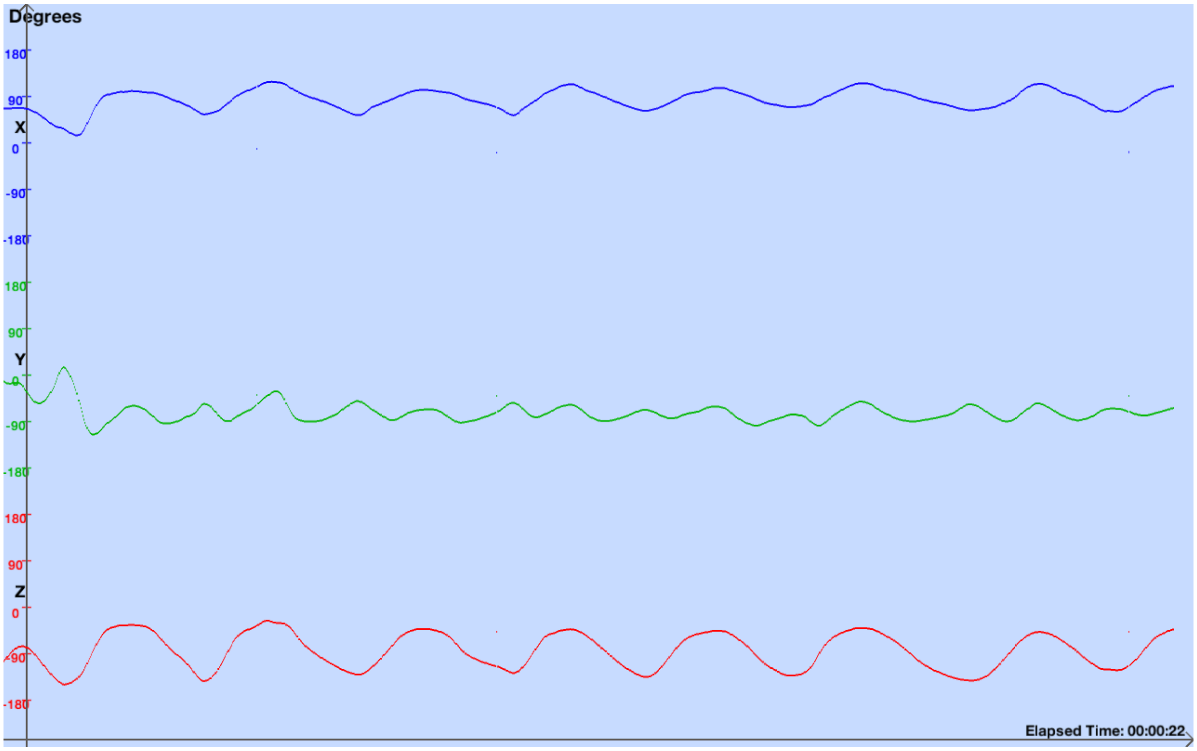


Figure 11: Orientation values in processing interface

2. *Gaming interface*

The gaming interface was developed in Unity, where the user will move a ball on a surface towards a hole. While doing so, there are collectibles on the way to increase the score. The ball moves when the user makes a fist and the left/right direction can be controlled by moving hand in horizontal direction. The speed and forward/backward direction are controlled by moving hand in vertical direction.

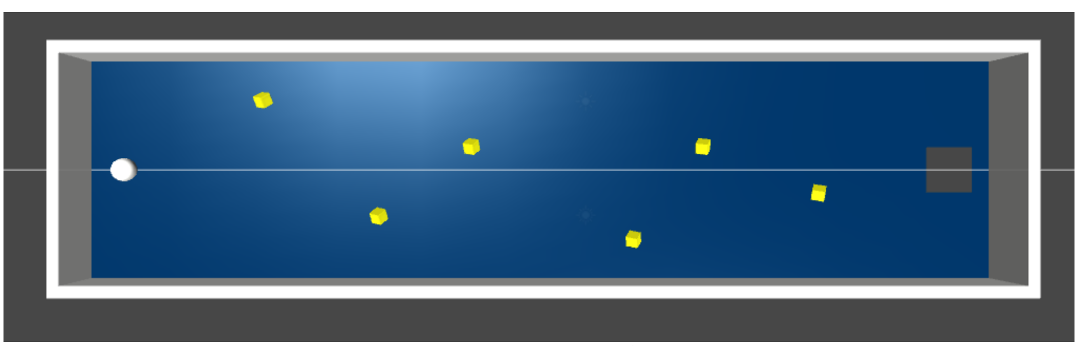


Figure 12: Gaming interface scene

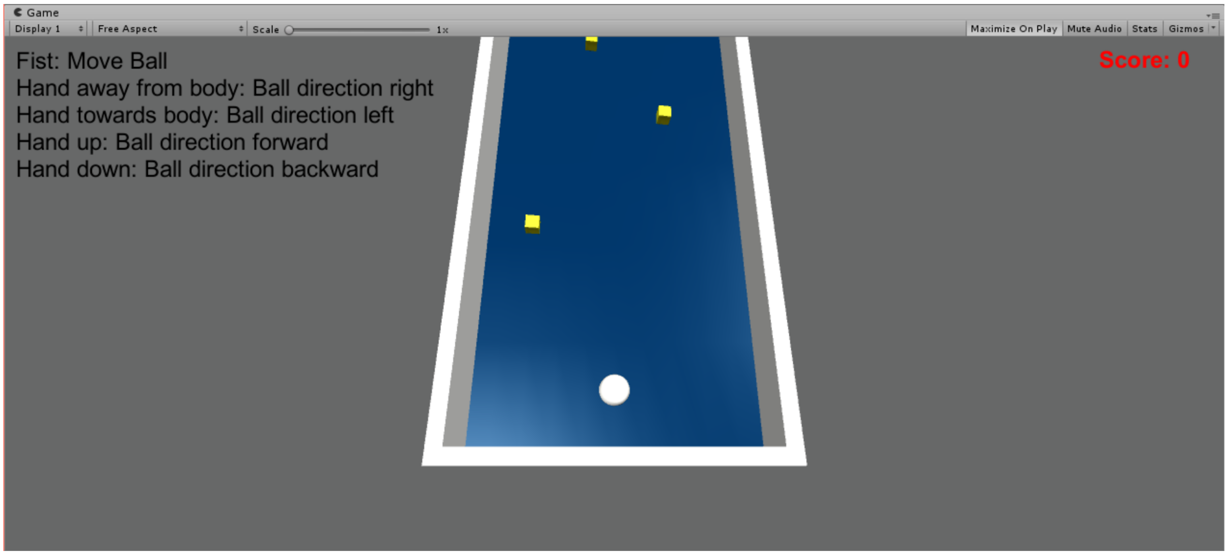


Figure 13: Starting scene of gaming interface

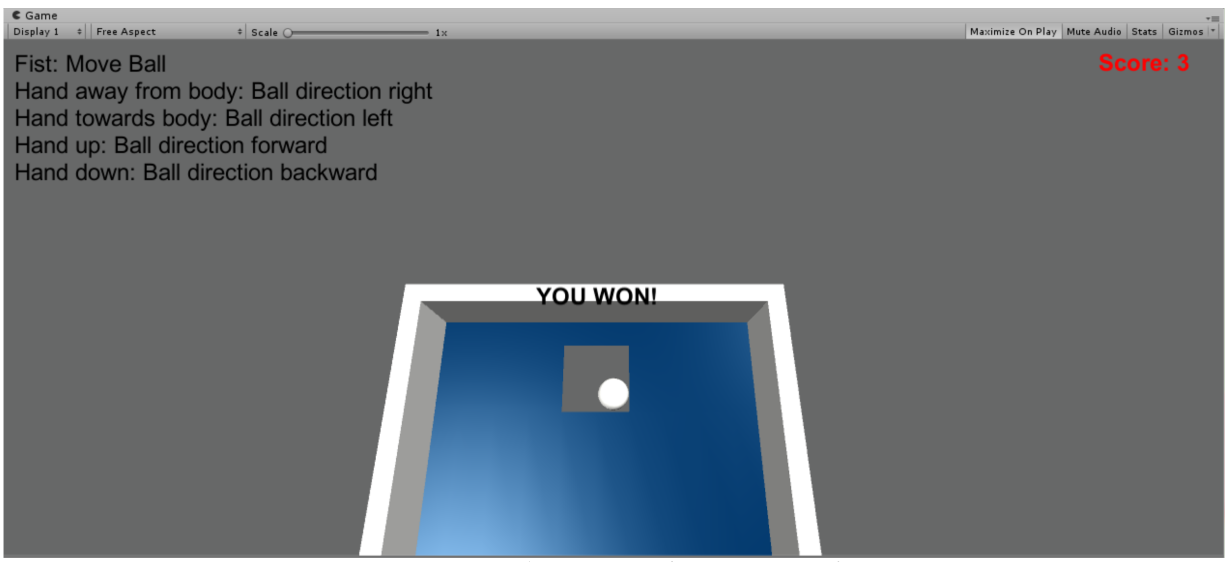


Figure 14: Ending scene of gaming interface

5. Experimental Setup

1. *<u>Procedure</u>: 10 healthy subjects were asked to perform the following tasks.*

Processing Interface

- *Task 1:* Move hand sideways 5 times, forward/backward 5 times, up/down 5 times.
    - The EMG, acceleration, and orientation data for the above task were measured individually.

Figure 15: Experimental setup for Task 1

- *Task 2:* Wave out 5 times and wave in 5 times.
  - The EMG, acceleration, and orientation data for the above task were measured individually.

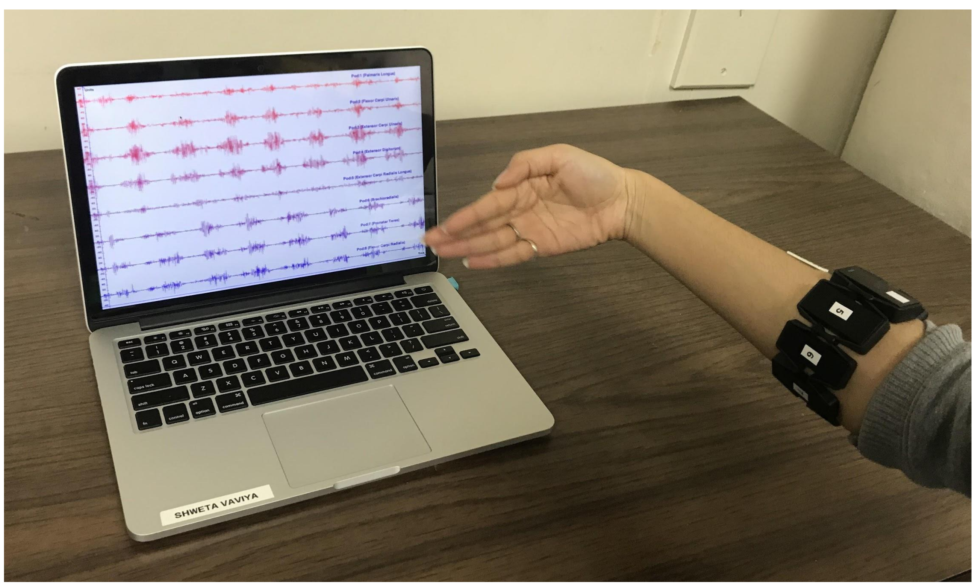


Figure 16: Experimental setup for Task 2

- *Task 3:* Press and move the grasp-rehabilitator 10 times.
  - The EMG, acceleration and orientation data from Myo and grasp & lift force from grasp-rehabilitator were measured.

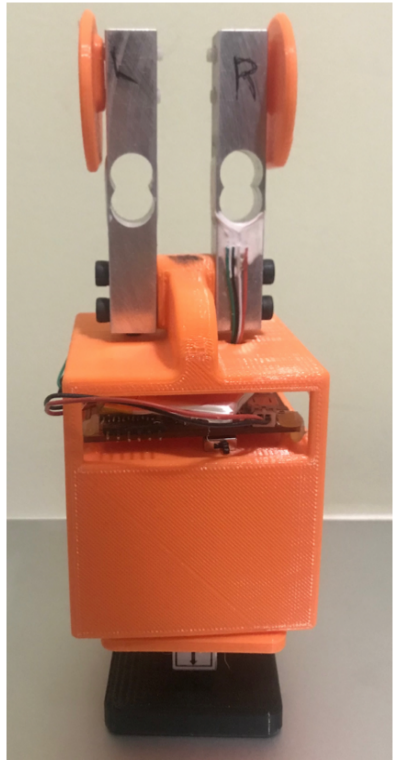


Figure 17: Instrumented object (Grasp rehabilitator) for Task 3

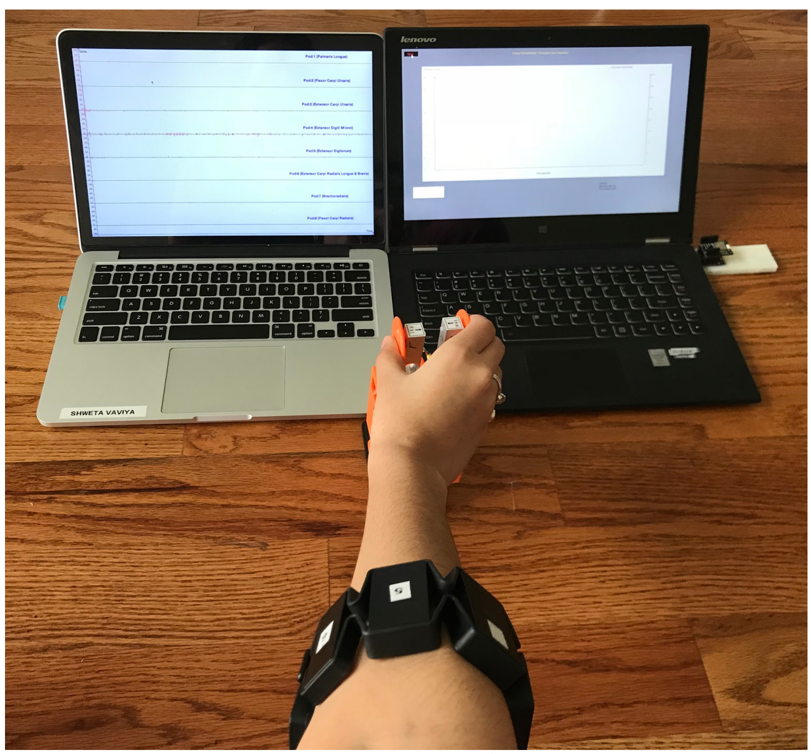


Figure 18: Experimental setup for Task 3

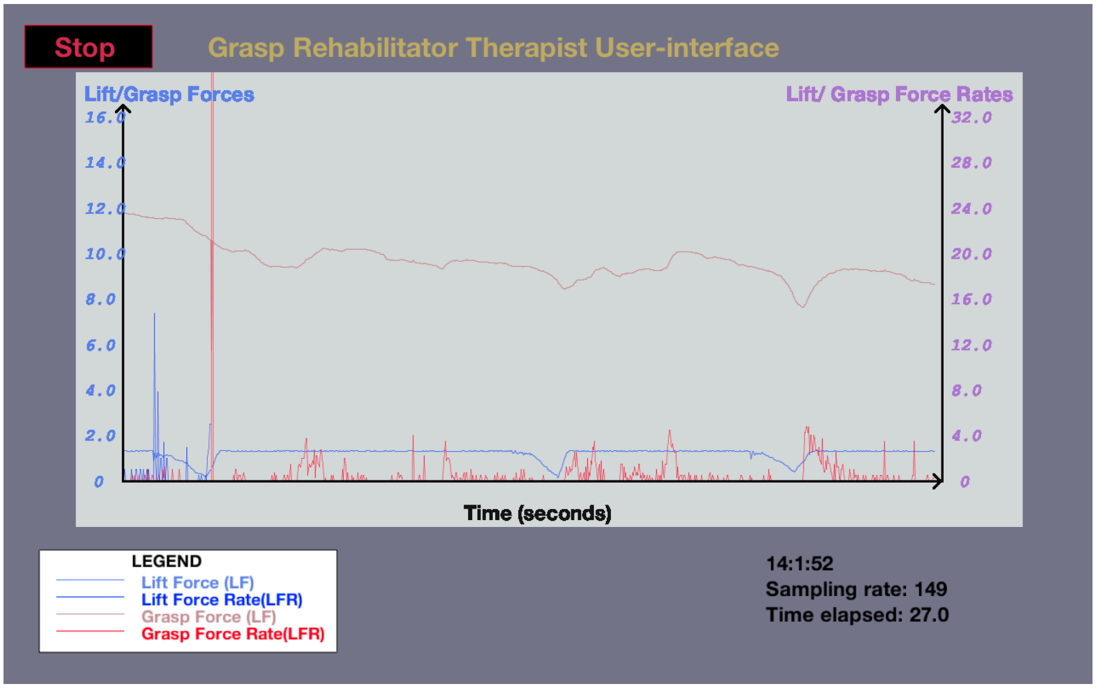


Figure 19: Interface for grasp-rehabilitator

Gaming Interface

- *Task 1:* Play the game for 10 times.
  - The success/failure, score, and timing of each game was recorded.

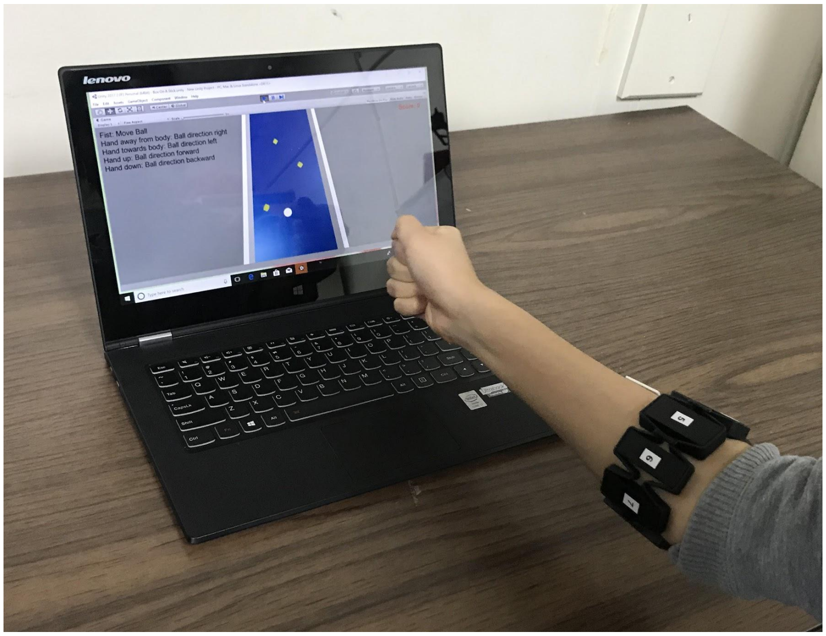


Figure 20: Experimental setup for Task 4

6. Evaluation

1. *Objective Evaluation*

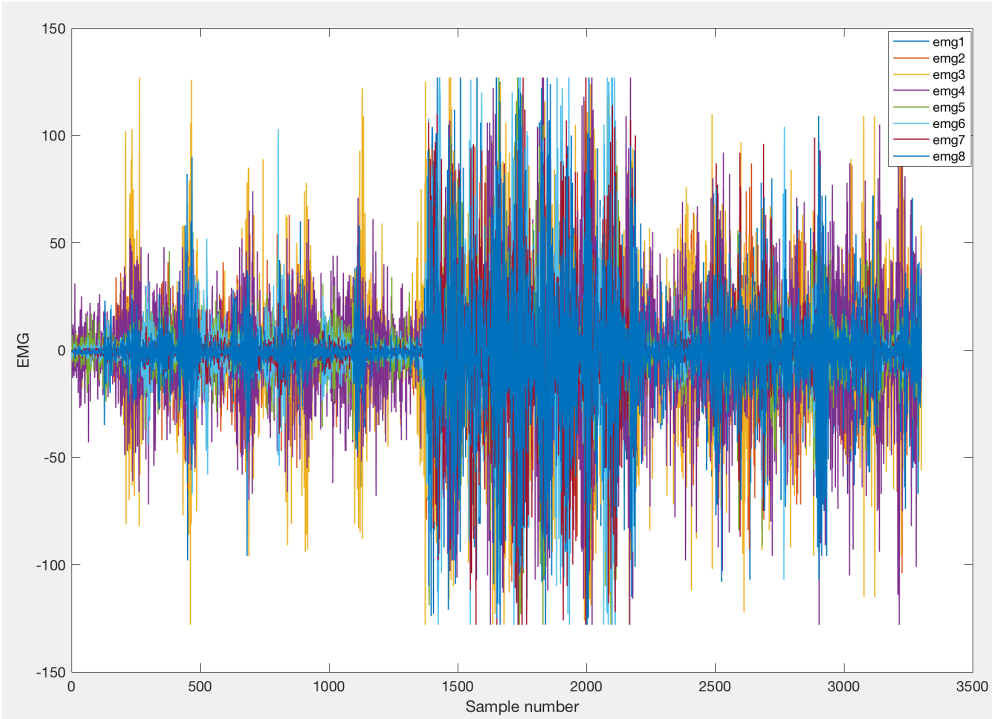


Figure 21: EMG data for Task 1

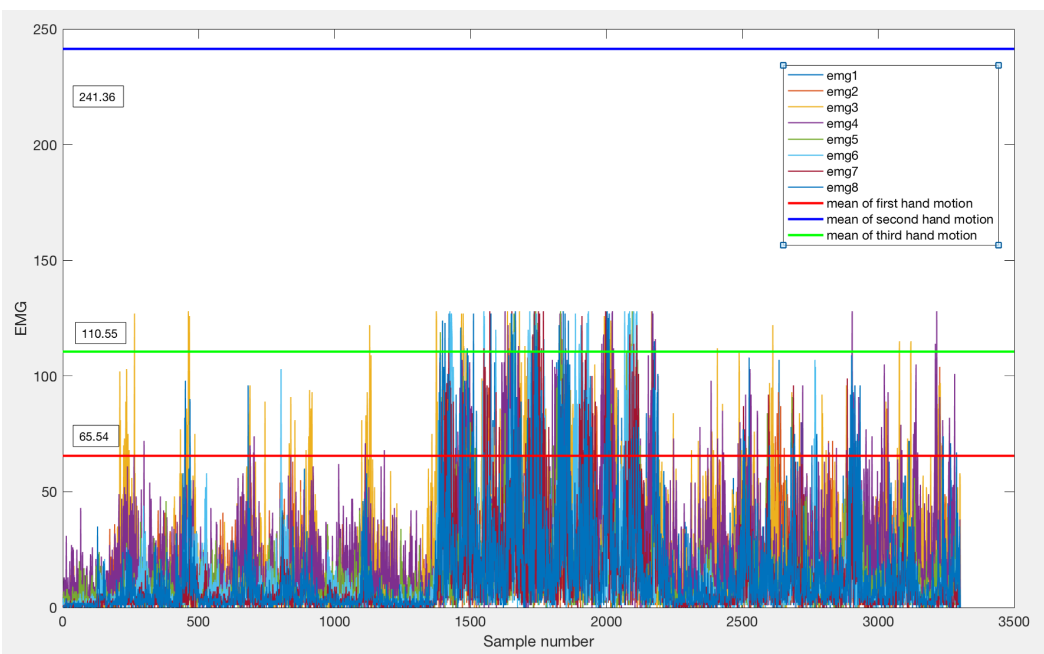


Figure 22: Rectified EMG data for Task 1

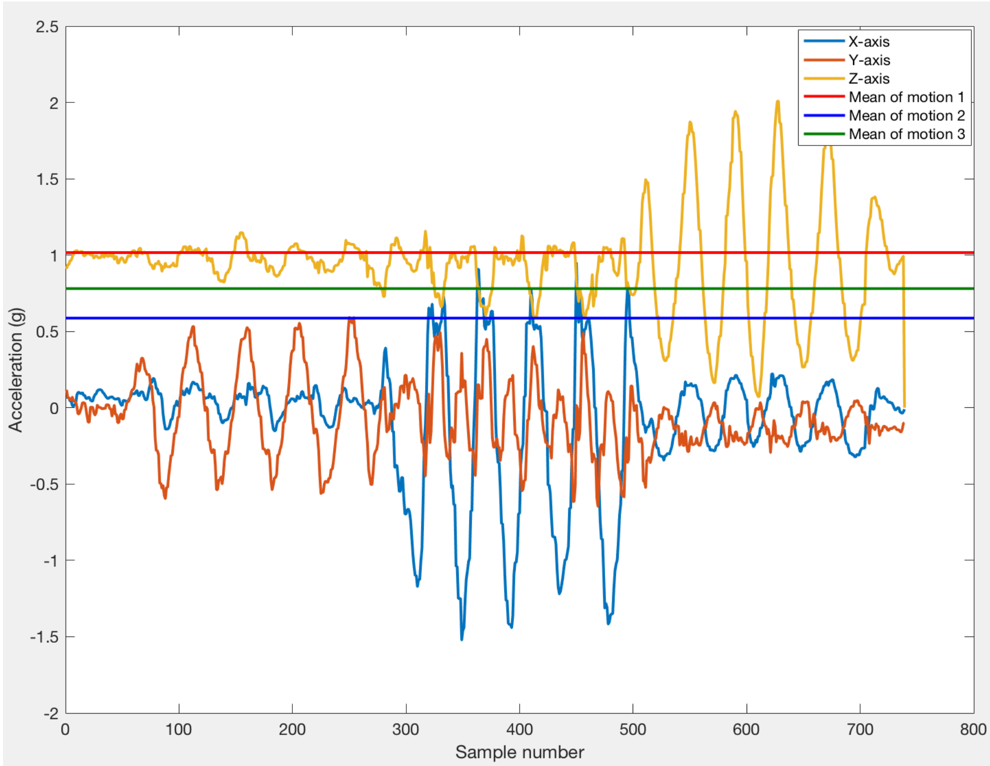


Figure 23: Acceleration data for Task 1

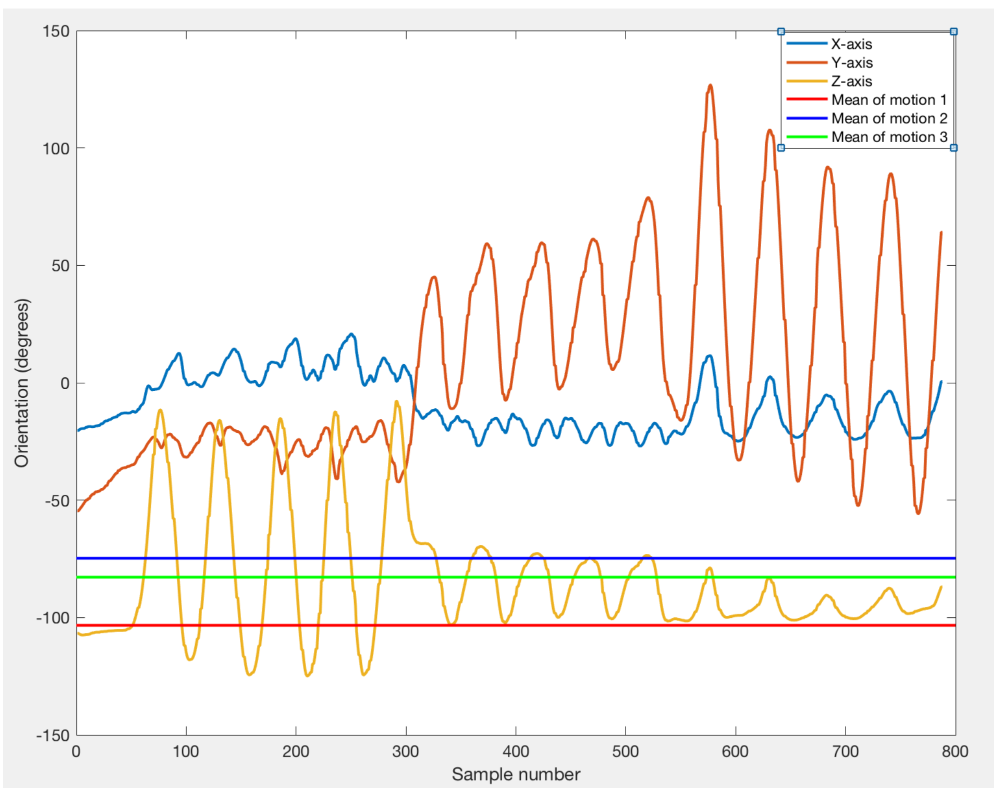


Figure 24: Orientation data for Task 1

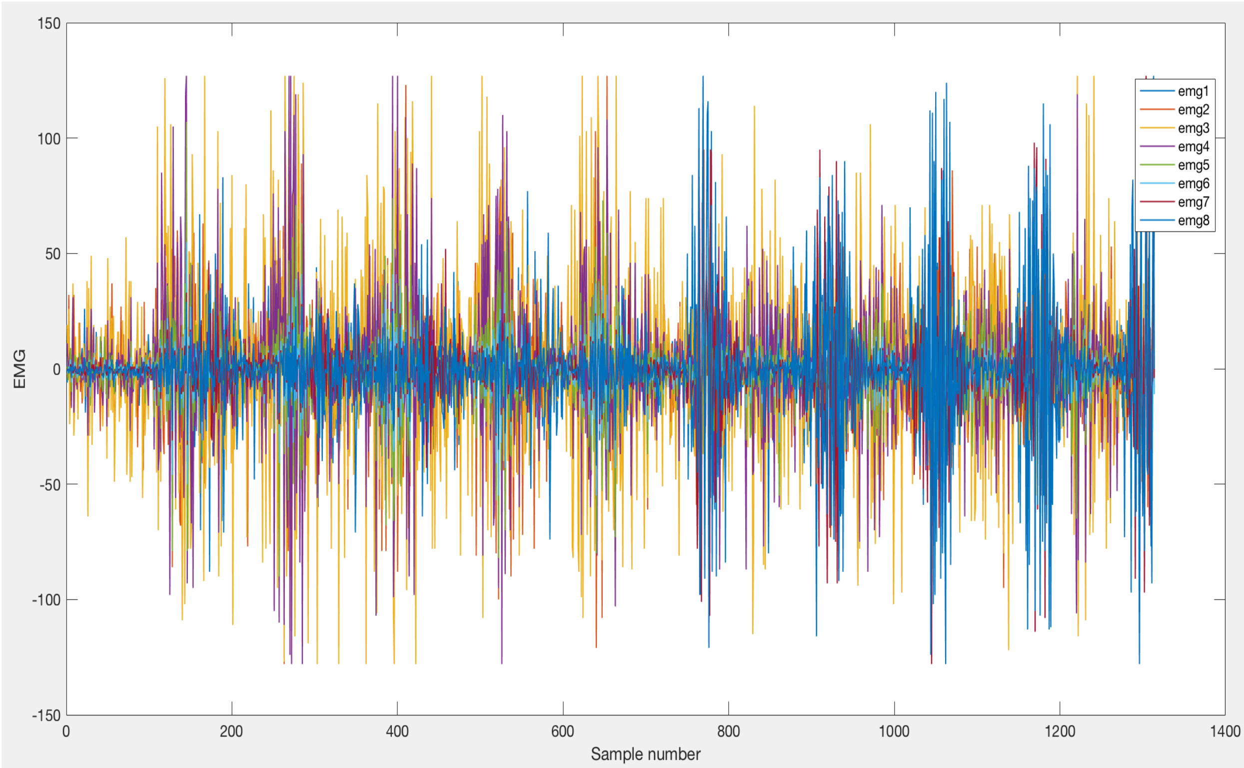


Figure 25: EMG data for Task 2

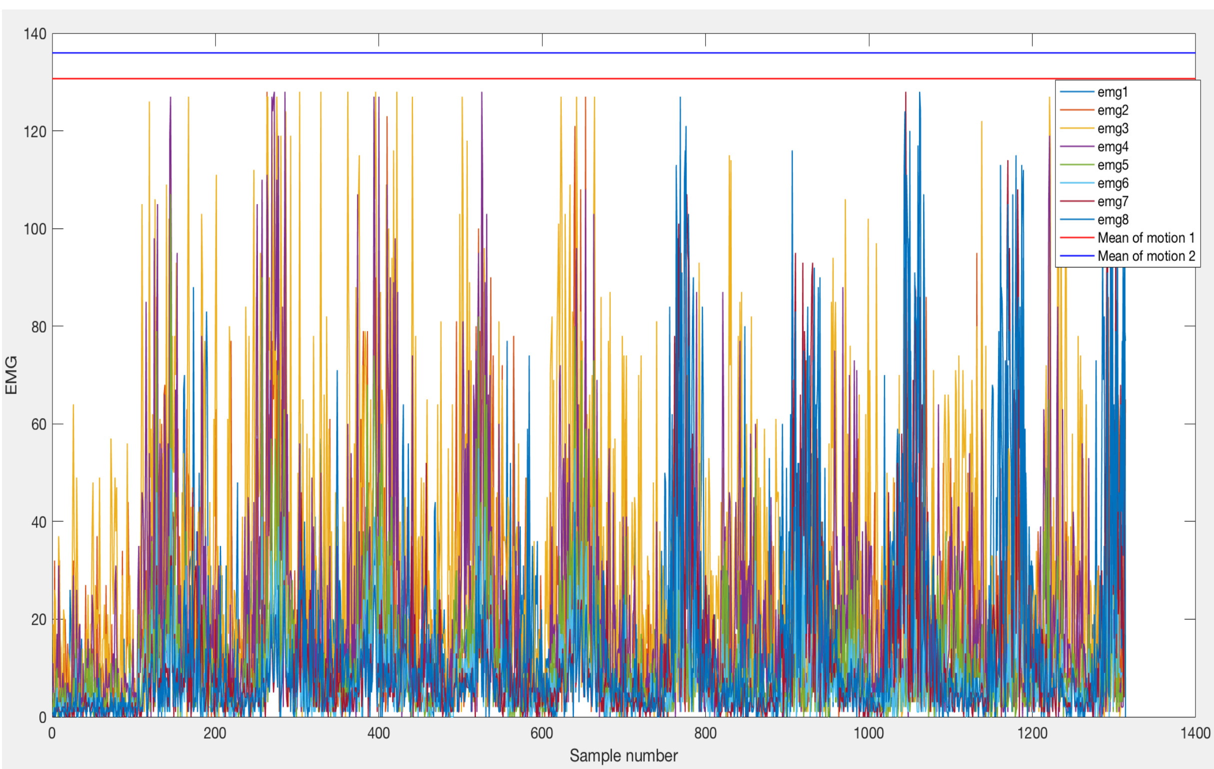


Figure 26: Rectified EMG data for Task 2

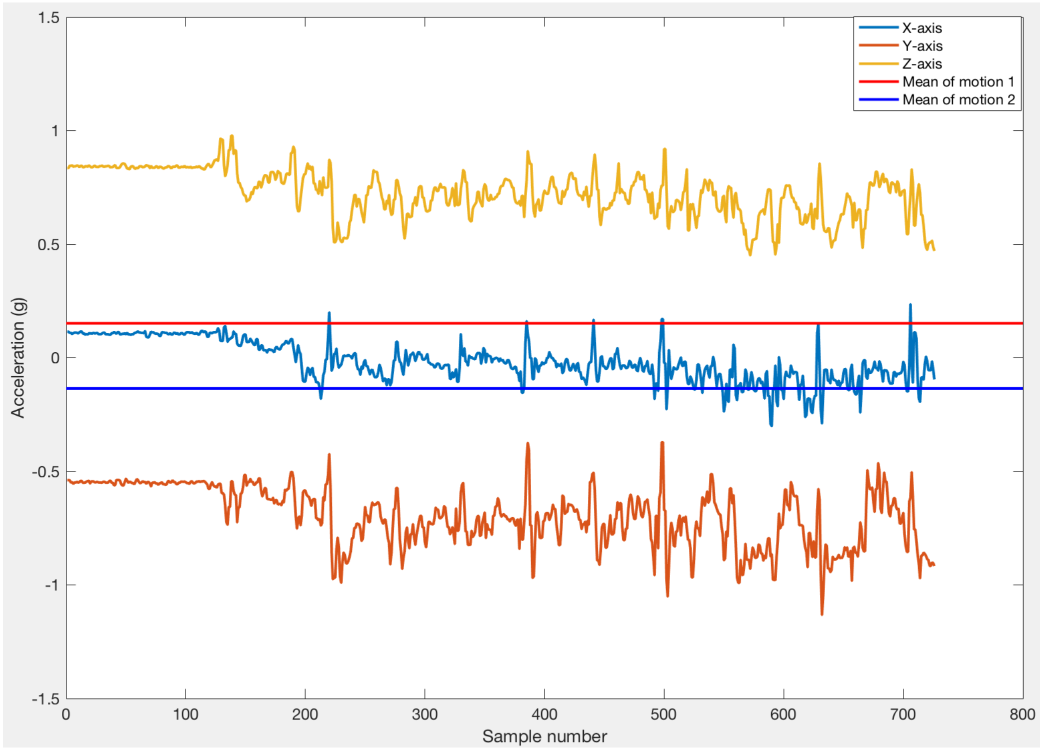


Figure 27: Acceleration data for Task 2

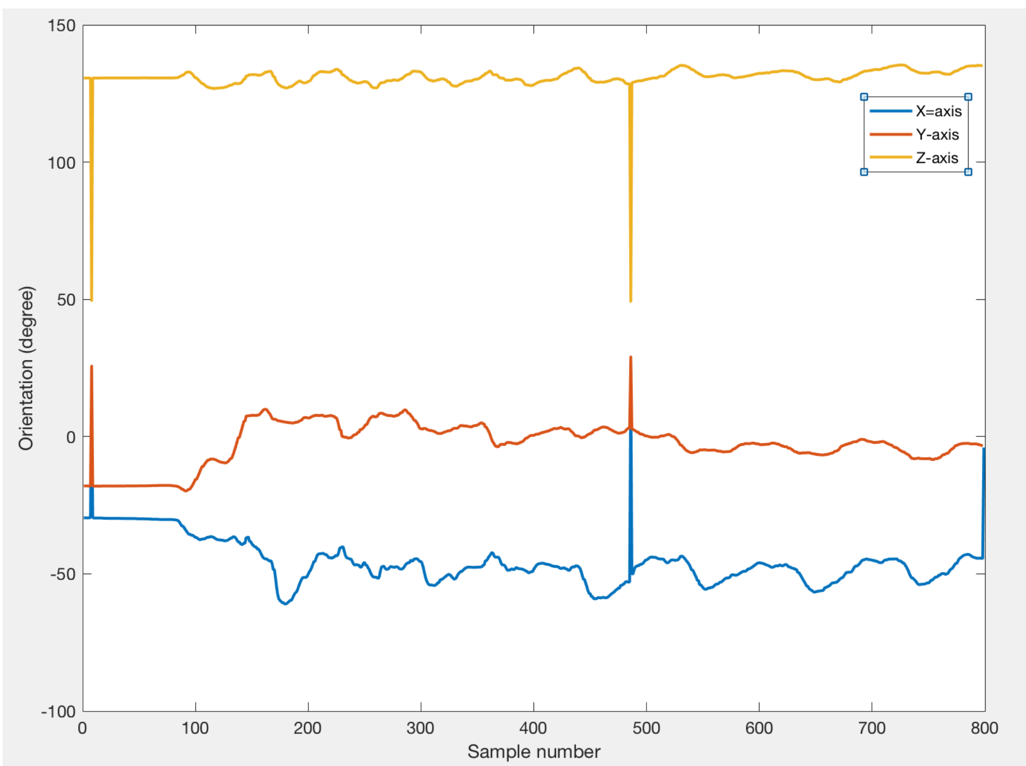


Figure 28: Orientation data for Task 2

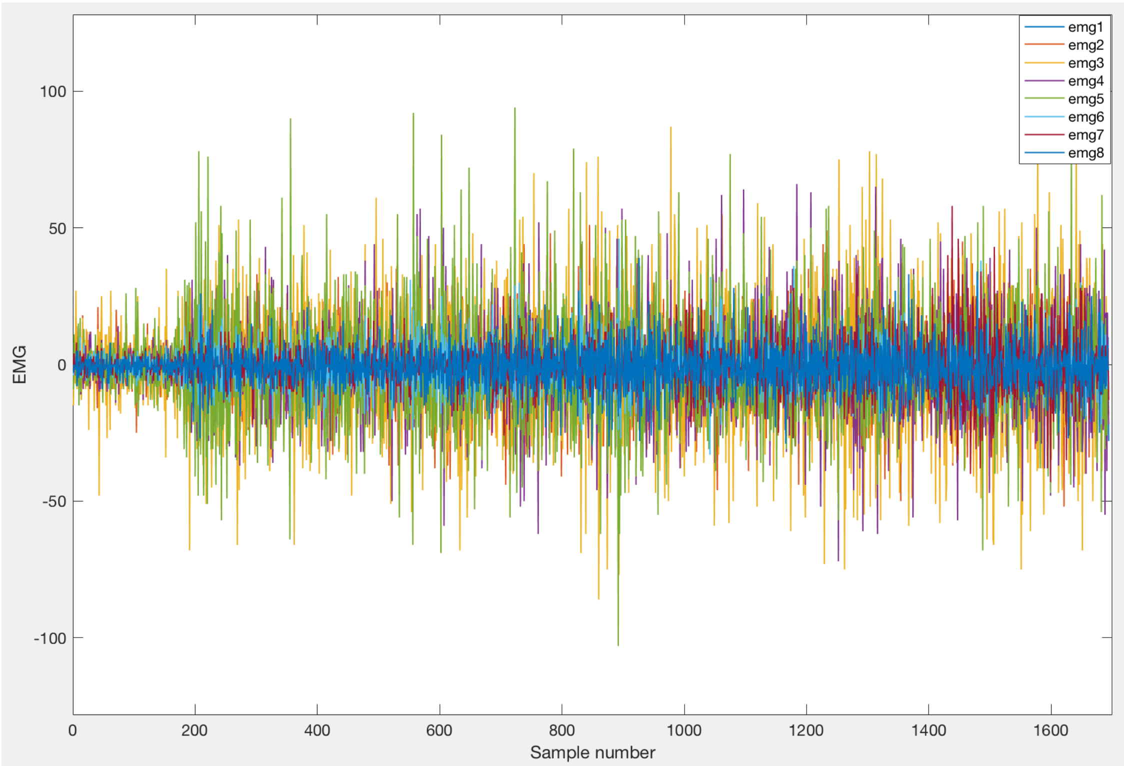


Figure 29: EMG data for Task 3

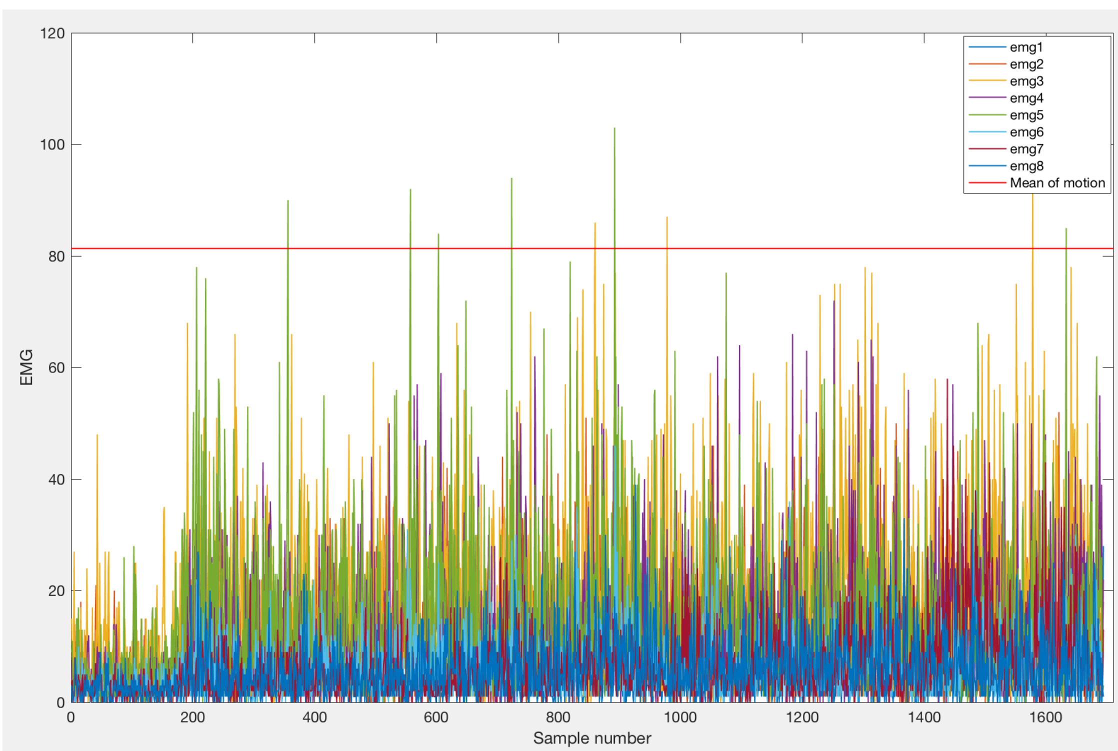


Figure 30: Rectified EMG data for Task 3

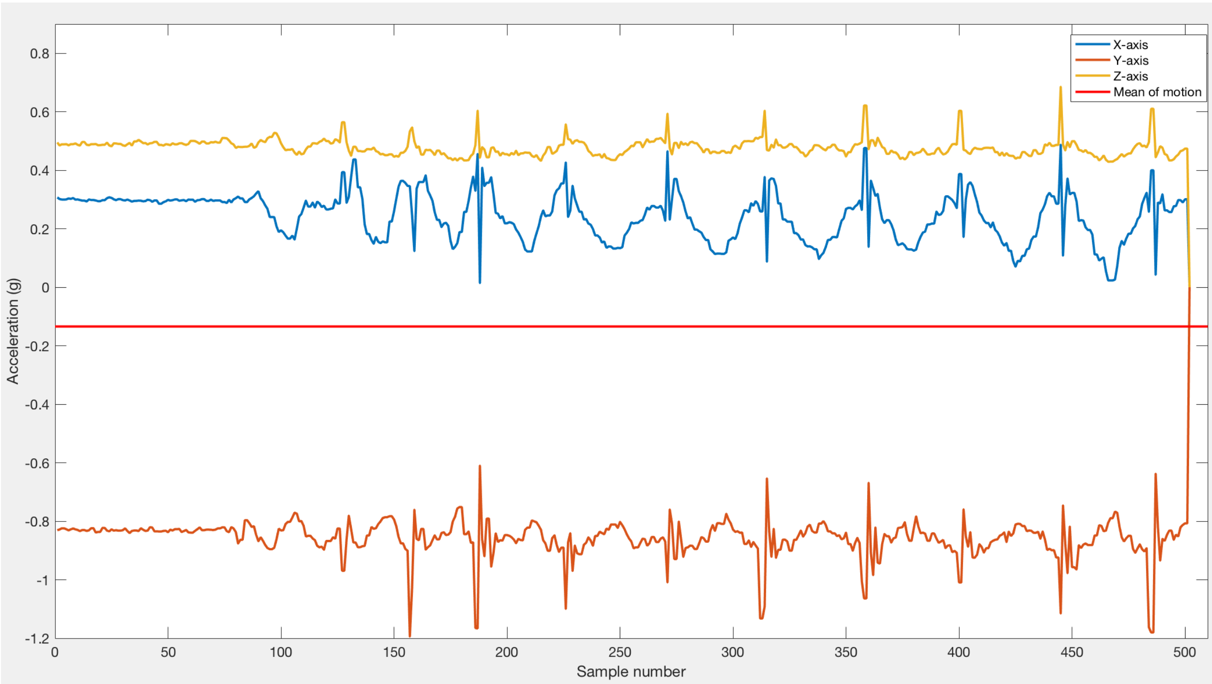


Figure 31: Acceleration data for Task 3

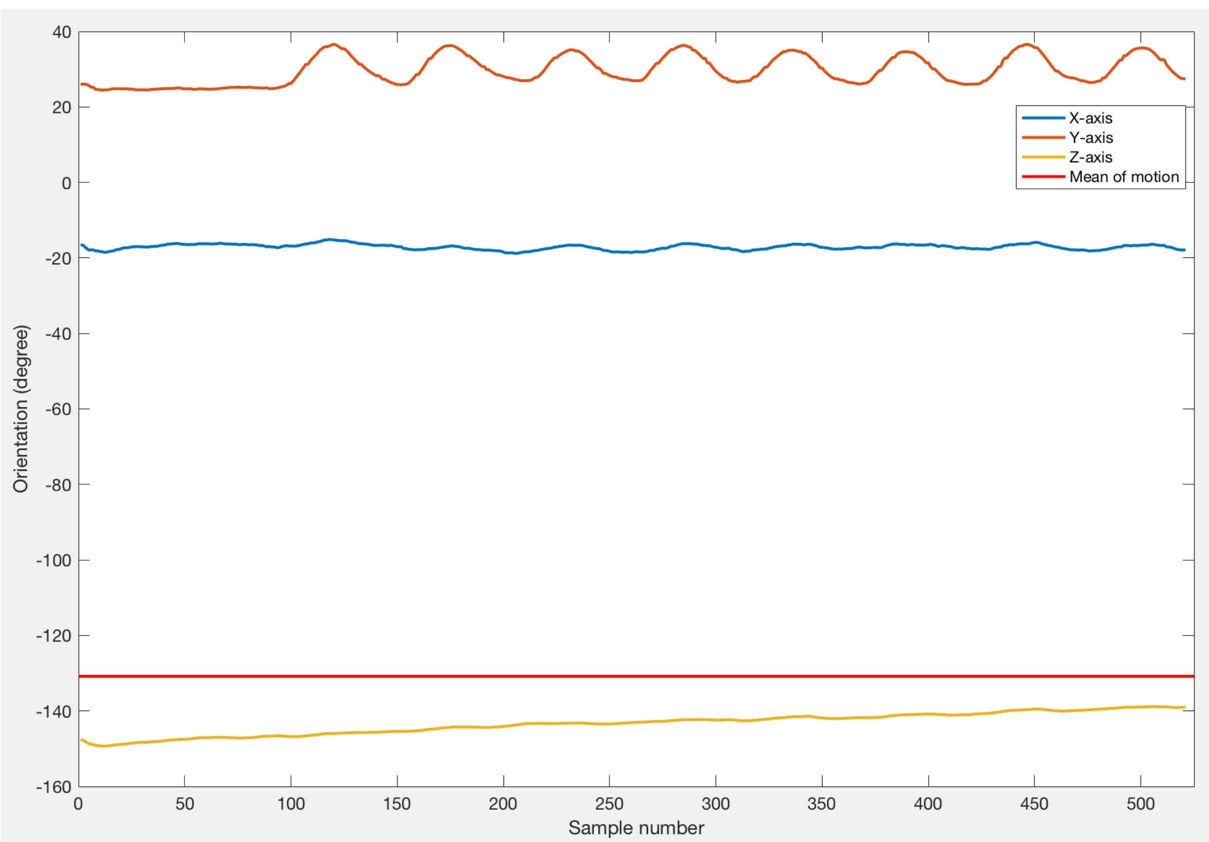


Figure 32: Orientation data for Task 3

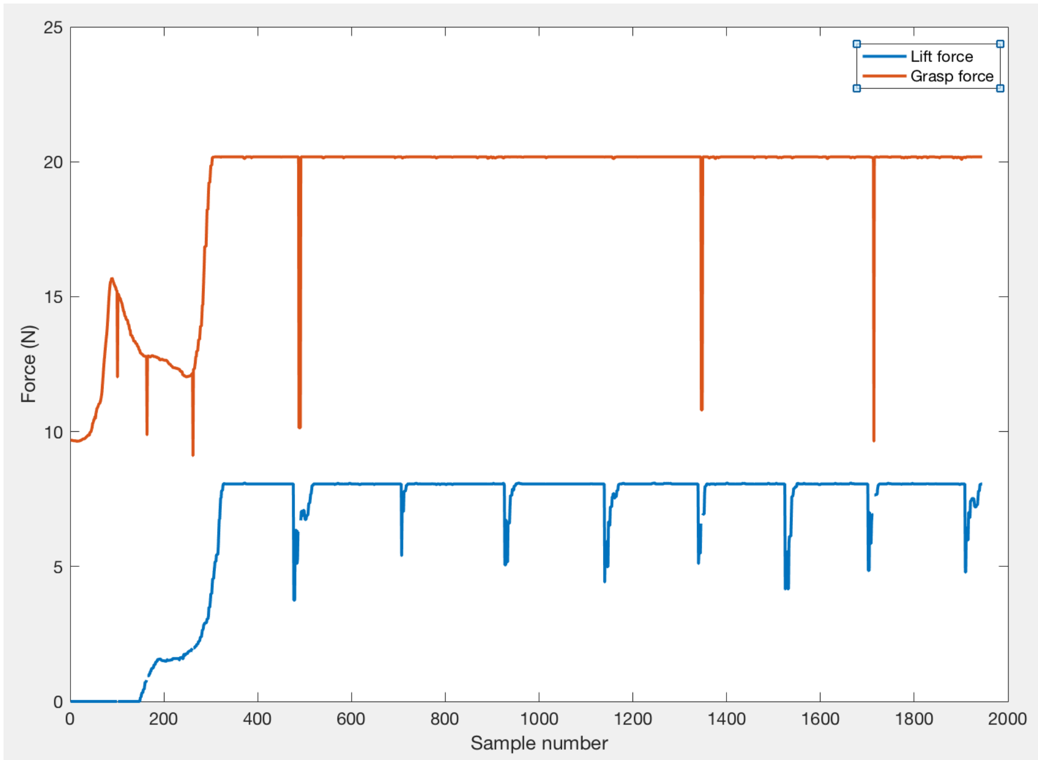


Figure 33: Lift and grasp data from grasp rehabilitator for Task 3

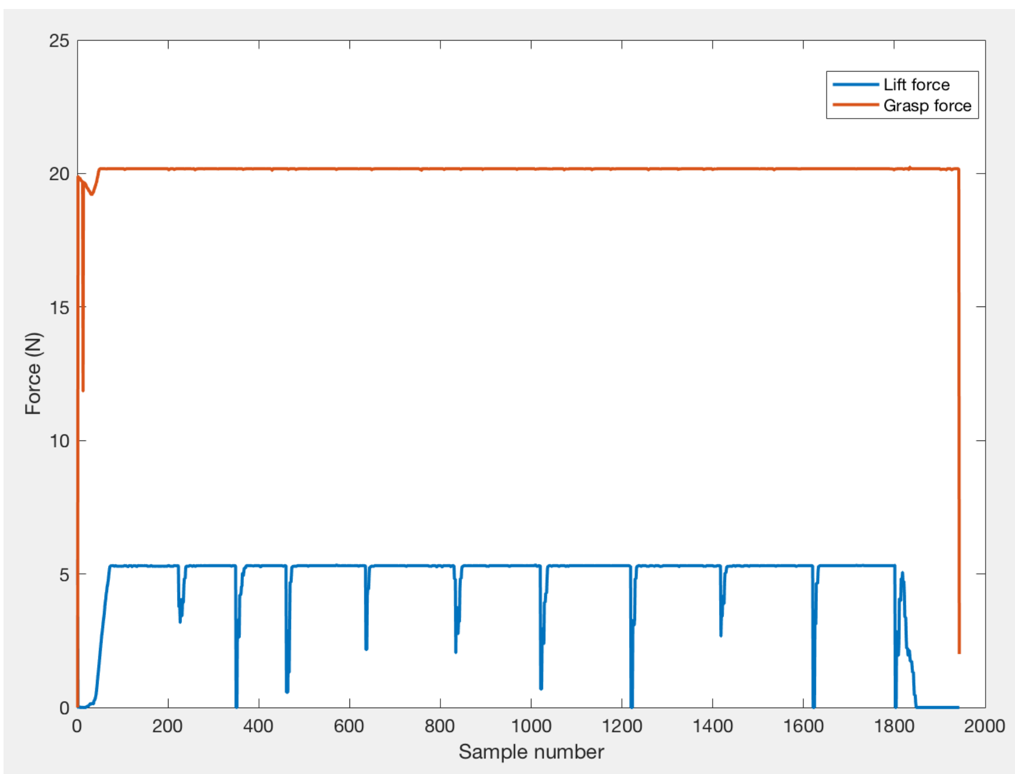


Figure 34: Lift and grasp data from grasp rehabilitator for Task 3

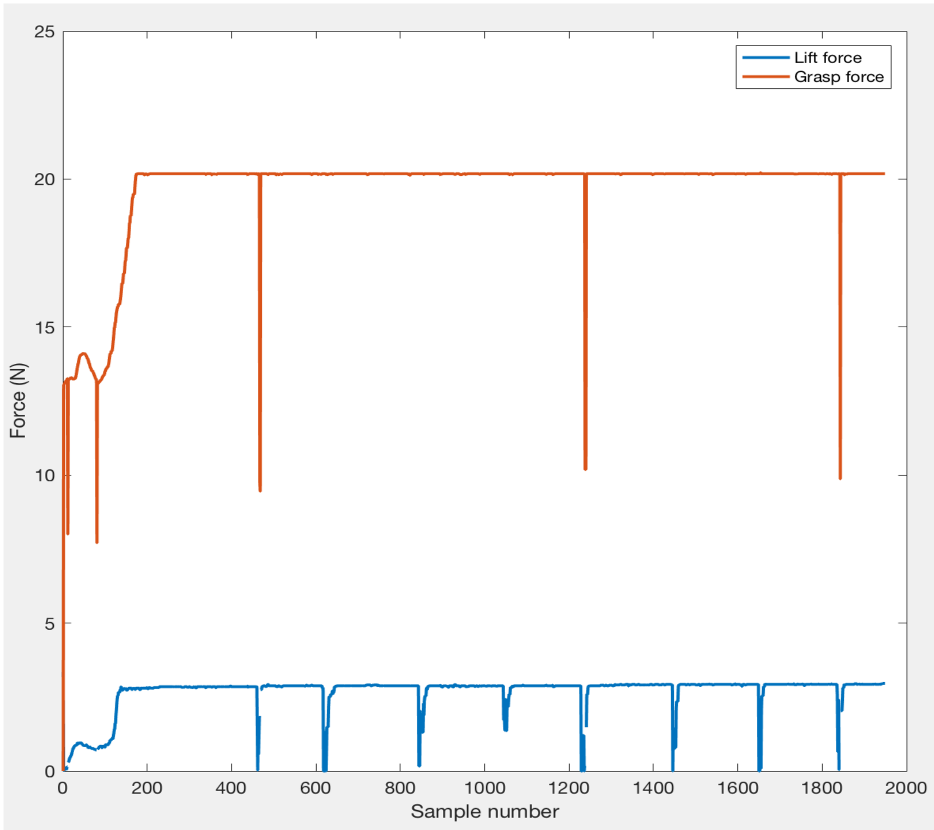
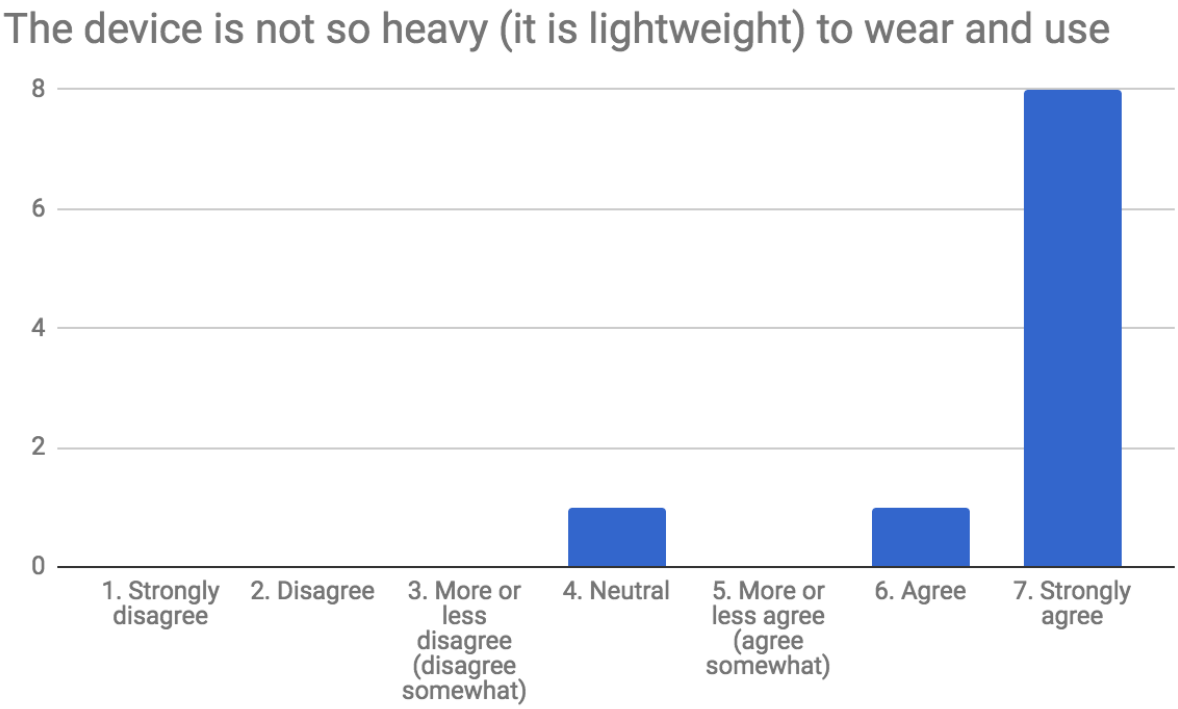
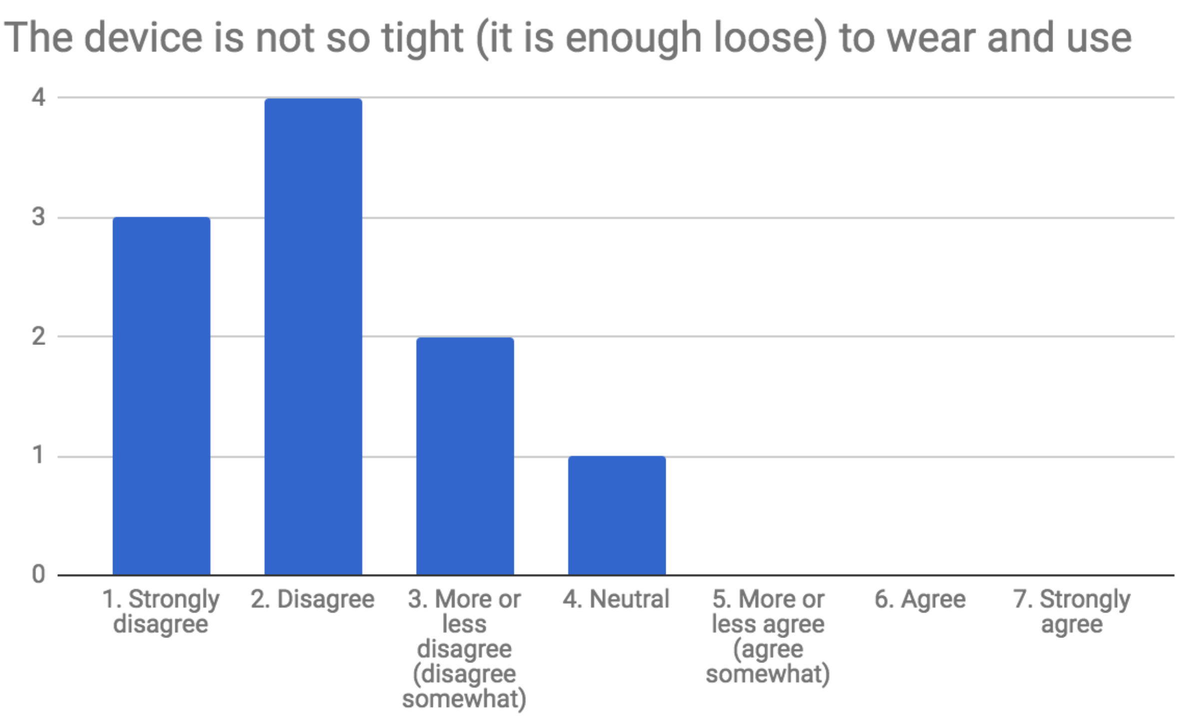


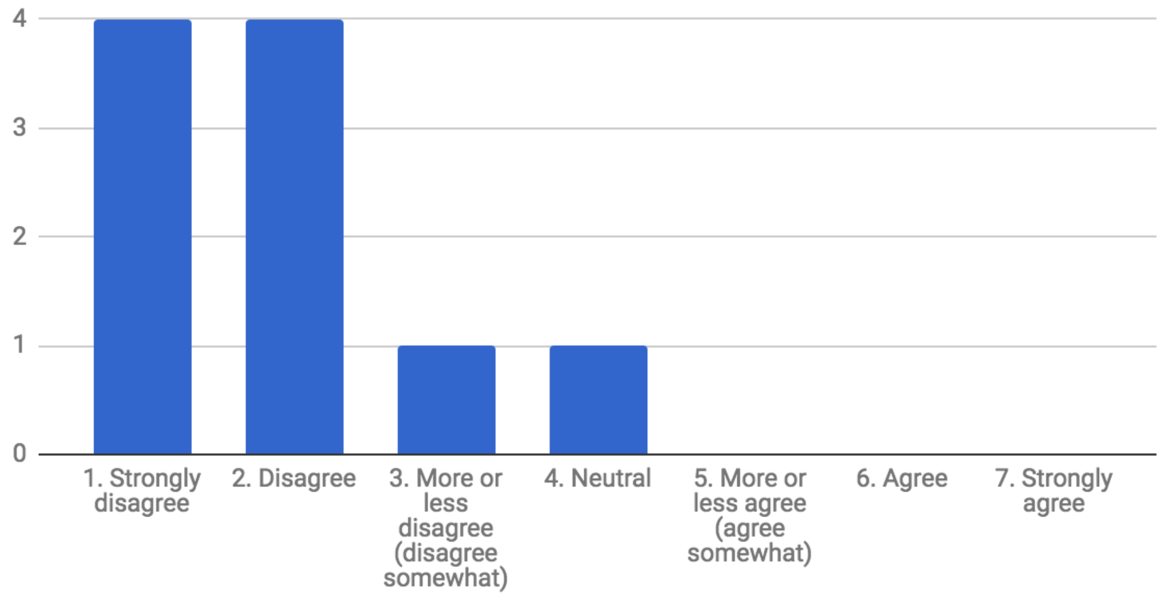
Figure 35: Lift and grasp data from grasp rehabilitator for Task 3

2. Subjective Evaluation

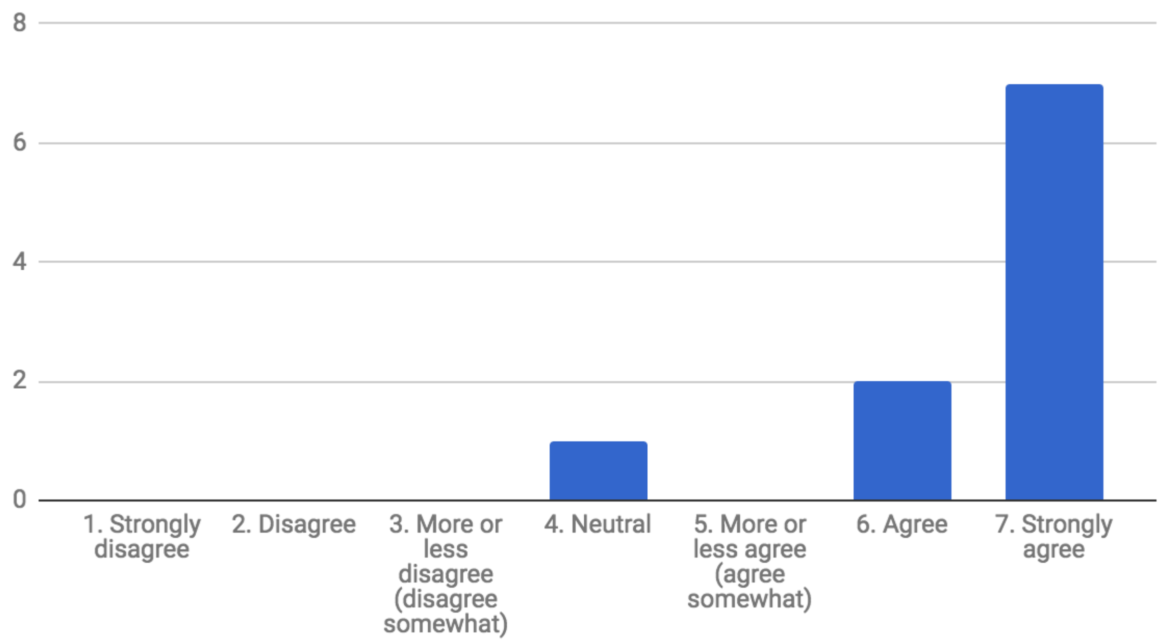


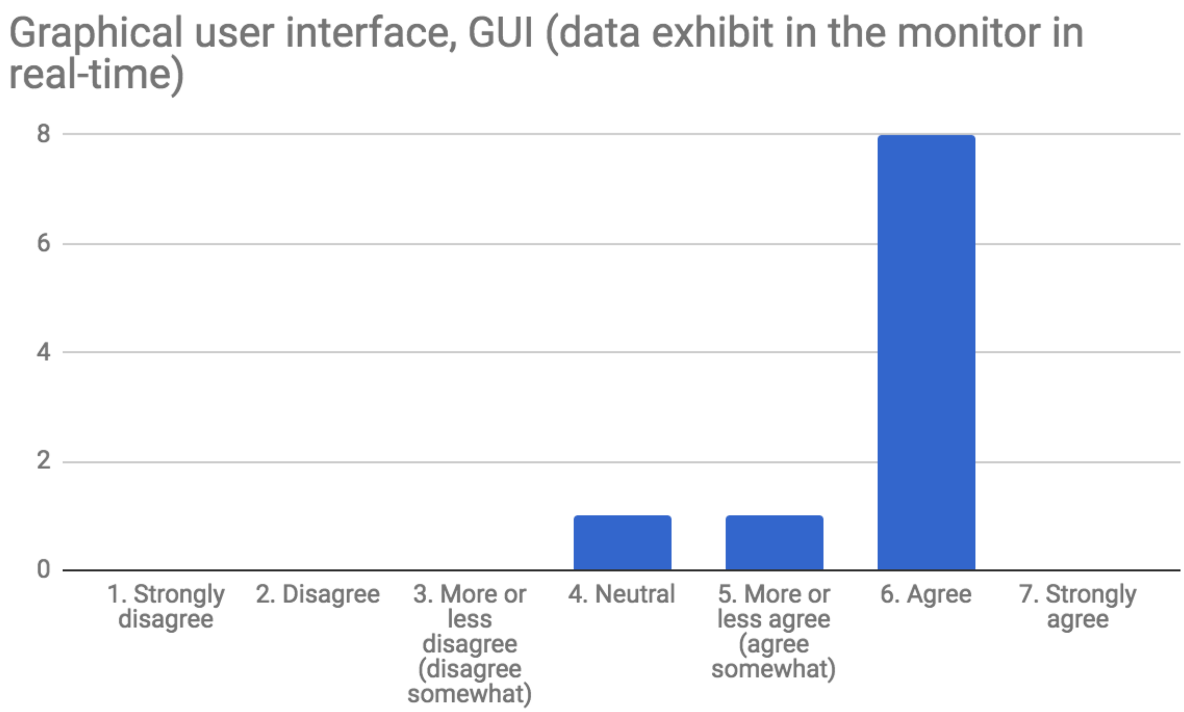


The system/device may cause fatigue if I continue to use it for long time (say, 30 minutes)

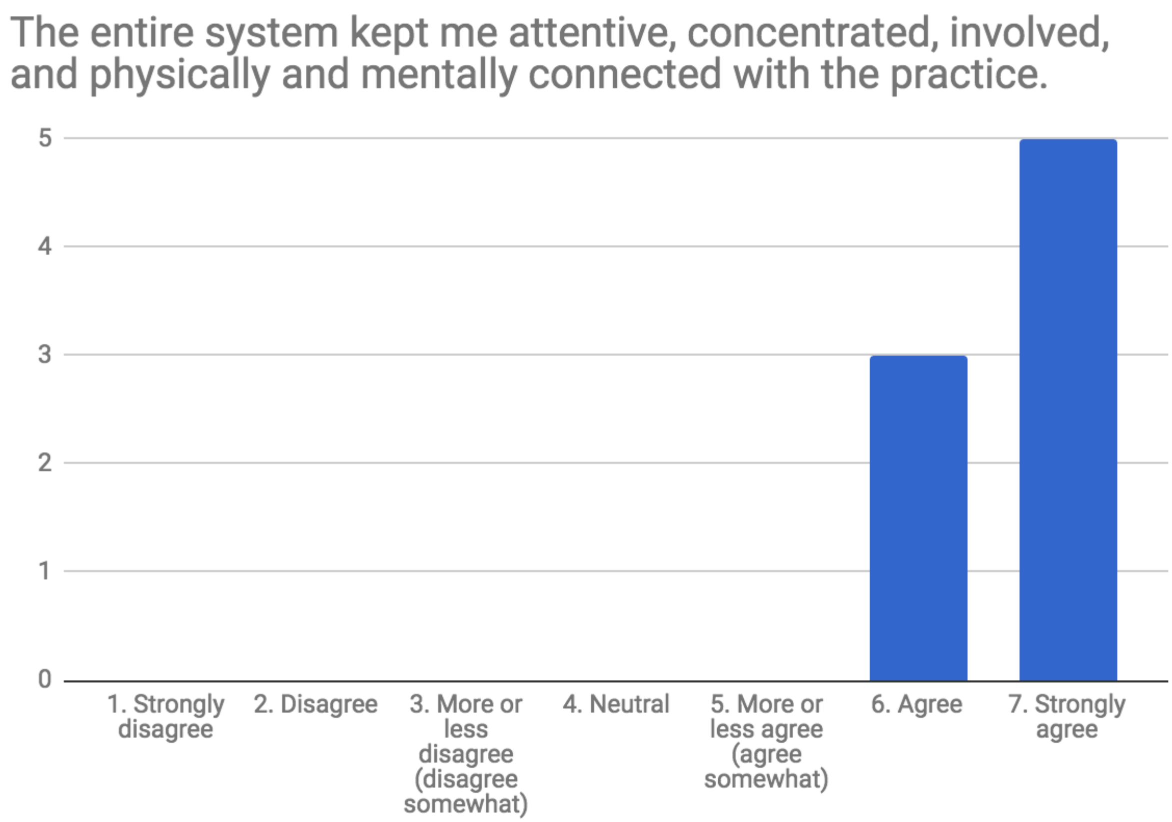


It is safe to wear and use the device

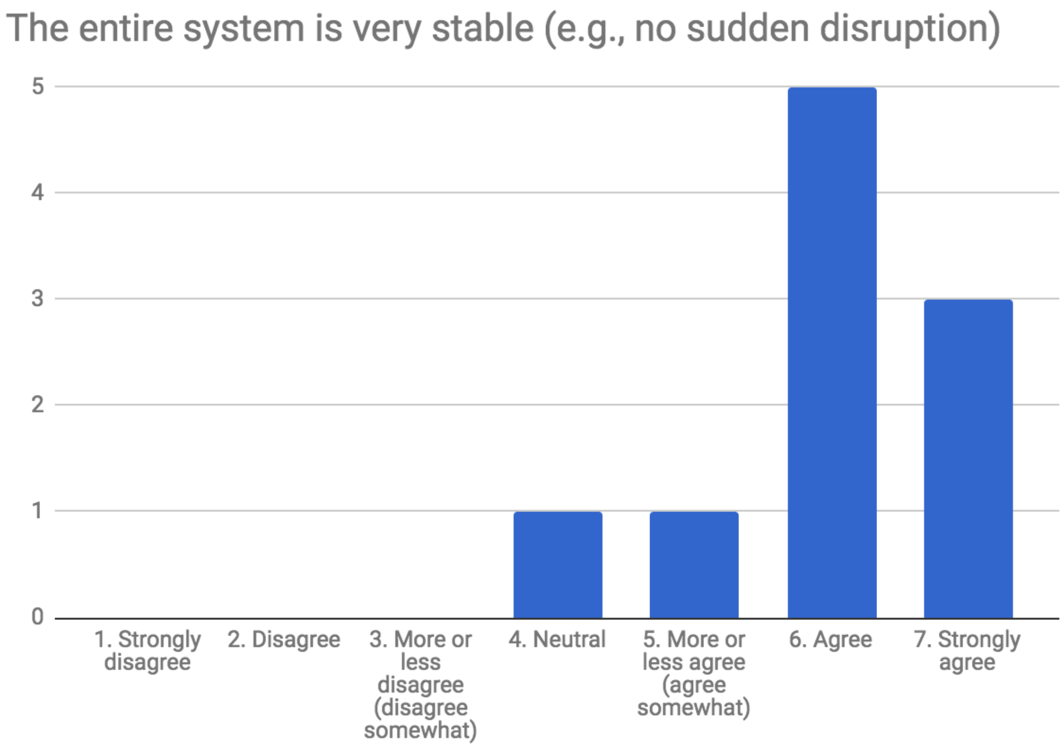


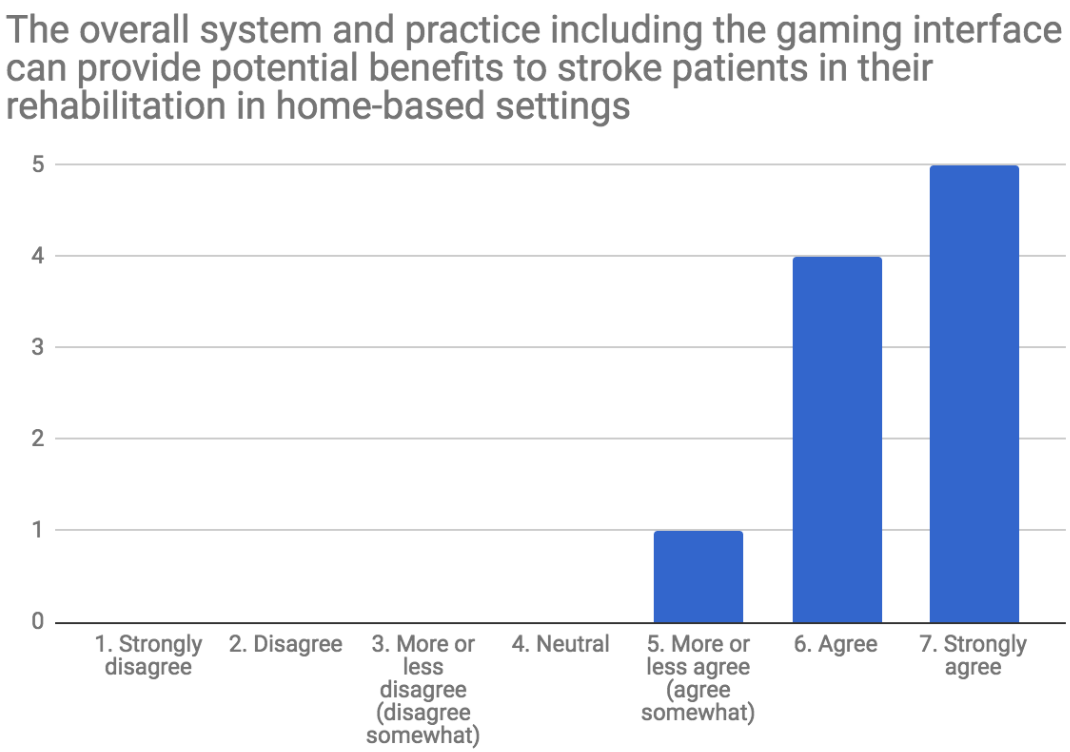


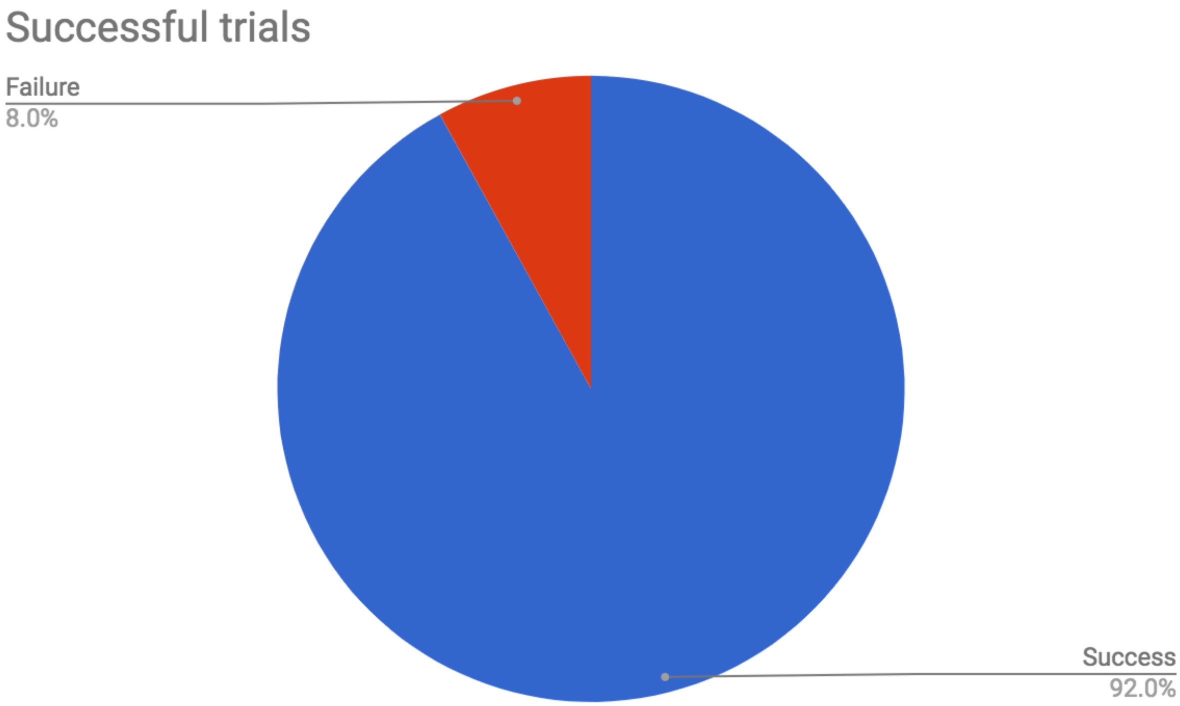
Graphical user interface, GUI (data exhibit in the monitor in real-time)
8
6
4
2
0
1. Strongly disagree
2. Disagree
3. More or less disagree (disagree somewhat)
4. Neutral
5. More or less agree (agree somewhat)
6. Agree
7. Strongly agree



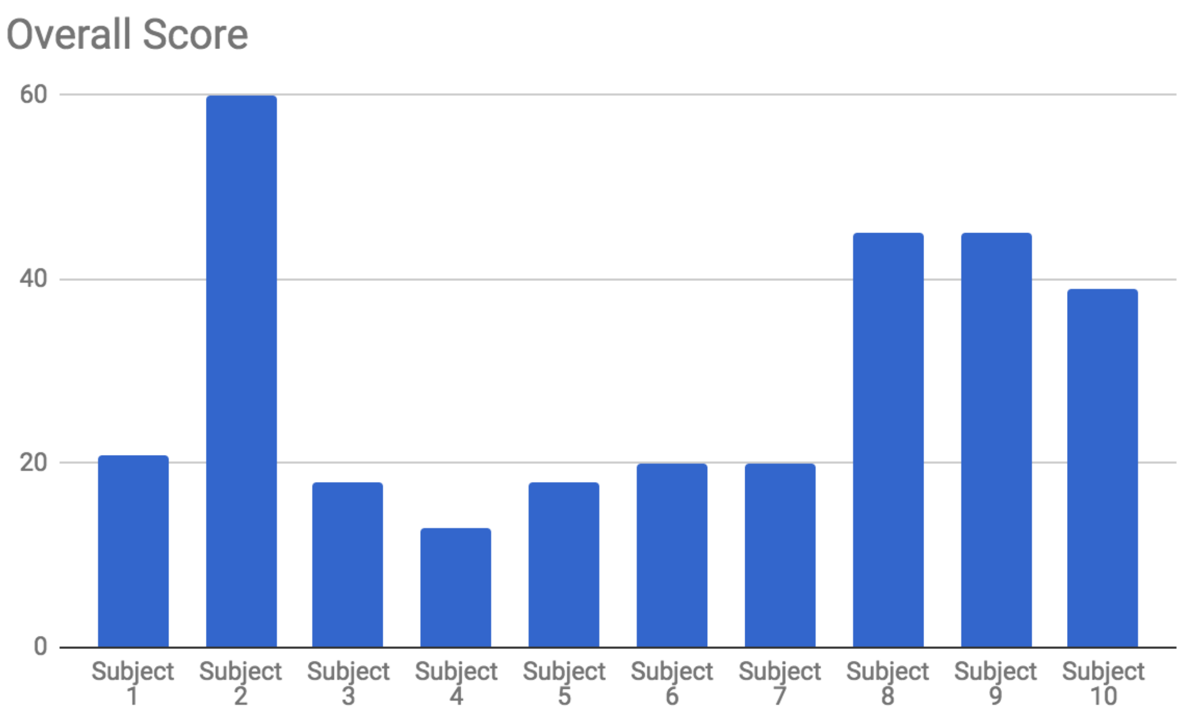
The entire system kept me attentive, concentrated, involved, and physically and mentally connected with the practice.
5
4
3
2
1
0
1. Strongly disagree
2. Disagree
3. More or less disagree (disagree somewhat)
4. Neutral
5. More or less agree (agree somewhat)
6. Agree
7. Strongly agree

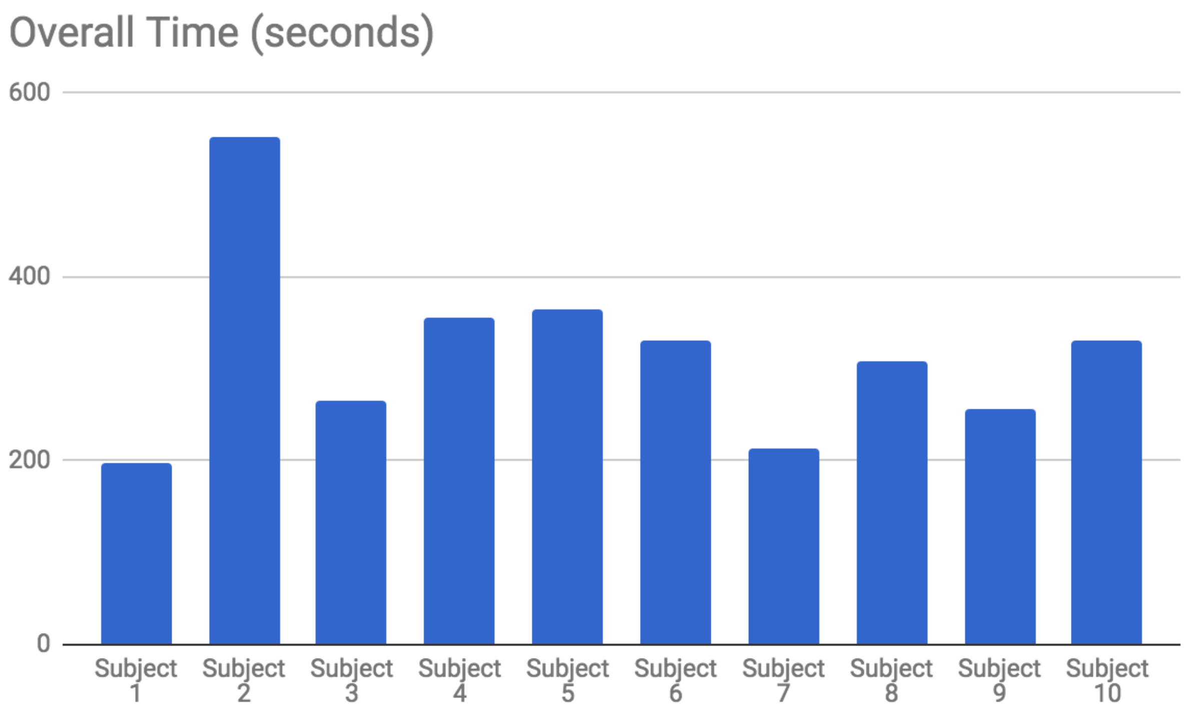

The entire system is very stable (e.g., no sudden disruption)
5
4
3
2
1
0
1. Strongly disagree
2. Disagree
3. More or less disagree (disagree somewhat)
4. Neutral
5. More or less agree (agree somewhat)
6. Agree
7. Strongly agree


The overall system and practice including the gaming interface can provide potential benefits to stroke patients in their rehabilitation in home-based settings
5
4
3
2
1
0
1. Strongly disagree
2. Disagree
3. More or less disagree (disagree somewhat)
4. Neutral
5. More or less agree (agree somewhat)
6. Agree
7. Strongly agree



- Additional 50 experiments were done and the final success and failure rates were 94% and 6% respectively.





7. Conclusion

The mean values of sensor data for each motion were determined which can help in measuring the rehabilitation progress of stroke patients. The developed interfaces can be used with other instrumented objects such as the grasp rehabilitator in this case, where the improvement in the lift and grasp forces was related to the muscle activity, acceleration, and orientation of the forearm.
From the subjective evaluation, it can be concluded that the Myo armband is comfortable to wear as it is not too tight/loose. It will be unobtrusive for stroke patients to incorporate into their activities of daily living. Also, the gaming interface was found to be engaging and motivating among the subjects. It could help stroke patients to exercise more and get faster recovery of their motor skills. Clinical validation needs to be done as future work.

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