Robotics Rehabilitation for Training and Assessment of Upper Extremities

by

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16545

Dissertation submitted in partial fulfillment of

the requirements for the

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(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
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Approved by,

(Assoc. Prof. Dr. Irraivan Elamvazuthi)

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TRONOH, PERAK
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(CHEE PUI SAN)

ABSTRACT

Robotic Rehabilitation is a prominent rehabilitation tool that provides comprehensive repetitive tasks, diversity and feedback for cost efficiency with quantitative measurement of human motor performances substituting the conventional physiotherapy. However, the current literature has a paucity of robotic devices assessment on the human motor performances with different handedness. Therefore, this study aims to investigate both hands kinematic abilities to accomplish a reaching task which is the virtual supermarket game (picking up the food) with their effect of handedness is conducted by using rehabilitation robotic, Armeo®Spring along with the surface electromyography (sEMG) to evaluate the ability of individual muscle activation when performing an upper extremities reaching task. Moreover, a Robotics Rehabilitation Management Tool is developed as a user-friendly clinical management tool for physiotherapist and patients. Fifteen (15) subjects, 9 males, and 6 females are divided into different groups; males right-handed, males left-handed, female right-handed, female left-handed and males both-handed. From the study, the range of motion (ROM) and muscle activation (sEMG signal) of the subject were significantly dependent on the handedness. On the contrary, the game scoring and hand position/opening reach were not affected by handedness.

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Besides that, I would like to thank my mentor and my teacher, Assoc. Prof. Dr. Irraivan Elamvazuthi for his teaching, guidance and support in completing this project. He prepared me well for this project and supported me tremendously throughout this project.

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CHAPTER 1
INTRODUCTION

1.1 Background Study

Musculoskeletal Disorders (MSDs) are a type of impairment that are related to body muscle, bone, joints, tendons, nerves and ligaments [1]. Tendinitis, Epicondylitis, and Carpal Tunnel Syndrome are some of the examples of MSD. For instance, extreme flexion and extension of the wrist or forceful exertion are the common causes of Carpal Tunnel Syndrome. Thus, it is stated that MSDs is the 2nd greatest leading factors of disability and 4th considerable consequence on the universal physical condition in the population which includes both disorder and demise that affects more than 1.7 billion of people worldwide [2]. According to Barthel Index [3], the ability to reach is crucial in performing for beyond half of the activities of daily living (ADL).

All defects and disabilities should be recorded for the sole purpose of strategizing a specific solution to tackle the issue at hand. This will produce promising results and subsequently, improve the life standard. A considerable amount of researches and interventions are being studied. The most common manner of rehabilitation to treat MSDs is by physiotherapy, medication and surgery however the lack of available time, expenses and transportation to the hospitals literacy difficult the effectiveness of rehabilitation the MSDs. Consequently, robotic rehabilitation becomes popular in the world of research that could provide comprehensive repetitive tasks, diversity and feedback for cost efficiency with better quality of rehabilitation repositioning the conventional therapy [3].

In recent studies, patients who initiated their own endeavour to rehabilitate have improved significant recovery and functional outcomes compared to complying solely on the passive robot, like robotics exoskeleton is one of the comprehensive examples [4]. Connecting Virtual Reality with task-oriented repetitive movements' robots as well improves muscular strength and movement coordination while creating a sense of encouragement in patients with MSDs [5].

On the other hand, hand function serves a great significant impact towards the independence of every ADL that performs self-care, social and work related functions and the quality of life [6]. Handedness is a conspicuous occurrence, refers to the tendency in the dominance of using one hand over the other in executing motor tasks. The dominant hand is hereby used in most of the motor tasks which includes writing, eating, drawing and throwing. From a survey, 90% of the society is right-handers while the remaining 10% is left-handers. In some rare case, less than 1% is reported as Ambidexterity who can use both left hand and right hand equally well either at the same time or not [7]. In [8], the risk of MSDs (wrist/hand pain) are affected by the handedness.

1.2 Problem Statement

With the drastic increase of MSDs in this globalization era, this may result in severe effects not only to the patients themselves but also to the organization and the economy of the country. For instance, MSDs cost the US approximately $45-55 billion annually which 80 percent of the adults are affected at certain age depending on their workload [9]. Therefore, the problem statements of this project are:

- Limited studies on the effect of handedness in the risk of MSDs
- In conventional physiotherapy, there is no continuous measurement on improvement which the result might not be as accurate.
- Lack of human friendly clinical management tool for physiotherapist and patients

1.3 Research Questions

Can Robotics Rehabilitation provide accurate assessment of handedness?

1.4 Hypothesis

The dominant hand should perform better in terms of range of motion while the game scoring, hand position reach and hand opening reach are independent of handedness and gender. Furthermore, muscle activation is affected by handedness and gender.

1.5 Research Objectives

The objectives are:

1. To investigate effects of handedness on both hands kinematics abilities.
2. To obtain quantitative data.
3. To develop a Robotics Rehabilitation Management Tool (RRMT).

1.6 Scope of Study

In this project, an experiment is conducted on Armeo®Spring to study on both hands kinematic abilities by performing reaching task which is the virtual supermarket exercise (picking up food) with their effect of handedness. Furthermore, muscle activation for two muscles (Extensor Carpi Radialis and Palmaris Longus) is recorded during the game using Delsys surface electromyography (sEMG) System. The students of Universiti Teknologi PETRONAS are the controlled healthy subjects mimicking the underlying involuntary movements by the difference in their both hands with their handedness. The resulting data is used to determine the coordinated arm and hand movements. In conclusion, quantitative data from the experiments are analyzed and its relationship with the quality of life.

1.7 Relevancy and Feasibility

The Robotics Rehabilitation for Training and Assessment of Upper Extremities is a project which is relevant to the electrical and electronics studies as it focuses majorly on the subject of control and instrumentation where it involves the study on the robotics control in human motion. Different modes of control and types of robotics rehabilitation are being studied to designate the foremost rehabilitation method for an optimal reintegration of human motion.

This project is feasible within 8 months of study which is consequently for two semesters as it is a research project. In this research project, an experiment was carried out and the results were analyzed to conclude the hypothesis which had been made upfront. Moreover, research papers, book, and journals are easily assessable in the library and websites.

1.8 Dissertation Outline

The rest of the chapter is outlined as follows:

Chapter 2 discusses the background of robotics technology in rehabilitation field with their different modes of control. Moreover, the different type of robotics rehabilitation and their pros and cons along with the related works will also be reviewed and summarized in the critical analysis section.

Chapter 3 describes the type of robotic rehabilitation being used in the experiment and the flow of FYP 1&2 using a flowchart, Gantt chart, and Key milestones. Furthermore, the experimental design is also being outlined in this chapter in detailed.

Chapter 4 gives the result of the experiment that has been conducted and a discussion based on the results obtained. The hypothesis is being deduced in this segment.

Chapter 5 provides a closure for the study and future recommendations are suggested in this section.

CHAPTER 2
LITERATURE REVIEW

2.1 Background

A robot is a machine competent of executing an intricate series of actions autonomously whereas rehabilitation is usually a complex and tedious process which involve task-oriented repetitive movements [10]. Hence, robots are best suited for repetitive movement tasks and better therapy conditions in terms of precision which make them the largest potential as rehabilitation tools.

Rehabilitation robots comprise of a mechanical frame with a few motorized degree-of-freedom (DOF) which is the function to move, translate or rotate, around or along an axis in space by integrating one or several systems together. Furthermore, they come with sensors to provide augmented feedback such as the position or force which empower the robot to carry out the task effectively and efficiently [11].

Certain constraints such as extremities sudden reflexes during the rehabilitation process, limitations on the conventional machines such as “Continuous Passive Motion” (CPM) that will potentially damage the patients’ muscle or tendon tissue as of irregular load outcome is inherently not suitable for MSDs patients. Hence, robotics rehabilitation which is designed according to the patient’s real-time feedback during rehabilitation process serves more advantages [12].

Rehabilitation robots aims are [13]:

1. To assist patients to return to suitable, sustainable and meaningful daily life activities in the shortest time.
2. To achieve physical movement support and psychological recovery

3. To replace or assist the therapist in performing repetitive exercises.

Principle Modes of Control

Different modes are defined in designing the rehabilitation robotics which includes active, passive, and interactive systems [14].

Passive: Patients are inactive and their movements are being moved either by robotics or therapist to keep the muscle from atrophying with the absence of voluntary control from the patients. Passive systems are composed of mechanical linkages to move patient's arm easily. For instance, stiff frames, bearings, and pulleys, and ropes with counter weights are the classic technical elements.

Active: Patients will initiate force to complete a motion. Active systems are made of electromechanical, pneumatic, hydraulic or other drives to enable the movement of patient's arm actively through a predefined path.

Interactive systems: Patients will initiate certain movement and the robot will react accordingly and assist the patient's movement using actuators, sophisticated impedance, and other control strategies.

Interactive systems type of control is the common choice in most therapy protocols designs as it serves significant benefits. For example, it is extremely encouraging for enabling patients to attain certain movement or reach which could be difficult to accomplish by them. Help will be activated when a patient initiated a motion of adequate momentum (MIT-Manus [15], ARM Guide [16]) or pressure (MIME) [17] or when EMG signal reaches the maximum threshold. This is a type of impedance control that is represented as a 'virtual slot' which is between the set point orientation and nominal orientation. These phenomena can be described as two springy walls to assist the patients' motion. The back wall is mobile along a minimum jerk orientation while the front wall is at rest. In conclusion, when the patient movement is slower than the mobile wall, assistance will be given while on the other hand, if the patient shows the contrary, assistance will be inactive [11].

Types of robotics rehabilitation

Types of robotics rehabilitation for upper extremities are defined as in Figure 1.

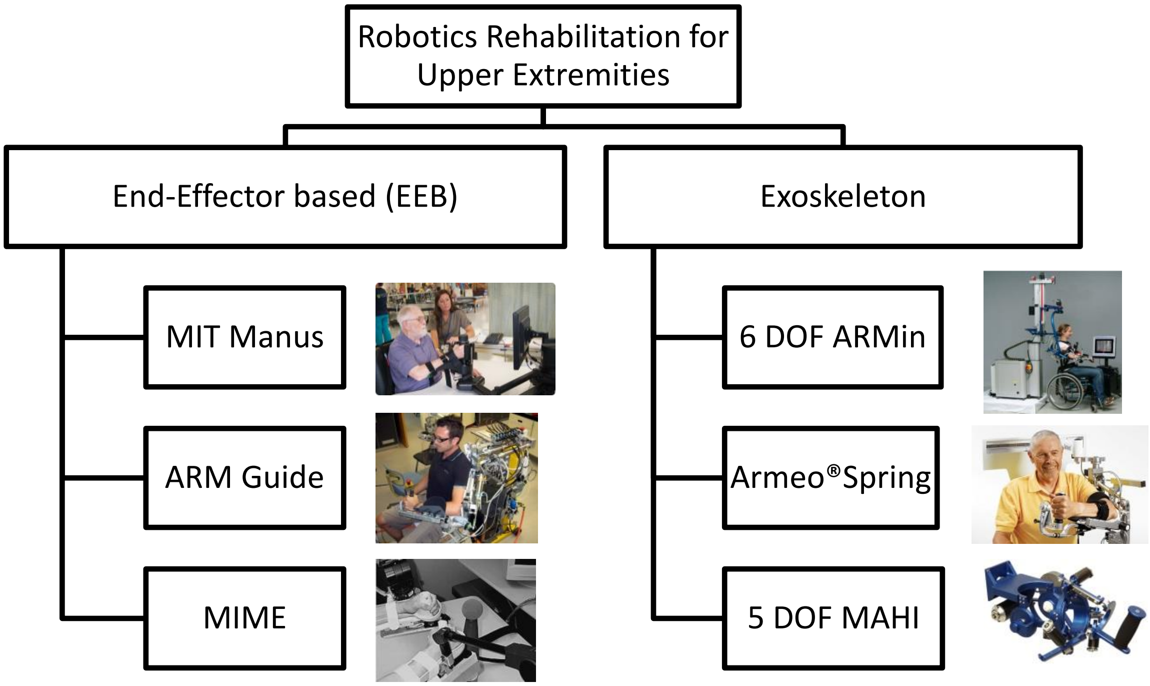


Figure 1: Type of Robotics Rehabilitation

In Figure 1, robotics rehabilitation is being categorized into two respective groups; EEB and exoskeletons. EEB robots do not possess the ability to apply torque to specific joints of the arm but it provides training capability to the distal segments of limbs in encapsulating a huge fragment of utility workspace by constantly applying mechanical forces. Meanwhile, exoskeletons are rigid external that designed similar to human anatomy and structures in order to empower human joint's motion. MIT-Manus, ARM Guide, and MIME are some of the few examples of EEB robots. On the contrary, examples of exoskeletons include 6 DOF ARMin, Armeo®Spring and 5 DOF MAHI.

Incomplete tetraplegia is often associated with loss of bladder and bowel control, sexual dysfunction, trunk disability, and walking which are highly ranked as the primary impairments according to [18]. The most significant impairment of all, however, being prioritized is the loss of arm and hand function as it serves a great significant impact towards the independence of every ADL that performs self-care, social and work related functions. The quality of life of this population is then affected in a huge way [6].

2.2 Related Work

A comparison of related robotics is defined as in Table 1.

Table 1: Analysis of Related Robotics

No	Author	Year	Type of Robotics Rehabilitation	Application	Merits	Demerits
1	Sharifi, et al. [15]	2012	End-Effector Based	MIT-Manus	Low cost	Less range of movement for possible exercise scenario
2	Staubli et al. [19]	2009	Exoskeleton	6 DOF ARMin	Features authoritative motion sequences, inclusive of coordinated interactions between wrist, elbow and shoulder joints	
3	Gupta, Abhishek et al. [20]	2007	Exoskeleton	5 DOF MAHI	Features a safe training environment and customized feedback	Limitation of torque output capability.
4	Lum et al. [17]	2006	End-Effector Based	MIME	Effective as an equivalent dose of conventional rehabilitation therapy	Lack of distinct treatment for distal joints such as wrists

5	Reinkensmeyer DJ et al. [16]	2000	End-Effector Based	ARM Guide	Adjustable slide to assist forearm movements	Limited working space for linear movements

In Table 1, MIT-Manus [15] which was commercialized by MIT in the USA is a 2 DOF system and one of the low-cost rehabilitation robots. It has a main controller that operates a virtual spring and curb between the task-oriented, stability point contingent on time and the orientation of the end effector. The ARMin [19] is a 6 DOF system . It features authoritative locomotion sequences and coordinated interactions between different articulation inclusive of the wrist, elbow and shoulder joints. On the other hand, MAHI [20] is a 5 DOF system designed at Rice University, which is specialized in virtualized rehabilitation. It features a safe training environment and customized feedback as its primary consideration is the kinematic design with the assistance for excessive weight and gravity compensation. In addition, MIME robot [17] developed by VA/Stanford University, Palo Alto is a traditional industrial robot. It is as efficacious as an alternative dose of conventional rehabilitation treatment due to its large dimensional motion in a 3D plane. The ARM-Guide [16] robot is a reasonable priced and simple designed 4 DOF system. It consists of an adjustable slide with two rotations which enable the 3D variation in the orientation of movements to assist forearm movements.

A comparison of related works is defined as in Table 2.

Table 2: Analysis of Related works

No	Author	Year	Experiment	Results	Limitation
1	Duthilleul et al. [21]	2015	Ten healthy subjects performing fine and wide movements using EMG.	Wide Movement - Left Hand has a higher number of muscle synergies than right hand regardless of handedness. Fine Movement - Dominant hand has higher number of muscle synergies than non-dominant hand.	- Small scale of subjects - Does not consider both-handed condition - Only depend on one result which is from EMG.
2	Park and Park. [22]	2015	Eighteen left-handers subject consisted of ten males and eight females subjects were experimented on the effects of using a scissor designed for left-handers and for right-handers	Scissor for left-handers - The degree of wrist flexion decreased which result in more functionality and higher accuracy.	- Only tested on left-handed subjects which the result is too subjective
3	Park [7]	2013	36 subjects (16 left-handers, 20 right-handers) performed an experiment on the muscle activation of upper extremity during writing.	Left-handers - Additional wrist flexion is needed during writing - Initiate more wrist and shoulder muscles Right-handers - Less wrist flexion is needed when writing - Less wrist and shoulder muscle needed	- Only depend on one result which is from EMG.

4	Park and Yang [23]	2012	25 subjects (12 left-handers and 13 right-handers) evaluated quantitatively the wrist flexion of right-handers and left-handers through writing.	Left-handers - Greater wrist flexion is needed during writing Right-handers - Lesser wrist flexion is needed when writing	- Does not consider both-handed condition
5	Yoshikawa et al. [24]	2007	Ten(10) male subjects (9 right-handed and one left-handed) evaluated quantitatively the dominance of handedness using haptic virtual reality technology	Position Control Test and Manipulation Test - The dominance hand performs better compared to the non-dominance hand. Force Test - Left hand for left handed and three other subjects left performed better than the right hand.	- Small scale of subjects - Does not consider both-handed condition - Limitation on gender
6	Tezel et al. [25]	2005	221 dental students (24 left-handed, 24 right-handed, 173 right-handed of different age groups) are studied to assess the frequency of MSDs-related during the dental practice.	Left-handed students tend to have higher frequency of MSDs as compared to right-handed students regardless of gender.	- Does not consider both-handed condition - No quantitative measurement or diagnosis (only based on questionnaire)
7	Roman-Liu. and T. Tokarski [26]	2002	Nine (9) healthy right-handed male students were evaluated on the handgrip force and EMG signal for five muscles by carrying out two tests (with maximum handgrip force and with 10% of maximum handgrip force)	The variation between maximum handgrip forces in the experiment does not show significant difference. However, the value of handgrip force exertion is significantly dependent on the upper limb location.	- Small scale of subjects - Constraints on the different type of handedness - Limitation on gender

Numerous studies have been carried out in the area of handedness. In Table 2, Duthilleul et al [21] have carried out a study on a sample of ten healthy subjects performing fine and wide movements using EMG in 2015. From the study, left hand has a higher number of muscle synergies than right hand regardless of handedness in wide movements, while for fine movement, the dominant hand has a higher number of muscle synergies than non-dominant hand. Park and Park [22] also conducted an experiment in the same year on the differences in upper extremities wrist flexion using a scissor made for different dominant. The degree of wrist flexion decreased which result in more functionality and higher accuracy when the left-handers subjects used the scissors that are specially designed for left-handers as compared to scissors that are designed for right-handers. The research concluded that left-handers needed additional wrist flexion and initiated more wrist and shoulder muscle during writing as compared to right-handers. In addition, Park [7] conducted an experiment on thirty-six subjects consisted of right-handers and left-handers to study on the muscle activation of upper extremities during writing. In this paper, it was reflected that left-handers needed additional wrist flexion and initiated more wrist and shoulder muscles during writing. Moreover, in 2012, Park and Yang [23] did a research on evaluating the wrist flexion for right-handers and left-handers through writing. The result was the left-handers actually need greater wrist flexion during writing compared to right-handers. On the other hand, in 2007, Yoshikawa et al [24] have conducted a study on a control group of ten male subjects (9 right-handers and one left-hander) to evaluate quantitatively the dominance of handedness using haptic virtual reality technology. The finding was the dominance hand performs better compared to the non-dominant hand in position control and manipulation test. In contrary, left hand for left handed and three other subjects' left hand performed better than the right hand in force test. In 2005, Tezel et al [25]conducted a study to assess the frequency of MSDs during the dental practice which focuses on a control group of 221 dental students (24 left-handed, 24 right-handed, 173 right-handed of different age groups). Left-handed students tend to have a higher frequency of MSDs as compared to right-handed students regardless of gender using questionnaire technique. Roman and Tokarski [26] presented a research to evaluate on the handgrip force and EMG signal for five muscles by carrying out two tests (with maximum handgrip force and with 10% of maximum handgrip force). The variation between maximum handgrip forces in the experiment does not show significant difference. However, the value of handgrip force exertion is significantly dependent on the upper limb location.

2.3 Critical Analysis

MIT-Manus [15] has less range of movement for possible exercise scenario due to it only designed for elbow and shoulder hand movement in a horizontal plane. On the other hand, MAHI [20] has a limitation of torque output capability. The only flaw in MIME [17] is it lacks distinct treatment for distal joints such as wrists. On top of that, the disadvantage of ARM-Guide [16] system is the limited working space for linear movements. From the analysis of the applications of robotics rehabilitation, it shows that Exoskeleton features more advantages especially in terms of joints movement compared to EEB robotics. In a nutshell, Armeo®Spring which is exoskeleton type is chosen as the experimentation tool to understand the human motion and the kinematic abilities of hand motion.

In [21], the study only depended on one result which was solely from the EMG. Moreover, it did not consider the both-handed condition and conducted on a small scale of subjects which affected the results' reliability. On the other hand, authors Park and Park study only tested on left-handed subjects which the result was too subjective [22]. In [7] [23], both the studies only depended on one result and did not consider both-handed condition which might affect the result. Besides, Yoshikawa et al [24] had a similar limitation which was a small scale of subjects and limitation on gender which in this case the research only conducted on a control group of ten male subjects. They also did not consider the both-handed condition. In [25], Tezel et al did not have a quantitative measurement or diagnosis as the author only depended on the questionnaire result which might affect the accuracy of his research. Last but not least, [26] had a constraint on the different type of handedness which the author only studied on right-handed subjects. The author did not consider other handedness and had a limitation on gender. In conclusion, all of the studies showed similar limitation where they did not consider the both-handed condition and often had a small scale of subjects. Furthermore, most of the studies were limited to only one source of tool to evaluate the result which is not reliable and supportive enough.

2.4 Summary

In this chapter, the functions and advantages of robotic rehabilitation which make them the most promising rehabilitation tools in the market are being discussed. In addition, the principle modes of control and the types of robotics rehabilitation are being reviewed in depth in this chapter. For instance, different modes in designing the rehabilitation robotics are active, passive and interactive systems. On the other hand, the types of robotics rehabilitation are the EEB robots (MIT-Manus, ARM Guide, MIME) and exoskeleton robots (ARMin, Armeo®Spring, MAHI). Last but not least, the related robotics advantages and disadvantages are discussed and related works are analyzed.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

The flow of project methodology is shown as Figure 2.

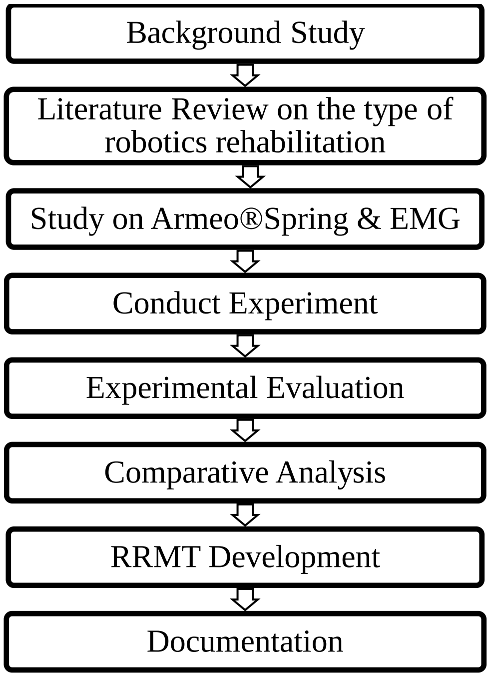


Figure 2: The flow of Methodology

In Figure 2, the project kick-off with a thorough background study on the project title as it is essential to understand the overview of the project in order to achieve the objectives of the project. Furthermore, various literature sources such as research papers were studied and analyzed for the compilation of literature review on different types of robotics rehabilitation.

Besides, the control mechanism of rehabilitation robotic which is the Armeo®Spring was studied to design a foremost method demonstrating the effect of human motion in the different type of handedness using robotics rehabilitation. The quantitative measurements include range of motion, hand position reach (3D) and hand opening reach (3D) were obtained from the rehabilitation robotic was then further studied and evaluated to determine the accuracy and significant of the statistical data. On the contrary, the sEMG device was used in conjunction with the rehabilitation robotic to get additional data for evaluation of the effect of handedness.

Next, the experiment was conducted and evaluated in fifteen (15) healthy subjects from Universiti Teknologi PETRONAS. From the results, a comparative analysis was carried out. Then, Robotics Rehabilitation Management Tool (RRMT) was developed as a user-friendly tool to manage the subjects' records and statistically data. Finally, the whole project was documented.

3.2 Experimental System

3.2.1 Rehabilitation Robotics

Figure 3 shows a patient with Rehabilitation Robotic device.

Figure 3: Armeo®Spring

In this project, Armeo®Spring from Hocoma as shown in Figure 2 was used to study the dynamic function of human motor control and motor learning. The Armeo Therapy Concept focuses on exercises that are self-initiate, self-directed, functional and intense, thus increasing the effectiveness of rehabilitation which is an enhancement version of (T-WREX) [27]. This robotics has an ergonomic arm skeleton with integrated spring mechanism that provides great gravity support system which cradles the entire arm. Furthermore, with the enhancement of any residual function and neuromuscular control, patients are able to move actively across an extensive 3D workspace providing an augmented feedback. There is also a pressure-sensitive handgrip in which is effective for exercising the hand motor motion by executing grasp and release exercises, movement of wrist. The integration of Armeo software that contains numerous of game-like movement exercises that are similar to ADL simulated in a virtual-reality training creates a motivating environment to the patients' along with the immediate feedback response [28].

3.2.2 Delsys sEMG System

Figure 4 shows the Delsys sEMG system used in quantifying the muscle activation.

Figure 4: Delsys sEMG Wireless System

Delsys sEMG System is a non-invasive biofeedback system features wireless surface EMG sensors aimed for motor control studies and unit behavior. This system will be used to determine the handedness-related differences in muscle activation. This innovation is an enhancement of conventional analysis of surface EMG which can produce a homogenous EMG signal with low muscle crosstalk and minimized motion artifact with an array of surface sensors.

3.2.3 Robotics Rehabilitation and Management Tool (RRMT)

Robotics Rehabilitation and Management Tool (RRMT) is a user-friendly and sophisticated management tool developed in this project using visual basic. It features

- Retrieve and save patient’s personal information
- Integration with Armeo®Spring and EMG
- Simple illustration (graph) to show the muscle activation

3.3 Experimental Design

The differences in handedness in healthy subjects were studied using robotic rehabilitation (Armeo®Spring from Hocoma) and EMG recording (Delsys dEMG System). For instance, it was expected that a left-handed subject, left hand will have a larger range of motion and opening reach as compared to his right hand because of the constant exertion activities. This experiment measured the range of motion, scoring from a computer-based exercise (collecting food and positioning them in a trolley) scores, hand position/opening reach and EMG signal during the exercise for both hands. The results were analyzed to make a conclusion.

Measurement:

1. *Range Of Motion (ROM)*
   The ROM was measured using Armeo®Spring by assessment of horizontal shoulder abduction/adduction, shoulder inner/outer rotation and shoulder flexion/extension.

2. *Game Scoring, Hand Position Reach and Hand Opening Reach*
   These were measured using Armeo®Spring by performing the computer-based exercise which is similar to daily activities exercise which is picking food and positioning them into the cart.

Hand Position Reach is how close the hand was to the target at the minimum point and the smoothness of the movements (ratio of their hand path-length to a straight line).

Hand Opening Reach is how much degree of opening and closing during the grabbing and release of the food.

3. *EMG signal*

EMG signal of two muscles (Extensor Carpi Radialis and Palmaris Longus) were obtained simultaneously by positioning the electrodes on these muscles during the execution of Armeo®Spring's exercise.

Filtering raw data using Root Mean Square

$$\boldsymbol{Root\ Mean\ Square, RMS} = \left[\frac{\mathbf{1}}{\boldsymbol{S}}\sum_{1}^{S} f^2(s)\right]^{\frac{\mathbf{1}}{\mathbf{2}}} \qquad (1)$$

where,

S = window lengths (points)

f(s) = data within the window

Analyzing the results

$$\boldsymbol{Mean, \mu} = \frac{\boldsymbol{\Sigma X_i}}{\boldsymbol{N}} \qquad (2)$$

where,

ΣX_i = sum of population observations

N = number of population observations

$$Standard\ Deviation, \boldsymbol{SD} = \boldsymbol{sqrt}\ \left[\frac{\boldsymbol{\Sigma(X_i - \mu)^2}}{\boldsymbol{N}}\right] \qquad (3)$$

where,

X_i = ith element from the population

μ = population mean

N = number of elements in the population

3.3.1 Subjects

There were a total of 15 healthy subjects from Universiti Teknologi PETRONAS without a history of MSDs enrolled in this study. They performed a computer-based exercise that was similar to the activity of daily life which was the picking food and positioning them in a shopping cart. These 15 subjects were divided into 3 distinct categories (Left-handed subjects, Right-handed subjects and Both-handed subjects). Both-handed is often a rare case but it was also included in this study. These subjects were given a set of questionnaire (LQ test) to place them into their respective categories. Each category has consisted of 3 male subjects and 3 female subjects except for the both-handed categories which only consisted of 3 male subjects due to its uncommon behavior.

Table 3 shows the subjects details calculated in mean for each respective group.

Table 3: Subjects Details

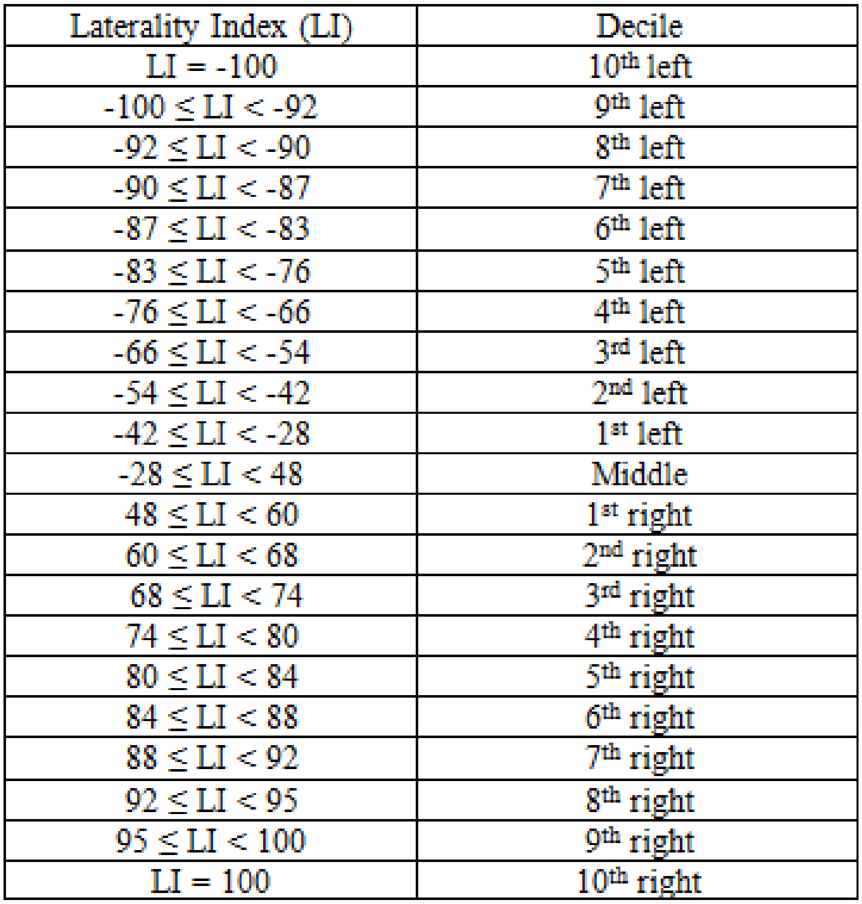
Groups	Age (yrs)	Weight (kg)	Height (cm)
M-LH	±22.67	±58.33	±167
M-RH	±23	±62.33	±175.67
F-LH	±23.33	±52.33	±163.67
F-RH	±25	±49.33	±162.33

Groups	Age (yrs)	Weight (kg)	Height (cm)
M-BH	±22.33	±58.67	±171.67

Table 4: Handedness Questionnaire

	LEFT	No preference	RIGHT	Do you ever use the other hand?
Writing				
Drawing				
Throwing				
Using Scissors				
Using a toothbrush				
Using a knife (without a fork) Using a spoon				
Using a broom (Upper hand)				
Striking a match				
Opening a box (holding the lid)				

Table 5: Handedness Evaluation



Laterality Index (LI)	Decile
$\text{LI} = -100$	10th left
$-100 \leq \text{LI} < -92$	9th left
$-92 \leq \text{LI} < -90$	8th left
$-90 \leq \text{LI} < -87$	7th left
$-87 \leq \text{LI} < -83$	6th left
$-83 \leq \text{LI} < -76$	5th left
$-76 \leq \text{LI} < -66$	4th left
$-66 \leq \text{LI} < -54$	3rd left
$-54 \leq \text{LI} < -42$	2nd left
$-42 \leq \text{LI} < -28$	1st left
$-28 \leq \text{LI} < 48$	Middle
$48 \leq \text{LI} < 60$	1st right
$60 \leq \text{LI} < 68$	2nd right
$68 \leq \text{LI} < 74$	3rd right
$74 \leq \text{LI} < 80$	4th right
$80 \leq \text{LI} < 84$	5th right
$84 \leq \text{LI} < 88$	6th right
$88 \leq \text{LI} < 92$	7th right
$92 \leq \text{LI} < 95$	8th right
$95 \leq \text{LI} < 100$	9th right
$\text{LI} = 100$	10th right

3.3.2 Experimental Procedure

The step-by-step procedure of the experiment is outlined as follows:

1. The Armeo®Spring is positioned to the left for left hand assessment.
2. The Armeo®Spring is set up according to the length of the upper and lower arm of the subject and the weight support (described in APPENDIX B) for upper and lower arm is constant which is D for both upper and lower arm as in Figure 5.

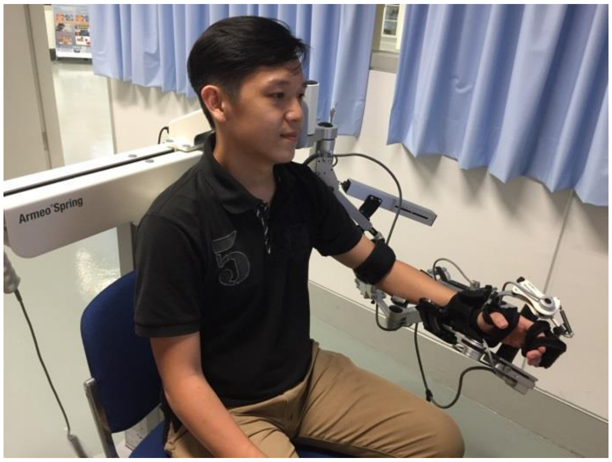


Figure 5: ArmeoSpring Set Up

3. The assessment started with measuring the range of motion (ROM) as in Figure 6.

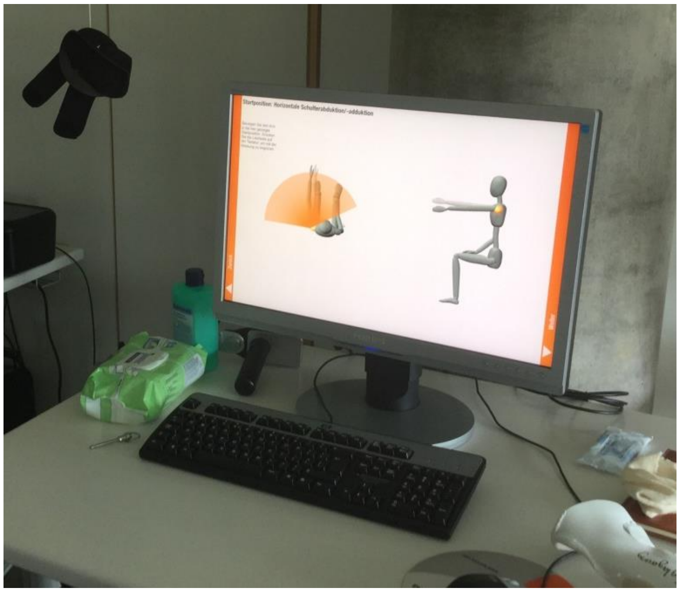


Figure 6: Measuring ROM

4. The active motion of the subject is measured by painting 5 walls which include the far wall, left & right walls, upper wall and lower wall as in Figure 7.

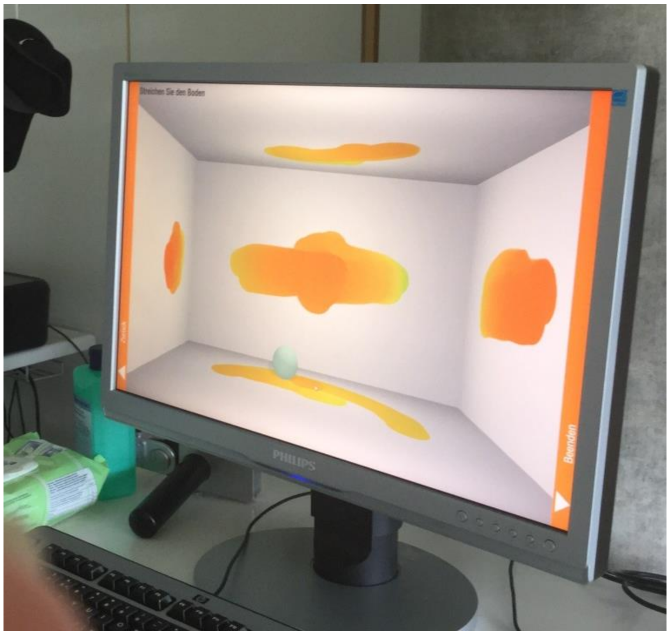


Figure 7: Measuring the active motion

5. Two electrodes are attached to the subjects’ muscles ((Extensor Carpi Radialis and Palmaris Longus) as in Figure 8 to measure the muscle activation during the exercise.

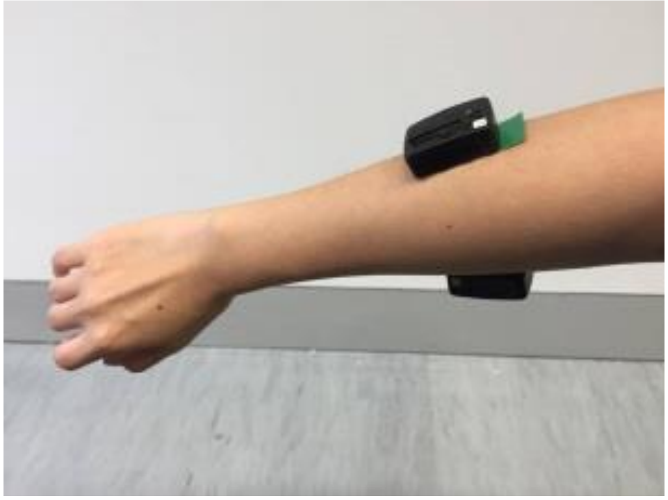


Figure 8: Measuring muscle activation

6. Lastly, the training and assessment for a reaching task which is the picking food exercise. The patient has to move his/her arm and grabbed the food and put them into a shopping cart as in Figure 9.

Figure 9: Picking food

7. Steps 1 to 5 will be repeated for right hand assessment.
8. The results will be tabulated and a graph for better analysis.

3.3.3 EMG Signal Collecting and Processing

1. The wireless sensors are turned on and attached to the two muscles of the subject (Palmaris Longus and Extensor Carpi Radialis) connected wirelessly to the Delsys sEMG System as shown in Figure 10.

Figure 10: Delsys sEMG System

2. EMG signals are obtained during the execution of exercise using the rehabilitation robotic which is the Armeo®Spring as shown in Figure 11.

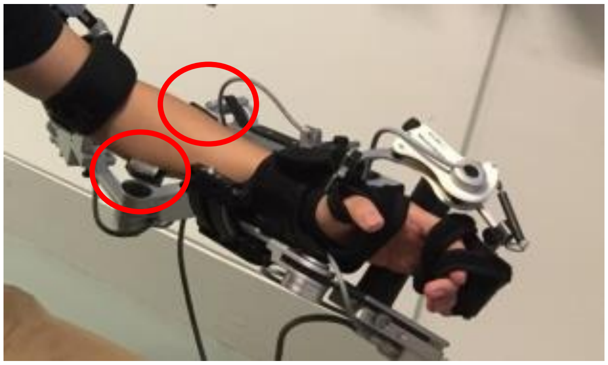


Figure 11: Acquiring sEMG Signal with Rehabilitation Robotic

3. Figure 12 is the raw sEMG data (Palmaris Longus and Extensor Carpi Radialis) obtained from the two minutes exercise (picking up food and placing them into the cart) which involved constantly grabbing and release of hand function.

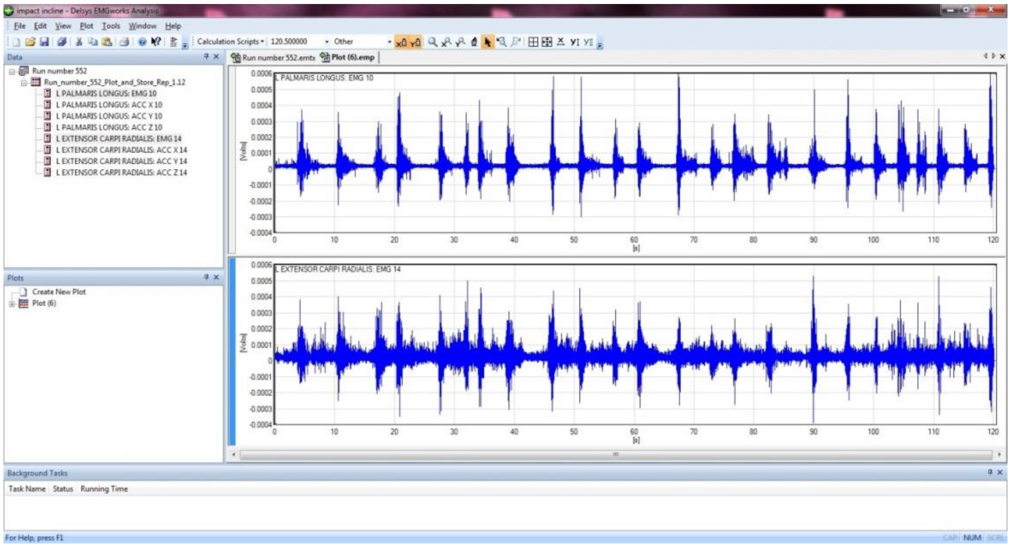
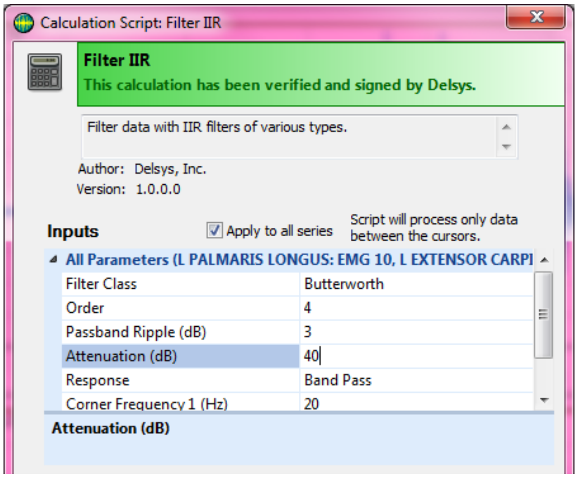


Figure 12: Raw sEMG data

4. The raw data are filtered using Butterworth with an order of 4, passband ripple of 3dB, attenuation of 40dB, a band pass response and a corner frequency of 20Hz as shown in Figure 13.



Calculation Script: Filter IIR

Filter IIR

This calculation has been verified and signed by Delsys.

Filter data with IIR filters of various types.

Author: Delsys, Inc.

Version: 1.0.0.0

Inputs ☑ Apply to all series Script will process only data between the cursors.

All Parameters (L PALMARIS LONGUS: EMG 10, L EXTENSOR CARPI

Filter Class	Butterworth
Order	4
Passband Ripple (dB)	3
Attenuation (dB)	40
Response	Band Pass
Corner Frequency 1 (Hz)	20

Attenuation (dB)

Figure 13: Obtaining Filtered Signal

5. Figure 14 shows the filtered sEMG Signals of Palmaris Longus at the top and Extensor Carpi Radialis at the bottom.

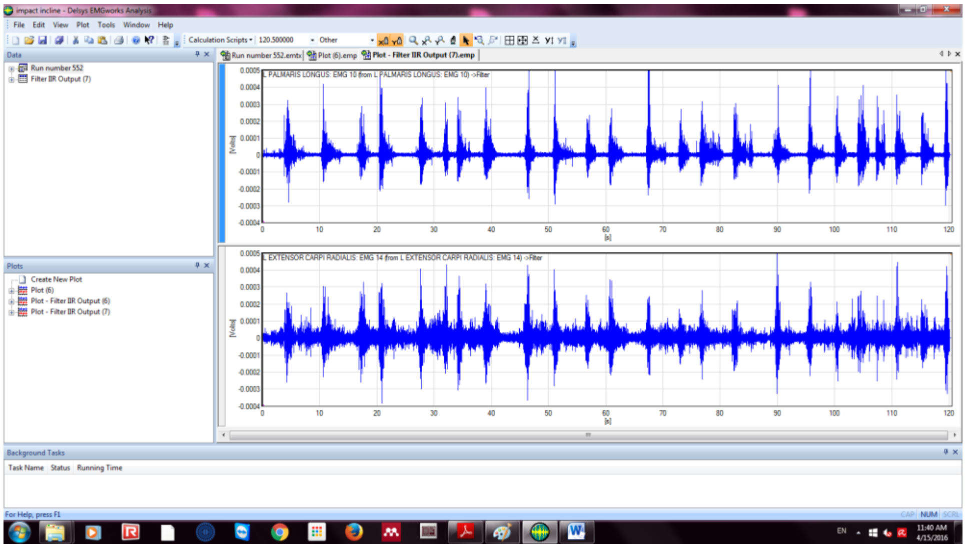
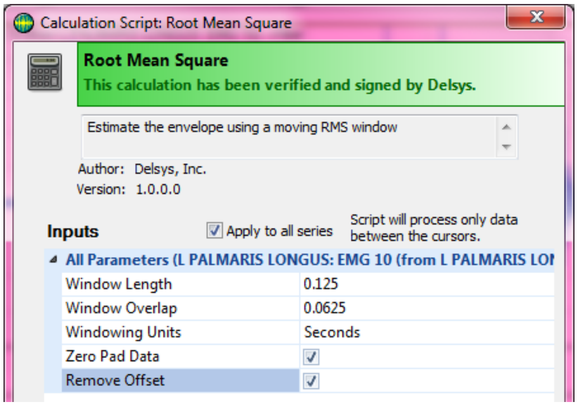


Figure 14: Filtered sEMG Signals

6. Figure 15 shows the function in obtaining the root mean square (RMS) of the filtered signals.



Calculation Script: Root Mean Square

Root Mean Square

This calculation has been verified and signed by Delsys.

Estimate the envelope using a moving RMS window

Author: Delsys, Inc.

Version: 1.0.0.0

Inputs ☑ Apply to all series

Script will process only data between the cursors.

All Parameters (L PALMARIS LONGUS: EMG 10 (from L PALMARIS LO

Window Length	0.125
Window Overlap	0.0625
Windowing Units	Seconds
Zero Pad Data	☑
Remove Offset	☑

Figure 15: Obtaining RMS of Filtered Signals

7. The RMS of the filtered signal is shown in Figure 16 with Palmaris Longus and Extensor Carpi Radialis positioned at the top and bottom respectively.

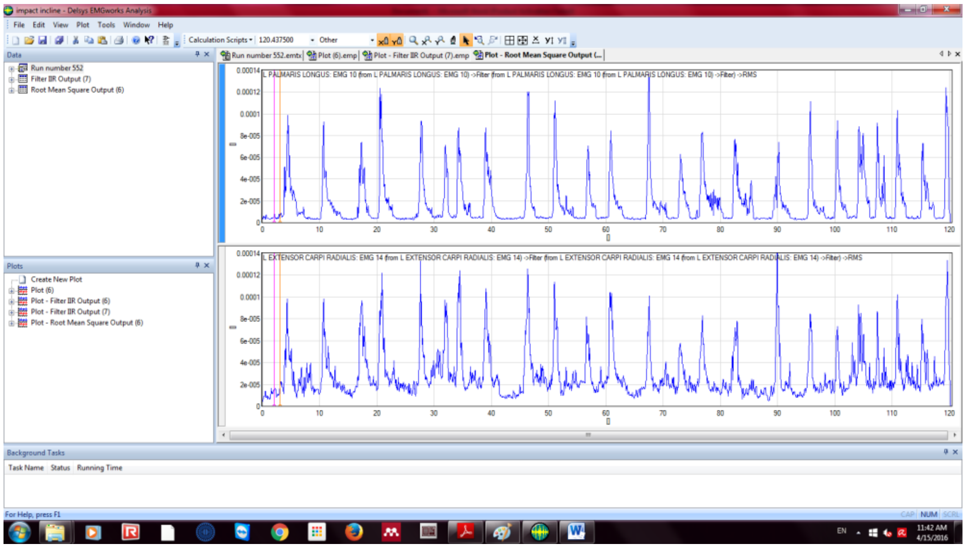
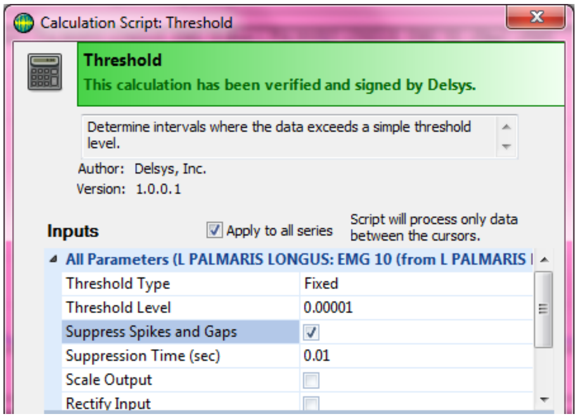


Figure 16: RMS of Filtered Signals

8. Figure 17 shows the function in obtaining threshold from the RMS of the filtered signal for the Palmaris Longus.



Threshold

This calculation has been verified and signed by Delsys.

Determine intervals where the data exceeds a simple threshold level.

Author: Delsys, Inc.
Version: 1.0.0.1

Inputs ☑ Apply to all series — Script will process only data between the cursors.

All Parameters (L PALMARIS LONGUS: EMG 10 (from L PALMARIS

Threshold Type	Fixed
Threshold Level	0.00001
Suppress Spikes and Gaps	☑
Suppression Time (sec)	0.01
Scale Output	☐
Rectify Input	☐

Figure 17: Obtaining Threshold from RMS of filtered Signal

9. The threshold obtained from the RMS of the filtered signal is shown in Figure 18.

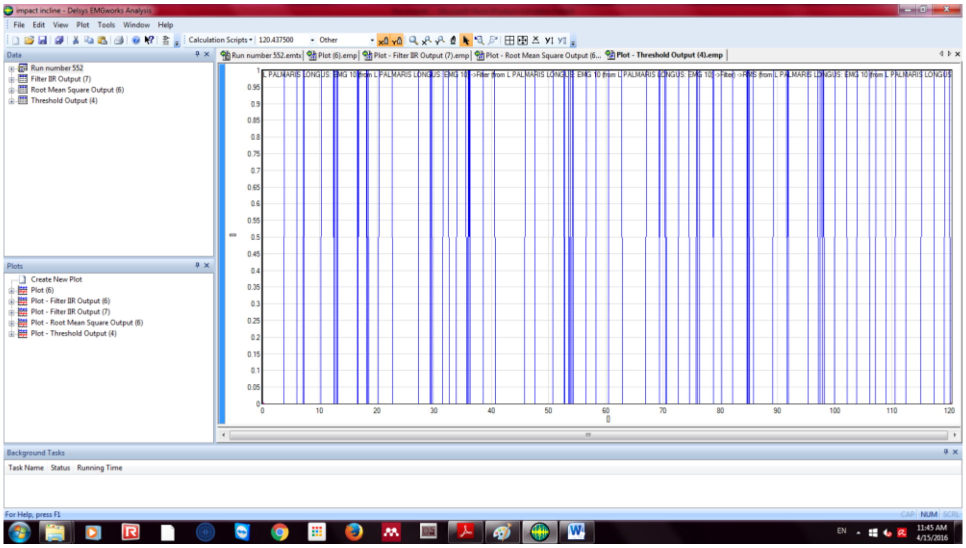
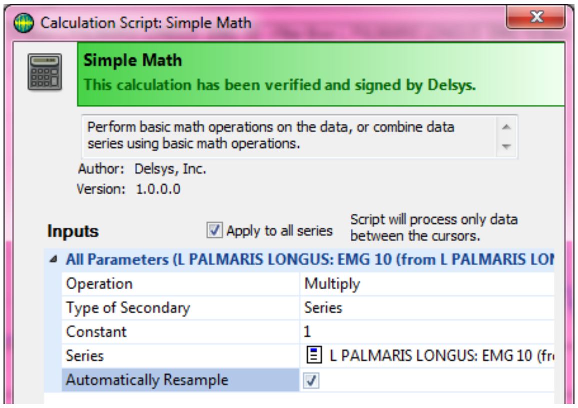


Figure 18: Threshold of RMS

10. Figure 19 shows the function in obtaining smooth filtered RMS signal using Simple Math (Multiply the RMS signal with the Threshold obtained in Figure 18) for the Palmaris Longus.


Calculation Script: Simple Math

Simple Math

This calculation has been verified and signed by Delsys.

Perform basic math operations on the data, or combine data series using basic math operations.

Author: Delsys, Inc.

Version: 1.0.0.0

Inputs ☑ Apply to all series — Script will process only data between the cursors.

All Parameters (L PALMARIS LONGUS: EMG 10 (from L PALMARIS LON

Operation	Multiply
Type of Secondary	Series
Constant	1
Series	L PALMARIS LONGUS: EMG 10 (fr
Automatically Resample	☑

Figure 19: Obtaining smooth filtered RMS signal using Simple Math

11. A smooth RMS of filtered signal for Palmaris Longus is shown in Figure 20. Steps 8 to 10 are repeated for Extensor Carpi Radialis.

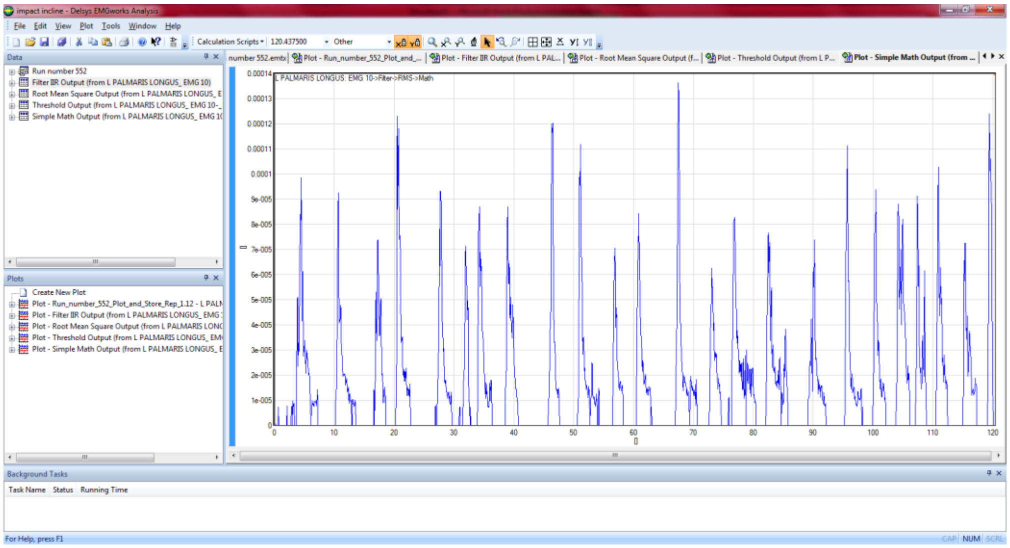
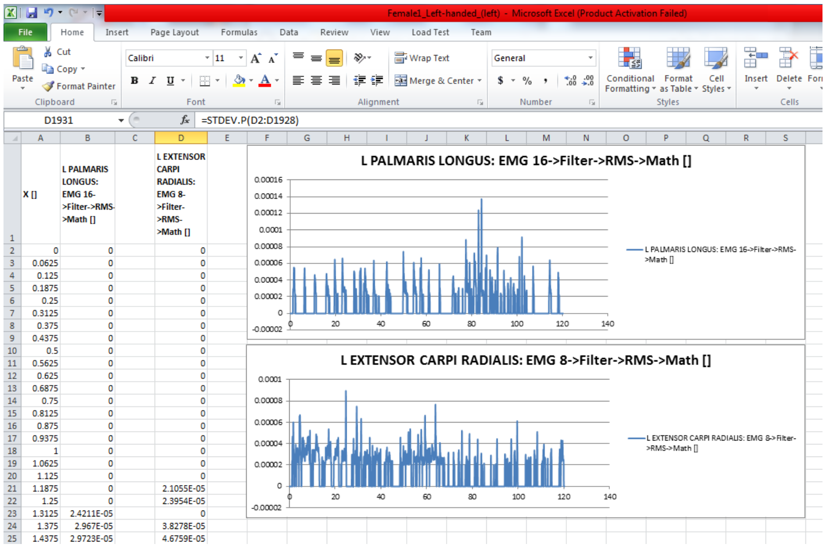


Figure 20: Smooth RMS of filtered signal

12. After completion of all the steps above, Figure 21 shows the smooth RMS data are exported to Excel for graph plotting and critical analysis of the mean and standard deviation of each subject’s muscle activation.



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 16->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 8->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		2.1055E-05
22	1.25	0		2.3954E-05
23	1.3125	2.4211E-05		0
24	1.375	2.967E-05		3.8278E-05
25	1.4375	2.9723E-05		4.6759E-05

Figure 21: Smooth RMS in Excel

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results from Rehabilitation Robotic

4.1.1 Range Of Motion (ROM)

Figure 22 shows the ROM of male subjects' left hand and right hand with their handedness.

Figure 22: ROM for Males

Left-handed (L-H), Right-handed (R-H)

Figure 23 shows the ROM of female subjects' left hand and right hand with their handedness.

Figure 23: ROM for Females

Left-handed (L-H), Right-handed (R-H)

Figure 24 shows the ROM of both-handed male subjects' left hand and right hand.

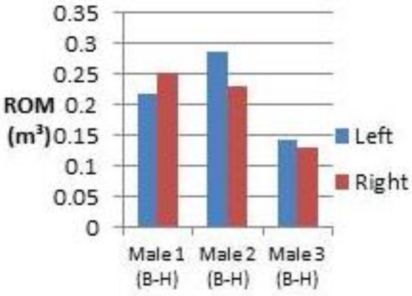


Figure 24: ROM for Males

Both-handed (B-H)

Figure 25 shows the mean of ROM of subjects' left hand and right hand with their handedness.

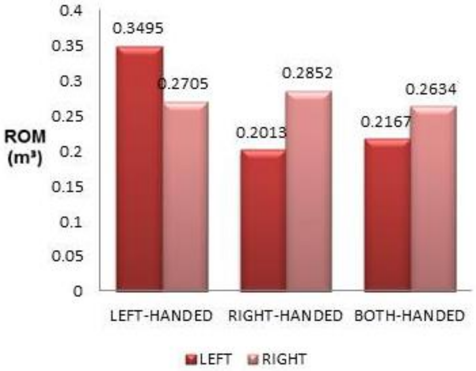


Figure 25: Mean ROM

In Figure 22 and Figure 23, the subjects' ROM tends to be larger for their dominant hand as compared to non-dominant hand regardless of genders with significant statistical difference for left-handed and right-handed subjects. On the other hand, in both-handed situation, the ROM differences between both hands are very small which the mean for the three subjects was ±0.0467m^3 while the mean for left-handed and right-handed have a significant difference as shown in Figure 25. This certainly proved that the hypothesis is eventually true. The dominant hand has a larger ROM due to constantly exercising of the hand in executing daily activities however, for the both handed subjects where they used both hands as good has a smaller difference of ROM between both hands due to they constantly exercising both of their hands in carrying out daily activities instead of just concentrating on one hand.

4.1.2 Game Scoring

Figure 26 shows the game scoring of male subjects' left hand and right hand with their handedness.

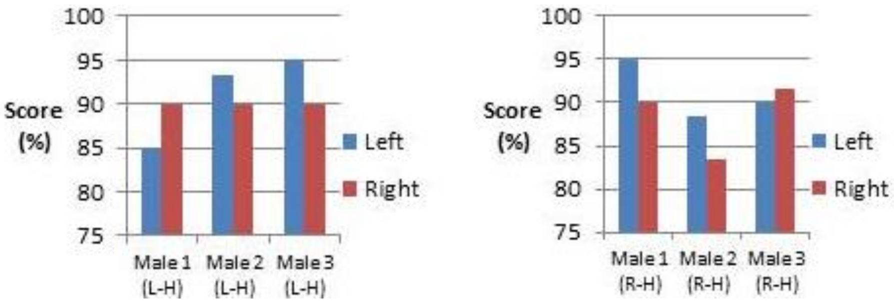


Figure 26: Game Scoring Male

Left-handed (L-H), Right-handed (R-H)

Figure 27 shows the game scoring of female subjects' left hand and right hand with their handedness.

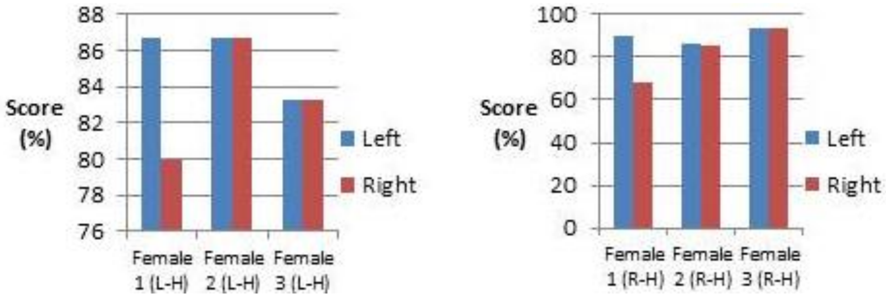


Figure 27: Game Scoring Females

Left-handed (L-H), Right-handed (R-H)

Figure 24 shows the game scoring of both-handed male subjects' left hand and right hand.

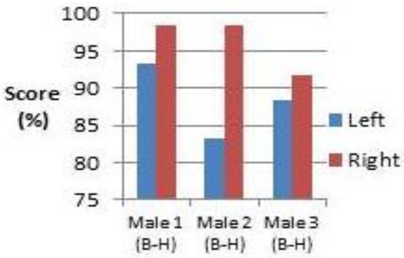


Figure 28: Game Scoring Males

Both-handed (B-H)

Figure 29 shows the mean of game scoring of subjects' left hand and right hand with their handedness.

Figure 29: Mean Score

In Figure 26 and 27, all the subjects showed that the tendency of getting high scores in this exercise was the left hand as compared to the right hand regardless of handedness except for male1 left-handed and male3 right-handed which showed the opposite result. This result is similar to the studies in [29] [30], when reaching, left hand tends to magnify online control even for adjacent target which eliminated the advantages of right hand regardless of handedness. Moreover, numerous studies have also proved that left-hand is better in playing video games since our left part of the body is being controlled by the right brain which emphasized on the visualization and arts (Motor Skill).

However, there was an exception case for the both-handed subjects where all the three males' both-handed subjects have a higher score with their right hand as shown in Figure 28. In Figure 29 showed the average score of each category of handedness, there was an enormous difference in the both-handed subjects which could be due the sensors error in the rehabilitation robotic or this uncommon behavior of both-handed subjects. Therefore, further studies on a bigger group of both-handed subjects should be carried out to study the differences of this rare ambidexterity group.

4.1.3 Hand Position Reach

Figure 30 shows the hand position reach of male subjects' left hand and right hand with their handedness.

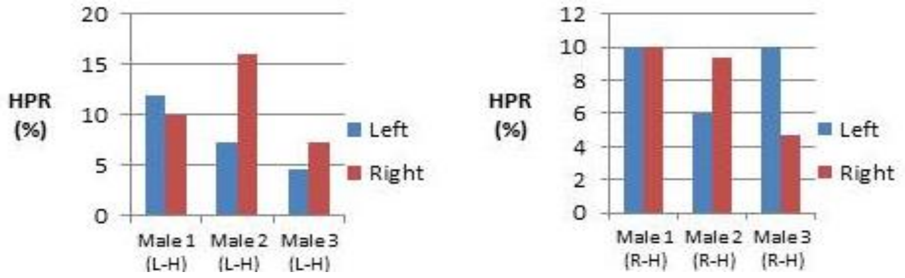


Figure 30: Hand Position Reach Males

Left-handed (L-H), Right-handed (R-H)

Figure 31 shows the hand position reach of female subjects' left hand and right hand with their handedness.

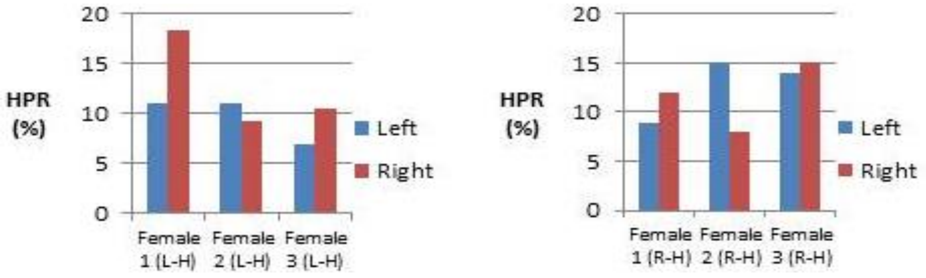


Figure 31: Hand Position Reach Females

Left-handed (L-H), Right-handed (R-H)

Figure 32 shows the hand position reach of both-handed male subjects' left hand and right hand.

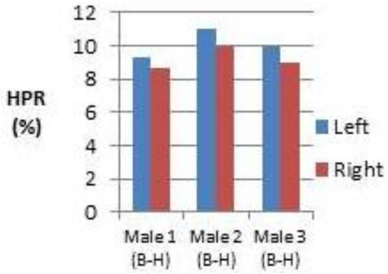


Figure 32: Hand Position Reach Males

Both-handed (B-H)

Figure 33 shows the mean of hand position reach of subjects' left hand and right hand with their handedness.

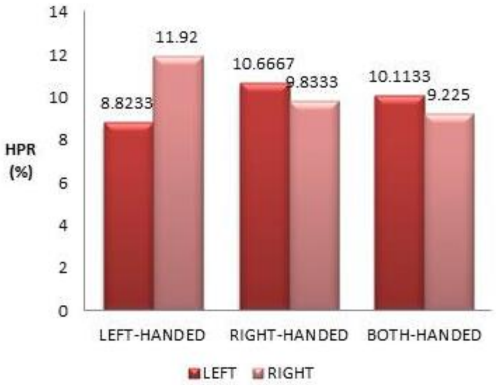


Figure 33: Mean Hand Position Reach

In Figure 30, 31 and 32, 53% of the subjects (8 out of 15) showed that the tendency of higher hand position reach in this exercise is the left hand as compared to the right hand regardless of handedness. This result notably supported the findings in the game scoring where the left hand scored higher in the exercise regardless of handedness. Furthermore, in Figure 33, the mean of hand position reach in right-handed and both-handed subjects were higher in left hand than the right hand whereas the left-handed subject showed the contrary with high difference between both hands. This denoted that there might be sensors error in the rehabilitation robotic on some of the subjects because it is quite impossible to have extreme high difference between both hands for the hand position reach.

4.1.4 Hand Opening Reach

Figure 34 shows the hand opening reach of male subjects' left hand and right hand with their handedness.

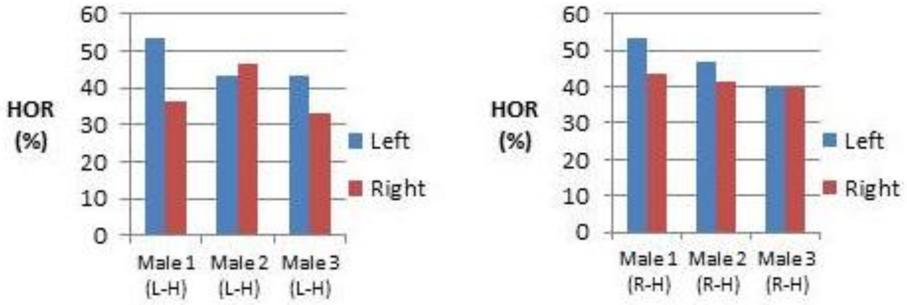


Figure 34: Hand Opening Reach Males

Left-handed (L-H), Right-handed (R-H)

Figure 35 shows the hand opening reach of female subjects' left hand and right hand with their handedness.

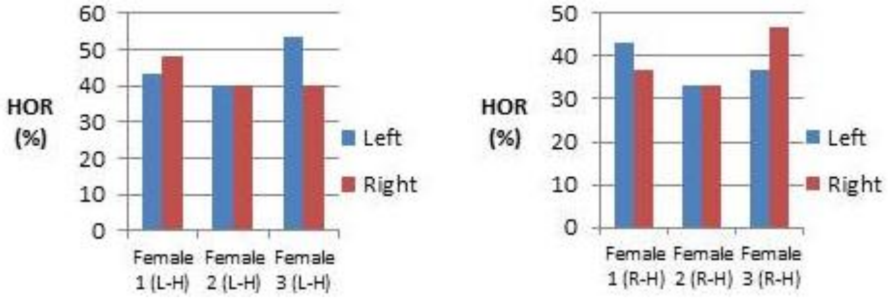


Figure 35: Hand Opening Reach Females

Left-handed (L-H), Right-handed (R-H)

Figure 36 shows the hand opening reach of both-handed male subjects' left hand and right hand.

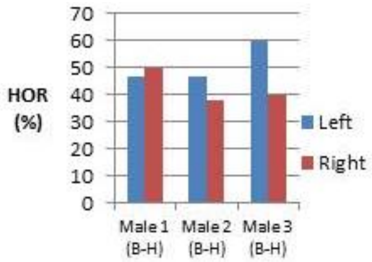


Figure 36: Hand Opening Reach Males

Both-handed (B-H)

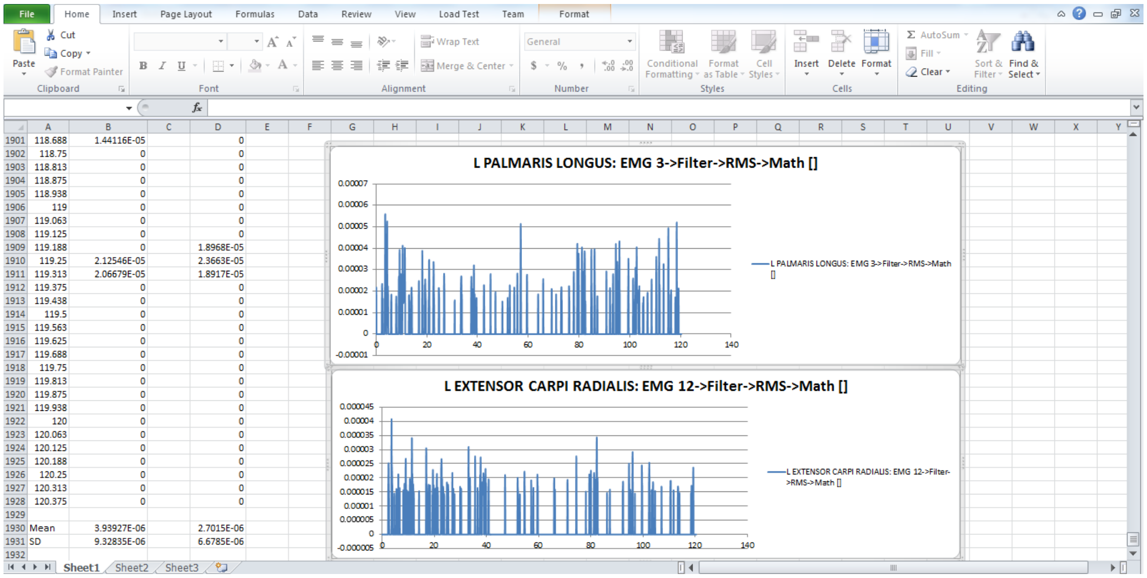
Figure 37 shows the mean of hand opening reach of subjects' left hand and right hand with their handedness.

Figure 37: Mean Hand Opening Reach

Hand opening reach measured data are shown in Figure 34, 35, and 36. 73.3% of the subjects (11 out of 15) have higher hand opening on the left hand as compared to the right hand in this exercise disregarding of handedness including the both-handed males where the left hand have obvious high contrast with the right hand as shown in Figure 34, 35, and 36. This is also further supported by the higher mean of hand opening reach on the left hand than the right hand as shown in Figure 37. In a nutshell, the outcome from the hand opening reach eventually supported the finding in the game scoring where the left hands were better in terms of virtual based exercise.

4.2 Muscle Activation

Smooth RMS curve for Male 1 (Left-handed) is plotted to determine the mean and standard deviation for assessment as shown in Figure 38. The RMS curves for other subjects are attached in APPENDIX C.



	A	B	C	D
1901	118.688	1.44116E-05		0
1902	118.75	0		0
1903	118.813	0		0
1904	118.875	0		0
1905	118.938	0		0
1906	119	0		0
1907	119.063	0		0
1908	119.125	0		0
1909	119.188	0		1.8968E-05
1910	119.25	2.12546E-05		2.3663E-05
1911	119.313	2.06679E-05		1.8917E-05
1912	119.375	0		0
1913	119.438	0		0
1914	119.5	0		0
1915	119.563	0		0
1916	119.625	0		0
1917	119.688	0		0
1918	119.75	0		0
1919	119.813	0		0
1920	119.875	0		0
1921	119.938	0		0
1922	120	0		0
1923	120.063	0		0
1924	120.125	0		0
1925	120.188	0		0
1926	120.25	0		0
1927	120.313	0		0
1928	120.375	0		0
1929				
1930	Mean	3.93927E-06		2.7015E-06
1931	SD	9.32835E-06		6.6785E-06
1932				

Figure 38: Smooth RMS in excel

Muscle Activation for Palmaris Longus of all the subjects’ left hand and right hand are defined as in Table 6.

Table 6: Muscle Activation for PALMARIS LONGUS

PALMARIS LONGUS	Left (Mean±SD)	Right (Mean±SD)
Male 1 (L-H)	3.93927E-06±9.32835E-06	1.54115E-05±2.5772E-05
Male 2 (L-H)	3.2393E-06±5.33812E-06	5.70268E-06±1.06945E-05

Male 3 (L-H)	1.01446E-05±1.07142E-05	1.03166E-05±1.10467E-05
Female 1 (L-H)	9.9432E-06±1.76649E-05	1.11492E-05±1.614E-05
Female 2 (L-H)	1.2727E-05±1.5957E-05	4.68018E-06±6.4777E-06
Female 3 (L-H)	1.543E-05±2.335E-05	4.07979E-06±1.88846E-05
Male 2 (R-H)	1.4265E-05±3.8811E-05	1.74546E-05±2.55453E-05
Male 3 (R-H)	2.4207E-05±3.24744E-05	1.33599E-05±2.00753E-05
Female 1 (R-H)	3.8158E-06±8.2214E-06	2.58557E-05±4.79397E-05
Female 2 (R-H)	8.37628E-06±1.84441E-05	2.18936E-05±2.41108E-05
Female 3 (R-H)	2.0865E-05±2.4383E-05	2.92188E-05±3.72826E-05
Male 1 (B-H)	3.47641E-06±6.46656E-06	2.83759E-06±3.59392E-06
Male 2 (B-H)	1.94223E-05±2.40247E-05	8.7832E-06±1.64156E-05
Male 3 (B-H)	9.38004E-06±1.54848E-05	7.68014E-06±1.22709E-05

Muscle Activation for Extensor Carpi Radialis of all the subjects' left hand and right hand are defined as in Table 7.

Table 7: Muscle Activation for EXTENSOR CARPI RADIALIS

Extensor Carpi Radialis	Left (Mean±SD)	Right (Mean±SD)
Male 1 (L-H)	2.70145E-06±6.67846E-06	7.34928E-06±8.43057E-06
Male 2 (L-H)	6.05337E-06±8.71497E-06	1.01563E-05±1.61447E-05
Male 3 (L-H)	7.04389E-05±5.45022E-05	2.91765E-05±3.56006E-05
Female 1 (L-H)	1.49647E-05±1.59889E-05	2.08223E-05±2.91445E-05
Female 2 (L-H)	1.71559E-05±2.28151E-05	2.22919E-05±2.36438E-05
Female 3 (L-H)	2.23949E-05±2.335E-05	2.26901E-05±2.5167E-05
Male 2 (R-H)	5.53283E-05±4.53589E-05	4.91524E-05±5.0052E-05
Male 3 (R-H)	2.64132E-05±2.06531E-05	2.55419E-05±1.61297E-05
Female 1 (R-H)	6.65021E-06±1.26741E-05	1.92115E-05±2.32019E-05
Female 2 (R-H)	1.62791E-05±1.5839E-05	3.23499E-05±3.24326E-05
Female 3 (R-H)	1.43958E-05±1.87501E-05	2.00249E-05±2.69614E-05
Male 1 (B-H)	9.18461E-06±1.2806E-05	2.24859E-05±2.4804E-05
Male 2 (B-H)	4.33967E-05±3.58404E-05	3.00904E-05±3.16132E-05
Male 3 (B-H)	2.75459E-05±2.73772E-05	1.27746E-05±1.59749E-05

Highest muscle activation for males between left and right hand are summarized in Table 8.

Table 8: Highest Muscle Activation for Males between Left and Right Hand

Subjects	Palmaris Longus		Extensor Carpi Radialis	
	L	R	L	R
Male L-H (n=3)	0	3	1	2
Male R-H (n=2)	1	1	2	0

In males' category, Table 6 and 7 showed the RMS value of EMG Signal for the following two muscles; Palmaris Longus and Extensor Carpi Radialis respectively during performing the computer based game. In Table 8 shows the highest muscle activation between left and right hand. This table explained that males left-handed have higher muscle activation with their right hand in both muscles; palmaris longus and extensor carpi radialis as compared to the left hand. On the other hand, males' right-handed shows higher muscle activation with their left hand in extensor carpi radialis while the palmaris longus does not show any notable difference.

Highest muscle activation for females between left and right hand are summarized in Table 9.

Table 9: Highest Muscle Activation for Females between Left and Right Hand

Subjects	Palmaris Longus		Extensor Carpi Radialis	
	L	R	L	R

Female L-H (n=3)	2	1	0	3
Female R-H (n=3)	3	0	0	3

In females’ category, Table 6 and 7 showed the RMS value of EMG Signal for the following two muscles; Palmaris Longus and Extensor Carpi Radialis respectively during performing the computer based game. In Table 9 shows the highest muscle activation between left and right hand. This table explained that females tend to have a similar pattern in these two muscles regardless of handedness. For instance, left-handed and right-handed females have higher muscle activation with their left hand on their Palmaris Longus. On the other hand, left-handed and right-handed females shows higher muscle activation with their right hand in extensor carpi radialis compared to the left hand.

Highest muscle activation for males both-handed between left and right hand are summarized in Table 10.

Table 10: Highest Muscle Activation for Males between Left and Right Hand

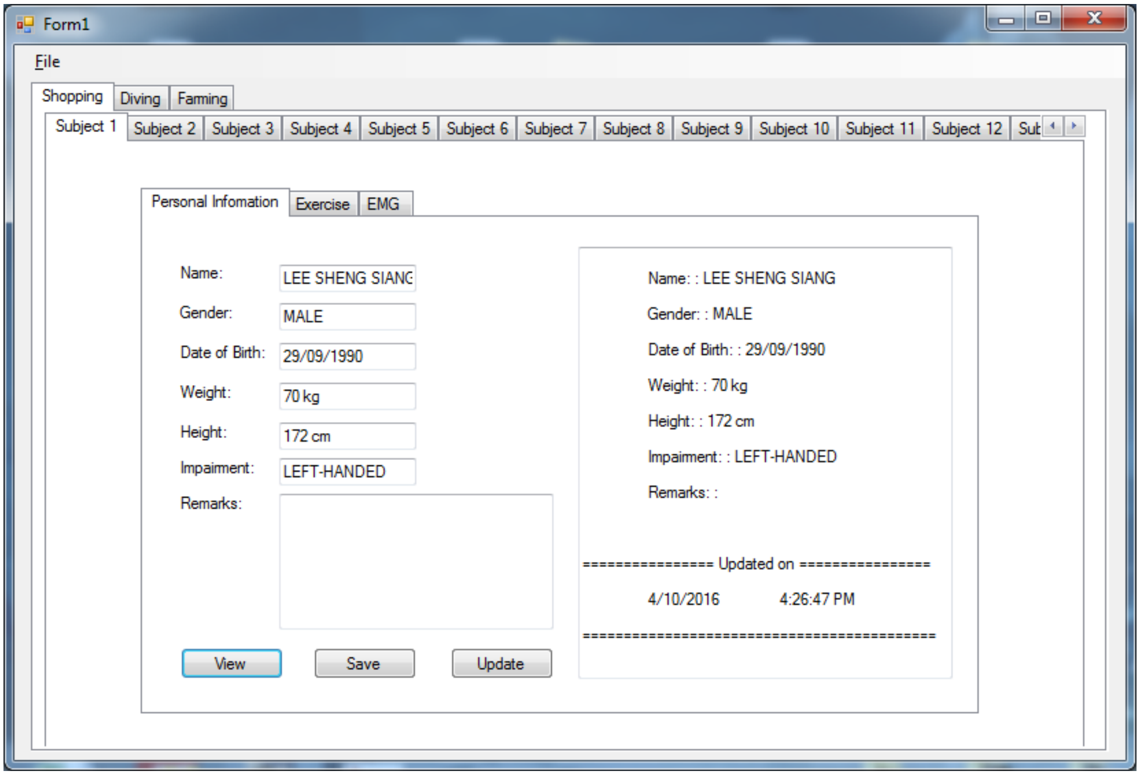
Subjects	Palmaris Longus		Extensor Carpi Radialis	
	L	R	L	R
Male B-H (n=3)	3	0	2	1

Subjects that write using their right hand and do other DAL using their left hand is grouped under this both-handed category after the assessment of LQ test. From Table 10, it concluded that their muscle activation in palmaris longus and extensor carpi radialis were higher on their left hand as compared the right hand show the opposite. This finding was actually similar to the male right-handed subjects. This result proved that it was statistically true because both-handed subjects write using their right-hand and execute other daily activities such as brushing their teeth and play sport with the left-hand.

In a nutshell, the effect of handedness in muscle activation was quite varies depending on gender. For instance, the finding in males' subjects was greatly affected by the handedness. All the males' subjects have a higher RMS value for the non-dominant hand except for 2 males' subjects who showed the contrary. However, for the females' subjects, they were not affected by handedness and have the same muscle activation for both the left-handed and right-handed females.

4.3 Robotics Rehabilitation Management Tool

Figure 39 shows the homepage of RRMT tool.



Name: LEE SHENG SIANG
Gender: MALE
Date of Birth: 29/09/1990
Weight: 70 kg
Height: 172 cm
Impairment: LEFT-HANDED
Remarks:

Name: : LEE SHENG SIANG
Gender: : MALE
Date of Birth: : 29/09/1990
Weight: : 70 kg
Height: : 172 cm
Impairment: : LEFT-HANDED
Remarks: :

================ Updated on ================
4/10/2016 4:26:47 PM
==

Figure 39: RRMT personal information

In Figure 39, it shows the interface of RRMT for patient’s personal information. With RRMT, physiotherapists can easily assess the details of each individual patient and simply update the progress of the patients or schedule an appointment. There are three parameters that will enable the quick interface which are 'view', 'save' and 'update'. The 'view' button enables user to quickly get an overview of the patients personal information, 'save' button simply saves the information inserted and 'update' overwrites the existing information with the new information inserted earlier.

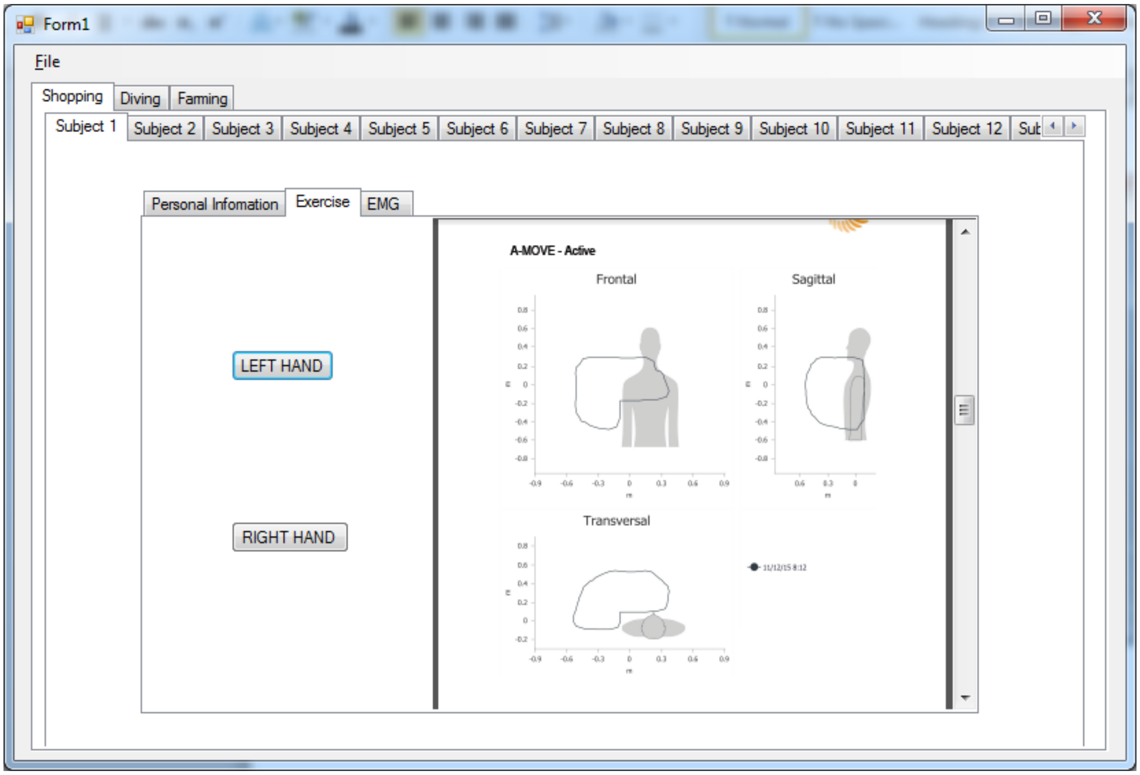
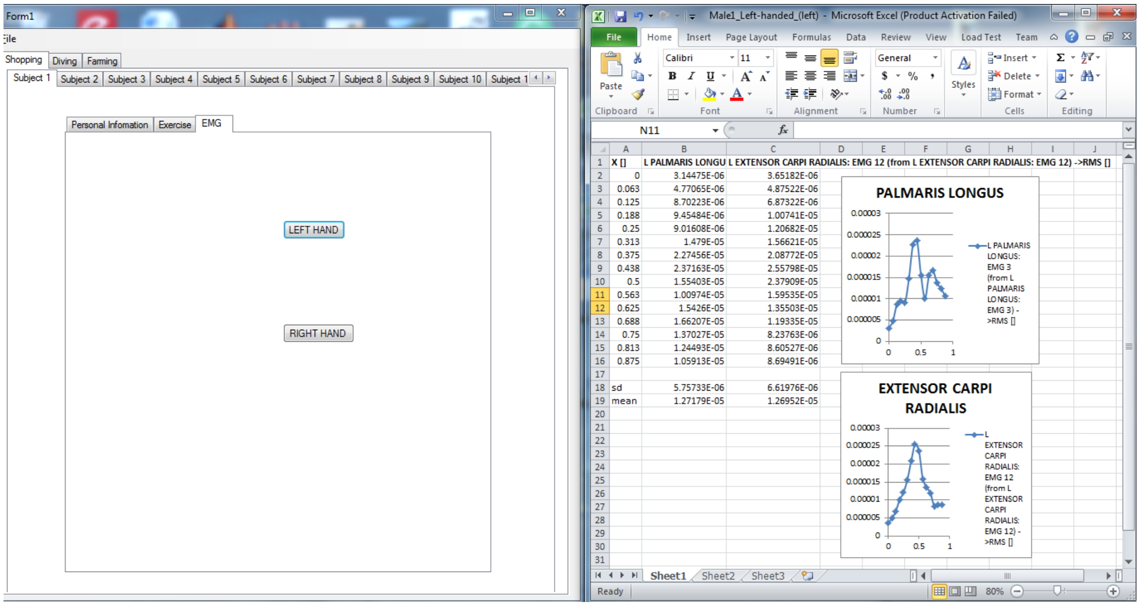


Figure 40: RRMT exercise records and data

Figure 40 shows the RRMT interface with rehabilitation robotic (Armeo®Spring). Using the RRMT, the physiotherapist or patients themselves are able to view their improvement or records from the rehabilitation robotic offline which is much more convenient without the need to install Armeo®Spring software. Therefore, patients are able to watch their improvement even at home.



X []	L PALMARIS LONGU	L EXTENSOR CARPI RADIALIS: EMG 12 (from L EXTENSOR CARPI RADIALIS: EMG 12) ->RMS []
0	3.14475E-06	3.65182E-06
0.063	4.77065E-06	4.87522E-06
0.125	8.70223E-06	6.87322E-06
0.188	9.45484E-06	1.00741E-05
0.25	9.01608E-06	1.20682E-05
0.313	1.479E-05	1.56621E-05
0.375	2.27456E-05	2.08772E-05
0.438	2.37163E-05	2.55798E-05
0.5	1.55403E-05	2.37909E-05
0.563	1.00974E-05	1.59535E-05
0.625	1.5426E-05	1.35503E-05
0.688	1.66207E-05	1.19335E-05
0.75	1.37027E-05	8.23763E-06
0.813	1.24493E-05	8.60527E-06
0.875	1.05913E-05	8.69491E-06
sd	5.75733E-06	6.61976E-06
mean	1.27179E-05	1.26952E-05

Figure 41: RRMT EMG records and data

Figure 41 shows the RRMT interface with EMG muscle activation of the patient. The physiotherapist or patients themselves are able to view their muscular fatigue in a graph form which is easier to interpret and understandable. Furthermore, the patients are able to assess their EMG data without the need to install the EMG Software which is not as user-friendly and requires payment to install the full version of EMG analysis from Delsys.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In a nutshell, the effects of handedness on both hands kinematic abilities were studied in this project by evaluating the quantitative measurement obtained from the rehabilitation robotic and surface electromyography (sEMG).

Four kinds of data which includes the range of motion (ROM), game scoring, hand position reach and hand opening reach were obtained from the rehabilitation robot. First of all, the ROM was significantly dependent on the handedness where the dominant hand had a higher ROM compared to non-dominant hand and both-handed subject showed small difference in ROM between both hands. On contrary, the finding in game scoring was that it was not affected by the handedness which supported by the results from hand position reach and hand opening reach. The left hand had a higher score in the game as compared to the right hand despite handedness excluding the both-handed subjects where all the three males' both-handed subjects achieved high score with their right hand.

Besides that, sEMG was used to obtain the muscle activation in palmaris longus and extensor carpi radialis. The key parameter that affects the handedness in muscle activation is the gender. For example, the results and findings for male subjects are affected greatly by the handedness. All male subjects have a higher RMS value for the non-dominant hand except for 2 male subjects who beat the odds. On the contrary, the results for female subjects show they were not affected by handedness and have similar muscle activation regardless of dominant or non-dominant handed females.

In conclusion, the range of motion and sEMG signal were dependent on handedness and gender while game scoring and hand position/opening reach were not affected by handedness or gender. This research is worthwhile considering that it presents technical statistic in matters of handedness and gender with evidence from other research papers.

On top of that, the development of RRMT significantly improves the tracking and recording of patients' statistically information. It also features a user-friendly outline which is easy to install with a simple interface for the patients.

Further investigation on a larger cohort of subjects especially for both-handed cases to confirm the study and to enhance the investigation of the differences in handedness-effect on the risk of MSDs is necessary.

5.2 Future Work

These are a few recommendations on future areas of research that is not scope of this project due to the limitation of time and other constraints.

- Musculoskeletal Disorder (MSD) patients should be invited to be subjects of study for the feasibility of rehabilitation robotic.
- Electroencephalography (EEG) which is for brain activity and electromyography (EMG) which is for muscle activity and functional near-indrared (fNIR) can combine to robustly command the exoskeleton robot.

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APPENDIX

APPENDIX A

Gantt Chart and Key Milestones

Table 11 shows the key milestones of activities that will be carried out in FYP 1.

Table 11: FYP 1

No.	**Details/ Week**		**FYP 1**													
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Background Study		■	■												
2	Literature Review on the types of robotics rehabilitation				■	■	■		■	■						
3	Study on Armeo®Spring								■	■		■	■	■	■	
4	Proposal Defense										●					
5	Documentation	Extended proposal						●								
		Interim Report														●

Table 12 shows the key milestones of activities that will be carried out in FYP 2.

Table 12: FYP 2

No.	**Details/ Week**		**FYP II**														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Conduct experiment		■	■	■												
2	Experimental Evaluation			■	■	■	■			■	■	■	■				
3	Comparative analysis						■	■	■			■	■	■			
4	Pre-sedex											●					
5	Project Viva														●		
6	Documentation	Progress Report							●								
		Draft Final											●				

		Report															
		Dissertation (soft copy)												●			
		Technical Paper												●			
		Dissertation (hard bound)															●

● Key milestone

■ Process

APPENDIX B

Figure 42: The Armeo®Spring Set Up

Brief Description: The Armeo®Spring study setup

Summary Description: The study setup is illustrated with the Armeo®Spring device facing a computer to provide the testing software and a subject wearing the device.

Detailed Description: The study setup includes three main components. First, the Armeo®Spring device which is a gravity-supporting exoskeleton apparatus that contains no robotic actuators. It is the commercialized product of Therapy Wilmington Robotic Exoskeleton (T-WREX) which has been redesigned by Hocoma, Inc. with user-friendly software and hardware interface to be used in the routine clinical settings. The main structure of the device consists of an arm exoskeleton with integrated springs providing a 5 DOF movement at the shoulder, elbow, and wrist levels. It encloses the entire upper extremities and compensates the load of patient's arm providing an arm floating sensation at every orientation. The second component is a computer facing the Armeo®Spring device with its display being set at the level of the subject's eyes to provide the testing software for the study. The third component is the subject who is wearing the Armeo®Spring device while seated and looking at the display of the computer.

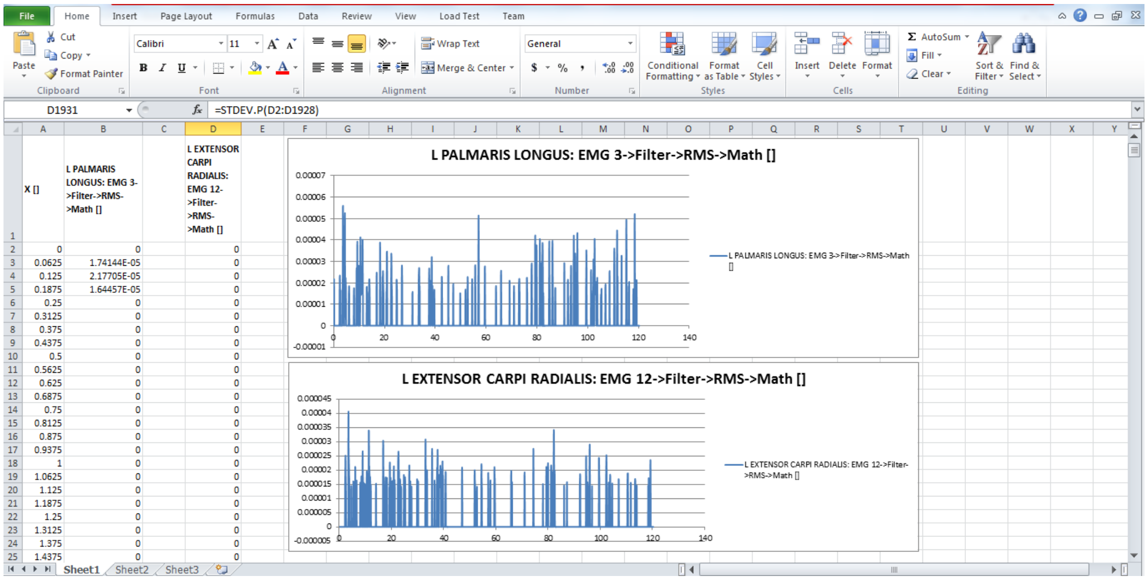
Figure 43: Armeo®Spring weight support system

Brief Description: Armeo®Spring weight support system.

Summary Description: The Armeo®Spring device contains two weight support systems at the upper arm level (1) and the forearm level (2).

Detailed Description: The main structure of the Armeo®Spring device consists of an arm exoskeleton with integrated springs providing a 5 DOF movement at the shoulder, elbow, and wrist levels. It encloses the entire upper extremities and compensates the load of patient's arm providing an arm floating sensation at every orientation. The upper arm support provided by an integrated spring contains multiple level of support. These levels are displayed on the device as a scale from A to K, with A is the minimum level of support and K is the maximum. The forearm support contains a scale from 1 to 5 displayed on the device with 1 is the minimum level of support and 5 is the maximum.

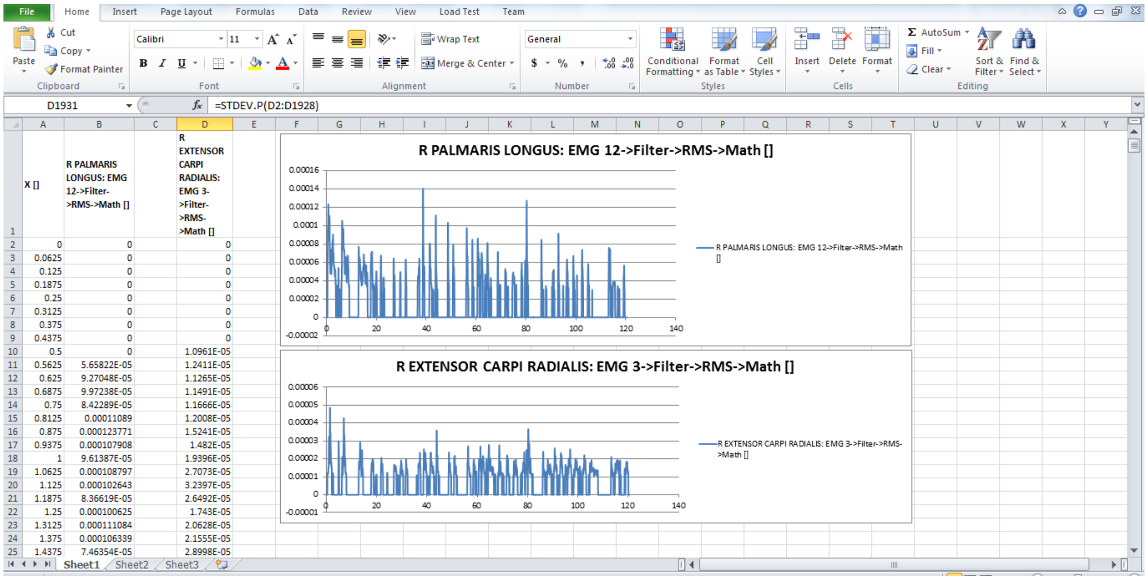
APPENDIX C



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 3->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 12->Filter->RMS->Math []
2	0	0		0
3	0.0625	1.74144E-05		0
4	0.125	2.17705E-05		0
5	0.1875	1.64457E-05		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0

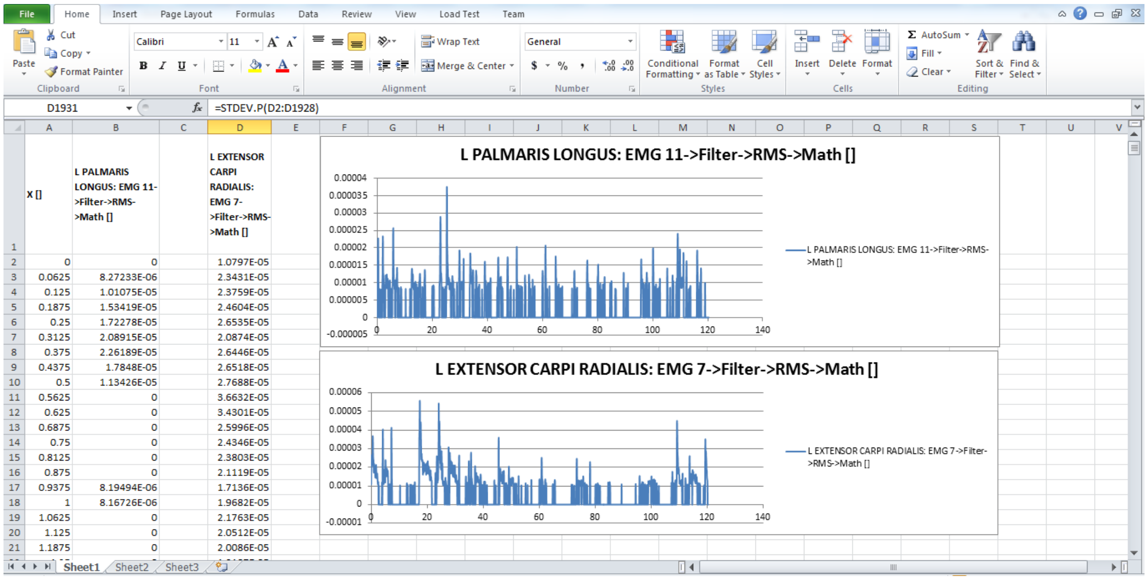
Figure 44: Male 1 Left-handed (Left)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 12->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 3->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		1.0961E-05
11	0.5625	5.65822E-05		1.2411E-05
12	0.625	9.27048E-05		1.1265E-05
13	0.6875	9.97238E-05		1.1491E-05
14	0.75	8.42289E-05		1.1666E-05
15	0.8125	0.00011089		1.2008E-05
16	0.875	0.000123771		1.5241E-05
17	0.9375	0.000107908		1.482E-05
18	1	9.61387E-05		1.9396E-05
19	1.0625	0.000108797		2.7073E-05
20	1.125	0.000102643		3.2397E-05
21	1.1875	8.36619E-05		2.6492E-05
22	1.25	0.000100625		1.743E-05
23	1.3125	0.000111084		2.0628E-05
24	1.375	0.000106339		2.1555E-05
25	1.4375	7.46354E-05		2.8998E-05

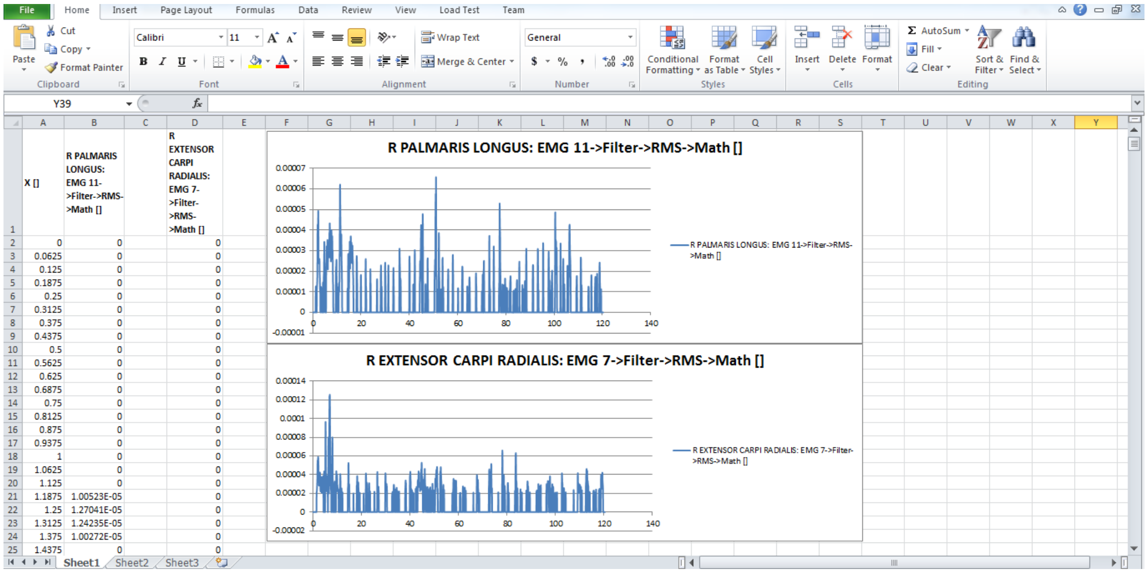
Figure 45: Male 1 Left-handed (Right)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 11->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 7->Filter->RMS->Math []
2	0	0		1.0797E-05
3	0.0625	8.27233E-06		2.3431E-05
4	0.125	1.01075E-05		2.3759E-05
5	0.1875	1.53419E-05		2.4604E-05
6	0.25	1.72278E-05		2.6535E-05
7	0.3125	2.08915E-05		2.0874E-05
8	0.375	2.26189E-05		2.6446E-05
9	0.4375	1.7848E-05		2.6518E-05
10	0.5	1.13426E-05		2.7688E-05
11	0.5625	0		3.6632E-05
12	0.625	0		3.4301E-05
13	0.6875	0		2.5996E-05
14	0.75	0		2.4346E-05
15	0.8125	0		2.3803E-05
16	0.875	0		2.1119E-05
17	0.9375	8.19494E-06		1.7136E-05
18	1	8.16726E-06		1.9682E-05
19	1.0625	0		2.1763E-05
20	1.125	0		2.0512E-05
21	1.1875	0		2.0086E-05

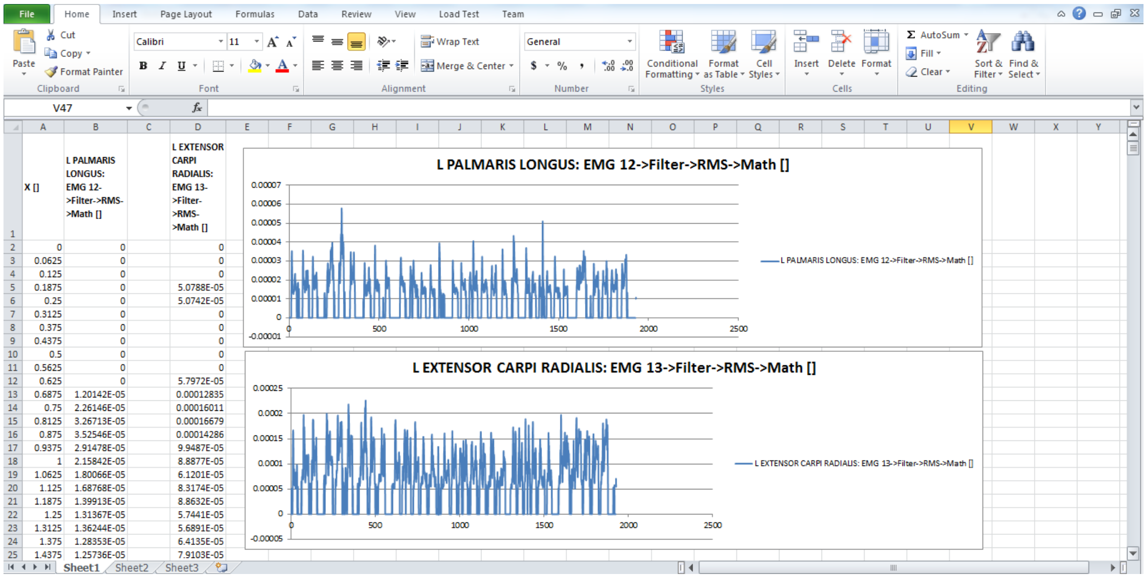
Figure 46: Male 2 Left-handed (Left)



Y39

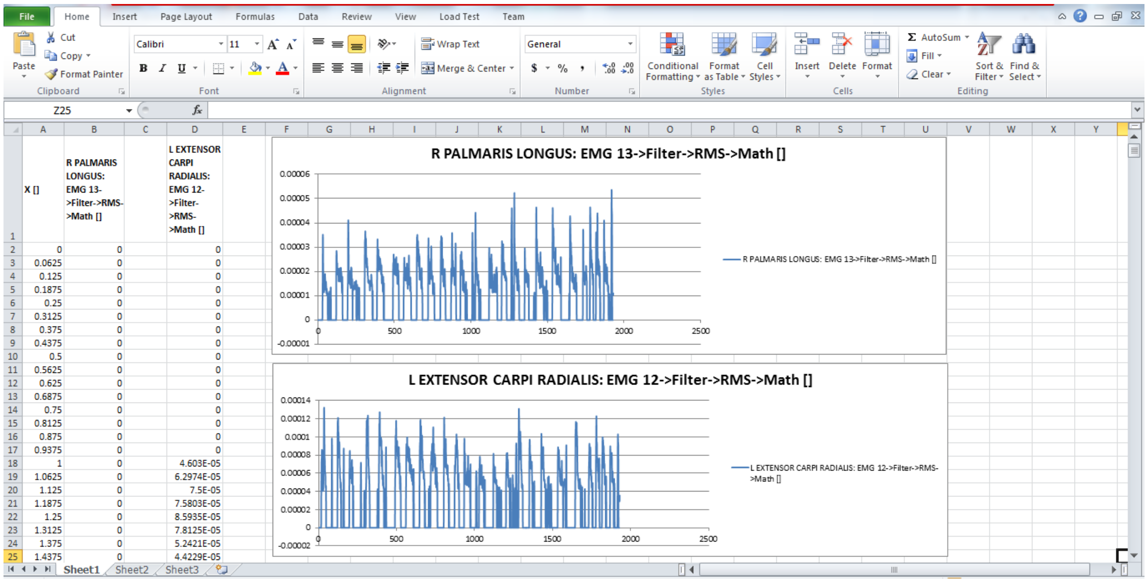
	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 11->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 7->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	1.00523E-05		0
22	1.25	1.27041E-05		0
23	1.3125	1.24235E-05		0
24	1.375	1.00272E-05		0
25	1.4375	0		0

Figure 47: Male 2 Left-handed (Right)



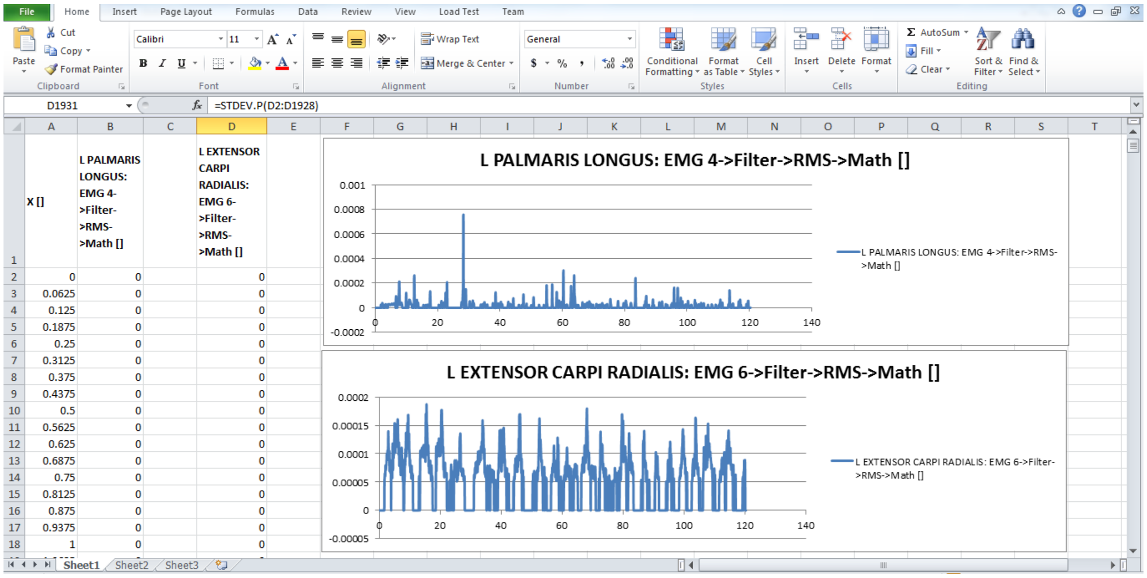
	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 12->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 13->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		5.0788E-05
6	0.25	0		5.0742E-05
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		5.7972E-05
13	0.6875	1.20142E-05		0.00012835
14	0.75	2.26146E-05		0.00016011
15	0.8125	3.26713E-05		0.00016679
16	0.875	3.52546E-05		0.00014286
17	0.9375	2.91478E-05		9.9487E-05
18	1	2.15842E-05		8.8877E-05
19	1.0625	1.80066E-05		6.1201E-05
20	1.125	1.68768E-05		8.3174E-05
21	1.1875	1.39913E-05		8.8632E-05
22	1.25	1.31367E-05		5.7441E-05
23	1.3125	1.36244E-05		5.6891E-05
24	1.375	1.28353E-05		6.4135E-05
25	1.4375	1.25736E-05		7.9103E-05

Figure 48: Male 3 Left-handed (Left)



	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 13->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 12->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		4.603E-05
19	1.0625	0		6.2974E-05
20	1.125	0		7.5E-05
21	1.1875	0		7.5803E-05
22	1.25	0		8.5935E-05
23	1.3125	0		7.8125E-05
24	1.375	0		5.2421E-05
25	1.4375	0		4.4229E-05

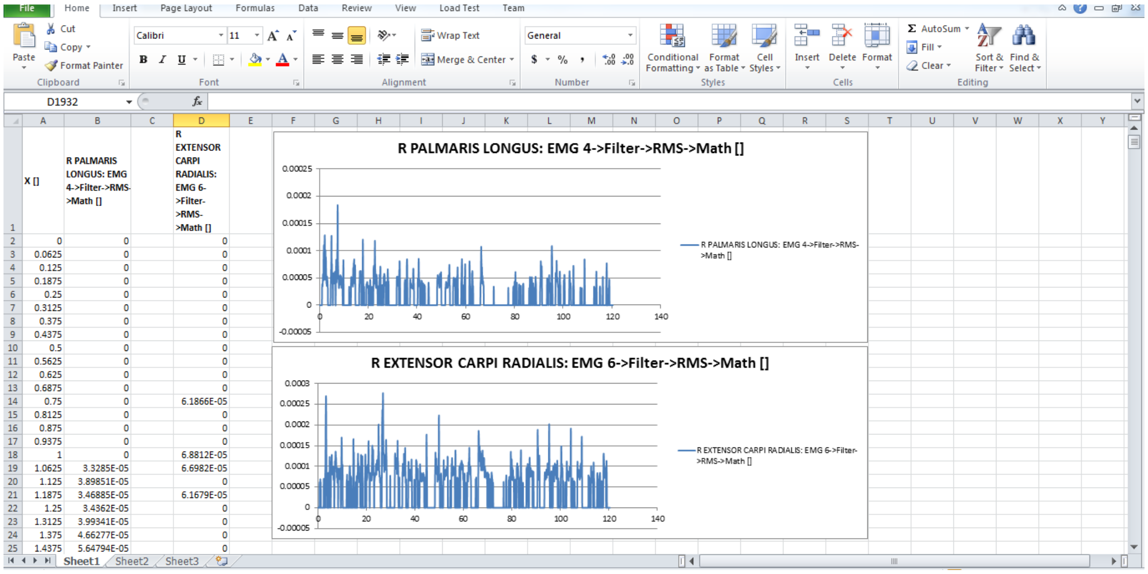
Figure 49: Male 3 Left-handed (Right)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 4->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 6->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0

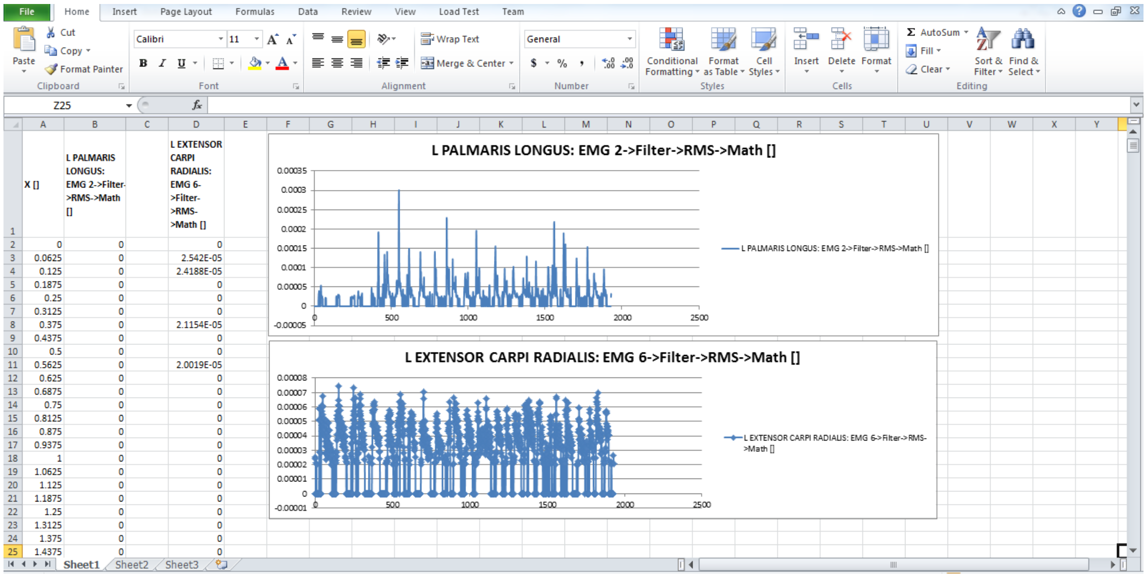
Figure 50: Male 2 Right-handed (Left)



D1932

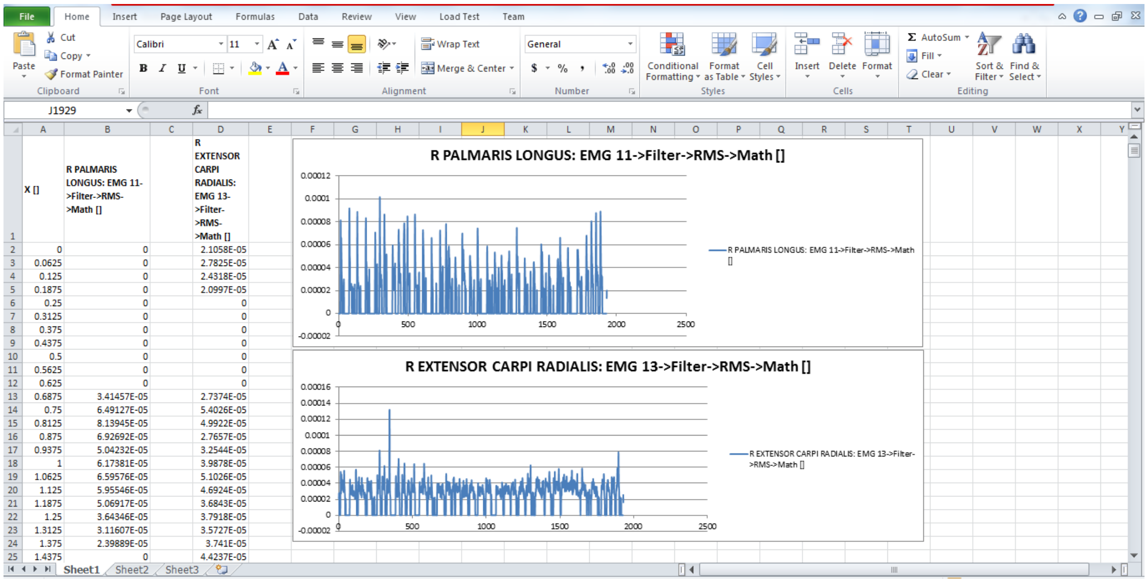
	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 4->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 6->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		6.1866E-05
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		6.8812E-05
19	1.0625	3.3285E-05		6.6982E-05
20	1.125	3.89851E-05		0
21	1.1875	3.46885E-05		6.1679E-05
22	1.25	3.4362E-05		0
23	1.3125	3.99341E-05		0
24	1.375	4.66277E-05		0
25	1.4375	5.64794E-05		0

Figure 51: Male 2 Right-handed (Right)



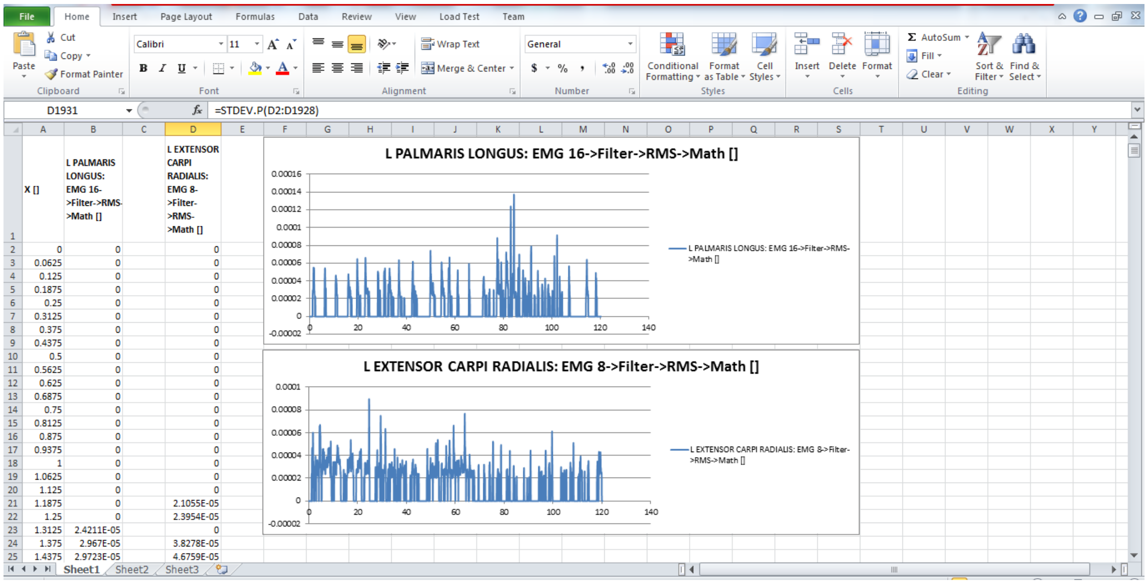
	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 2->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 6->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		2.542E-05
4	0.125	0		2.4188E-05
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		2.1154E-05
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		2.0019E-05
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0

Figure 52: Male 3 Right-handed (Left)



	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 11->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 13->Filter->RMS->Math []
2	0	0		2.1058E-05
3	0.0625	0		2.7825E-05
4	0.125	0		2.4318E-05
5	0.1875	0		2.0997E-05
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	3.41457E-05		2.7374E-05
14	0.75	6.49127E-05		5.4026E-05
15	0.8125	8.13945E-05		4.9922E-05
16	0.875	6.92692E-05		2.7657E-05
17	0.9375	5.04232E-05		3.2544E-05
18	1	6.17381E-05		3.9878E-05
19	1.0625	6.59576E-05		5.1026E-05
20	1.125	5.95546E-05		4.6924E-05
21	1.1875	5.06917E-05		3.6843E-05
22	1.25	3.64346E-05		3.7918E-05
23	1.3125	3.11607E-05		3.5727E-05
24	1.375	2.39889E-05		3.741E-05
25	1.4375	0		4.4237E-05

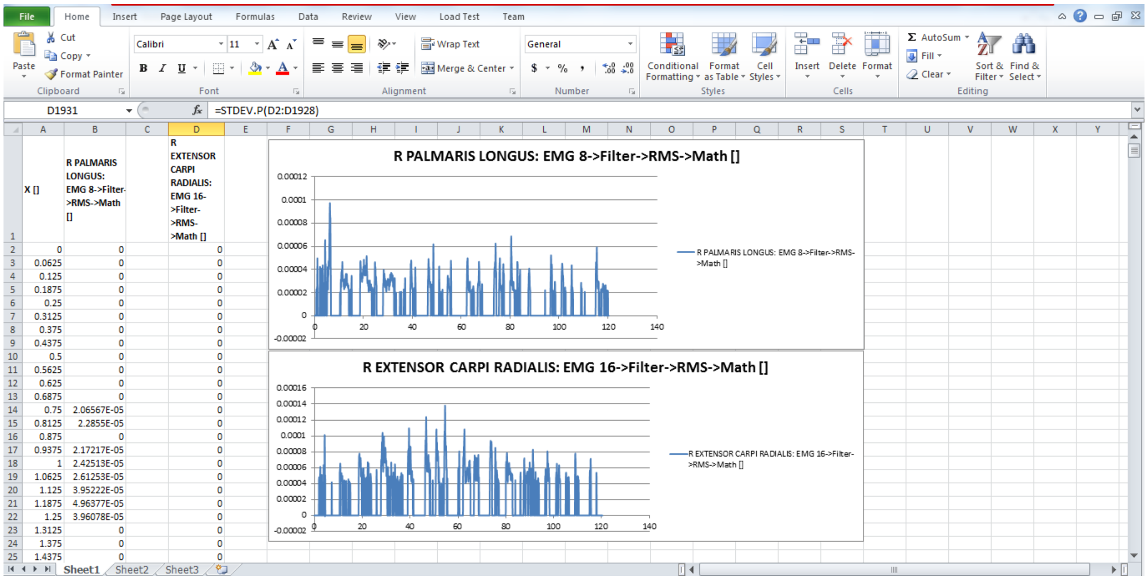
Figure 53: Male 3 Right-handed (Right)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 16->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 8->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		2.1055E-05
22	1.25	0		2.3954E-05
23	1.3125	2.4211E-05		0
24	1.375	2.967E-05		3.8278E-05
25	1.4375	2.9723E-05		4.6759E-05

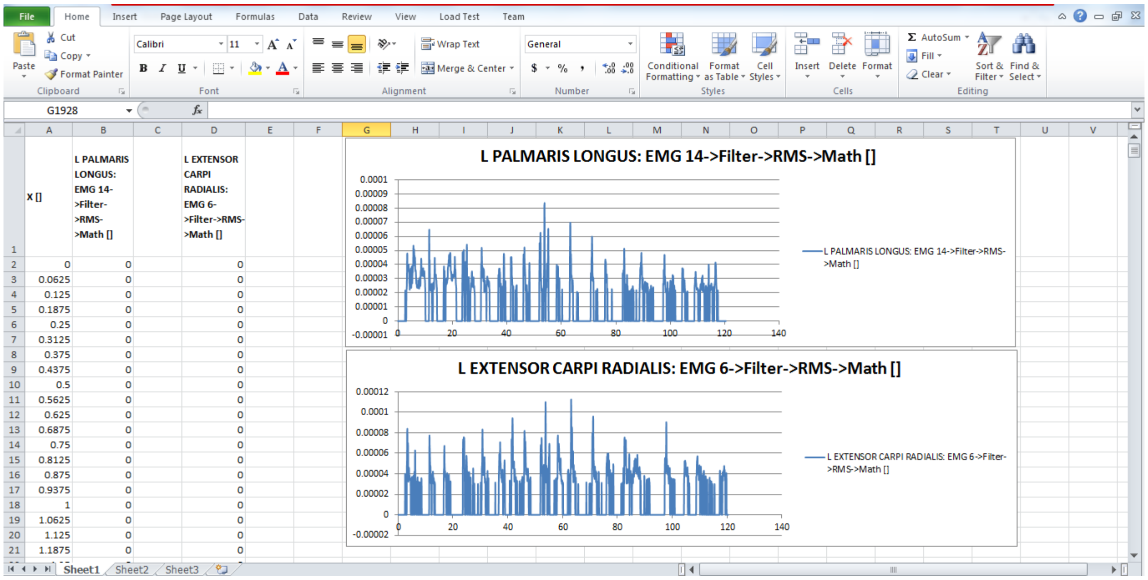
Figure 54: Female 1 Left-handed (Left)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 8->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 16->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	2.06567E-05		0
15	0.8125	2.2855E-05		0
16	0.875	0		0
17	0.9375	2.17217E-05		0
18	1	2.42513E-05		0
19	1.0625	2.61253E-05		0
20	1.125	3.95222E-05		0
21	1.1875	4.96377E-05		0
22	1.25	3.96078E-05		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0

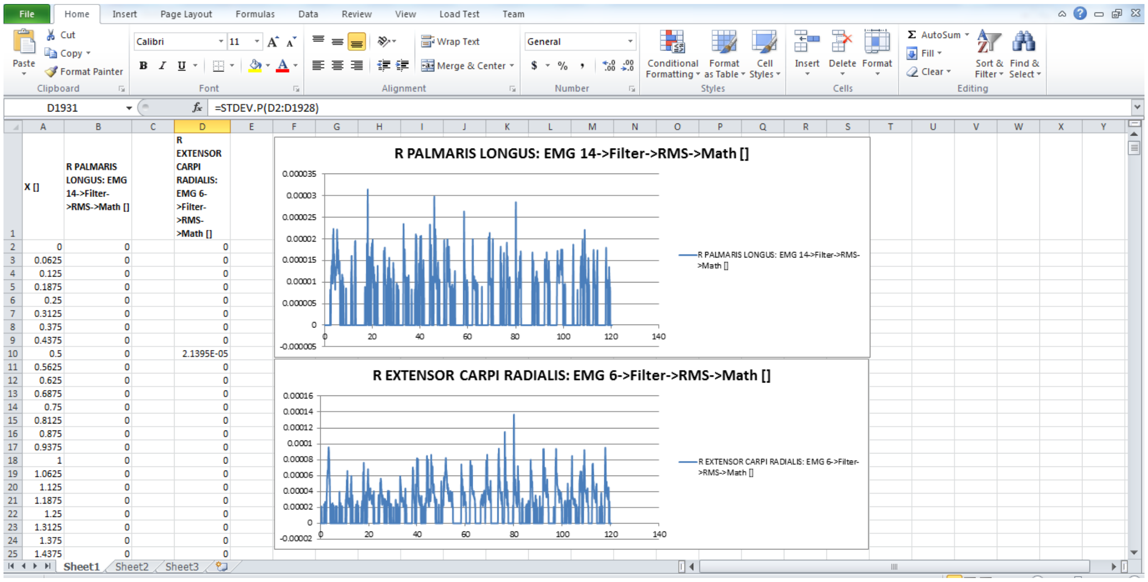
Figure 55: Female 1 Left-handed (Right)



G1928

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 14->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 6->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0

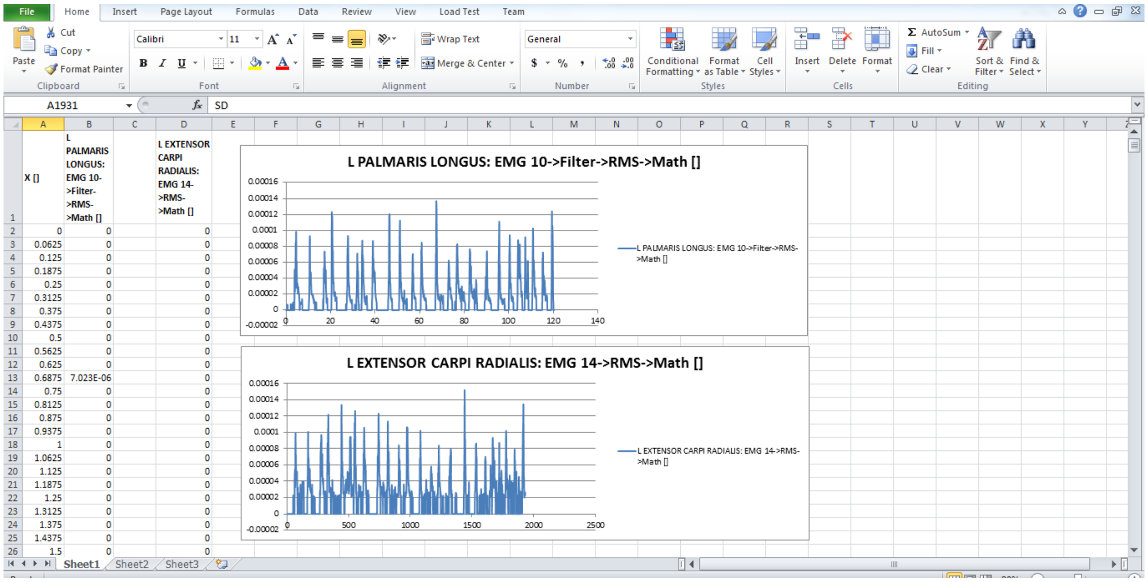
Figure 56: Female 2 Left-handed (Left)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 14->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 6->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		2.1395E-05
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0

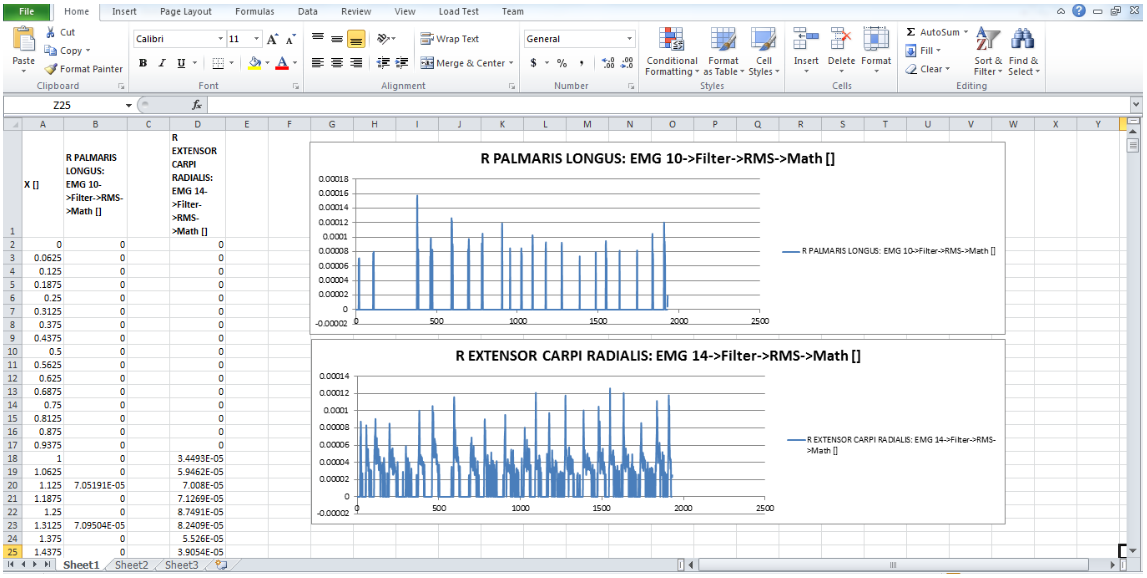
Figure 57: Female 2 Left-handed (Right)



A1931 SD

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 10->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 14->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	7.023E-06		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0
26	1.5	0		0

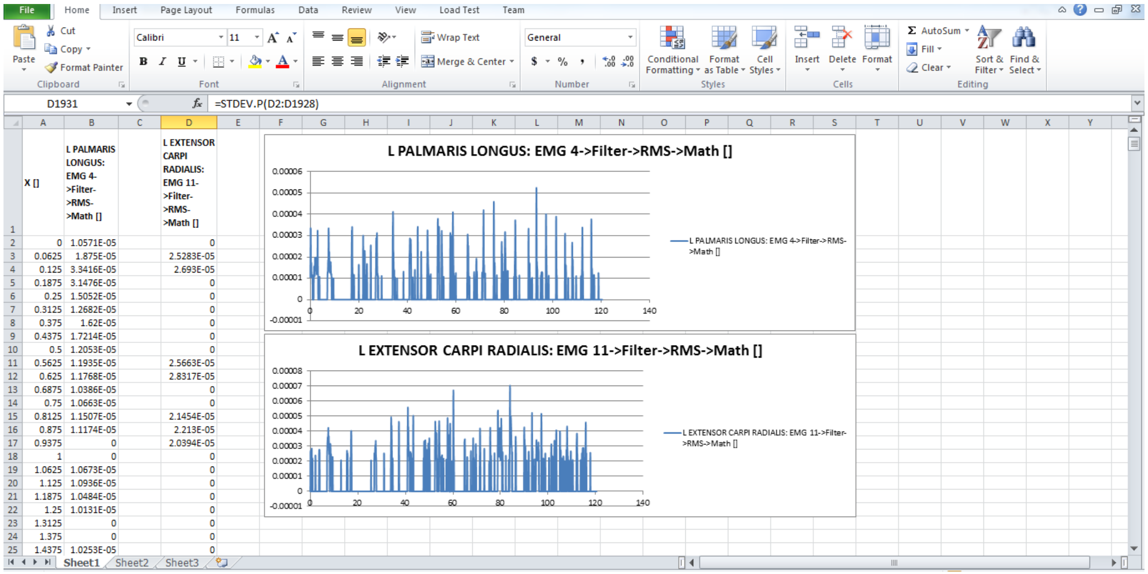
Figure 58: Female 3 Left-handed (Left)



Z25

	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 10->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 14->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		3.4493E-05
19	1.0625	0		5.9462E-05
20	1.125	7.05191E-05		7.008E-05
21	1.1875	0		7.1269E-05
22	1.25	0		8.7491E-05
23	1.3125	7.09504E-05		8.2409E-05
24	1.375	0		5.526E-05
25	1.4375	0		3.9054E-05

Figure 59: Female 3 Left-handed (Right)



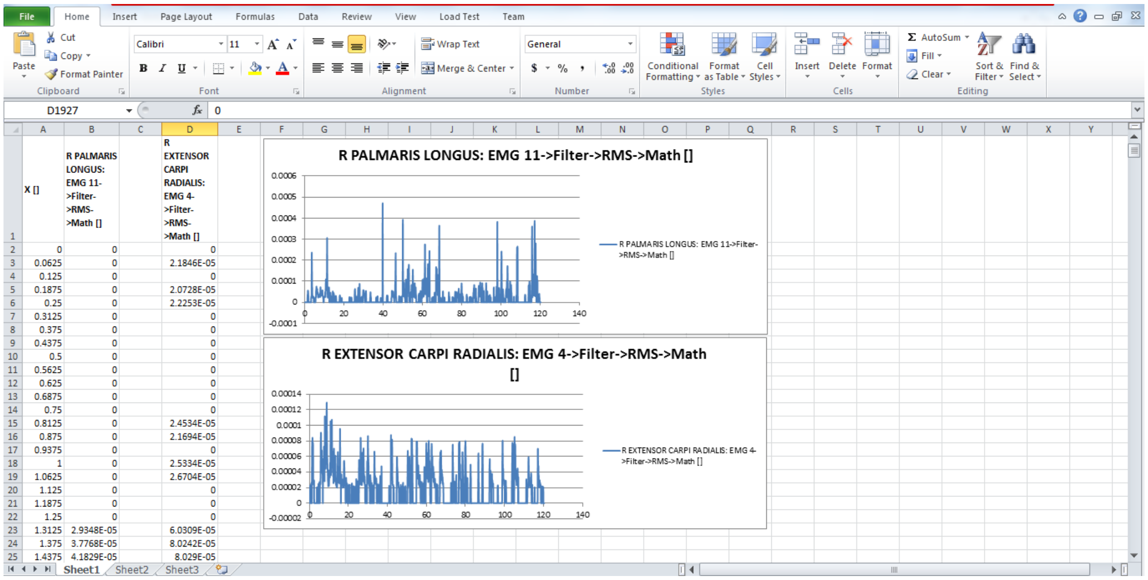
D1931 =STDEV.P(D2:D1928)

	A	B	C	D	E
1	X []	L PALMARIS LONGUS: EMG 4->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 11->Filter->RMS->Math []	
2	0	1.0571E-05		0	
3	0.0625	1.875E-05		2.5283E-05	
4	0.125	3.3416E-05		2.693E-05	
5	0.1875	3.1476E-05		0	
6	0.25	1.5052E-05		0	
7	0.3125	1.2682E-05		0	
8	0.375	1.62E-05		0	
9	0.4375	1.7214E-05		0	
10	0.5	1.2053E-05		0	
11	0.5625	1.1935E-05		2.5663E-05	
12	0.625	1.1768E-05		2.8317E-05	
13	0.6875	1.0386E-05		0	
14	0.75	1.0663E-05		0	
15	0.8125	1.1507E-05		2.1454E-05	
16	0.875	1.1174E-05		2.213E-05	
17	0.9375	0		2.0394E-05	
18	1	0		0	
19	1.0625	1.0673E-05		0	
20	1.125	1.0936E-05		0	
21	1.1875	1.0484E-05		0	
22	1.25	1.0131E-05		0	
23	1.3125	0		0	
24	1.375	0		0	
25	1.4375	1.0253E-05		0	

L PALMARIS LONGUS: EMG 4->Filter->RMS->Math []

L EXTENSOR CARPI RADIALIS: EMG 11->Filter->RMS->Math []

Figure 60: Female 1 Right-handed (Left)



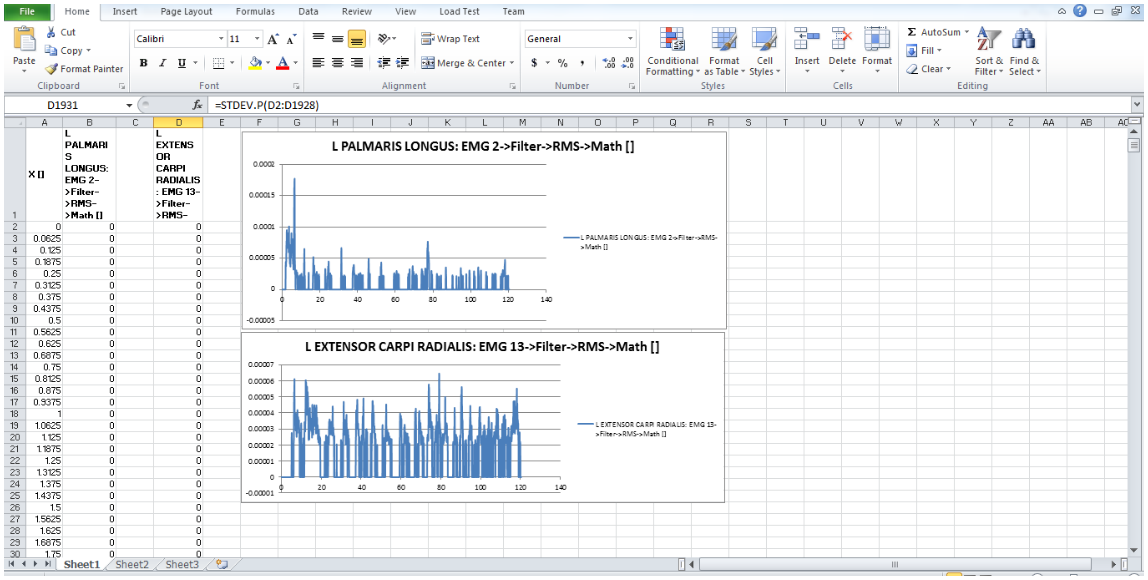
D1927 0

	A	B	C	D	E
1	X []	R PALMARIS LONGUS: EMG 11->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 4->Filter->RMS->Math []	
2	0	0		0	
3	0.0625	0		2.1846E-05	
4	0.125	0		0	
5	0.1875	0		2.0728E-05	
6	0.25	0		2.2253E-05	
7	0.3125	0		0	
8	0.375	0		0	
9	0.4375	0		0	
10	0.5	0		0	
11	0.5625	0		0	
12	0.625	0		0	
13	0.6875	0		0	
14	0.75	0		0	
15	0.8125	0		2.4534E-05	
16	0.875	0		2.1694E-05	
17	0.9375	0		0	
18	1	0		2.5334E-05	
19	1.0625	0		2.6704E-05	
20	1.125	0		0	
21	1.1875	0		0	
22	1.25	0		0	
23	1.3125	2.9348E-05		6.0309E-05	
24	1.375	3.7768E-05		8.0242E-05	
25	1.4375	4.1829E-05		8.029E-05	

R PALMARIS LONGUS: EMG 11->Filter->RMS->Math []

R EXTENSOR CARPI RADIALIS: EMG 4->Filter->RMS->Math []

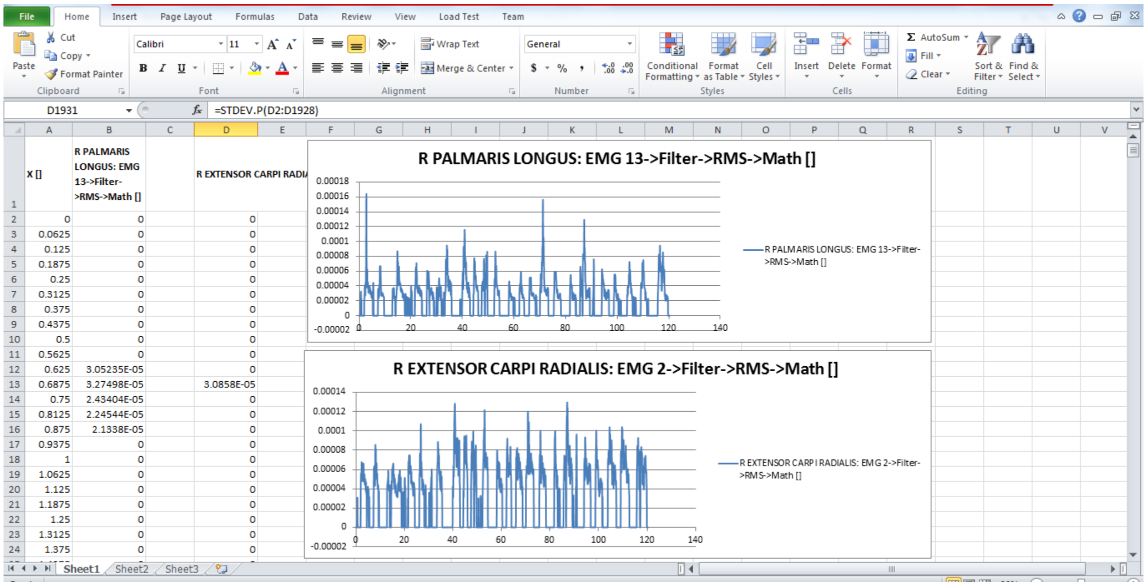
Figure 61: Female 1 Right-handed (Right)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 2->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 13->Filter->RMS-
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0
26	1.5	0		0
27	1.5625	0		0
28	1.625	0		0
29	1.6875	0		0
30	1.75	0		0

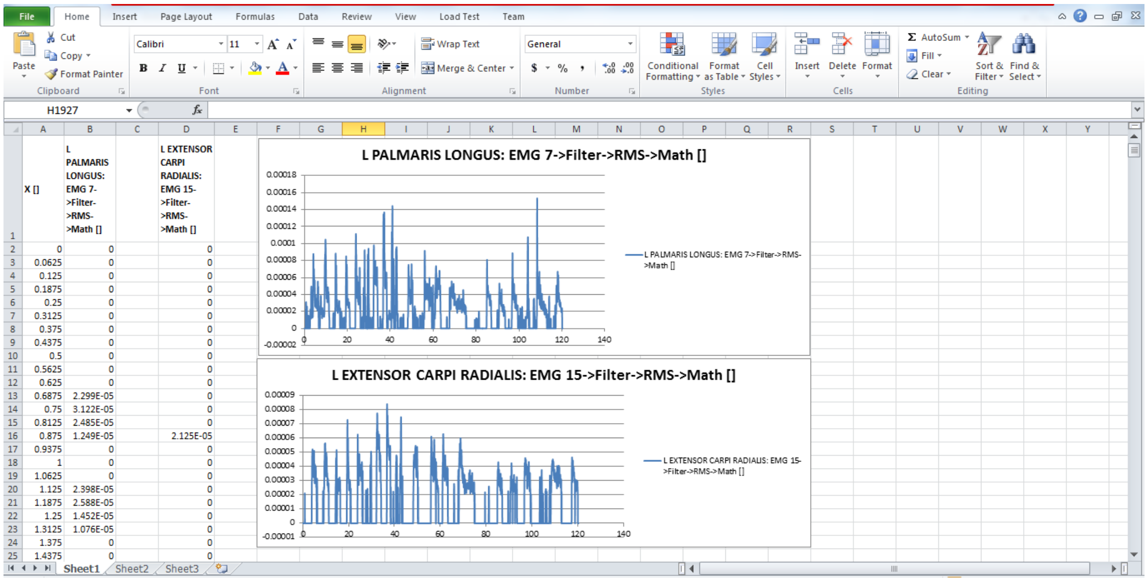
Figure 62: Female 2 Right-handed (Left)



D1931 =STDEV.P(D2:D1928)

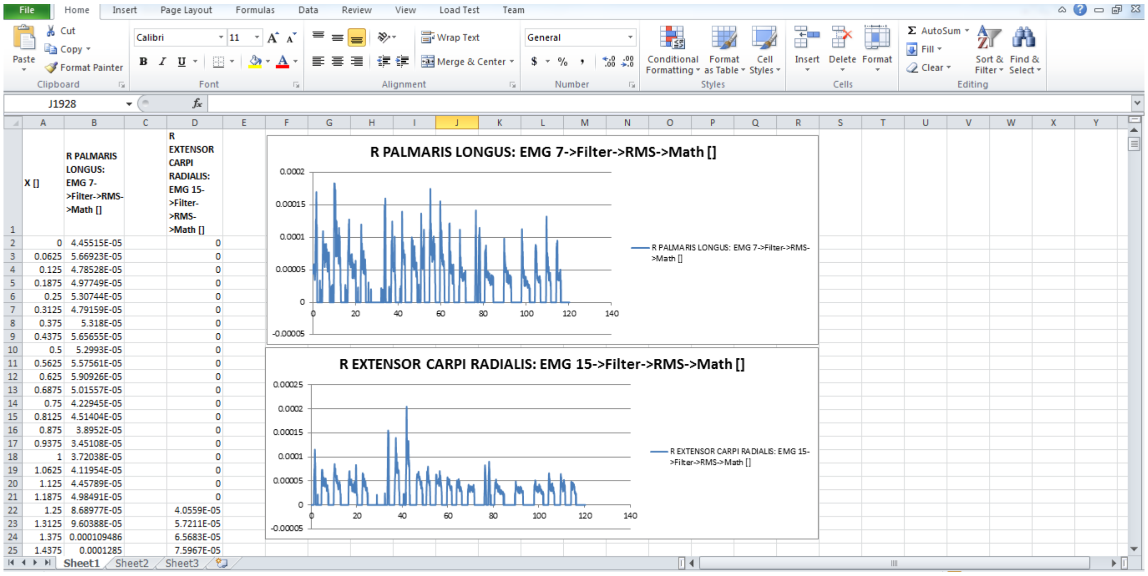
	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 13->Filter->RMS->Math []		R EXTENSOR CARPI RADI
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	3.05235E-05		0
13	0.6875	3.27498E-05		3.0858E-05
14	0.75	2.43404E-05		0
15	0.8125	2.24544E-05		0
16	0.875	2.1338E-05		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0

Figure 63: Female 2 Right-handed (Right)



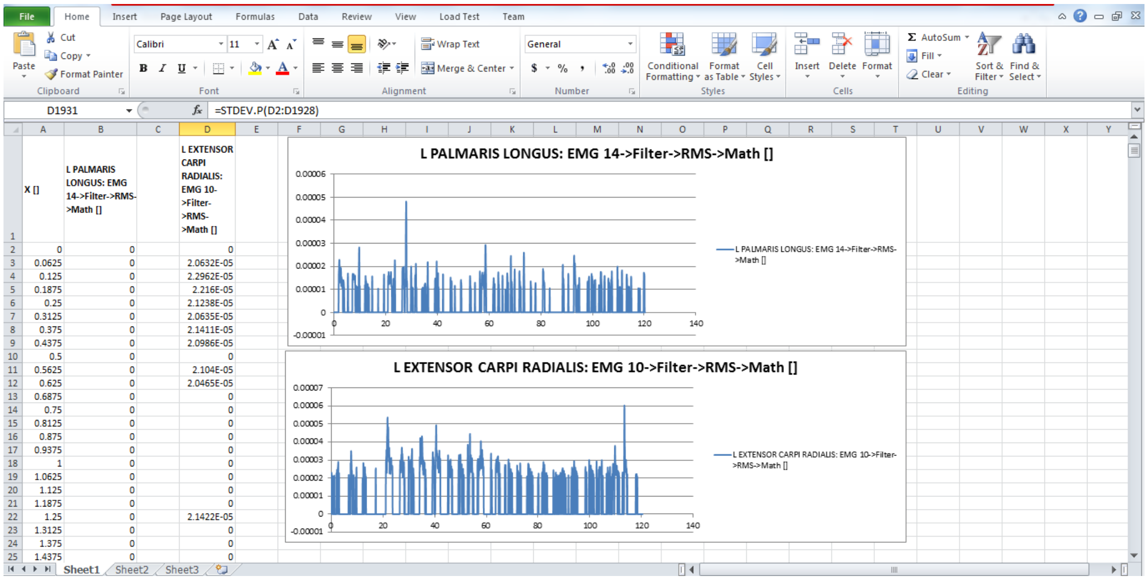
	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 7->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 15->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	2.299E-05		0
14	0.75	3.122E-05		0
15	0.8125	2.485E-05		0
16	0.875	1.249E-05		2.125E-05
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	2.398E-05		0
21	1.1875	2.588E-05		0
22	1.25	1.452E-05		0
23	1.3125	1.076E-05		0
24	1.375	0		0
25	1.4375	0		0

Figure 64: Female 3 Right-handed (Left)



	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 7->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 15->Filter->RMS->Math []
2	0	4.45515E-05		0
3	0.0625	5.66923E-05		0
4	0.125	4.78528E-05		0
5	0.1875	4.97749E-05		0
6	0.25	5.30744E-05		0
7	0.3125	4.79159E-05		0
8	0.375	5.318E-05		0
9	0.4375	5.65655E-05		0
10	0.5	5.2993E-05		0
11	0.5625	5.57561E-05		0
12	0.625	5.90926E-05		0
13	0.6875	5.01557E-05		0
14	0.75	4.22945E-05		0
15	0.8125	4.51404E-05		0
16	0.875	3.8952E-05		0
17	0.9375	3.45108E-05		0
18	1	3.72038E-05		0
19	1.0625	4.11954E-05		0
20	1.125	4.45789E-05		0
21	1.1875	4.98491E-05		0
22	1.25	8.68977E-05		4.0559E-05
23	1.3125	9.60388E-05		5.7211E-05
24	1.375	0.000109486		6.5683E-05
25	1.4375	0.0001285		7.5967E-05

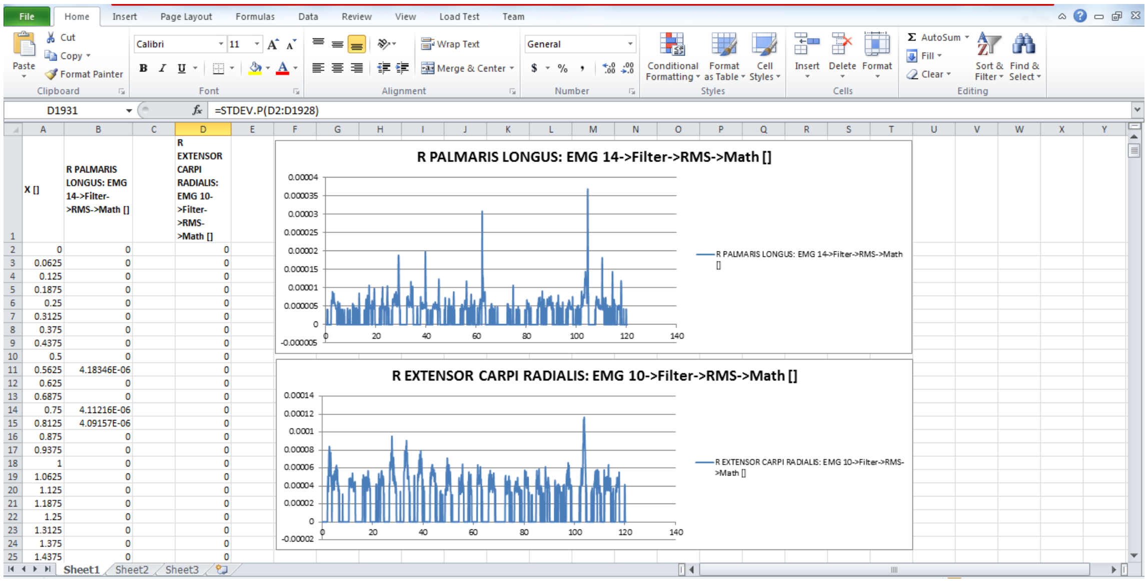
Figure 65: Female 3 Right-handed (Right)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 14->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 10->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		2.0632E-05
4	0.125	0		2.2962E-05
5	0.1875	0		2.216E-05
6	0.25	0		2.1238E-05
7	0.3125	0		2.0635E-05
8	0.375	0		2.1411E-05
9	0.4375	0		2.0986E-05
10	0.5	0		0
11	0.5625	0		2.104E-05
12	0.625	0		2.0465E-05
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		2.1422E-05
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0

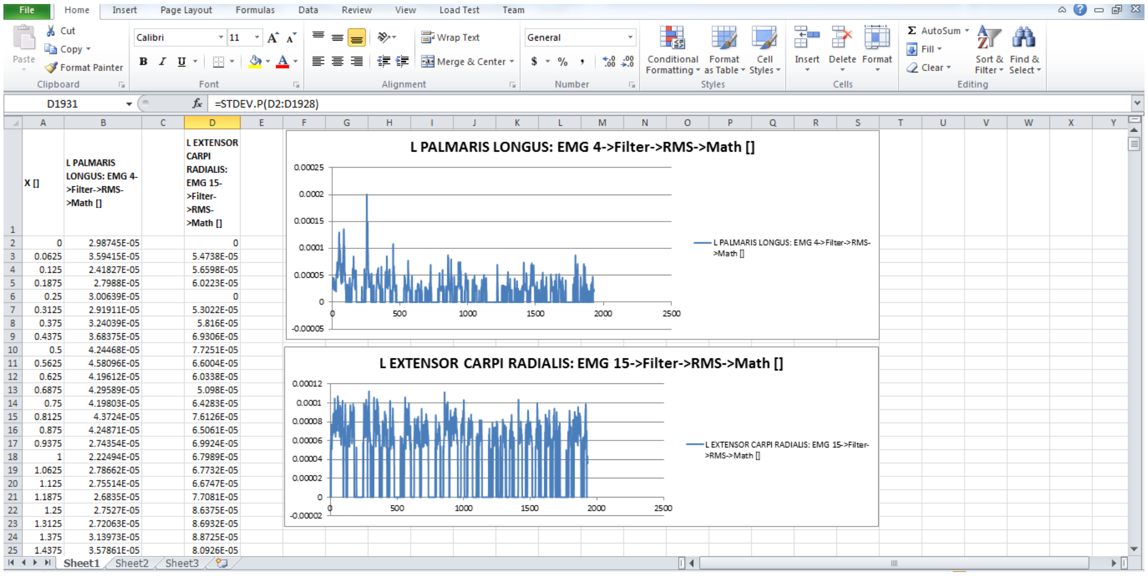
Figure 66: Male 1 Both-handed (Left)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 14->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 10->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	4.18346E-06		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	4.11216E-06		0
15	0.8125	4.09157E-06		0
16	0.875	0		0
17	0.9375	0		0
18	1	0		0
19	1.0625	0		0
20	1.125	0		0
21	1.1875	0		0
22	1.25	0		0
23	1.3125	0		0
24	1.375	0		0
25	1.4375	0		0

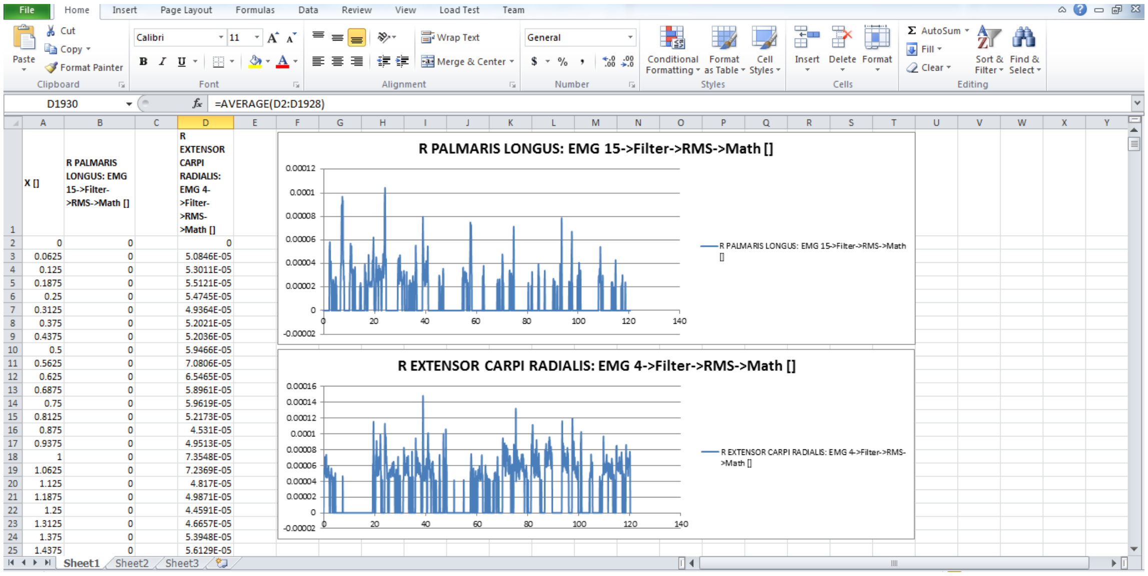
Figure 67: Male 1 Both-handed (Right)



D1931 =STDEV.P(D2:D1928)

	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 4->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 15->Filter->RMS->Math []
2	0	2.98745E-05		0
3	0.0625	3.59415E-05		5.4738E-05
4	0.125	2.41827E-05		5.6598E-05
5	0.1875	2.7988E-05		6.0223E-05
6	0.25	3.00639E-05		0
7	0.3125	2.91911E-05		5.3022E-05
8	0.375	3.24039E-05		5.816E-05
9	0.4375	3.68375E-05		6.9306E-05
10	0.5	4.24468E-05		7.7251E-05
11	0.5625	4.58096E-05		6.6004E-05
12	0.625	4.19612E-05		6.0338E-05
13	0.6875	4.29589E-05		5.098E-05
14	0.75	4.19803E-05		6.4283E-05
15	0.8125	4.3724E-05		7.6126E-05
16	0.875	4.24871E-05		6.5061E-05
17	0.9375	2.74354E-05		6.9924E-05
18	1	2.22494E-05		6.7989E-05
19	1.0625	2.78662E-05		6.7732E-05
20	1.125	2.75514E-05		6.6747E-05
21	1.1875	2.6835E-05		7.7081E-05
22	1.25	2.7527E-05		8.6375E-05
23	1.3125	2.72063E-05		8.6932E-05
24	1.375	3.13973E-05		8.8725E-05
25	1.4375	3.57861E-05		8.0926E-05

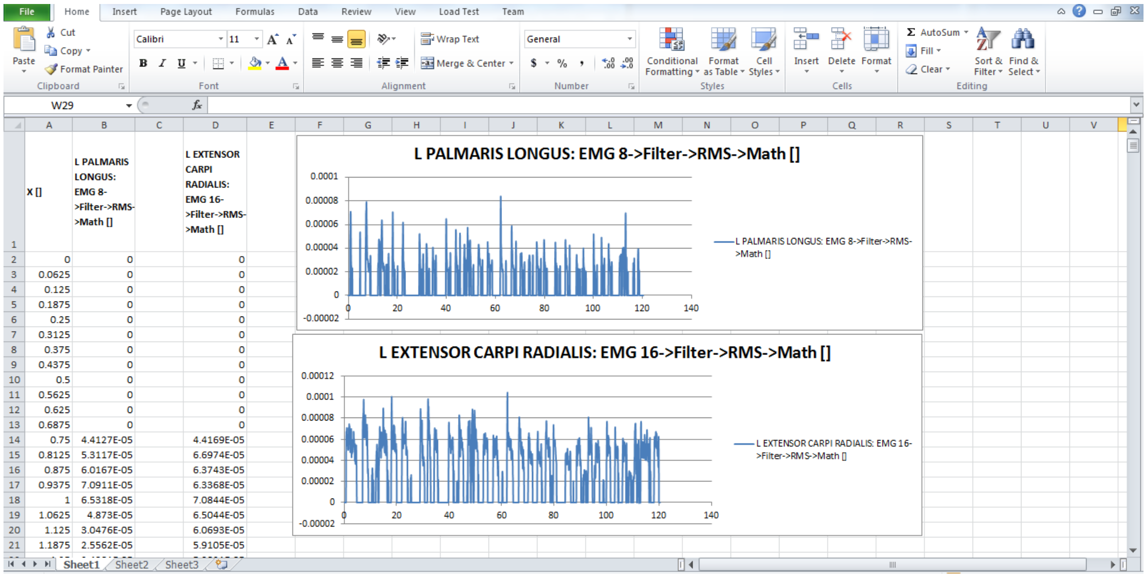
Figure 68: Male 2 Both-handed (Left)



D1930 =AVERAGE(D2:D1928)

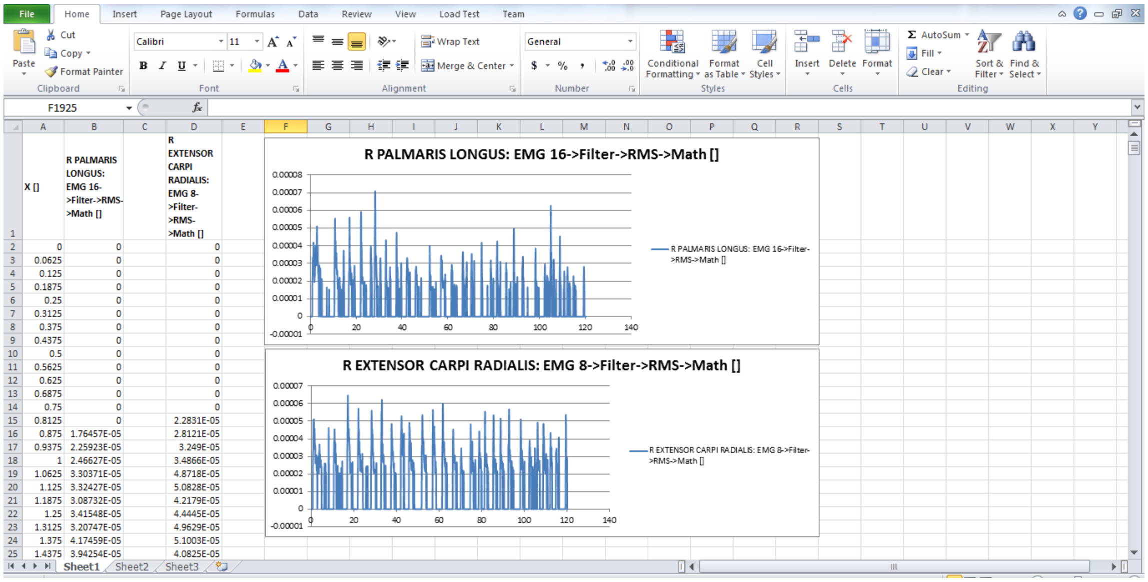
	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 15->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 4->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		5.0846E-05
4	0.125	0		5.3011E-05
5	0.1875	0		5.5121E-05
6	0.25	0		5.4745E-05
7	0.3125	0		4.9364E-05
8	0.375	0		5.2021E-05
9	0.4375	0		5.2036E-05
10	0.5	0		5.9466E-05
11	0.5625	0		7.0806E-05
12	0.625	0		6.5465E-05
13	0.6875	0		5.8961E-05
14	0.75	0		5.9619E-05
15	0.8125	0		5.2173E-05
16	0.875	0		4.531E-05
17	0.9375	0		4.9513E-05
18	1	0		7.3548E-05
19	1.0625	0		7.2369E-05
20	1.125	0		4.817E-05
21	1.1875	0		4.9871E-05
22	1.25	0		4.4591E-05
23	1.3125	0		4.6657E-05
24	1.375	0		5.3948E-05
25	1.4375	0		5.6129E-05

Figure 69: Male 2 Both-handed (Right)



	A	B	C	D
1	X []	L PALMARIS LONGUS: EMG 8->Filter->RMS->Math []		L EXTENSOR CARPI RADIALIS: EMG 16->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	4.4127E-05		4.4169E-05
15	0.8125	5.3117E-05		6.6974E-05
16	0.875	6.0167E-05		6.3743E-05
17	0.9375	7.0911E-05		6.3368E-05
18	1	6.5318E-05		7.0844E-05
19	1.0625	4.873E-05		6.5044E-05
20	1.125	3.0476E-05		6.0693E-05
21	1.1875	2.5562E-05		5.9105E-05

Figure 70: Male 3 Both-handed (Left)



	A	B	C	D
1	X []	R PALMARIS LONGUS: EMG 16->Filter->RMS->Math []		R EXTENSOR CARPI RADIALIS: EMG 8->Filter->RMS->Math []
2	0	0		0
3	0.0625	0		0
4	0.125	0		0
5	0.1875	0		0
6	0.25	0		0
7	0.3125	0		0
8	0.375	0		0
9	0.4375	0		0
10	0.5	0		0
11	0.5625	0		0
12	0.625	0		0
13	0.6875	0		0
14	0.75	0		0
15	0.8125	0		2.2831E-05
16	0.875	1.76457E-05		2.8121E-05
17	0.9375	2.25923E-05		3.249E-05
18	1	2.46627E-05		3.4866E-05
19	1.0625	3.30371E-05		4.8718E-05
20	1.125	3.32427E-05		5.0828E-05
21	1.1875	3.08732E-05		4.2179E-05
22	1.25	3.41548E-05		4.4445E-05
23	1.3125	3.20747E-05		4.9629E-05
24	1.375	4.17459E-05		5.1003E-05
25	1.4375	3.94254E-05		4.0825E-05

Figure 71: Male 3 Both-handed (Right)