POSITIONAL PARAMETERS OF EMG FOR UPPER LIMB AMPUTATIONS

ABDIRAHMAN HADI OMAR

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2018

POSITIONAL PARAMETERS OF EMG FOR UPPER LIMB AMPUTATIONS

ABDIRAHMAN HADI OMAR

RESEARCH REPORT SUBMITTED TO THE FACULTY OF
ENGINEERING UNIVERSITY OF MALAYA, IN PARTIAL
FULFILMENT OF THE REQUIREMENT FOR THE DEGREE
OF MASTER OF BIOMEDICAL ENGINEERING

2018

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: **Abdirahman Hadi Omar**

Matric No: **KQB160011**

Name of Degree: **Master of Biomedical Engineering**

Title of Project Paper/Research Report/Dissertation/Thesis:

Positional Parameters of EMG For Upper Limb Amputations

Field of Study: **Biomedical Engineering**

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:

Designation

ABSTRACT

The human hand is a remarkable creature, which facilitating many uses in our daily life activity (ADLs). A person who has lost a part of his upper limb is called amputee. Amputation is removal of limb caused by variety of reasons which include severe traumatic injuries, surgery and accidents by car or mostly by motorcycle. Different type of amputation occurs including transhumeral and transradial amputation. Myoelectric prosthesis is artificial limb (uses electromyographic (EMG) signal) used to restore the function of removal limb using muscle activity from the remaining limb for the control of prosthesis device. One of the challenges facing the myoelectric prosthesis is the position of EMG sensor which static inside the socket and sometimes attached to the non-active muscle, resulting inefficiency prosthetic limb function. The aim of this study is to investigate the positional parameters of EMG for transradial prosthetics users by finding the strongest detectable position outside the socket and to compare it with normal human activities. DELSYS Trigno wireless EMG instrument was used in this study to achieve this goal. Ten normal subjects and two subjects with transradial amputees were involved in this study. Two wireless EMG sensor and four different locations from upper limb muscles were selected. Two different tests were performed. The first test, two muscles were selected from upper arm muscles (biceps and triceps muscles) where two EMG sensors were placed respectively. Three different activities were performed during this test which are muscle strength, flexion and extension and flexion and extension with 5kg weight. Muscles selected for the second test were extensor carpi ulnaris (ECU) muscle and Brachioradialis muscle from the forearm muscles and repeated the same activities. The study found that during all the activities, upper arm muscles were performed better EMG activity than forearm muscles for the both transradial amputees and normal subjects. Biceps muscles have demonstrated the strongest muscle that showed the highest value of EMG signal. Based on the results, the study suggests that EMG sensor should be

placed outside the socket so that to be adjustable and for user’s convenience to control the myoelectric prosthesis.

ABSTRAK

Tangan manusia adalah anggota yang istimewa, yang memudahkan banyak kegunaan dalam aktiviti kehidupan harian kita (*ADL*s). Seseorang yang telah kehilangan sebahagian anggota dipanggil amputasi. Amputasi adalah penyingkiran anggota badan yang disebabkan oleh pelbagai sebab termasuk kecederaan trauma, pembedahan dan kemalangan kereta atau kebanyakannya oleh motosikal. Jenis amputasi yang berlainan berlaku adalah termasuk amputasi transhumeral dan transradial. Prostetik Myoelektrik adalah anggota tiruan (menggunakan isyarat *electromyography* (EMG)) yang digunakan untuk menggantikan fungsi anggota yang disingkirkan dengan menggunakan aktiviti otot daripada anggota badan yang masih ada untuk mengawal peranti prostesis. Salah satu cabaran yang dihadapi oleh peranti prostetik myoelektrik ialah kedudukan sensor EMG yang statik di dalam soket dan kadang kala dilekatkan pada otot yang tidak aktif, yang mengurangkan kecekapan fungsi peranti prostetik. Tujuan kajian ini dijalankan adalah untuk mengkaji parameter kedudukan EMG untuk pengguna prostetik transradial untuk mengetahui kedudukan yang terkuat di luar soket dan untuk membandingkannya dengan aktiviti normal manusia. Instrumen DELSYS Trigno digunakan dalam kajian ini untuk mencapai objektif ini. Sepuluh subjek normal dan dua subjek transradial telah terlibat dalam kajian ini. Dua sensor EMG tanpa wayar dan empat lokasi berbeza dari otot anggota atas dipilih. Dua ujian yang berlainan telah dijalankan. Pada ujian pertama, dua otot dipilih dari otot lengan atas (otot biceps dan otot trisep) dan EMG sensor diletakkan pada kedua-duanya. Tiga aktiviti yang berlainan telah dilakukan semasa ujian ini iaitu kekuatan otot, fleksi dan ekstensi, and fleksi dan ekstensi bersama pemberat seberat 5kg. Otot yang dipilih untuk ujian yang kedua adalah otot *extensor carpi ulnaris* (ECU) dan otot *Brachioradialis* dari otot lengan bawah dan diulangi dengan aktiviti yang sama. Kajian mendapati bahawa dalam semua aktiviti, otot lengan atas melakukan aktiviti EMG yang lebih baik daripada otot lengan bawah untuk kedua-dua amputees transradial dan

subjek normal. Otot bisep telah menunjukkan otot terkuat yang menunjukkan nilai tertinggi isyarat EMG. Berdasarkan hasil kajian, kajian mencadangkan bahawa sensor EMG harus diletakkan di luar soket supaya ianya dinamik dan mudah dikendalikan oleh para pengguna peranti prostetik myoelektrik.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

EMG	Electromyographic
EEG	Electroencephalography
AVG	Average
TR	Transradial
BP	Body Powered
MES	Myoelectric Signal
Bb	Biceps brachii
Tb	Triceps brachii
BR	Brachioradialis,
ECU	Extensor carpi ulnaris
ADLs	Activities of daily living
V	Voltage

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1: Overview

The upper limb or upper extremity is the region in a vertebrate animal which is extending from the deltoid region up to and including the hand, including the arm, axilla and shoulder. When a person has lost a part of the upper limb, he faces difficulties in interaction of his social, environmental and daily life activities such as eating, climbing, using socks and dressing. A person who has lost a part of his upper limb is called amputee.

Amputation is removal of limb caused by variety of reasons includes severe traumatic injuries, surgery and accidents by car or mostly by motorcycle. There are different types can occur of upper limb amputation which includes: Hand & Partial-Hand Amputations, Wrist Disarticulation, Transradial (below elbow amputations), Transhumeral (above elbow amputation), Shoulder Disarticulation and Forequarter Amputation.

To overcome these challenges, amputees uses prosthetic devices which is an artificial body part replacement designed and developed by professional rehabilitation engineers. The purpose of these prosthesis is to provide an individual who has an amputated limb with the opportunity to perform functional tasks and mimic his lost limbs before amputation. Several prostheses have been developed to achieve these goals. The type of prosthesis (artificial limb) used is determined largely by the extent of an amputation or loss and location of the missing upper limb extremity (Ovadia & Askari, 2015).

These prostheses can be divided based on their functions into two major classes which are passive prosthesis and active prosthesis. For passive prosthesis are classified into (i) cosmetic prosthetics which its main objective is for aesthetic replacement of the missing body part and (ii) functional prosthetics which primary aim is to facilitate specific activities such as those relevant to sport or work (Maat, Smit, Plettenburg, & Breedveld, 2018). While active prosthesis divided into body-powered and externally powered. For body powered is one that controlling by cable to fastened to the sound of limb by means harnesses and requires a high expenditure of energy from the user's which consider it a disadvantage of this prothesis (Carey, Lura, & Highsmith, 2015). But, for the external powered which use an external power source such battery pack to increase energy needed for movements. These can be subdivided into two categories which are myoelectric (uses electromyographic (EMG) signal to control the movements) and electric (ideal for example for phocomelic people who can command the prosthesis by means of external buttons) (Jiang & Farina, 2014).

1.2: Problem Statement

The loss of upper limb is a major disability that limits capabilities of daily life activities. when the amputation occurs, complete healing post amputation, the problem lies in the residual muscles which led to severe weakness in the muscle and high possibility of losing their function which affected completely. To restore the ability interaction of the real world, amputees uses body powered or myoelectric control where the electromyogram (EMG) signals produced by the remaining muscles are used to derive control commands for powered upper-limb prosthesis. Sometimes, the position of EMG sensor which static inside the socket attached non-active muscle, resulting reduced the efficiency of functionality of prosthetic limb.

1.3: Objectives

This project attempts

1. To investigate the positional parameters of EMG for transradial prosthetics users to figure out the strongest detectable position outside the socket for upper limb amputees.
2. To compare the EMG parameter between the amputee and the normal human while conducting different activities.

1.4: Report Organization

This project contains five chapters that consists of an introduction, literature review, methodology, results and discussion and conclusion. The introduction part gives an overview about upper limb amputation and causes, types and available solution of the amputation. Problem statement and objective also discussed in the same part.

Then for literature review, some valid information is gathered to support the objective based on the previous research work. The methodology part covers the detailed explanation of experimental procedure, the instrumentation used, the background of the participants, the activities that have done by the participants to generate results. Results are tabulated and analysed briefly. Lastly, conclusion suggests the improvement from the current work and future work.

1.5: Scope of the research

This research is conducted under the field of Rehabilitation Engineering and is conducted under Centre for Prosthetics and Orthotics Engineering, Biomechanics and Human Motion Laboratory, Department of Biomedical Engineering, UM authorization for studying position electromyography (EMG) for upper limb amputation for improvement of upper limb prosthesis. The study provided an introduction of full background information regarding upper limb amputation that covers types of upper limb amputation, types of prosthesis and reviewed the previous studies that relevant to the positional parameter of EMG for upper limb amputation. DELYSS Trigno wireless EMG instrument were used to collect the data and tested with transradial amputees and their performances were compared with normal subjects. Results and discussion provided a comprehensive analysis of the data collected. The study concluded the impact of the results that proven the objectives of the study. The limitations of the study were also presented with some recommendation for future work.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews the previous studies that relevant to the positional parameter of EMG for upper limb amputation.

2.1: Upper Limb Amputation

The human hand is a remarkable creature, which facilitating many uses in our daily life activity (ADLs). Hand is a very crucial in interacting with social life and establishes the frontiers between what belongs to the Self and what belongs to the environment. partial or full loss of an upper limb may cause devastating damage to human life. This damage affects several aspects of the person. While it affects the level of autonomy, it will limit the ability of performing working, environmental and daily living activities. Furthermore, it will change human lifestyle. (Adewuyi, Hargrove, & Kuiken, 2016). A person without a hand or both hands are called as a person with hand amputee. Amputation is the removal of limb by medical illness, surgery or trauma. The level of amputation related to the upper limb can be categorized as transcarpal, wrist disarticulation, transradial, elbow disarticulation, transhumeral, shoulder disarticulation and forequarter (Figure 1)(F. Cordella et al., 2016).

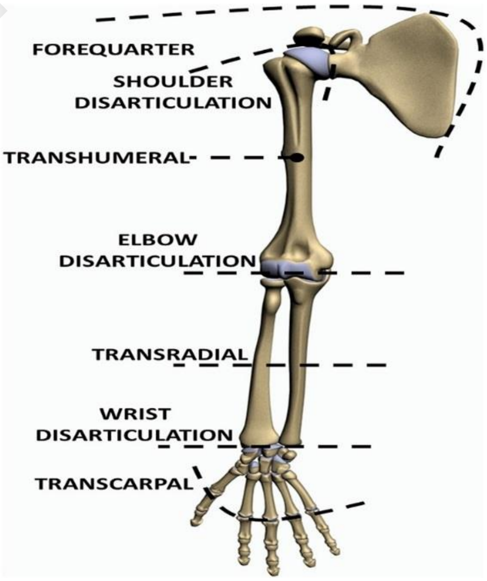


Figure 2.1: Levels of Upper limb absence(F. Cordella et al., 2016)

Around 10 % of world population are disabled, in 2005 one in 190 Americans is suffering different levels of upper limb loss. These numbers are expecting to double by 2050 (Ziegler-Graham, MacKenzie, Ephraim, Travison, & Brookmeyer, 2008). Each year, around 3500 and 5200 are living with loss of limb in Italy and United Kingdom, respectively. The occurrence of the different levels of upper limb loss is also illustrated in figure 2.2. Study by cordelle, (2016) conducted that upper limb absence in Italy and united kingdom are: 16%trans-humeral (above elbow amputations): any amputation occurring in the upper arm from the elbow to the shoulder , 12%transradial (below elbow amputations):any amputation occurring in the forearm, from the elbow to the wrist, 2%forequarter Amputation , 3%shoulder disarticulation: at the level of the shoulder, with the shoulder blade remaining, 1%elbow disarticulation, 2% wrist disarticulation : limb is amputated at the level of the wrist ,61%transcarpal, and 3%bilateral limb loss. There are many factors that cause the amputation. Traumatism is considering the first cause of upper limb amputation, mostly for males. it is followed by vascular and neoplasia or in infectious diseases.

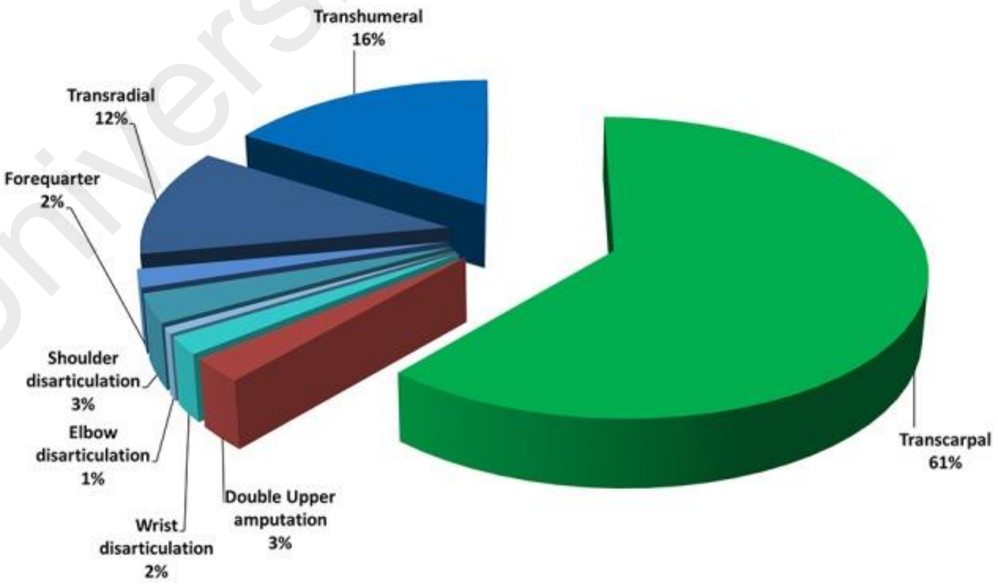


Figure 2.2: Statistics on level of upper limb absence in Italy and United Kingdom(Cordella, 2016)

The loss of a limb interrupts the closed-loop with the brain that takes place by means of the efferent and afferent pathways, responsible for motor control and sensory feedback, respectively. (F. Cordella et al., 2016)

2.1.1: Anatomy and Physiology of the Hand

Human hand has 31 muscles around the forearm and hand, 27 major bones, 19 joint articulation with more than 25 degree of freedom (DOF) and another 7 degrees of freedom for arm (van Duinen &Gandevia, 2011). There are two major level of upper limb movements which are transradial prosthetics which covers from lower elbow until the arm while transhumeral part covers from upper elbow until the shoulder. Transradial parts has one of the two large bones which are radius and ulna. These bones permit a motion called pronation and supination and covered by muscles like biceps brachii, supinator, pronator teres and pronator quadrates which are involved in generating the supination and pronation movements. Some amputees may lose these bones (radius and ulna) but some muscles will be still in active like biceps brachii and supinator with low reaction due to the incomplete muscles.

Table 2.1: Transradial Motion System and Muscles

Motion	**Muscle involved**
Flexion	Biceps Brachii, Brachioradialis, Pronator Teres
Extension	Triceps Brachii, Anconeous
Pronation	Brachioradialis, Pronator Teres, Pronator Quadrates
Supination	Biceps Brachii, Brachioradialis, Supinator

Pronation and supination of the forearm involve the rotation of the radius around the ulna. The major movement for the pronation muscle is known as pronator (pronator quadratus) where it is attached to the distal ulna and radius (Table 2.1), The pronator teres will cross the proximal radioulnar joints as the pronation is in a resting position. The supinator muscle is the most common one that is involved in supination motion by the time the elbow is in flexion, the tension in the supinator lessens and the biceps assist the supination (Fite et ol, 2006)

Wrist bones are involved in the motion of the flexion and extension of the wrist (see figure 2.11). The wrist reacts like a pulley joint between the transradial and the am. Flexor carpi radialis and flexor carpi ulnaris are the main muscles involved in flexion and extension motions the movement of the wrist occurs depending on the transfer of the muscle motion that is synchronous with the movement of all fingers on the palm (Hara ef al, 2005).

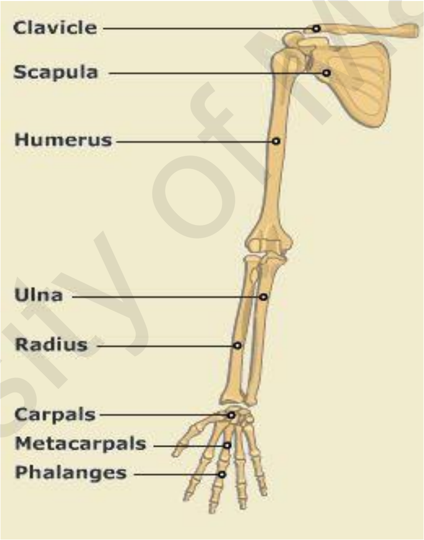


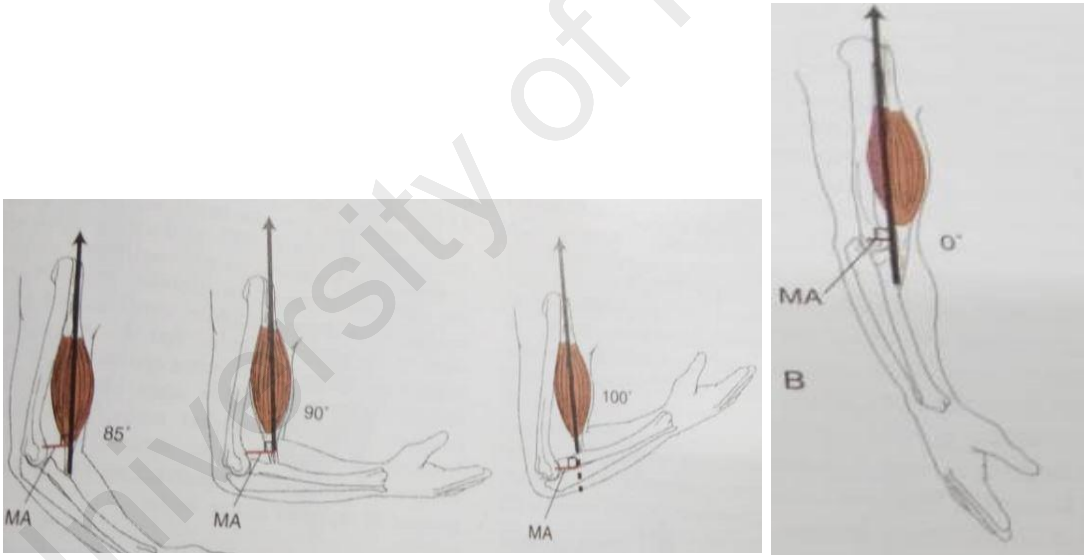
Figure 2.3: Upper Limb Bones("The Human Skeletal System," 2000)

2.1.2: Pronation and Supination

Pronation of transradial motion means that the transradial part (lower elbow until the wrist) rotates about 90 into the body segment. Furthermore, pronation is the rotation of the forearm when the palm faces down anteriorly, Normal human hand usually rotates the pronation between 85° to 90 depending on the task (Figure 2 12) There are several daily human tasks that are involved with the pronation motion such as filling up a cup of water, opening a door, holding a spoon, and many others.

2.1.3: Flexion and Extension of elbow

Muscles that involve flexion of elbow are Biceps Brachii, Brachioradialis, Pronator Teres. Biceps brachii considers mobility muscles because of it insertion close to the elbow joints. It has the largest moment arm flexion of elbow which is between 80° and 100° degrees as shown in Figure 2.4, therefore it can generate its greatest torque in this range. However, the biceps are less affected when the elbow is fully extended. There are several human activities that involved flexion motion like drinking from a cup which requires a range of elbow flexion between 72° and 129° and with 58 Arc (Safaee-Rad, Shwedyk, Quanbury, & Cooper, 1990), combing hair between 112 and 157 with 45 Arc (Magermans, Chadwick, Veeger, & Van Der Helm, 2005) and eat with frog 85 and 128 with 29 Arc (Morrey, Askew, & Chao, 1981),



A B

Figure 2.4: Moment arm of the biceps between 85 to 100 of elbow flexion (A) and the fully extensor of the moment of arm of the biceps (B)

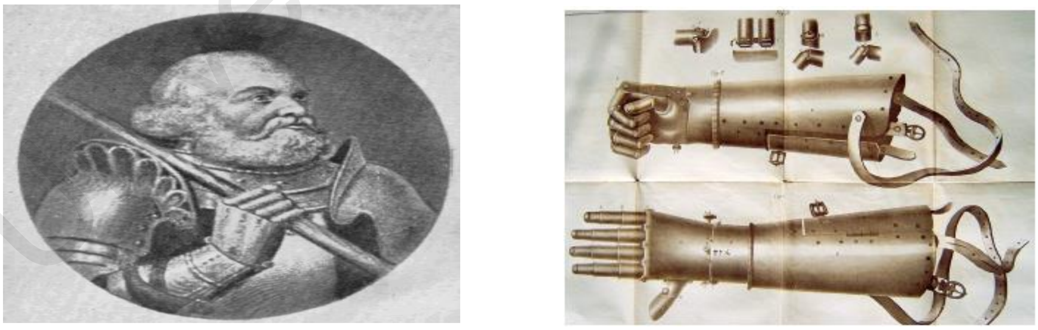
Muscles involve the extension of elbow include triceps brachii. The effectiveness of this muscle as whole are affected by changes in the position of elbow not the forearm. In addition, it is more active during activities that requires the stabilization of elbow. the other extensor of elbow which is anconeus also help the elbow to stabilize during Pronation and Supination.

2.2: Upper-Limb Prostheses

The goal of a prosthetic is to restore the form and function of the lost extremity. Several types of prosthetics have been developed to achieve this goal. Major types include passive, body powered, and externally powered. Passive prosthetics, also referred to as cosmetic prosthetics, primarily focus on achieving a naturally appearing extremity. The improved cosmesis comes with the cost of reduced functionality. These prosthetics are limited to basic tasks such as pushing and pulling, as well as stabilizing a held object (Ovadia & Askari, 2015).

2.2.1: Body-Powered Upper-Limb Prostheses

The history of amputations and prostheses from the early days until 1975 has been described by VanDerwerker Jr. (1976) and Putti (1925, 2005). Putti’s famous example is the story of the knight, poet and adventurer Gottfried “Götz” von Berlichingen, who lost his hand in a battle in 1504. Technical expertise of workshops in the nearby cities made him a mechanical replacement hand of iron as shown in Fig 2.3(Fougner, 2013).



(a) Götz von Berlichingen (b)Götz von Berlichingen’s prosthetic hand

Figure 2.5: Franconian knight Götz von Berlichingen and a painting of his Iron Hand from circa 1509. Image sources: Putti (1925); Wikipedia (2012)

and at least three versions of this hand are known. Presumably it was used with success in battles. In those situations, one important property of the prosthetic hand was that it looked scary and that it was more robust than a healthy limb. The autobiography of Götz made the basis for one of Goethe’s most famous plays, approximately 270 years later (Goethe 1848).

Also described by Putti are the “petit Lorrain” hand (Fig. 2.4) and the “Stibbert” hands and arms (Fig. 2.5). All of these hands from the 15th–16th century were inspired by the body armour used in battle at the time. They were designed with function and robustness as the main criteria, rather than aesthetics. Several of these early designs thus had joints that could be locked by a spring ratchet mechanism, through a metal lever operated by the other hand.(V, 2005).

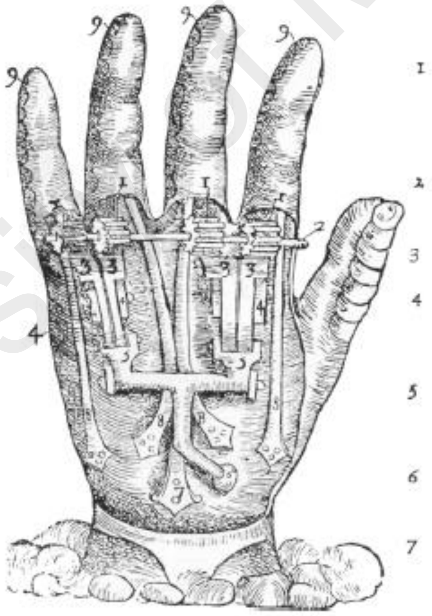


Figure 2.6: Demonstration of the mechanism in the “petit Lorrain” hand (16th century).

Image source: Putti (1925)

Figure 2.7: Arms and hands (15th–16th century) from the “Stibbert” museum in Florence, Italy. Image source: Putti (1925)

Another interesting design as shown in Fig. 2.6 from the end of the 19th century. “The elbow joint can be moved by releasing a spring, whereas the top joint of the wrist allows a degree of rotation and an up-and-down motion. The fingers can also curl up and straighten out.” (British Science Museum 2012). It has similar mechanisms to the older hands, but it is more lightweight, has more degrees of freedom and has a leather socket.

The next important steps in the development of upper limb prostheses have been described by Kuniholm (2010) and consist of the hook design as shown in Fig. 2.7 and the split-hook design invented by Dorrance (1912) (Fig. 2.8a).

Figure 2.8: Artificial left arm, Europe, 1850–1910. Image source: Science & Society Picture Library, British Science Museum (2012)

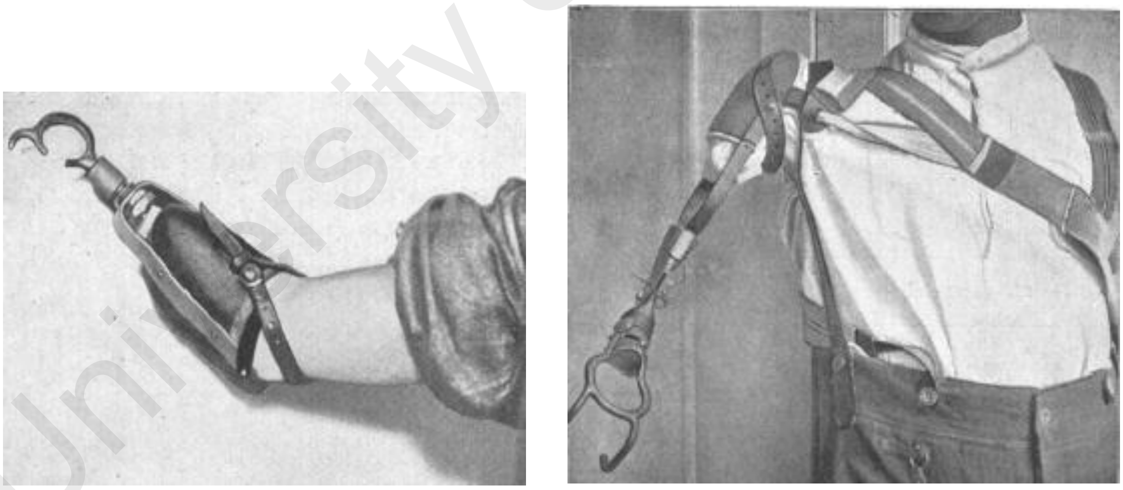
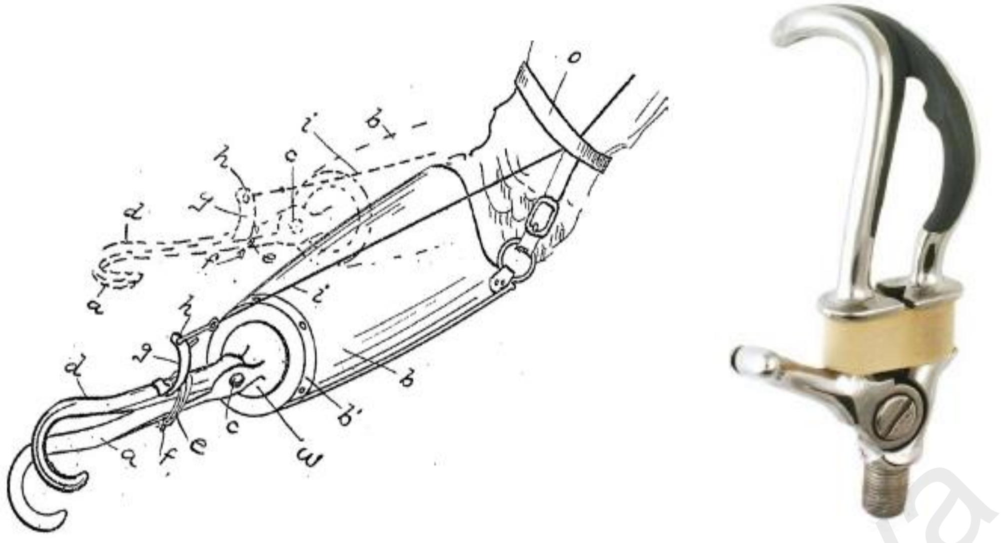


Figure 2.9: Passive hooks and shoulder harness by Weimar. Image source: Lange (1922)



(a) A drawing of Dorrance's first split hook (1912) (b) A modern Hosmer Dorrance split hook. Image source: Hosmer Dorrance Corp. (2012).

Figure 2.10: Old and modern split hooks

Even now, 74 years after the demonstration of the first myoelectrically controlled device (described in the next section), body-powered hooks and hands are still quite popular. The hooks have not changed much since 1919 (example in Fig. 2.8b), but more anthropomorphic body-powered prostheses have emerged (examples in Fig. 2.9). One of the reasons for their popularity is that these devices are relatively cheap, simple and durable; important properties especially in developing countries and in countries with a sparsely distributed population and few prosthetic and orthotic workshops available to the users, as well as in countries without any public health service. Another reason is that they have sensory feedback, a concept often referred to as extended physiological proprioception (Simpson 1974). This allows for precise handling of small or fragile objects.

Figure 2.11: Modern body-powered anthropomorphic prosthetic hand and harness.

Image source: Otto Bock GmbH (2012)

2.2.2 Myoelectric Control

According to Childress (1985), the first known powered prosthesis was a German pneumatic hand, patented by Dahlheim (1915). Drawings of the first electric powered hand was published by Schlesinger (1919). Thirty years later Reiter demonstrated the first simple myoelectric prosthetic device (Reiter 1948), and other research groups published similar material shortly after (Berger et al. 1952; Battye et al. 1955; Bottomley et al. 1963). The focus of the prosthetics research was changed towards myoelectric control, and the first commercial myoelectric hands were available from the middle of the 1960's (Sherman 1964).

Myoelectric control is by definition the control of a prosthesis or other system through the use of "muscle electricity": The term myo comes from the greek word mys (muscle). The origin of the myoelectric signal; the "electrical activity produced by a contracting muscle", is well described in literature (Childress 1992; Lovely 2004b).

2.3: Electromyography

Electromyography (EMG) refers to the collective electric signal from muscles, which is controlled by the nervous system and generated during muscle contraction or rest (Khushaba, Kodagoda, Takruri, & Dissanayake, 2012). The signal represents the anatomical and physiological properties of muscles; in fact, an EMG signal is the electrical activity of a muscle’s motor units. This signal can be recorded using either needle EMG or surface EMG (Alkan & Günay, 2012). With needle EMG, the needle electrode is inserted through the skin into the muscle of interest and displayed on an oscilloscope while muscle contracts. Needle EMG gives more detailed information regarding wave shape of motor units action potential. Surface EMG electrode are placed onto the skin which makes the non-invasive method. They are less accurate when it comes to use for prosthesis control but are still considered as a good measure of muscle activity or muscle force and they give more global information about the muscles (Chowdhury et al., 2013).

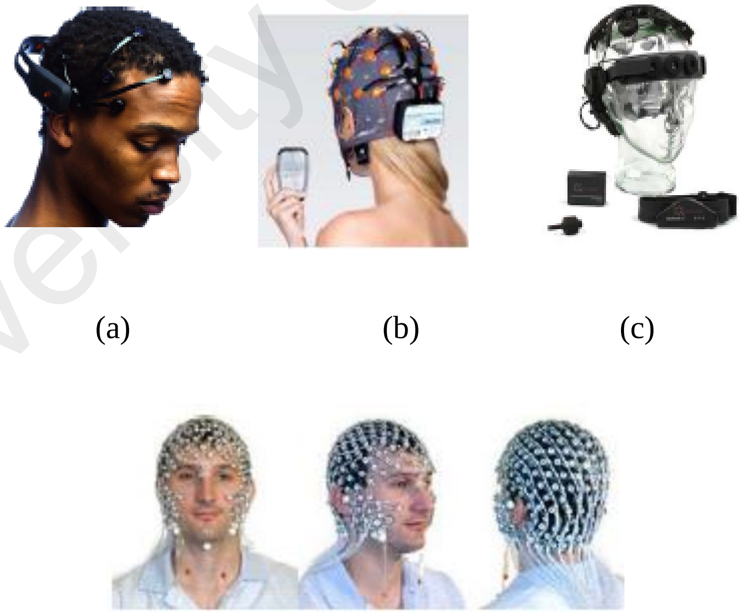
2.3.1: Characteristics of EMG Signal

Amplitude of the EMG signals is usually stochastic or random in nature and so it can be represented by a Gaussian distribution function approximately. The peak to peak value of the EMG signal amplitude is usually within 0-10 [mV] range. The usable energy of the signal is typically around 0 to 500 [Hz] frequency range, with the dominant energy being in the 50-150 [Hz] range (Viitasalo & Komi, 1977). Variations of EMG signals are different from person to person. Moreover, EMG signals are differed for the same motion even with the same person. On the other hand, physical conditions such as tiredness, muscle fatigue, sleepiness, etc. and psychological conditions such as stress, etc. can affect the EMG signals. Therefore, these characteristics should be considered carefully when developing control method for prosthetic limb control.

2.4: EEG signal acquisition systems

Electroencephalography (EEG) is the recording of electrical activity along the scalp produced by the firing of neurons within the brain. The EEG can be defined as electrical activity of an alternating type recorded from the scalp surface after being picked up by metal electrodes and conductive media. (Sanei & Chambers, 2013).

EEG acquisition system is one of the most important parts in any application that used EEG signals. Different types of EEG signal acquisition systems have been developed and their features and capabilities may different from each other. However, basically in any EEG acquisition system, EEG signals are measured by EEG electrodes. Normally these EEG electrodes are holding on a cap that can be wore over the head. Then as the measured signals are weak, they are amplified. Finally, those amplified analog signals are digitized before sending to a computer. Figure 2.10 shows some of the existing EEG acquisition systems that are being used among research community (Usakli, 2010).



(a) (b) (c)

(d)

Figure 2.12: EEG acquisition systems. (a) Emotiv EEG Headset (b) g. Nautilus wireless EEG system (c) DSI 10/20 Dry sensor interface (d) EGI dense array EEG

of the EEG acquisition systems need more time to prepare the EEG system. In those types of systems, it takes considerably long time to connect a subject to EEG, as it needs accurate placement of many electrodes around the head and the use different kinds of gels, saline solutions, and/or pastes to keep them in place. However, recently introduced EEG systems do not need such an extensive preparation. Some of them are using dry EEG electrode technologies and therefore, those systems can be connected to a user much faster. Moreover, newer version of EEG acquisition systems is comparably small and are capable of wireless data transmissions. Another important fact is the number of EEG electrodes. Some of the EEG systems are only consisted of few EEG electrodes, whereas several EEG systems boast high density EEG electrodes such as 128 or 256 electrodes [51]. High density EEG systems are helping to increase the spatial resolution of EEG signals. Moreover, most of these EEG acquisition systems can measure or record EEG signal data at high sample rates such as even up to the 20 [kHz] in some cases (Jackson, Moritz, Mavoori, Lucas, & Fetz, 2006).

As mentioned above, there are some advantages as well as limitations of each EEG acquisition system, therefore it is necessary to select an appropriate EEG acquisition system that required for research application or device.

2.5: Summary

Table 2.2: Related studies to the research

	Research title	Aim of the study	Methodology	Results	Pros	Cons
1	"An Analysis of Intrinsic and Extrinsic Hand Muscle EMG for Improved Pattern Recognition Control." (Adewuyi et al., 2016)	To quantify the contribution of EMG data from extrinsic and intrinsic hand muscles to pattern recognition	Combined EMG data from intrinsic and extrinsic muscles to classify up 19 types of hand grasp and finger motion to be decoded	A system trained with both intrinsic and extrinsic muscle were found. Wrist position increased completion rates from 73% 96 and from 88% to 100% for hand amputees and non-amputees respectively	The comparison with another trained system with extrinsic EMG data	Intrinsic EMG data in neutral wrist position is not included
2	"Literature Review on Needs of Upper Limb Prosthesis Users" (F. Cordella et al., 2016)	list out the main critical aspects of the current prosthetic solutions and study Literature review	A systematic review was performed on database: PubMed, Google Scholar, Cochrane Database	(i) provide guidelines for improving the level of acceptability and usefulness of the prosthesis (ii) propose a control architecture of PNS-based prosthetic systems able to satisfy the analysed user wishes; (iii) provide hints for improving the quality of the methods	Thorough and detailed information provided regarding the needs of prosthetic users	only seven studies have been focused in this study

3	"Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms." (Kuiken et al., 2009)	“To evaluate the performance of patients with upper-limb amputation who had undergone TMR surgery, using a pattern recognition algorithm to decode EMG signals and control prosthetic-arm motions”.	Surface EMG were recorded from all subjects and pattern recognition algorithm were used to be decoded	Patient were able performed 10 different wrist, elbow and motion with virtual prosthetic arm and completed successfully with a mean of 96.3% (SD, 3.8) of elbow and wrist movements and 86.9% (SD, 13.9) of hand movements within 5 seconds, compared with 100% (SD, 0) and 96.7% (SD, 4.7) completed by controls	reinnervated muscles can produce sufficient EMG information for real-time control of advanced artificial arms	
4	"Effect of arm position on the prediction of kinematics from EMG in amputees." (Jiang, Muceli, Graimann, & Farina, 2013)	to investigate the effect of arm posture on the simultaneous and proportional myoelectric control over multiple degrees of freedom (DoFs) of the hand/wrist in both able bodied and amputee subjects	8 subjects participated in the experiment 3 individuals with unilateral trans-radial amputation All are users of conventional myoelectric prostheses which articulate one DoF And 5 are able body subjects	Changes position of arm effect adversely the performance of algorithm for the both subjects but less influence in amputee subjects		The data were not including from different position during the training of the ANN
5	"Toward improved control of prosthetic fingers using surface electromyogram (EMG) signals."	Investigate accurately discriminating between individual and combined	two EMG electrodes located on the human forearm are utilized to collect the EMG data from eight participants	the feasibility of the proposed system using different classifiers achieving 92% offline and 90% online classification	Thorough and detailed information provided	

		fingers movements using surface EMG signals		accuracy results with the LIBSVM classifier and Bayesian fusion		
6	“Electromyographic Activity of the Upper Limb in Three Hand Function Tests” (Silva et al., 2017)	“evaluate the differences in muscle activation patterns during the performance of three hand dexterity tests”	surface electromyographic (sEMG) assessment with 8 upper limb muscles, conducted by twenty subjects	proximal muscles were more active during BBT, whereas FDT and NHPT activated more distal muscles and had no significant statistical differences between them		A small sample size can affect the generalization of the results
7	“Comparison study of the prosthetics interface pressure profile of air splint socket and ICRC polypropylene socket for upper limb prosthetics” (N. A. Razak, Osman, Ali, Gholizadeh, & Abas, 2015)	investigate the interface pressure differences at the stump socket between an ICRC polypropylene socket and an air splint socket for a common wearer of transhumeral amputee using F-socket transducers.	Transhumeral amputee was fitted with ICRC polypropylene socket, then continue with the air splint socket. Two F-socket sensors arrays 9811E (supplier a) were attached to the residual limb Conducting with some activities	User's ICRC polypropylene socket maximizes the pressure distribution of the socket. The air splint socket might reduce the pressure within the interface of residual limb in comparison to the ICRC polypropylene socket		This study does not allow for generalizations to be made pertaining to the use of ICRC polypropylene socket and air splint socke

8	"Differences in myoelectric and body-powered upper-limb prostheses: Systematic literature review" (Carey et al., 2015)	Investigate the difference between BP and myoelectric upper limb prosthesis to inform the prescription of these devices and training users	Systematic review	Body-powered prostheses have advantages in durability, training time, frequency of adjustment, maintenance, and feedback Myoelectric prostheses have been shown to improve cosmesis and phantom-limb pain and are more accepted for light-intensity work		The study shows that there is a lack of empirical evidence regarding functional differences in upper-limb prostheses
9	"Multi-Position Training Improves Robustness of Pattern Recognition and Reduces Limb-Position Effect in Prosthetic Control" (Beaulieu et al., 2017)	To investigate specific covariates, including features like hand height, elbow angle, and shoulder angle, moreover, a novel 3D training paradigm to generate a more robust classifier to function in multiple positions.	EMG signal features to drive the generation of unique LDA classifier algorithm	Elbow angle shown the strongest impact on EMG signal And Hand height demonstrated a consistent increase in EMG signal with increasing height		Completed only offline analysis of classification error

10	"Effect of upper-limb positions on motion pattern recognition using electromyography" (Chen, Geng, & Li, 2011)	To investigated effects of the variation of limb positions on classification performance	EMG technique and LDA to classifier used to identify seven classes of forearm movements in five transradial amputees	Results demonstrate that classification error of inter-position was about 4 times more than that of single position across the five transradial amputees ($p<0.02$),		Small sample size was used
11	"Passive prosthetic hands and tools: A literature review" (Maat et al., 2018)	Review the peer-reviewed literature on passive prostheses for replacement of the hand	Four electronic databases were searched using a Boolean combination of relevant keywords	Publications on passive prosthetic hands describe their users, usage, functionality, and problems in activities of daily living. Publications on prosthetic tools mostly focus on sport, recreation, and vehicle driving	present a new and clear classification of passive prostheses	
12	Biomechanics principle of elbow joint for transhumeral prostheses: comparison of normal hand, body-powered, myoelectric & air splint prostheses (N. A. A. Razak, Osman, Gholizadeh, & Ali, 2014)	A comparison of a mathematical model of elbow joint using three different types of prosthetics for transhumeral user	The study modeled the elbow as a universal joint with intersecting axes of x-axis and y-axis in a plain of upper arm and lower arm.	The force and torque applied at the elbow joint by wearing the prosthetics can help improve the design and rehabilitation procedure. The pressure applied to the socket can determine the future shape and figure of the residual limb.	Thorough and detailed information provided	

13	Evaluation of EMG pattern recognition for upper limb prosthesis control: a case study in comparison with direct myoelectric control (Resnik et al., 2018)	Compare self-report and performance outcomes of a transradial amputee immediately after training and one week after training of direct myoelectric control and EMG pattern recognition (PR) for a two (DOF) prosthesis	Participants were randomized to receive either PR control or direct control (DC) training of a 2 DOF myoelectric prosthesis first. Participants were 2 persons with traumatic transradial (TR) amputations who were 1 DOF myoelectric users.	Showed better scores in 2 (18%) dexterity measures, 1 (50%) dexterity measure with cognitive load, and 1 (50%) self-report functional measure using DC, as compared to PR. Scores of all other metrics were comparable. Both subjects showed decline in dexterity after training		limited by the small sample size and descriptive analyses
14	Analysis of voluntary opening Ottobock Hook and Hosmer Hook for upper limb prosthetics: a preliminary study (Hashim, bin Abd Razak, Gholizadeh, & Osman, 2017)	To analyse the voluntary opening (VO) Ottobock model 10A18 and Hosmer model 99P hooks (one band) during opening operation and to find out favourable features in the design	Timple bench tool to investigate cable excursion and hook opening angle and force sensor to find out the force supplied at a different hook opening angle	The average cable excursion for both hooks is approximately 30% less than the hook's opening span with the force at the hook's tip section being inversely proportional to the force at the lateral section		

CHAPTER 3: METHODOLOGY

This chapter describes the steps that have been done in the laboratory which includes: the instruments used for recording EMG signal and positions of upper limb, the placement of electrode sites and muscles, the guidelines for selection for test subjects and the choices of activities to be recorded to form data sets used to develop of upper-limb prostheses.

3.1: Technical specification

3.1.1: EMG Measurement Instrument

To measure and record surface EMG activity during different activities, the DELSYS Trigno wireless EMG instrument was used as shown in Figure 3.1. Generally, Trigno $^{\text{TM}}$ Wireless EMG System is physiological monitoring device that allow practitioners and researchers to acquire EMG and relevant signals from subjects for biofeedback purposes. It considers a high-performance device designed which make EMG signal detection easy and reliable.

Figure 3.1: DELSYS Trigno wireless EMG instrument. Available online: /http://www.delsys.com/products/ (accessed on 3 July 2018).

Each of EMG sensor which shown in Figure 3.2 has a built-in triaxial accelerometer, a transmission range of 40 m and has a rechargeable battery which is lasting at least 7 hours. This system can stream the data to EMG works acquisition and analysis software.

Figure 3.2: Wireless EMG sensor

online: /http://www.delsys.com/products/wireless-emg/ (accessed on 3 July 2018)

Figure 3.3 illustrates the overview of the DELSYS Trigno wireless EMG instrument base station which each base station equipped its own features such as high-speed USB communication with PC, recharging cradle for 16 sensor, detachable antenna, convenient carry case design, 64-channel analog output connector (16 EMG, 48 ACC), communication & power feedback LEDs, full trigger capability (Start/Stop, Input/Output) and ± 5V analog output range

Figure 3.3: Trigno base station. Online:

http://delsys.com/Attachments_pdf/manual/MAN-012-2-7

Table 3.1: Trigno base station

1.Wireless Sensor	5.Analog Output Connectors
2.Base station	6.Trigger Port
3.USB Port	7.Antenna
4.Power Jack/Power supply	8.EMGwork Software

Trigno system also equipped an isolated medical grade power supply which designed only to function the power supply provided. when the power supply connected to the base station, the green power LED on the base will illuminate. Also, the power supply provided with interchangeable country-specific plug adapters as shown in Figure 3.4.

Figure 3.4: Trigno SC-P05 International Medical Power Supply with plug adapter kit.

http://delsys.com/Attachments_pdf/manual/MAN-012-2-7

3.2: Ethical Approval

The experimental protocol for this work was approved by the Ethical Community of the University Malaya Medical Centre (UMMC), Kuala Lumpur Malaysia. Written informed consent was granted by the participants from the authors for the publication. Approval ID: 829:15. One registered prosthetist fabricated all the prostheses to avoid alterations due to manufacturing, alignment and fitting. All the procedure of socket making, and fitting involves the Certified Prosthetics and Orthotics (CPO) which had been recognized by International Society of Prosthetics and Orthotics (ISPO).

3.3: Test Subjects

EMG position measurements was conducted voluntarily on ten healthy students and two transradial amputees with different age, height and weight. participants were postgraduate students in biomedical engineering. The subjects had no history of muscle pain, trauma, discomfort, or a sequela relevant to the upper extremities. They were divided into categories which are 5 male volunteers with average age and five female volunteers. One of these females was pregnant in her seventh months. But for two transradial amputees, their subjective assessment describes as following:

Subject 1

29 years old, male and still active and independent person. He is a transrdial amputee with right hand. Amputation caused by electric shock with a high voltage approximately 33KV in 2010. After few days, the doctor decided to remove his limb. The length of below elbow amputation is 10cm, while the width of the radial is 7.5 cm. Now he is using a myoelectric control prosthetic more 7 years.

Subject 2

29 years old, male and still active and independent person. He is a transrdial amputee with left hand. Amputation caused by trauma. The length of below elbow amputation is 7.5cm, while the width of the radial is 7 cm. He did a surgery more than 5 time. And still not using prosthetic limb. The information for non-amputee subjects are shown in table 3.2.

Table 3.2: Subject’s Demographic Data

Participants	Sex	Age (y)	Weight (kg)	Height (m)	BMI (kg/m^2)	Marks
S1	Female	27	49	1.54	20.66	Normal
S2	Female	28	49	1.52	21.20	Normal
S3	Female	25	55	1.56	22.60	Normal
S4	Female	29	63	1.64	23.42	Normal
S5	Female	28	58	1.55	24.14	Normal
S6	Male	28	128	1.86	36.99	Obesity
S7	Male	28	78	1.72	26.36	Overweight
S8	Male	27	84	1.76	27.11	Overweight
S9	Male	25	83	1.74	27.41	Overweight
S10	Male	23	65	1.70	22.49	Normal

Note. BMI = Body Mass Index. S= Non-amputee subject.

3.4: EMG electrode site placement and Muscles

When selecting the placement of EMG electrode, the sensor should place as close as possible to the relevant muscles to get accurate and reliable EMG output. It has vast effect on the strength of signal. In this experiment, selection of the electrode placement was divided in two tests.

During test 1, two electrodes were positioned on the two upper arm muscles. One was placed on the biceps muscles and the other one was placed on triceps muscles. Illustration of the upper arm and electrode placement site are in Figure 3.5 and Figure 3.6 respectively.

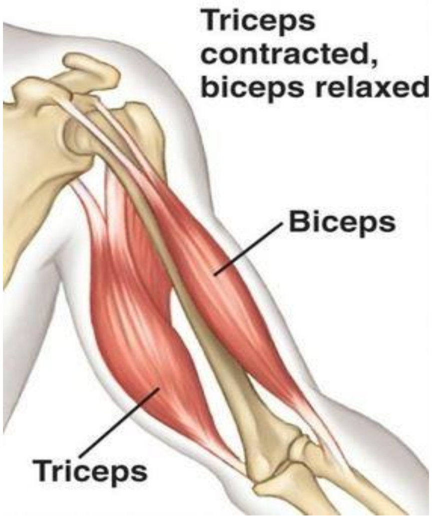


Figure 3.5: Upper Arm Muscles

Figure 3.6: Electrode placement and upper arm muscles

Muscles selected in this experiment during test 1 were based on their stabilization and movements of the shoulder and elbow joints during activity performance (Ferrigno, Cliquet Jr, Magna, & Zoppi Filho, 2009; Naider-Steinhart & Katz-Leurer, 2007). also Figure 3.7 shows the placement of the two-electrode site for the transradial amputees.

Figure 3.7: Electrode placement site for transradial amputee during test 1

During test 2, the experiment was conducted on below elbow. Two muscles from the forearm muscles were chosen. Figure 3.8 below illustrates the forearm muscles for both anterior and posterior view.

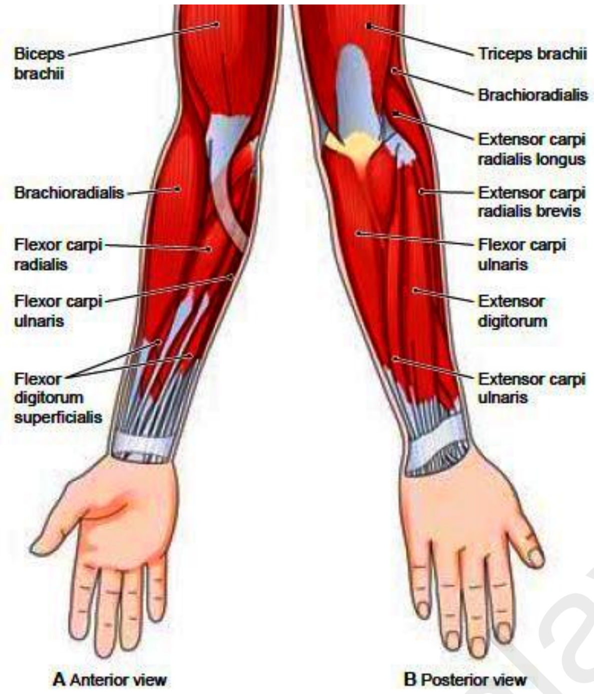


Figure 3.8: forearm muscles for anterior and posterior view. from encyclopedia. Retrieved July 12, 2016 http://encyclopedia.lubopitko bg.com/Muscles_of_the_Upper_Extremities.html

For the anterior view, the Brachioradialis (BR) muscle were selected and placed on the first electrode. And for the posterior view, the Extensor Carpi Ulnaris (ECU) muscle was used to position the second electrode as shown in figure 3.9.

Figure 3.9: forearm muscles and the respective electrode placement on the muscles

For the transradial amputees, in order to place the two electrodes on the oriented muscles as same as non-amputees that mentioned above, it was very difficult to pinpoint the required muscles which are the Brachioradialis (BR) muscles and the Extensor Carpi

Ulnaris (ECU) muscles due to the limit surface area of the forearm muscles and the two electrodes were placed on the residual limbs of the amputees as shown in figure 3.10. (N. A. Razak et al., 2017)

Figure 3.10: Muscles utilized during test two and respective electrode placement of muscles for transradial amputees

An important concern is for each normal and amputee person, the electrodes should be positioned accurately and correct way and at the same place every time, thus that the classification procedure is adapted to the correct signals.

3.5: Choice of Activities

In order to get valid results, participants were asked to perform different movements. These movements were based on the capability of doing both normal subjects and amputee subjects without support from the prosthesis. a set of movements based on daily living activities were selected such as eating, slicing the bread, cutting paper. However, these movements will be normally done with healthy hand not the prothesis, and such that the healthy hand does the main movement while the prosthesis does the support. This resulted very difficult to record with EMG measurements (which do not record) and movements was very small, and it was not suitable for the objectives of this study. Another set of activities were done by both non-amputee subjects and amputee subjects without support from the prosthesis. And the activities are classified into three categories which are as follows:

3.5.1: Muscle strength

When the two electrodes placed on the oriented muscles (biceps muscles and triceps muscles) above the elbow during test 1, all participants including both normal subjects and two transradial amputees were required to strengthen muscles. These activities recorded in the laboratory and repeated at least three times for ach normal subjects and five times for each amputee subjects.

For the test 2 which was conducted on the below elbow, the two electrodes were located on different muscles which are the Brachioradialis (BR) muscle in anterior view and the Extensor Carpi Ulnaris (ECU) muscle in posterior view. but, repeated the same task as test 1 which is to strengthen the two muscles for each measurement.

3.5.2: Flexion and Extension of Elbow

Participants were required to flex and expense the elbow (see Figure3.11) with contacting the EMG sensor on the skin above the muscles similar test 1. Electrode one was placed on the biceps, while electrode two was placed on the triceps. The illustration of the location of the electrodes for both amputee and non-amputee subjects performing flexion and extension of elbow are shown in Figure 3.12 and Figure 3.13 respectively.

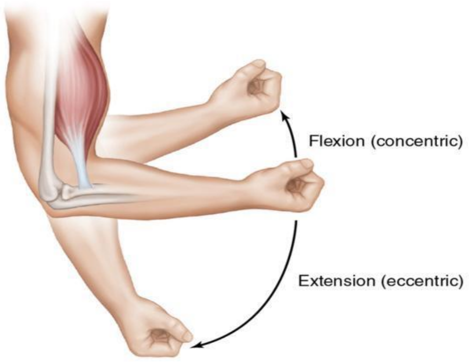


Figure 3.11: Flexion and Extension of elbow. Retrieved July.3.2018

http://beyondachondroplasia.org/blogue/

Figure 3.12: Flexion and Extension of the muscles above elbow for non-amputee subjects during test 1

Figure 3.13: Flexion and Extension of the muscles above elbow for amputee subjects during test 1

For test 2, participants repeated the same activity which is flexion and extension of elbow, but with different location of the electrode, which were positioned on the Brachioradialis (BR) muscle and Extensor Carpi Ulnaris (ECU) muscle of the below elbow for normal subjects while amputee subject were placed on the remaining muscles. Figure 3.14 shows normal subject performing flexion and extension of elbow with placement of the electrodes site on the muscles below elbow. While Figure 3.15 shows flexion and extension of elbow for amputee subjects with respective of placement site of the electrodes.

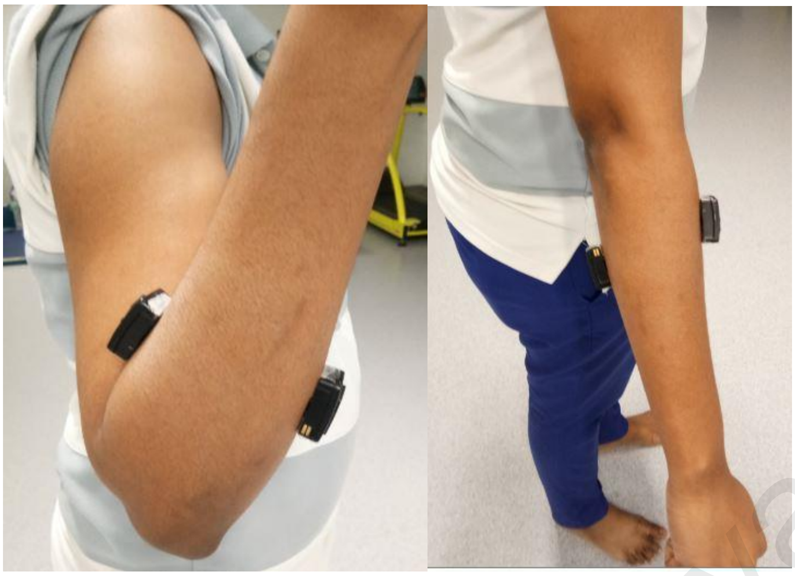


Figure 3.14: Flexion and Extension of the muscles below elbow for non-amputee subjects during test 2

Figure 3.15: Flexion and Extension of the muscles below elbow for amputee subjects during test 2

3.5.3: Flexion and Extension with Weight

This activity was similar with the previous activity of doing flexion and extension of elbow with a slight difference which is an addition of a 5kg weight. During test 1, all non-amputee subjects were asked to carry a 5 kg weight. Two electrodes were placed on biceps muscles for interior view and triceps for posterior view respectively. EMG were recorded. Figure 3.16 shows normal subjects carry out flexion and extension of elbow with 5kg weight and electrode placed on the muscles of the above elbow.

Figure 3.16: Flexion and Extension of the muscles above elbow with 5kg weight for non-amputee subjects during test 1

While amputee subjects were asked to lift up a weight equivalent with 3 kg weight, in order to see his capability of his remaining muscles how much can be tolerate see Figure 3.17.

Figure 3.17: Flexion and Extension of the muscles above elbow with 3kg weight for amputee subjects during test 1

After the amputees has done successfully with flexion and extension of elbow with 3kg weight, they were asked again to carry a 5kg weight as normal subjects did to compare between them. Figure 3.18 shows the success of amputee subjects to raised it 5kg weight with flexion and extension of elbow.

Figure 3.18: Flexion and Extension of the muscles above elbow with 3kg weight for non-amputee subjects during test 1

For test 2, all non-amputee participants were done flexion and extension with 5 kg weight successfully with the electrodes placed on the below muscles of the elbow as shown in Figure 3.19.

Figure 3.19: Flexion and Extension of the muscles below elbow with 5kg weight for non-amputee subjects during test 2

On other hand, amputee subjects were not able to perform this test because of limitation of a place in the residual limbs for weightlifting after the two electrodes took place on the surface of remaining muscles as shown in Figure 3.20 below.

Figure 3.20: electrode placement site on the remaining residual muscles below elbow for amputee subjects

CHAPTER 4: RESULTS AND DISCUSSION

This chapter provides the relevant data that have been collected from EMG data measurement and analyze it.

4.1: Muscles Strength Activity

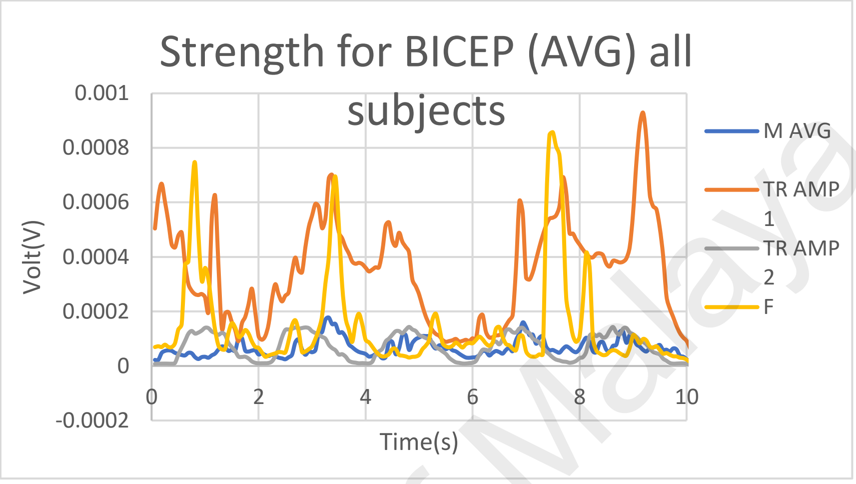


Figure 4.1: The average of biceps muscles (which is calculated from appendix A) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during muscle strength activity

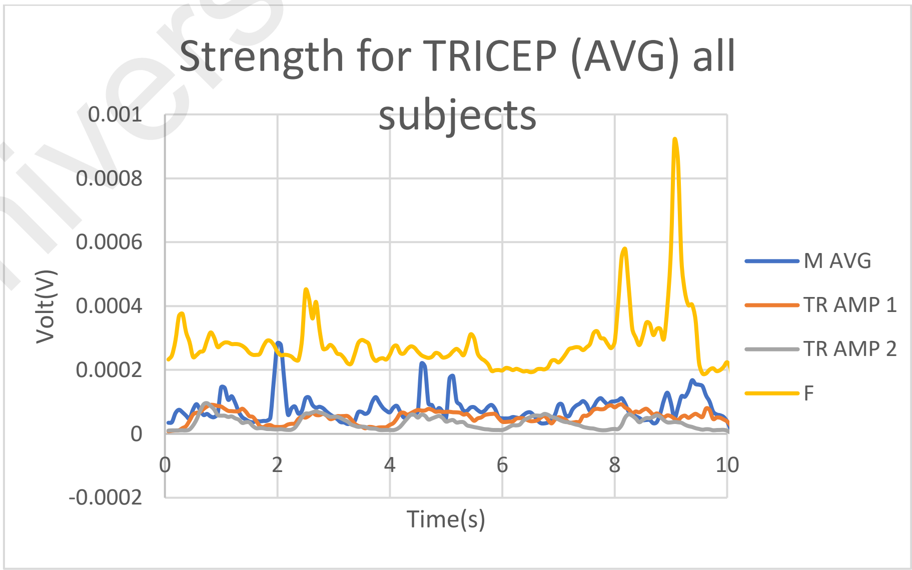


Figure 4.2: The average of triceps muscles (which is calculated from appendix B) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during muscle strength activity

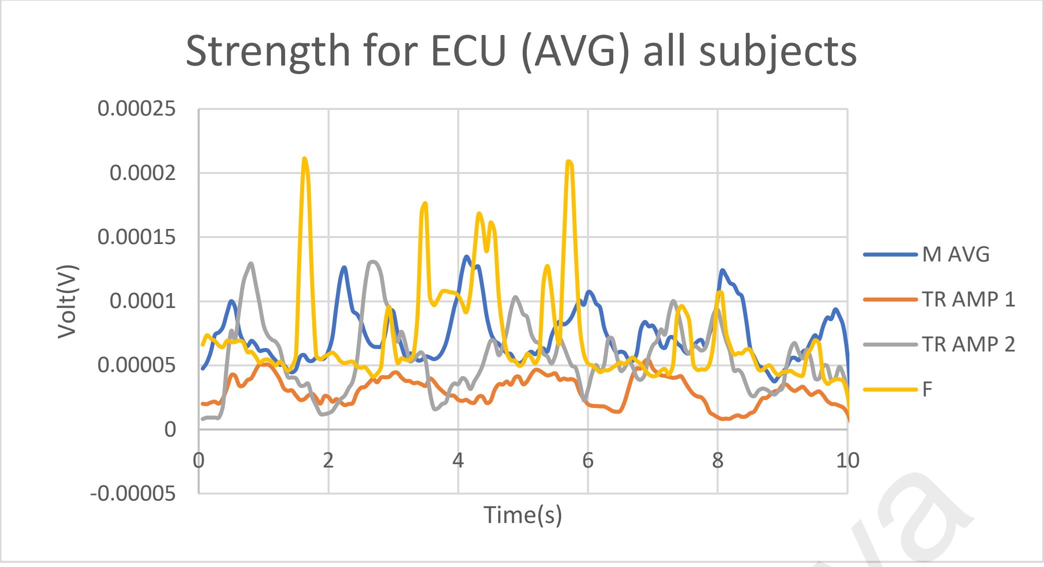


Figure 4.3: The average of extensor carpi ulnaris (ECU) muscles (which is calculated from appendix C) from male subjects (M), female subjects (F), and two transradial amputee subjects ((TR AMP 1) and (TR AMP 2) during muscle strength activity

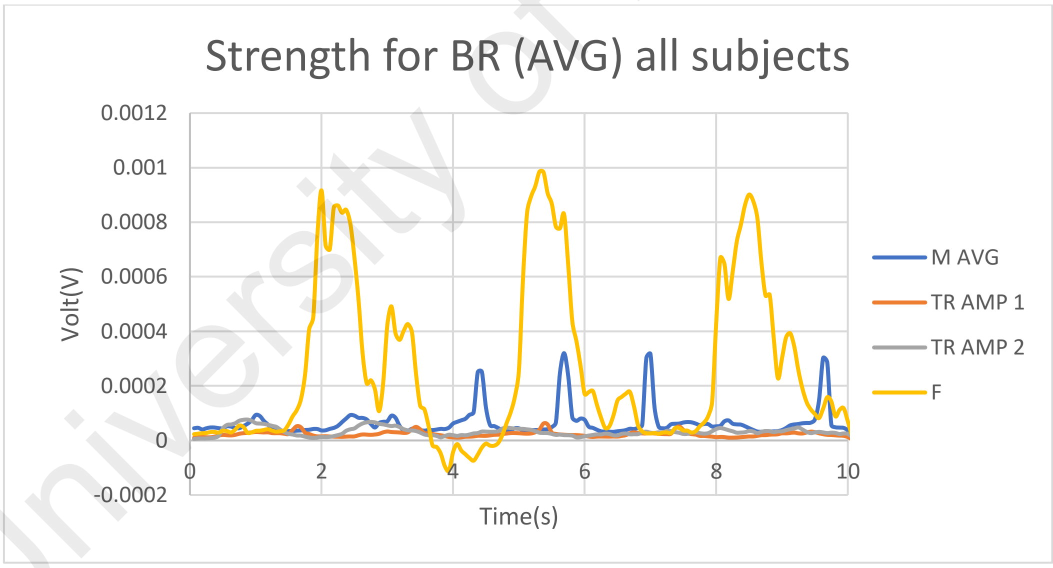


Figure 4.4: The average of brachioradialis muscles (which is calculated from appendix D) from male subjects (M), female subjects (F), and two transradial amputee subjects ((TR AMP 1) and ((TR AMP 2) during muscle strength activity

From Figure 4.1 until figure 4.4 describes the first activity of the study which is the strength of muscles. Figure 4.1 gives a comparison of the average of biceps muscles that have taken from female and male participants and two transradial amputees (TR AMP 1), and (TR AMP 2) during muscles strength. The duration of the experiment to record EMG data for each experiment was 10 second. Male and female subjects represent an average of biceps muscles of five males and five females respectively. Meanwhile the two transradial amputees is an average of five trails for each amputee. All subjects have starting point of the action which is nearly to zero volt(v) except first amputee subject (TR AMP 1) which was faster than the other subjects. Transradial amputee one (TR AMP 1) and female participants observed similar pattern, and the transradial amputee one has showed the highest value during the strength of bicep muscles, next to the female participants which is very closed to him.

In Figure 4.2. focus on the triceps muscles, female participants have the maximum value of strength comparing to the other three subjects, which also has similar value comparing to bicep muscles. another similar studies which assess at low force levels shows that female participants have higher percentage of maximum voluntary contraction (MVC) of increased EMG activity during stabilization of hand test (Endo & Kawahara, 2011). On the other hand, the strength of biceps muscles for both amputees showed better strength than triceps muscles.

Figure 4.3 shows the average of extensor carpi ulnaris (ECU) muscles during muscle strength for all subjects. No significant activation was observed amongst all subjects. And the strength of the signal detected from these muscles was small and unsatisfied.

During muscle strength activity, the average of brachioradialis muscles from all subjects in Figure 4.4 showed that only healthy subjects have found good signal while both amputees generated weak EMG signal from strength activity.

4.2: Flexion and Extension Activity

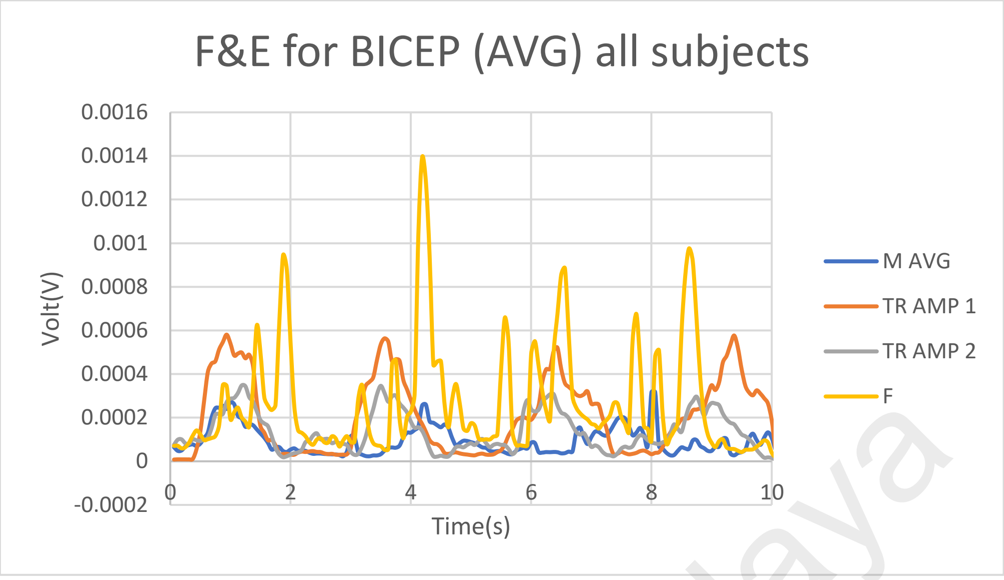


Figure 4.5: The average of biceps muscles (which is calculated from appendix E) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during flexion and extension activity

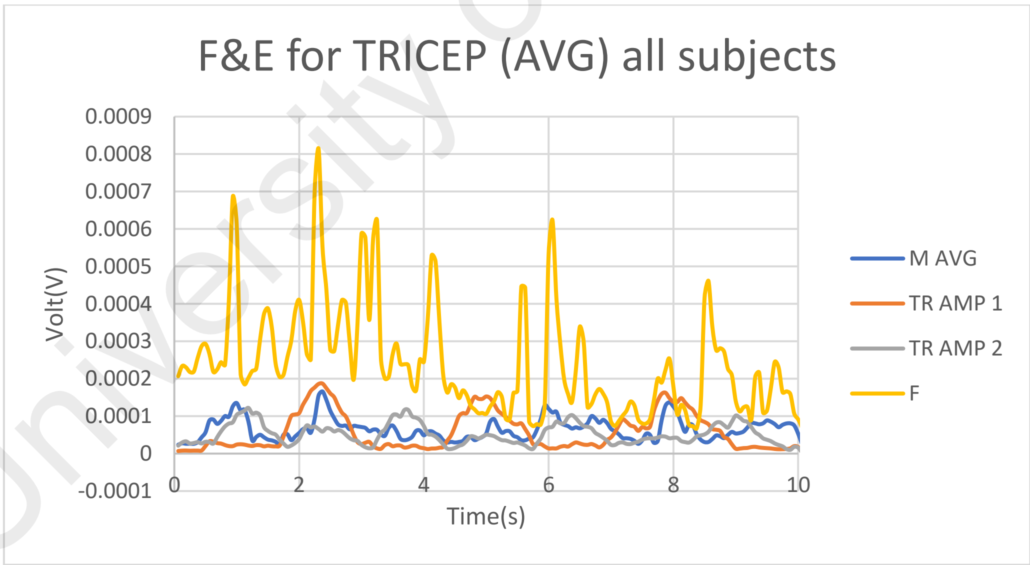


Figure 4.6: The average of triceps muscles (which is calculated from appendix F) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during flexion and extension activity

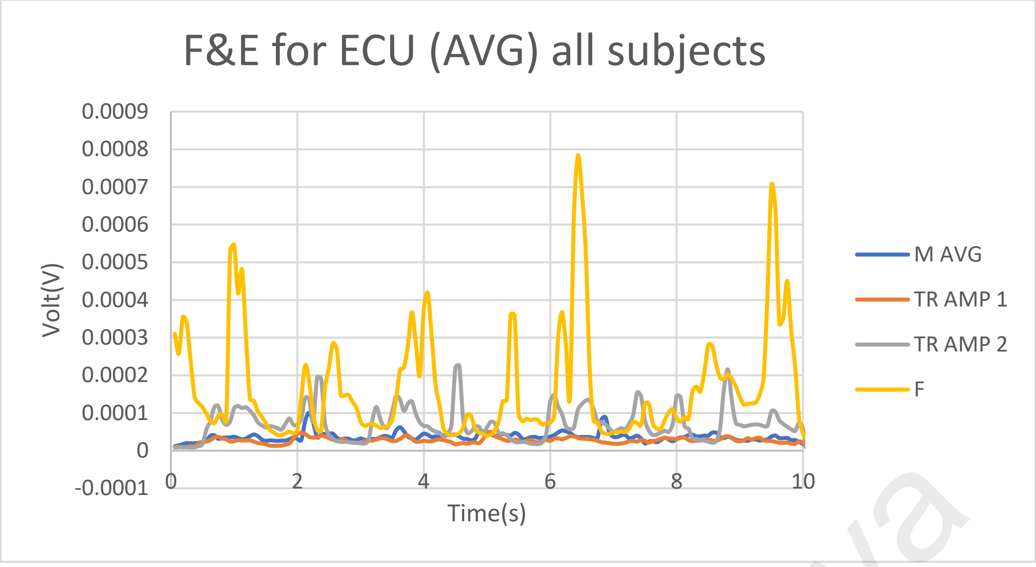


Figure 4.7: The average of extensor carpi ulnaris (ECU) muscles (which is calculated from appendix G) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during flexion and extension activity

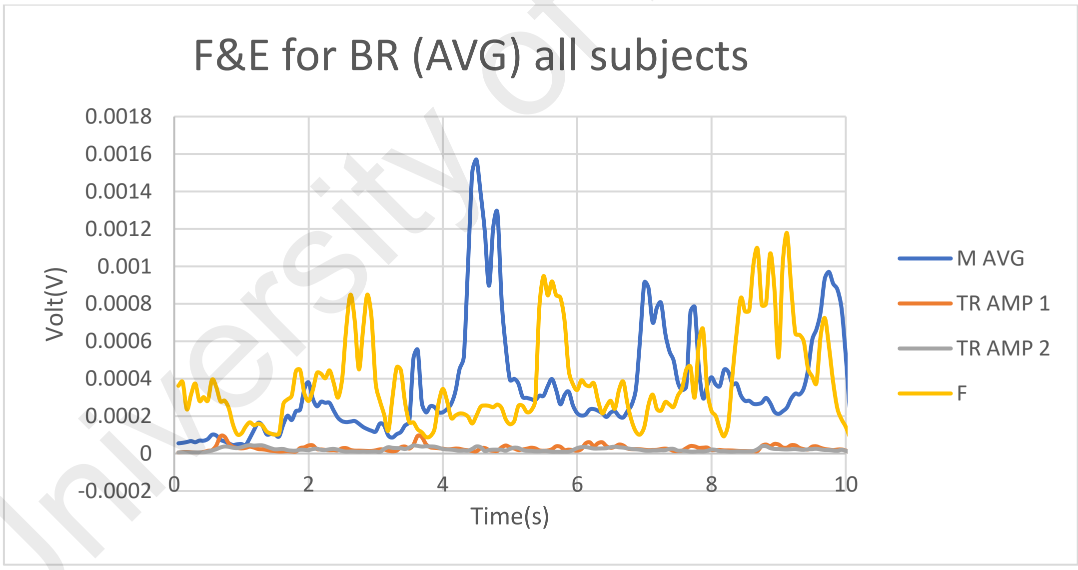


Figure 4.8: The average of brachioradialis muscles (which is calculated from appendix H) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during flexion and extension activity

From Figure 4.5 to Figure 4.8 showed about the second activity of the study which is the flexion and extension. In Figure 4.5 gives an average of biceps muscles from all subjects during flexion and extension activity. These results were significant for female participants for flexion and extension. For amputees have similar values and performed better EMG data comparing to the male subjects.

In Figure 4.6 shows the average of triceps muscles EMG data represents all subjects. Male subjects and amputees have similar pattern and approximate values whereas female participants scored highest values.

In Figure 4.7 focus on the average of extensor carpi ulnaris (ECU) muscles that have taken from all subjects. Transradial amputee (TR AMP 2) have better values than transradial amputee (TR AMP 1) and male participants. On other hand, female have the maximum values amongst all subjects.

Figure 4.8 illustrates the average of brachioradialis muscles from all subjects. non-amputees showed much higher values than amputees subjects during flexion and extension activity.no significant results observed this muscle for amputees.

Together these results indicated upper arm muscles (biceps muscles and triceps muscles have great EMG activity comparing to the forearm muscles during flexion and extension activity toward all subjects. female participants have the maximum values amongst all subjects due to the less fat on surface of the muscles for female subjects that facilitate to detect the sensor accurately. Similar results were observed in the study that aimed to evaluate the differences in muscle activation patterns during the performance of three hand dexterity tests also found that women showed a higher muscle activation than men (Silva et al., 2017). For amputee subjects have demonstrate the best EMG activation on the upper arm muscles.

4.3. Flexion and Extension with 5kg weight Activity

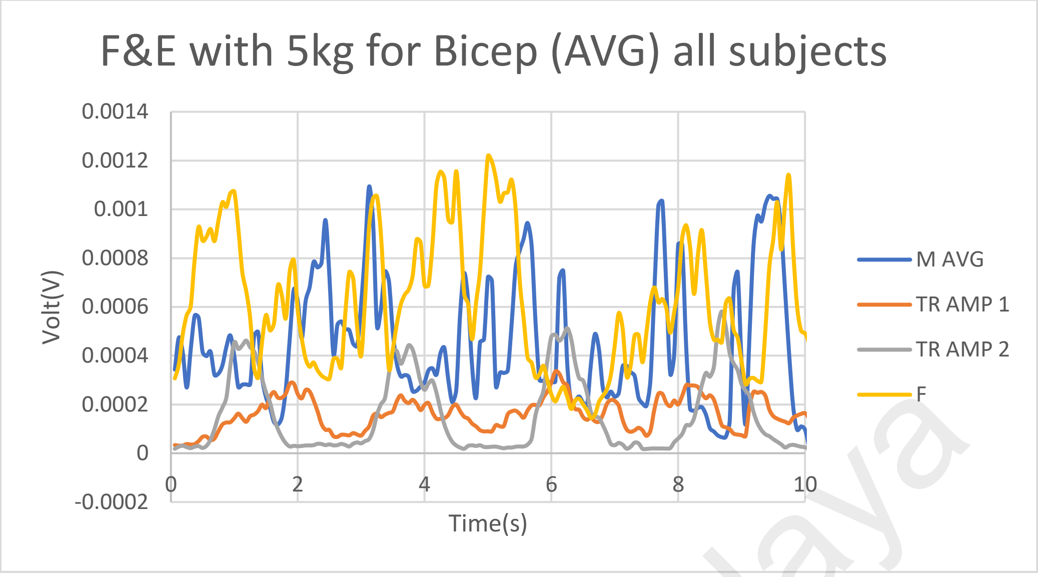


Figure 4.9: The average of biceps muscles (which is calculated from appendix I) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during the activity of flexion and extension with 5kg weight

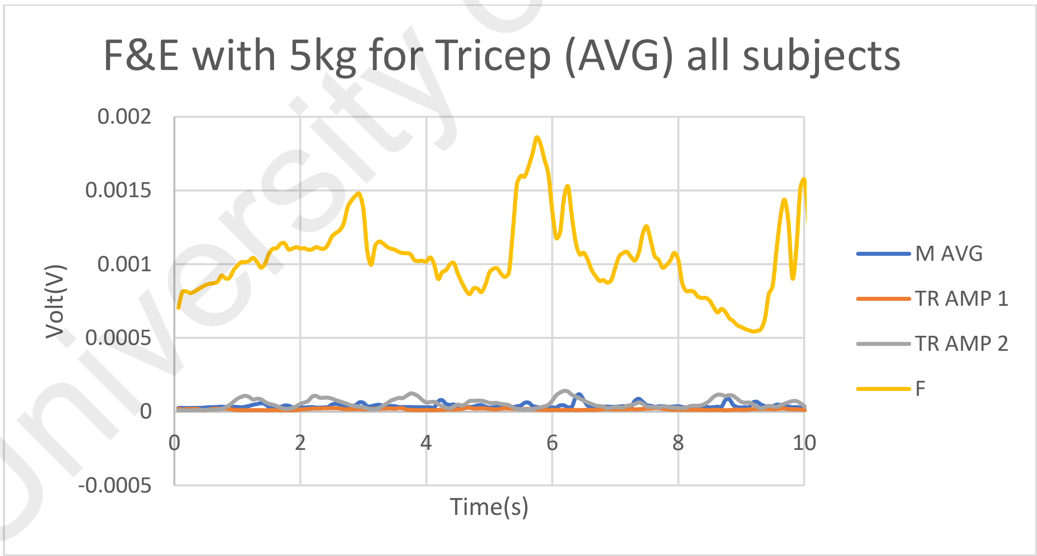


Figure 4.10: The average of triceps muscles (which is calculated from appendix J) from male subjects (M), female subjects (F), and two transradial amputee subjects (TR AMP 1) and (TR AMP 2) during the activity of flexion and extension with 5kg weight

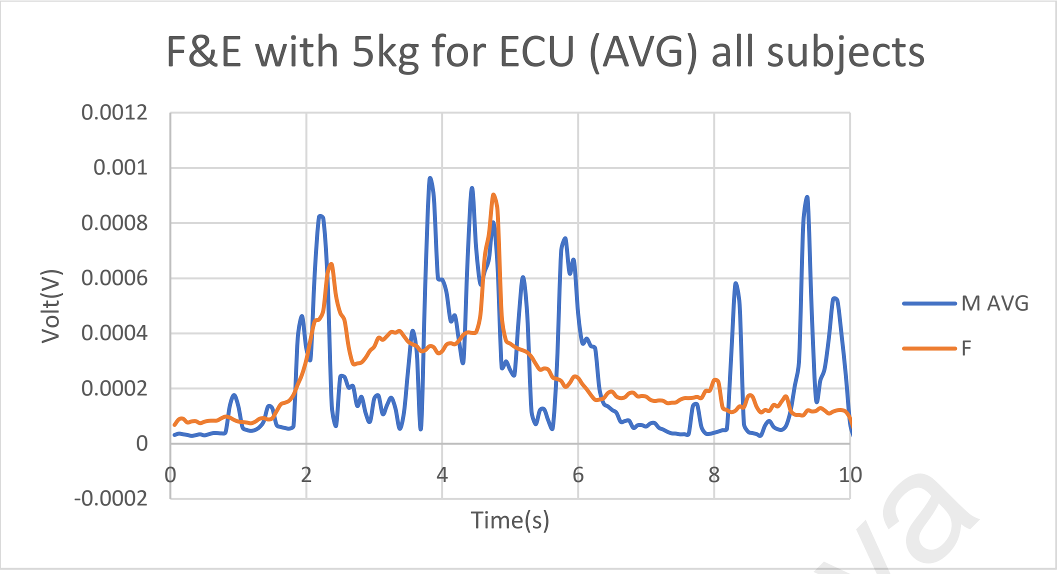


Figure 4.11: The average of extensor carpi ulnaris (ECU) muscles (which is calculated from appendix K) from male subjects (M), female subjects (F) during the activity of flexion and extension with 5kg weight

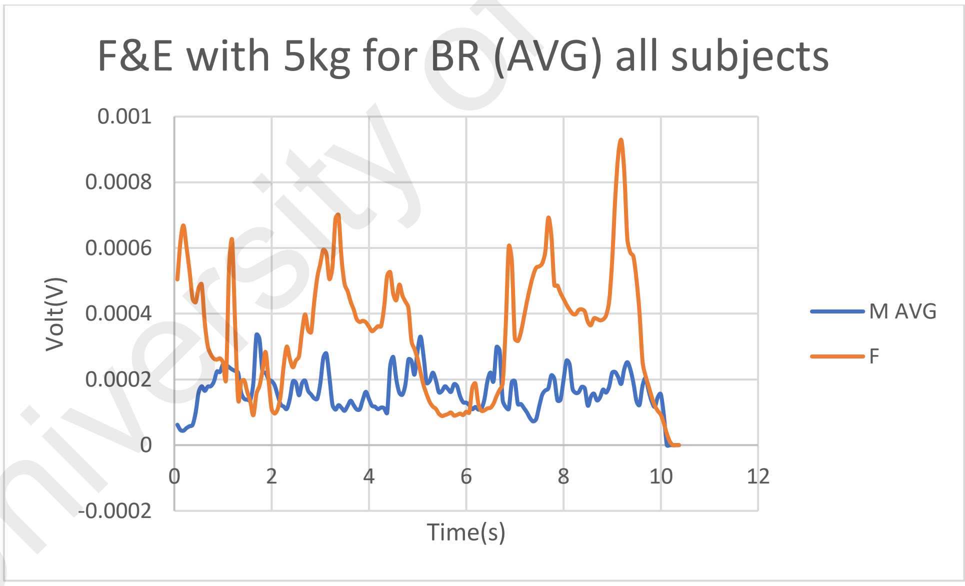


Figure 4.12: The average of brachioradialis muscles (which is calculated from appendix L) from male subjects (M), female subjects (F) during the activity of flexion and extension with 5kg weight

Figure 4.9 until figure 4.12 presented the last activity of the study that is flexion and extension with 5 kg weight. This activity aimed to observe the capability of the amputees to overcome the challenges that are similar to this activity.

In Figure 4.9 gives the average of the biceps muscles that generated from four subjects during the activity of flexion and extension of the upper limb with 5 kg weight. In this result, the amputees performed less than able body subjects on the biceps activation. Female and male participants have recorded the same EMG activity and the two transradial activity also have found similar EMG activity compared to each other.

In Figure 4.10 gives the average of triceps muscles of the all subjects during the activity of the flexion and extension with 5 kg weight. In this figure we found that triceps muscles did not generate significant differences between the male participants and amputee subjects, which also the signal that generated from this muscle is very weak comparing to the biceps activation.

For the below elbow muscles, Figure 4.11 shows that the EMG activity date collected from the extensor carpi ulnaris (ECU) muscle which represents an average from two subjects which are male and female subjects. No EMG data collected from amputee subjects for this activity due to the lack limit surface of remaining muscles from his lost limb (N. A. Razak et al., 2017). Also figure 4.12 shows another below elbow muscle (Brachioradialis muscle) that recorded by EMG activity and presents the average of the female and male subjects collected from this muscle. For extensor carpi ulnaris (ECU) muscle, the two subjects have similar peak values but, for Brachioradialis (BR) muscle, female subjects demonstrated higher values than male subjects during the activity of flexion and extension with 5 kg weight. This result may be justified by different neural activation strategies used by each sex.

CHAPTER 5: CONCLUSION

5.1: Conclusion

The project was set out to investigate the positional parameter of EMG for transradial prosthetic users to find out the best position of EMG sensor to place out the socket for upper limb amputees. Myoelectric prosthesis electrodes mounted inside the socket and amputees were trained to use myoelectric prosthesis only with forearm muscle activity. This study was conducted on the two upper arm muscles (biceps brachii and triceps brachii muscles) and forearm muscles extensor (extensor carpi ulnaris and brachioradialis muscles) by doing three different activities which are muscle strength, flexion and extension, and flexion and extension with 5kg weight. The study found that during all the activities, upper arm muscles were performed better EMG activity than forearm muscles for the both transradial amputees and normal subjects. on other hand, normal human subjects have showed higher EMG activity than amputee subjects. Comparing between upper arm muscles which are biceps brachii and triceps brachii, biceps muscles have demonstrated the strongest muscle that showed the highest value of EMG signal during all activities. Based on the result, the study suggest that EMG sensor should be placed outside the socket so that to be adjustable and controlled by the users to control the myoelectric prosthesis.

5.2: Study Limitation and Future Work

The study has several limitations. Normal human subjects were only 10 subjects and only two amputee subjects were conduct the study which is consider a small sample size and can be influence the generalization of the study. Furthermore, the majority of male participants were overweight that disturb the EMG electrode to be fitted on the required muscle.

Further research is required to increase the number of amputee subjects to be conducted the study. In doing so, this will help to compare more within amputee subjects and non-amputee subjects. furthermore, it should be suggested to develop new user-friendly App that facilitates and helps for the amputee subject to know the best muscle that should be placed the EMG sensor outside the socket.

REFERENCES

Adewuyi, A. A., Hargrove, L. J., & Kuiken, T. A. (2016). An Analysis of Intrinsic and Extrinsic Hand Muscle EMG for Improved Pattern Recognition Control. *IEEE Trans Neural Syst Rehabil Eng, 24*. doi: 10.1109/tnsre.2015.2424371

Alkan, A., & Günay, M. (2012). Identification of EMG signals using discriminant analysis and SVM classifier. *Expert Systems with Applications, 39*(1), 44-47.

Beaulieu, R. J., Masters, M. R., Betthauser, J., Smith, R. J., Kaliki, R., Thakor, N. V., & Soares, A. B. (2017). Multi-Position Training Improves Robustness of Pattern Recognition and Reduces Limb-Position Effect in Prosthetic Control. *Journal of prosthetics and orthotics: JPO, 29*(2), 54.

Carey, S. L., Lura, D. J., & Highsmith, M. J. (2015). Differences in myoelectric and body-powered upper-limb prostheses: Systematic literature review. *Journal of Rehabilitation Research & Development, 52*(3).

Chen, L., Geng, Y., & Li, G. (2011). *Effect of upper-limb positions on motion pattern recognition using electromyography*. Paper presented at the Image and Signal Processing (CISP), 2011 4th International Congress on.

Chowdhury, R. H., Reaz, M. B., Ali, M. A. B. M., Bakar, A. A., Chellappan, K., & Chang, T. G. (2013). Surface electromyography signal processing and classification techniques. *Sensors, 13*(9), 12431-12466.

Cordella, F., Ciancio, A. L., Sacchetti, R., Davalli, A., Cutti, A. G., Guglielmelli, E., & Zollo, L. (2016). Literature review on needs of upper limb prosthesis users. *Frontiers in Neuroscience, 10*, 209.

Endo, H., & Kawahara, K. (2011). Gender differences in hand stability of normal young people assessed at low force levels. *Ergonomics, 54*(3), 273-281.

Ferrigno, I. S. V., Cliquet Jr, A., Magna, L. A., & Zoppi Filho, A. (2009). Electromyography of the upper limbs during computer work: a comparison of 2 wrist orthoses in healthy adults. *Archives of physical medicine and rehabilitation, 90*(7), 1152-1158.

Fougner, A. (2013). Robust, Coordinated and Proportional Myoelectric Control of Upper-Limb Prostheses.

Hashim, N. A., bin Abd Razak, N. A., Gholizadeh, H., & Osman, N. A. A. (2017). Analysis of voluntary opening Ottobock Hook and Hosmer Hook for upper limb prosthetics: a preliminary study. *Biomedical Engineering/Biomedizinische Technik, 62*(4), 447-454.

Jackson, A., Moritz, C. T., Mavoori, J., Lucas, T. H., & Fetz, E. E. (2006). The Neurochip BCI: towards a neural prosthesis for upper limb function. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 14*(2), 187-190.

Jiang, N., & Farina, D. (2014). *Myoelectric control of upper limb prosthesis: current status, challenges and recent advances.* Paper presented at the Front. Neuroeng. Conference Abstract: MERIDIAN 30M Workshop. doi: 10.3389/conf. fneng.

Jiang, N., Muceli, S., Graimann, B., & Farina, D. (2013). Effect of arm position on the prediction of kinematics from EMG in amputees. *Medical & Biological Engineering & Computing, 51*(1), 143-151. doi: 10.1007/s11517-012-0979-4

Khushaba, R. N., Kodagoda, S., Takruri, M., & Dissanayake, G. (2012). Toward improved control of prosthetic fingers using surface electromyogram (EMG) signals. *Expert Systems with Applications, 39*(12), 10731-10738.

Kuiken, T. A., Li, G., Lock, B. A., Lipschutz, R. D., Miller, L. A., Stubblefield, K. A., & Englehart, K. B. (2009). Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms. *JAMA, 301*(6), 619-628.

Maat, B., Smit, G., Plettenburg, D., & Breedveld, P. (2018). Passive prosthetic hands and tools: A literature review. *Prosthetics and Orthotics International, 42*(1), 66-74.

Magermans, D., Chadwick, E., Veeger, H., & Van Der Helm, F. (2005). Requirements for upper extremity motions during activities of daily living. *Clinical biomechanics, 20*(6), 591-599.

Morrey, B., Askew, L., & Chao, E. (1981). A biomechanical study of normal functional elbow motion. *The Journal of bone and joint surgery. American volume, 63*(6), 872-877.

Naider-Steinhart, S., & Katz-Leurer, M. (2007). Analysis of proximal and distal muscle activity during handwriting tasks. *The American journal of occupational therapy, 61*(4), 392.

Ovadia, S. A., & Askari, M. (2015). *Upper extremity amputations and prosthetics.* Paper presented at the Seminars in plastic surgery.

Razak, N. A., Gholizadeh, H., Hasnan, N., Osman, N. A., Fadzil, S. M., & Hashim, N. (2017). An anthropomorphic transhumeral prosthesis socket developed based on an oscillometric pump and controlled by force-sensitive resistor pressure signals. *Biomedical Engineering/Biomedizinische Technik, 62*(1), 49-55.

Razak, N. A., Osman, N. A., Ali, S., Gholizadeh, H., & Abas, W. W. (2015). Comparison study of the prosthetics interface pressure profile of air splint socket and ICRC polypropylene socket for upper limb prosthetics. *Biocybernetics and Biomedical Engineering, 35*(2), 100-105.

Razak, N. A. A., Osman, N. A. A., Gholizadeh, H., & Ali, S. (2014). Biomechanics principle of elbow joint for transhumeral prostheses: comparison of normal hand, body-powered, myoelectric & air splint prostheses. *Biomedical engineering online, 13*(1), 134.

Resnik, L., Huang, H. H., Winslow, A., Crouch, D. L., Zhang, F., & Wolk, N. (2018). Evaluation of EMG pattern recognition for upper limb prosthesis control: a case study in comparison with direct myoelectric control. *Journal of NeuroEngineering and Rehabilitation, 15*(1), 23.

Safaee-Rad, R., Shwedyk, E., Quanbury, A., & Cooper, J. (1990). Normal functional range of motion of upper limb joints during performance of three feeding activities. *Archives of physical medicine and rehabilitation, 71*(7), 505-509.

Sanei, S., & Chambers, J. A. (2013). *EEG signal processing*: John Wiley & Sons.

Silva, N. S., de Almeida, P. H. T. Q., Mendes, P. V. B., Komino, C. S. M., Jùnior, J. M. N., & Da Cruz, D. M. C. (2017). Electromyographic activity of the upper limb in three hand function tests. *Hong Kong Journal of Occupational Therapy, 29*(1), 10-18.

Usakli, A. B. (2010). Improvement of eeg signal acquisition: An electrical aspect for state of the art of front end. *Computational intelligence and neuroscience, 2010*, 12.

V, P. (2005). Historical Prostheses. *Journal of Hand Surgery, 30*(3), 310-325. doi: 10.1016/J.JHSB.2005.01.001

Viitasalo, J. H., & Komi, P. V. (1977). Signal characteristics of EMG during fatigue. *European Journal of Applied Physiology and Occupational Physiology, 37*(2), 111-121.

Ziegler-Graham, K., MacKenzie, E. J., Ephraim, P. L., Travison, T. G., & Brookmeyer, R. (2008). Estimating the prevalence of limb loss in the United States: 2005 to 2050. *Archives of physical medicine and rehabilitation, 89*(3), 422-429.