THE POSITIONAL PARAMETER OF EMG FOR TRANSTIBIAL PROSTHETIC USERS

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ABSTRACT

Amputation is an operation that involves partial or total removal of a limb. Amputations are limited to the two main parts of the body (upper limb and lower limb) and each limb has its amputation levels. This study will focus on the lower limb amputation (transtibial amputee). Transtibial Amputations (TT Amp) is one of the most amputated types of the lower limb, also known as below-knee (BK) amputation. Prosthetic limbs are found and manufactured to serve those affected, by overcoming difficulties or challenges that may be encountered in their daily activities such as walking, jumping, squatting and other movements. One of the advance powered lower limb prostheses (transtibial) that improves the movement performance of the users of these limbs using electromyography (EMG) sensor known as C-LEG. The main challenge faced by the prosthetic limb is the position of the EMG sensor. EMG sensor within the socket in a fixed position sometimes leads to contact with inactive muscles, which causes reduction in efficiency of use. The aim of the study is to investigate the best positional parameter of EMG for transtibial prosthetic users (TTAmp) to be effective in multiple movement activities and compare with the normal human muscle's activities. DELSYS Trigno wireless EMG instrument was used in this study to achieve this aim. Ten non-amputee subjects and two transtibial amputee subjects were involved in this study. The surface EMG signals were recorded from two anterior and posterior below knee muscles; tibialis anterior (TA) and gastrocnemius lateral head (LG), and two anterior and posterior above knee muscles; rectus femoris (RF) and biceps femoris (BF) during five activities; muscles strengthening, flexion and extension, gait cycle (normal walking), descending the stairs and ascending the stairs. The result is that some muscles are active and useful in the performance of certain activities, but they are not effective in other activities, so it is difficult to rely entirely on the static positioning of the EMG sensor

within socket due to the possibility of that sensor to be in contact with inactive muscle so there will be a gap in the control leads to decrease the functional efficiency of the powered prostheses. There is, therefore, a need to put the EMG sensor out of the socket to reduce this gap in prosthetic limbs control by amputees and to ensure that each sensor is connected to an active muscle of which through the EMG signal from that active muscles can increase the control efficiency.

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ABSTRAK

Amputasi adalah operasi yang melibatkan pemotongan sebahagian atau keseluruhan anggota. Amputasi adalah terhad kepada dua bahagian utama badan (anggota bahagian atas dan anggota bahagian bawah) dan setiap anggota badan mempunyai tahap amputasinya. Kajian ini akan memberi tumpuan kepada amputasi anggota bawah (transtibial). Amputasi Transtibial (TT Amp) adalah salah satu jenis anggota bawah yang paling kerap dipotong, yang juga dikenali sebagai amputasi bawah lutut (BK). Anggota prostetik telah dihasilkan untuk memberi bantuan kepada mereka yang terjejas, dengan mengatasi masalah atau cabaran yang mungkin dihadapi dalam aktiviti harian mereka seperti berjalan kaki, melompat, jongkok dan pergerakan lain. Salah satu prostetik anggota badan anggota bawah (transtibial) yang dapat meningkatkan prestasi pergerakan pengguna adalah dengan menggunakan sensor *electromyography* (EMG) yang dikenali sebagai C-LEG. Cabaran utama yang dihadapi oleh pihak perindustrian adalah kedudukan penderia EMG, kerana ia berada di dalam soket dan ini kadangkala bersentuhan dengan otot yang tidak aktif, dan menyebabkan pengurangan kecekapan penggunaan. Tujuan kajian ini adalah untuk mengkaji parameter kedudukan EMG yang terbaik untuk pengguna prostetik transtibial (TTAmp), supaya berkesan dalam pelbagai aktiviti pergerakan dan juga membandingkan dengan aktiviti otot manusia yang normal. Instrumen EMG tanpa wayar DELSYS Trigno digunakan dalam kajian ini untuk mencapai matlamat ini. Sepuluh subjek amputee dan dua subjek transtibial amputasi terlibat dalam kajian ini. Isyarat *electromyography* permukaan (EMG) direkodkan dari dua *anterior* dan *posterior* di bawah lutut otot; *tibialis anterior* (TA) dan *gastrocnemius lateral head* (LG), dan dua *anterior* dan *posterior* di atas lutut otot; *rectus femoris* (RF) dan *biceps femoris* (BF) untuk lima aktiviti (otot kekuatan, fleksi dan ekstensi), kitaran 'gait' (berjalan normal), menaiki dan menuruni tangga. Hasilnya ialah

beberapa otot aktif dan berguna dalam prestasi aktiviti tertentu, tetapi mereka tidak berkesan untuk aktiviti lain, jadi ianya sukar untuk bergantung sepenuhnya pada kedudukan statik penderia EMG dalam soket dan akan berkemungkinan sensor bersentuhan dengan otot yang tidak aktif dan menyebabkan terdapatnya jurang dalam kawalan membawa kepada penurunan kecekapan fungsi peranti prostetik. Oleh itu, ada keperluan untuk meletakkan penderia EMG di luar soket untuk memudahkan amputi mengawal anggota badan palsu dan untuk memastikan bahawa setiap penderia disambungkan ke otot aktif dan melalui isyarat EMG dari otot aktif, boleh meningkatkan kecekapan kawalan oleh amputi.

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LIST OF ABBREVIATIONS AND SYMBOLS

EMG	Electromyograph
AE	Above Elbow
BE	Below Elbow
TTAmp	Transtibial Amputee
TTAmp S1	Transtibial Amputee Subject 1
TTAmp S2	Transtibial Amputee Subject 2
AK	Above Knee
BK	Below Knee
MTF	Military Medical Treatment
PTB	Patella Tendon Bearing
TSB	Total Surface Bearing
UMMC	University Malaya Medical Centre
TA	Tibialis Anterior
LG	Gastrocnemius Lateral Head
RF	Rectus Femoris
BF	Biceps Femoris
G	Gender
BMI	Body Mass Index
M	Male

F	Female
N	Normal
S	Non-Amputee Subjects
O	Obesity
OW	Over weight
N/A	Not-Available
AVG	Average
S	Seconds
V	Volt
L	Left

CHAPTER 1: INTRODUCTION

1.1. Overview

Losing limbs is a crucial event in a person's life, and currently, the prostheses are the only solution to compensate for the shortfall of movement caused by amputation. Individuals with lower limb amputation face numerous challenges in daily activities. Prosthetic limbs are able to support those affected by their daily activities, such as walking, ascending, descending and other activities (Ernst, Altenburg, Bellmann, & Schmalz, 2017; Nakamura & Hahn, 2017). The most important goal of rehabilitation is to develop the performance of the residual limbs to reach the highest level, which should be very close to the normal level before the amputation. There are many achievements that are somewhat satisfactory in improving the lives of those affected, but there is a need for further development to achieve the goal of simulating their normal lives before amputation. Researches and studies are still ongoing to achieve that goal (Herdiman, Adiputra, Tirtayasa, & Manuaba, 2015).

General statistic shows that there are ten million amputees in the world of which the dominant type of amputation is the lower limbs; especially the most common one is under the knee. In general, the forces, balance, and movement of amputees are changed due to permanent physiological change that happened to them. There are some statistics on the proportion of landmine victims during Colombia's internal war, which numbered 11,000 people. This number is divided into two categories of people (civilians, who accounted for 38%, and military who had the largest share of the damage amounted to 62%). More than 2,000 mine-affected people died, and some were injured, in which some of the injured ones were amputated at their lower extremities. The predominant type of amputation was transtibial amputation. It is estimated that more than 60,000 Colombians had amputations in their lower limbs, at least each of whom was amputated at one of his lower extremities. The predominant amputation was transtibial amputation (Contreras, Casallas, & Guardiola, 2018). In World War II, mortars, artillery, landmines, and bombs were classified as highly explosive and were the most common cause of transtibial amputation. Since the end of the war so far, landmines have been a source of great concern for all, because so far, they are being cultivated very heavily in several countries in Africa, Asia, and the Balkans. The number of remaining landmines is estimated at 110 million. But so far, the real number of mines is still unknown. In such stricken areas, many of its residents and peacekeepers face numerous injuries, leading to many amputations (Dougherty, 2001). In the United States from 1988 to 1996, transtibial amputation was the second most common type of amputation, and there were obvious major causes of amputation such as vascular diseases, and injuries. 1.6 million people had one or more amputations for their limbs. This was in 2005, and by 2050 it is expected to increase to 3.6 million, based on the number reported in 2005. A high percentage of these individuals have lost one of their lower limbs, which is estimated at 40% (Fey, Silverman, & Neptune, 2010). There are still many studies, research and statistics on the causes of amputations (especially in the lower limbs that required transtibial amputation) which are different from the reasons mentioned previously, such as diabetes, serious infection, accidents and others. EMG used in many studies and research is specialized in measuring the bio signal generated by the muscles to study muscle patterns and behaviours in motion. The use of robotic technology has become popular in all fields due to the continuous evolution of this technology that helps improve human life. With rapid progress and successive advances in robotics technologies, it has become possible to develop the powered prosthetic limbs of the lower limbs. The main motivation of these types of powered prosthetic limbs is to enable the ability to support and contribute to mechanical force in the walking cycle and other motions to replace the mechanical force lost as a result of amputation (Huang & Ferris, 2012; Jimenez-Fabian & Verlinden, 2012; Karlsson, 2010).

1.2. Problem Statement

When an amputee wears a powered prosthesis (transtibial prosthetic users) the problem lies in the position of EMG parameter, so, that position of the sensors inside the socket is appropriate for the case in some activities. However, it is not useful because of dynamic change in other activities, for example; normal walking, running, climbing, squatting, and others. So, it is useless to have sensors in fixed positions in the socket because each case has its own conditions and requirements. For example, C-leg is one of the powered prostheses that use the EMG sensor placed inside the socket in a fixed position (Garikayi, Van den Heever, & Matope, 2018). There are also some cases where the muscle strongest position change after the pre-post prosthetics procedure. During the initial process, the clinician suggested that the EMG should be put at one point, however after several months, the position no longer active to get the signal and it was discovered at other places. That is why the positional parameter to place the EMG should be dynamically changed from time to time.

1.3. Report Organization

This report comprises five chapters, namely: introduction, literature review, methodology, result and discussion and finally, conclusion. The introduction explains the types of lower limb amputation, specially transtibial amputation briefly and its main causes. The problem statement and objective of the project are also debated in the same chapter. Literature review gives detailed information background of transtibial amputation. It also discusses the techniques used in rehabilitation of this kind of amputation, the types of sockets used and the different studies about the EMG to measure and improve the efficiency of the residual limb in order to overcome the daily challenges faced by the affected. The methodology includes explaining the method of data collection and the equipment used. In the same chapter, the demographic information is detailed. Result and discussion supply a comprehensive analysis of the data collected and discusses the significance, differences and similarities in results. The conclusion summarizes the overall work that has been done and a mini-discussion on the future vision in this research study.

1.4. Objectives

The objectives of the study are:

1. To investigate the positional parameter of EMG for transtibial prosthetic users to be effective in multiple movement activities.
2. To compare the EMG parameter of active muscles between the amputee and the normal human activities.

These can be determined by identifying the active muscles in lower limb amputees for both tibial and femoral, so these positions are tested with several activities such as normal walking, running, climbing, squatting and others.

1.5. Scope of the research

This research is conducted under the field of Rehabilitation Engineering and is managed by Centre for Prosthetic and Orthotic Engineering (CPOE), Body Performance and Motion Analysis Laboratory, Department of Biomedical Engineering, Licensed by UM for demonstrating patterns, behaviours, and characteristics of electromyography signals to promote, contribute and development of prosthetics. The research deal with the amputees and instrumentation known as EMG, the study gathers all the EMG signals from ten healthy subjects before capture EMG signals from two amputee subjects. From the signals, the amputee which conduct different kinds of annual daily life activities were analyzed. The parameter of where the EMG signals should be captured will also be analyzed.

CHAPTER 2: LITERATURE REVIEW

2.1. The Amputation

Surgical amputations are performed in two parts of the body (upper limb, lower limb) and each part has its different types of amputation. There are several common causes that always prompt surgeons to amputate the injured party such as accidents, side effects of diabetics including gangrene, infections or burns, tumors, diseases, and other causes (Prosthetics, 2017a, 2017b). In general, the length of the residual limbs gives better control of the prosthetic limbs. As shown in Figure 2.1, the top tip amputation types for upper limb are as follows; Forequarter- here the shoulder amputation is done with the collarbone and the blade, Shoulder Disarticulation- the side of the shoulder is amputated while keeping the blade and shoulder intact, Transhumeral Above Elbow (AE)- amputation occurs at the top of the arm (from elbow to shoulder), Elbow Disarticulation- amputation occurs in the elbow, Transradial Below Elbow (BE)- amputation is done in the forearm (from elbow to wrist), Wrist Disarticulation- The amputation is done at the wrist level, and others (Prosthetics, 2017b).

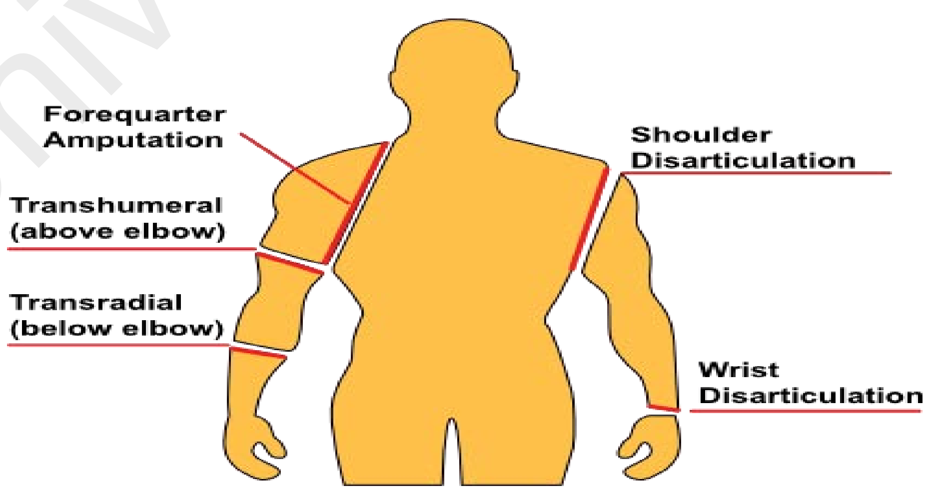


Figure 2.1: Amputation in the upper limb (Prosthetics, 2017b)

Basically, this study addresses the subject of amputation of the lower limbs especially the transtibial (TTAmp). The amputations in the lower limbs are as shown in Figure 2.2: Hip Disarticulation- amputation occurs from the hip joint with the entire thigh and leg, Transfemoral Amputation (AK)- the amputation occurs from any level of the femur to the knee joint, Disarticulation- The amputation occurs at the level of the knee joint, Transtibial Amputation (BK)- amputation occurs at any level of the tibial to the ankle, Foot Amputations- the amputation occurs at any level of the foot (Prosthetics, 2017a).

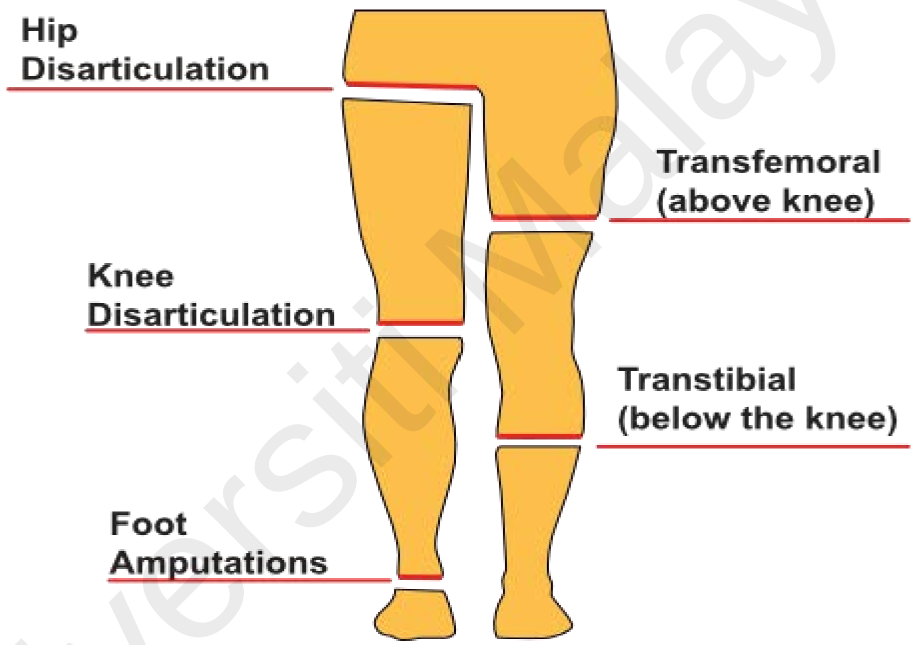


Figure 2.2: Amputation in the lower limb (Prosthetics, 2017a)

Losing one of the lower limbs is never easy, most amputees feel very frustrated after amputation, and this feeling is normal because they suffer from the dependencies of this amputation as suffering from pain for a long time, but this will turn into a positive energy that prompts them to try to adapt to the new situation regardless of the nature of loss. The cases of depression differ from one patient to another, some of them suffer from despair or anger and some with indifference (Mark T. Maguire, 2013), It can be said that this is one of the obstacles that may be faced by researchers. The challenges are different depending on the circumstance of each case, such as age, occupation and other differences (Douglas G. Smith, 2003). For example, in one study by Susan Kapp and Joseph A. Miller, two groups of amputees (TTAmp) of the population (a civilian group and a military group), are ostensibly similar but totally different in treatment and rehabilitation methods. Each group has its independence in the various types of prosthetic devices and training to improve and maximize the rehabilitation. Appropriate medical prescriptions are also important factors in improving the rehabilitation of those affected. Military medical treatment facility (MTF) personnel, the members of this medical facility designed a program called the Comprehensive Team Approach, a program based on a multidisciplinary team approach. It consists of two teams providing all the comprehensive rehabilitation services, the first is the medical professionals (surgeons, psychiatrists, nurses, psychiatrists, health care providers and others). The second is non-specialist specialists (case managers, volunteers, and others) (Kapp, Miller, Pasquina, & Cooper, 2009). The aim of this approach is to empower people affected by integrated rehabilitation so that they can carry out their daily activities more easily and adapt to the needs of the new life. Experience has shown that this group has outperformed many of the more advanced systems.

2.2. Transtibial Amputations (TTAmp)

Transtibial Amputations (TTAmp) is one of the most amputated types of the lower limb, also known in short as “BK” (below-knee) as shown in Figure 2.3. It is one of the most common types of amputation of the lower limb. Statistics have shown that half of all major lower limb amputations are transtibial. The success rate of rehabilitation for amputees is very high in most cases of transtibial, although advances in surgical techniques and prostheses are currently underway, it should be borne in mind that there are few cases of transtibial that do not recover well. More work needs to be done to reduce this situation (Douglas G. Smith, 2003).

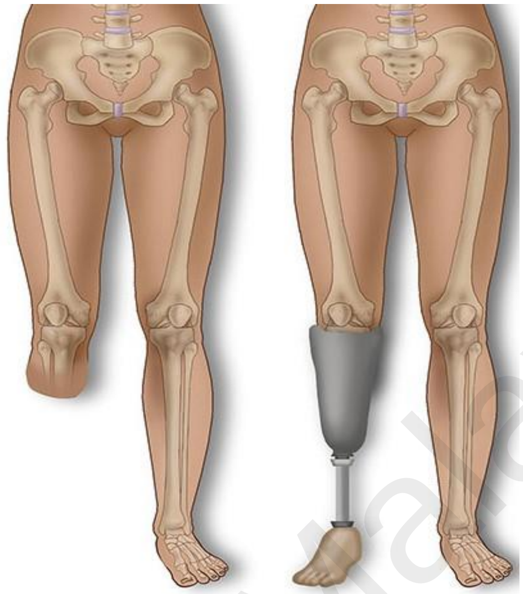


Figure 2.3: Transtibial Amputations (TTAmp) (Association, 2018)

“For the transtibial amputee, the major challenge is replacing the foot and ankle, which are filled with many bones and small joints that work together in a unique fashion” (Douglas G. Smith, 2003). The foot and ankle combination consist of 33 joints, 112 ligaments, 28 bones, controlled by 34 muscles (13 superficial muscles and 21 internal muscles). The foot is divided into three sections (the rearfoot, midfoot, and forefoot) as shown in Figure 2.4. The structure of the foot and the complex ankle joint make it responsible for several important functions, pushing many researchers to do studies on how to qualify the transtibial amputees in a manner suitable for these functions, such as how it works as a flexible helix fit movement with different terrain to make movement balanced as well as support the weight and mass of the body on the ground. Figure 2.5 shows the movement of the ankle joint (Physiopedia, 2018).

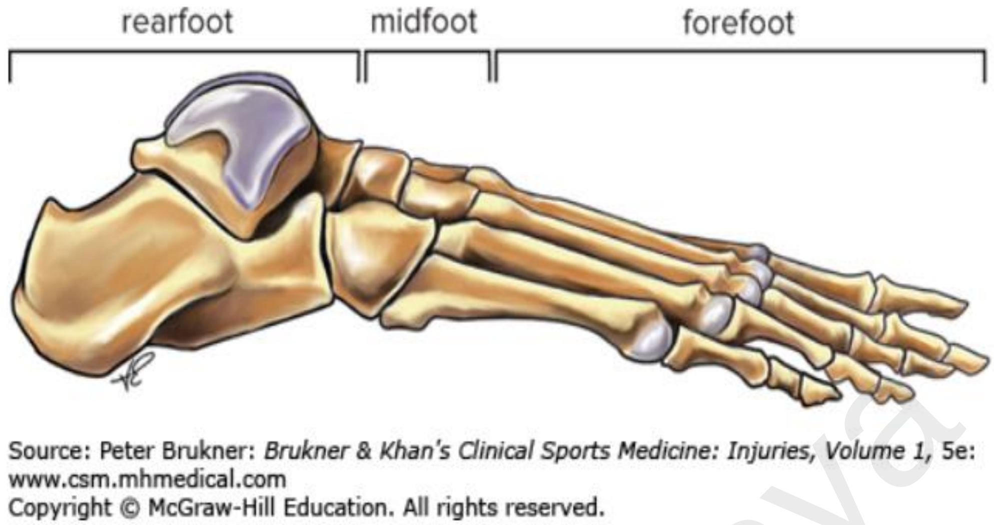


Figure 2.4: Regions of the foot: rearfoot, midfoot and forefoot (Sports injuries: overuse | Brukner & Khan's Clinical Sports Medicine: Injuries, 2018)

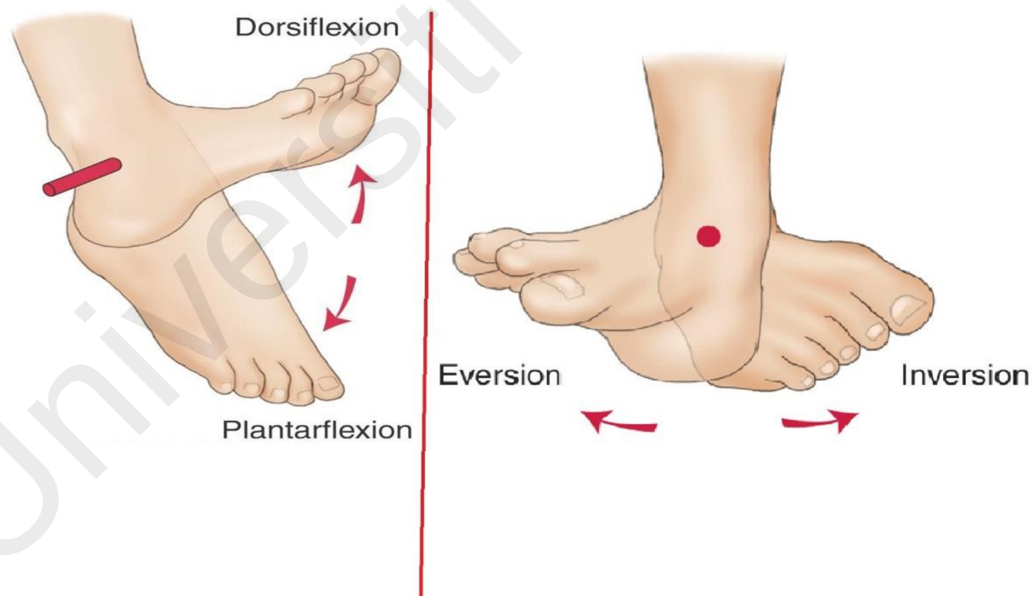


Figure 2.5: Dorsiflexion, Plantarflexion, Eversion, and Inversion (Singapore, 2015, May 22)

2.2.1. Importance of knee joint for Transtibial Amputees

The surgical surgeons always try to keep the knee joint intact as it is one of the most important pillars of human mobility, whether the person is healthy or transtibial amputee. In general, it is very important for amputees, whether transtibial amputees (below-knee) or transfemoral amputees (above-knee), to understand very well the extent and effect of the existence or absence of the knee joint. Knee joint provides many functional advantages for movement and general balance as shown in Figure 2.6, which is not available in hip disarticulation or transfemoral amputation (AK). In short, the knee joint is very useful for daily activities such as climbing stairs, descending the slopes, moving from place to place, rushing forward, slowing the movement and others (Douglas G. Smith, 2003).

Figure 2.6: The importance of the knee joint for movement and general balance (Center, 2018)

Amputees who have lost the knee joint are compensated with an auxiliary prosthesis and an alternative to the knee joint, which only helps in bending function, but does not help in force generation as the natural knee as shown in Figure 2.7. In one study by Douglas G. Smith, a patient turned from transtibial amputee to transfemoral amputee because of a severe knee injury that resulted in amputation. The proportion of difficulties and challenges faced by the patient in the new situation was ten times worse than before (Douglas G. Smith, 2003).

Figure 2.7: C-LEG: prosthetic knee joint for transfemoral amputee (prosthetic, 2015)

2.3. Bones vs. Lower Limb

The human skeleton is divided into two main parts; the appendicular skeleton that forms the limbs of the body which are upper limb and lower limb consists of 126 bones, the axial skeleton is the central core of the body, consists of 80 bones. It has two primary functions; the first function is responsible for the support and protection of internal organs, the second one supports the attachment of muscles by creating a surface that serves it as shown in Figure 2.8 (TeachPE.com, 2018). The bones of the leg and foot are part of the appendicular skeleton, which is the main backbone of many lower limb muscles. These muscles work together to form movements such as walking, running, jumping and others, supported at the same time by the bones and joints in the leg and foot strong enough to support weight, balance, and movement (InnerBody, 2018).

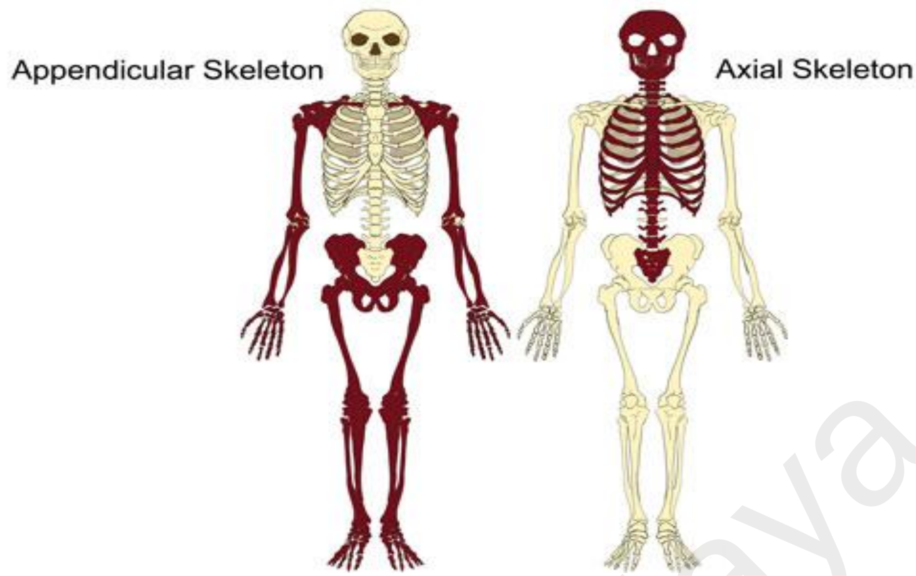


Figure 2.8: Skeletal parts (the appendicular skeleton & the axial skeleton) (TeachPE.com, 2018)

The most important lower limb bones that should be known are femur, patella, tibia, and fibula, tarsals, and metatarsals and phalanges.

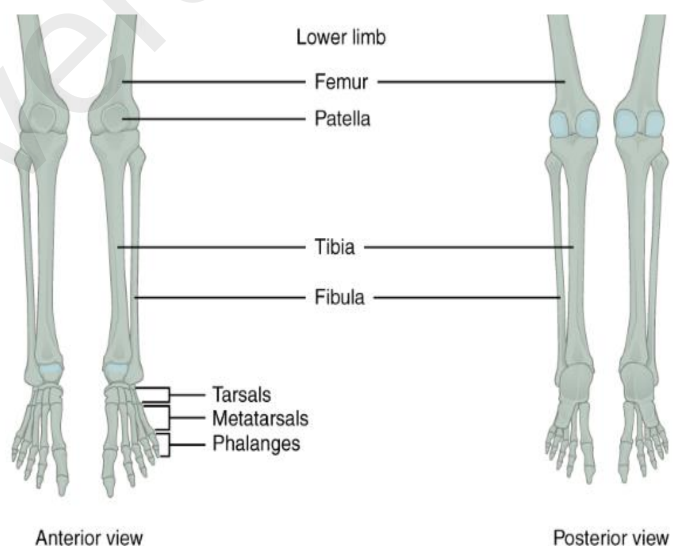


Figure 2.9: Lower limb bones that should be known (Lumen, 2018, July 29)

2.4. Muscles vs. Lower Limb

Muscle function is to contribute to the formation of the movement of the body. Without muscle, the body cannot move. This study focuses on the lower limb muscles of the body. One of the most important activities that determine the efficiency of the muscle is flexion and extension, which is responsible for the control of joints because of the angle controlling the degree of flexion and extension of the joint. For example, the knee joint, or called tibiofemoral joint, has two sets of anterior and posterior muscles at the above knee and below the knee that control the degree of flexion and extension of the joint. The quadriceps group consists of four anterior muscles (rectus femoris, the vastus medialis, the vastus intermedius, and the vastus lateralis) that are responsible for the extension of the knee joint. The posterior muscle group of the thigh, called hamstrings (biceps femoris, the semimembranosus, and the semitendinosus), is responsible for flexion of the joint. For the posterior muscles group below the knee, the closest muscle to the surface of the skin and the largest in the group is called gastrocnemius, which enhances the flexion and extension of the knee joint. Tibial anterior is one of the most important anterior muscles below the knee that share with their group to ensure stability and balance during the walking cycle (Burner, 2011; Hamilton, 2011; Levangie & Norkin, 2011).

2.5. Type of prosthetic socket

The socket is the part of the prosthesis that encloses the stump and forms union between the stump and artificial limb as shown in the Figure 2.6. The importance of the socket is to reduce the pressure on the residual limb connected to the artificial limb, to contribute to make the blood circulation at the end of the residual limb in a normal range, to fix of the prosthetic in the residual limb, which means not to allow it to slide with the movement and to ensure effective control of movement (Faustini, Neptune, Crawford, Rogers, & Bosker, 2006).

2.5.1. Patella Tendon Bearing Sockets (PTB)

This type of socket is known as Specific Weight Bearing sockets, as opposed to TBS sockets. They are designed to load the force on certain parts of the stump. The first construction and manufacture of these sockets were in California in 1957 and was officially approved in 1959. Inside these socket there is always an inner liner, made of soft material such as pelite, to fit the interior shape and give greater comfort to the remaining limb and recently the newest liner such as silicone liners, which is the latest material is used with this type of socket to give better comfort with the additional wear of socks made from wool or cotton to relieve sweating and protect the limb (Fergason & Smith, 1999). The most important aspect of forming a PTB cast is to pay extra attention in the pressure sensitive and pressure tolerant areas. Apart from that, re-confirmation of the measurements must be taken because any possible difference can lead to complications for the patient which later gives negative effects on the residual limb and the patient's motion.

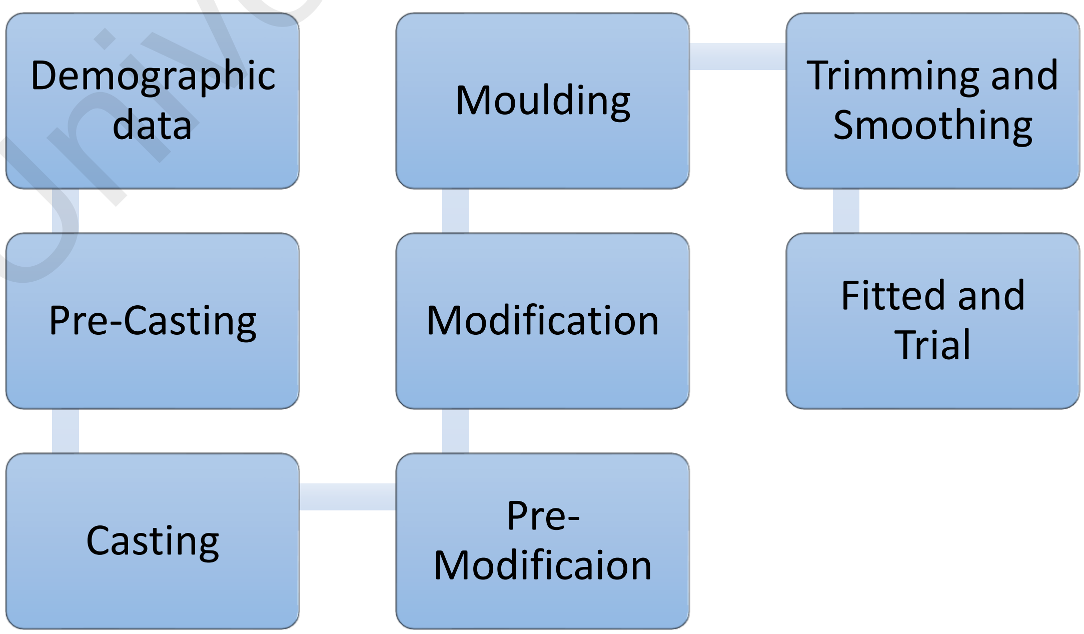
Figure 2.10: PTB socket (Fitzsimons, 2010)

2.5.2. Total Surface Bearing Sockets (TSB)

These sockets were designed on a theory that all parts of the remaining limb should now bear part of the weight of the amputees. Its advantages are that the pressure area is applied over a larger area, allowing greater knee flexion, and lighter than PTB. The most important disadvantages are that it increases the rate of sweating, friction, and pain in the remaining part (Fergason & Smith, 1999; Staats & Lundt, 1987).

Figure 2.11: TSB socket (Fitzsimons, 2010)

2.6. Flowchart of the Fabrication Process



2.7. Electromyograph (EMG)

EMG is used in many most important clinical studies and research. Most of these studies occur in short term which specializes in measuring the bio-signal generated by the muscles. The muscle signal is taken in two ways; either invasive by direct contact with the muscle or non-invasive by the surface of the skin in which the latter type is preferred. Problems that EMG signals may face as a control element in the powered prosthetic limb are skin conditions such as sweating, burns and others although the need to determine the appropriate location for the sensor is important, because the location of the EMG sensor should be very precise above the target muscle (Karlsson, 2010).

2.7.1. EMG for transtibial

Several studies have been conducted on the study of muscle patterns and behaviours in motion using EMG. The interaction between humans and robots continues to increase, and human usage of the robot has entered into all fields. Closed loop control methods in the lower limb prostheses focus on the kinetic/kinetic sensation by EMG or socket itself sensing of the residual limb muscles (Jimenez-Fabian & Verlinden, 2012). Powered robotic prostheses need a normal user interface and a strict and robust control system, due to its sensitivity. In one study, the capacity of the nonlinear autoregressive model was monitored and recorded, to continuously map the kinematics of transtibial (TT) prosthesis and EMG signal activity was recorded in the socket to estimate or predict the angles of the artificial ankle in three TTAmp subjects. In this study, the EMG signals contributed significantly to the estimation of future ankle angles. The nonlinear model of autoregressive for continuous prediction of ankle joint movements which use, activate muscles in the residual limb, gives a very good chance of optimal joint control. The prosthetic limb that is based on kinetic/kinematic sensing to controlling provides very accurate information continuously about the condition of the prosthesis. However, some information is difficult to analyze quickly, resulting in a control gap in the understanding of this signal (Farmer, Silver-Thorn, Voglewede, & Beardsley, 2014).

With the remarkable advances in robotics technologies, it has become possible to develop powered lower limb prostheses (transtibial & transfemoral) that improve the movement performance of the users of these limbs. The main advantage in these types of powered limbs is the ability to support and contribute to the mechanical power in the gait cycle to replace the mechanical force lost as a result of amputation or in other words loss of muscles in the limb. According to one study, if the powered prosthetic of the lower limbs can reach the control signals through the user's nervous system, they will be more efficient and accurate. The main purpose of this study was to determine whether it is possible to record the activation signal of the remaining muscle in the residual limb at the prosthetic socket-limb interface during gait cycle (normal walking) or not. The study recorded the EMG signals from three muscles at below knee; tibialis anterior, gastrocnemius medial head, gastrocnemius lateral head and four above knee muscles; namely vastus lateralis, rectus femoris, biceps femoris, and gluteus medius. The number of subjects participating in this study is 24 persons; 12 unilateral transtibial amputee and 12 non-amputee subjects. During treadmill walking activity in a certain condition, EMG signals were recorded from the interior of the prosthetic socket for the muscles below the knee and above knee. Cross-correlation analyses were used to identify the differences in the muscles activity between the amputees and normal subjects during treadmill walking. The result of this analysis was that muscles in the residual limb for amputee subjects gave more reliable signals than ordinary people (Huang & Ferris, 2012).

2.8. Summary

Table 2.1: Related studies to the research

	Research title	Aim of the study	Methodology	Results	Pros	Cons	Contributors
1	"Myoelectric Activation Pattern Changes in the Involved Limb of Individuals with Transtibial Amputation During Locomotor State Transitions" (Nakamura & Hahn, 2017).	To investigate whether lower extremity muscle activation patterns differ in the strides leading to locomotive state transitions in the involved limb of individuals with transtibial amputation.	9 (TTAmp) subjects (mean age, 48.8±12.1y; mean height, 1.74±0.09m; mean weight, 86.1±24.7kg) had volunteered for the study. Surface EMG was used to measure muscle activation from 7 muscles. Subjects walked across 8 different terrain conditions transitioning.	No muscle activation changes were observed in ramp transitions Within stair transitions, 6 muscles which are: (biceps femoris (BF), gluteus maximus (Gmax), gluteus medius (Gmed), Medial gastrocnemius (MG), rectus femoris (RF), vastus lateralis (VL)	The research was thorough, and 9 subjects were involved	The lack of significant differences in ramp transitions begs the question of whether ramp transition classification is important or whether those transition types must use some signal other than electromyography.	Nakamura, B. H. and M. E. Hahn (2017)
2	"Voluntary Control of Residual Antagonistic Muscles in Transtibial Amputees: Feedforward Ballistic Contractions and Implications for	Investigate whether TTAmp is capable of generating such a ballistic-like activation pattern accurately using their residual ankle muscles in order to assess whether volitional postural	10 TTAmp were asked to generate ballistic-like activation patterns using their (LG) and (TA) to control a 2D computer cursor via proportional myoelectric control to hit targets positioned at 20% and 40% of maximum voluntary contraction of	TTAmp were able to generate consistent and accurate feedforward control signals using ballistic-like residual muscle contractions, but the ability to store and recall accurate motor commands would require more training. The		Given the scope of this study, they are not able to conclude whether ballistic-like movements generated using residual muscles are predominant and natural for	Stephanie Huang, and He (Helen) Huang, (2018)

	Direct Neural Control of Powered Lower Limb Prostheses" (Huang & Huang, 2018).	control of a powered ankle prosthesis using proportional myoelectric control via residual muscles could be feasible.	the corresponding residual muscle.	implementing the controller using a powered prosthesis during standing tasks is needed to assess feasibility and reliability of the complete amputee-prosthesis system.		transtibial amputees. However, they are confident that transtibial amputees are capable of generating ballistic-like residual muscle contractions during an isolated task.	
3	"Analysis of surface electromyography signal features on osteomyoplastic transtibial amputees for pattern recognition control architectures" (Garikayi et al., 2018).	To identify the specific muscles that can be used to guarantee optimal control of a multichannel powered prosthetic ankle.	Subjects were instructed to perform normal gait. 5 motions (dorsiflexion-rest-plantarflexion) 5 motions (dorsiflexion-plantarflexion)	The study revealed that there are electromyography signals present on the residual limb after amputation.	Multiple sessions and activities were recorded	Electromyography signals strength present on the residual limb after amputation is far much lower than that of normal subjects	Talon Garikayi et al (2017)

4	"The influence of increasing steady-state walking speed on muscle activity in below-knee amputees" (Fey et al., 2010).	to identify changes in muscle activity in below-knee amputees in response to increasing steady-state walking speeds.	Bilateral electromyographic (EMG) data were collected from 24 subjects: • 14 amputees • 10 non-amputees (as a normal people). During four over ground walking speeds.	Most amputee EMG patterns were similar between legs and increased in magnitude with speed. Differences occurred in the residual leg biceps femoris long head, vastus lateralis and rectus femoris, which increased in magnitude during braking compared to the intact leg.	Finding out different points of muscular activities	The variety of surgery outcomes can result in variable muscular alignments which are unique to each individual.	N.P. Fey, A.K. Silverman, R.R. Neptune (2009)
5	"Muscle activation patterns during walking from transtibial amputees recorded within the residual limb-prosthetic interface" (Huang & Ferris, 2012).	The purposes of this study was to determine if muscle activation signals could be recorded from residual lower limb muscles within the prosthetic socket-limb interface during walking	It is possible to record artifact-free muscle activation patterns from residual limb muscles within the prosthetic socket-limb interface with surface electromyography electrodes.	recorded surface electromyography from three lower leg muscles (tibilias anterior, gastrocnemius medial head, gastrocnemius lateral head) and four upper leg muscles (vastus lateralis, rectus femoris, biceps femoris, and gluteus medius)	The results support the potential use of myoelectric controllers for direct feedforward control of robotic lower limb prostheses. The results of this study are encouraging for the development of powered lower limb prosthesis under myoelectric control.	they did not present data from overground walking because the primary focus was to quantify differences in signal patterns and variability between amputee and non-amputee groups and within groups.	Stephanie Huang1,2* and Daniel P Ferris1,2,3 (2012)

6	“A Noncontact Capacitive Sensing System for Recognizing Locomotion Modes of Transtibial Amputees” (Zheng, Wang, Wei, & Wang, 2014).	It is to investigate the usability of locomotion mode recognition systems based on electromyography (EMG) signals and systems based on capacitance signals obtained from skin contact. To evaluate the performance of C-Sens	Experiments were carried among six transtibial amputees with varying levels of amputation when they engaged in six common locomotive activities	Obtained sufficiently informative signals even for amputees with severe muscle atrophy (i.e., amputees lacking quality EMG from shank muscles for mode classification)	Detailed study regarding EMG effective signals.		Enhao Zheng, Long Wang, Kunlin Wei, and Qining Wang
7	“Effect of take-off from prosthetic versus intact limb on transtibial amputee long jump technique” (Nolan, Patritti, & Simpson, 2012).	To investigate kinematic differences in long jump technique in athletes with a unilateral transtibial ampution (TT) who take off from their prosthetic limb versus those who take off from their intact limb.	Two-dimensional sagittal plane kinematic analysis was performed on all athletes competing in the men’s Paralympic TT long jump finals. Five athletes took off from their prosthetic limb (TOprosth) and five from their intact limb (TOintact).	No differences were seen between the two groups in terms of jump distance, approach speed or vertical velocity at touch down. While in contact with the take-off board, the two groups gained a similar amount of vertical velocity.	Results were accurate and clear		L Nolan, Benjamin L Patritti and Kathy J Simpson

8	"Equilibrium and movement control strategies in trans-tibial amputees" (Viton et al., 2000).	This study was aimed at identifying changes in equilibrium and movement control strategies in trans-tibial amputees (TTA) related to both the biomechanical changes and the loss of afferent inflow	Each subject was asked to stand on the force plate with his feet 100mm apart, his hands behind his back and his eyes gazing at two electroluminescent diodes placed symmetrically 5m in front of the subject's eyes	Significant differences were found between TTA and controls in the duration of the weight transfer phase, in the length of the initial centre of pressure (CP) displacement and in the electromyographic (EMG) patterns		Weak novelty of the study	J-M. Viton, L. Mouchnino, M. L. Mille, M. Cincera, A. Delarque, A. Pedotti, A. Bardot And J. Massion
9	"Within-socket myoelectric prediction of continuous ankle kinematics for control of a powered transtibial prosthesis" (Farmer et al., 2014).	Here, they examined the ability of a nonlinear autoregressive model to continuously map the kinematics of a transtibial prosthesis and electromyographic (EMG) activity recorded within socket to the future estimates of the prosthetic ankle angle in three transtibial amputees	Model performance was examined across subjects during level treadmill ambulation as a function of the size of the EMG sampling window and the temporal 'prediction' interval between the EMG/kinematic input and the model's estimate of future ankle angle to characterize the trade-off between model error, sampling window and prediction interval	Deviations in the estimated ankle angle from the actual movement were robust to variations in the EMG sampling window and increased systematically with prediction interval. For prediction intervals up to 150 ms, the average error in the model estimate of ankle angle across the gait cycle was less than 6°.		Only three subjects were recruited in the study while more evidence need to be taken from more subjects	Samuel Farmer, Barbara Silver-Thorn, Philip Voglewede and Scott A Beardsley

10	"A new approach for the pistoning measurement in transtibial prosthesis" (Hossein Gholizadeh et al., 2011).	To introduce and evaluate a new simple method for measuring the pistoning between the soft liner and socket in transtibial prostheses	Five transtibial prostheses with Iceross silicone liner and shuttle lock were made for the subjects. The pistoning was measured between the liner and socket by a photographic method in single limb support on the prosthetic limb (full weight bearing), non-weight bearing and under three static axial loading conditions (30, 60 and 90 N).	This new method enabled us to measure the pistoning between the liner and prosthetic socket. The reproducibility of measurements in different trials of one session and between two sessions by two observers was shown to be high. The average of pistoning increased consistently by adding the loads.	The method used was inexpensiv e and easy		Hossein Gholizadeh, Noor Azuan Abu Osman, Ása Gulaug Lúvíksdóttir , Arezoo Eshraghi, Mojtaba Kamyab and Wan Abu Bakar Wan Abas1
11	"Transtibial prosthesis suspension systems: Systematic review of literature" (H Gholizadeh, Osman, Eshraghi, Ali, & Razak, 2014).	The review attempted to find scientific evidence pertaining to various transtibial suspension systems to provide selection criteria for clinicians.	Databases of PubMed, Web of Science, and ScienceDirect were explored to find related articles.	It Based on the selection criteria, 22 articles (15 prospective studies, and 7 surveys) remained. Sweat control was found to be a major concern with the available suspension liners. Donning and doffing procedures for soft liners are also problematic for some users, particularly those	Reviewing more than 300 articles		H. Gholizadeh , N.A. Abu Osman, A. Eshraghi, S. Ali, N.A. Razak

				with upper limb weakness. Moreover, the total surface bearing (TSB) socket with pin/lock system is favoured by the majority of amputees.			
12	“Comparison study of the prosthetics interface pressure profile of air splint socket and ICRC polypropylene socket for upper limb prosthetics” (Razak, Osman, Ali, Gholizadeh, & Abas, 2015).	Examining 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	Two F-socket sensors arrays were attached to the residual limb. The subject was asked to complete the following tasks: Normal position, stand in a normal position without conducting any motion and shoulder movements, flexion/ extension and abduction.	the interface pressure applied using ICRC polypropylene socket was maximize at the end distal of the limb and give more pressure contact to any shoulder movements. Conversely, while using air splint socket, the socket was able to auto-adjust for required socket fitting even for any change while doing shoulder movements.	Relevant results and benefits of the study		N.A. Abd Razak *, N.A. Abu Osman, S. Ali, H. Gholizadeh, W.A.B. Wan Abas

13	"Standing on slopes – how current microprocessor-controlled prosthetic feet support transtibial and transfemoral amputees in an everyday task" (Ernst et al., 2017)	to investigate to what extent these commercially available microprocessor controlled prosthetic feet support a natural posture while standing on inclines and which concept is most beneficial for lower limb amputees	subjects wore five different microprocessor-controlled prosthetic feet in addition to their everyday feet	Differences in the biomechanical parameters were observed between the different prosthetic feet and compared to the reference group for the investigated situations		Minimal number of subjects were recruited	Michael Ernst, Björn Altenburg, Malte Bellmann and Thomas Schmalz
14	"High energy spectrogram with integrated prior knowledge for EMG-based locomotion classification" (Joshi, Nakamura, & Hahn, 2015).	a spectrogram-based approach was developed to classify (EMG) signals for locomotion mode	Spectrograms for each muscle were calculated and summed to develop a histogram. If-else rules were used to classify test data based on a matching score	Classification error was <20% across all modes.			Deepak Joshi, Bryson H. Nakamura, Michael E. Hahn

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter discusses the processes performed in the body performance and motion analysis laboratory and begins to describe the device used to measure and process the EMG signal, the surface of the program used to control the device, the muscles that were tested, the description of the activities used in the experiment, the number of subjects and the explanation of the special cases. Data collection and analysis.

3.2. Technical Specification

3.2.1. Overview

The DELSYS TrignoTM Wireless EMG System as shown in Figure 3.1 is a device that enables researchers and specialist physicians to obtain the EMG signals from subjects and other types of signals related to biofeedback study in a reliable and very easy manner, which is classified as a physiological monitoring device (delsys.com, 2018).

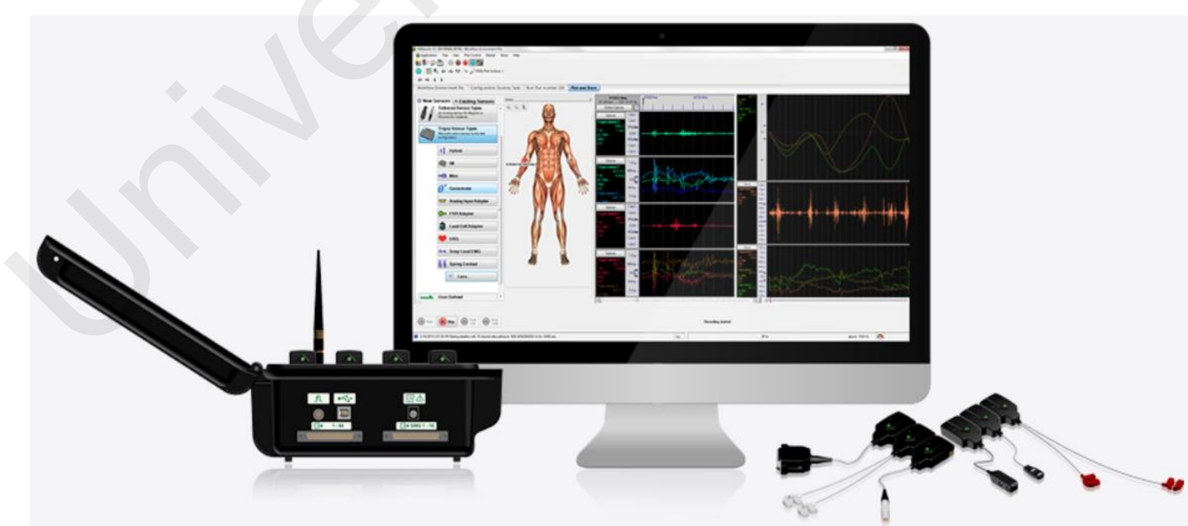


Figure 3.1: DELSYS TrignoTM Wireless EMG device (delsys.com, 2018)

The EMG sensors as shown in Figure 3.2 has many specifications, including a three-axis accelerometer, a very convenient transmission range of up to 20 meters so the subjects move inside the lab easily while the measurements are being taken, a rechargeable battery that operates for a minimum of seven continuous hours and others (delsys.com, 2018).

Figure 3.2: Wireless EMG 4-channel sensor (delsys.com, 2018)

Figure 3.3 clarifies the overview of the DELSYS Trigno wireless EMG instrument base station. Each base station is build-in with the following features; recharging cradle for 16 sensors, detachable antenna, high-speed USB communication with PC, convenient design to carry the device, 64-channel analog output connector (16 EMG, 48 ACC), communication and power feedback LEDs, full trigger capability (Start/Stop, Input/Output) and ± 5V analog output range (delsys.com, 2018).

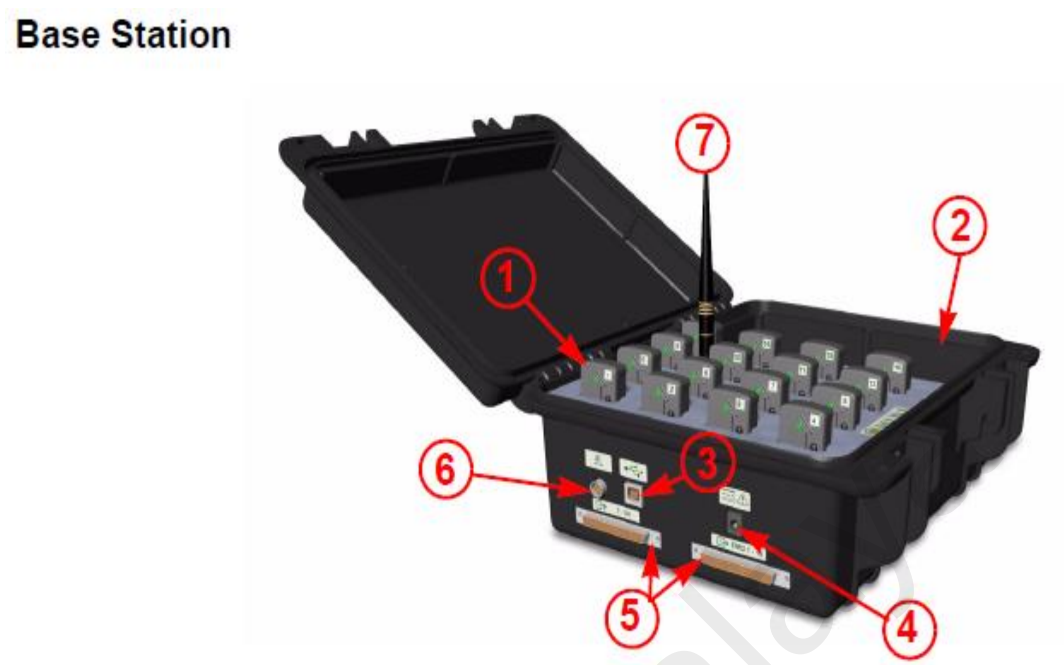


Figure 3.3: DELSYS Trigno wireless EMG instrument base station (delsys.com, 2018)

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.EMG work Software

Trigno systems are equipped with an insulated power supply of medical standard. The power supply is supplied with interchangeable country-specific plug adapters as shown in Figure 3.4 (delsys.com, 2018).

Figure 3.4: DELSYS Trigno wireless EMG Power Supply (International Medical Power Supply with plug adapter kit) (delsys.com, 2018)

3.2.2. Electrode placement and skin preparation

Figure 3.5 shows 4 silver strips at the bottom of the Trigno EMG Sensors. The function of these strips is to detect the EMG signal on the surface of the skin directly above the target muscle away from the tendons and edges of the muscle where the EMG sensor is installed on the skin with tape. It is important to direct these strips perpendicular to the direction of the muscle fibers. At the top of the sensor, there is a helping arrow to determine the direction as shown in Figure 3.6. The purpose of all these are to make sure to gain maximum signal capacity. Before starting the measurement and placing the sensor on the skin, the specialist must be sure to clean the skin from all of the oils produced by the skin or any layer of dead skin and then shave the site. Next, the EMG sensor is installed on the skin with tape. This process ensures the signal quality to be guaranteed good (delsys.com, 2018; Garikayi et al., 2018).

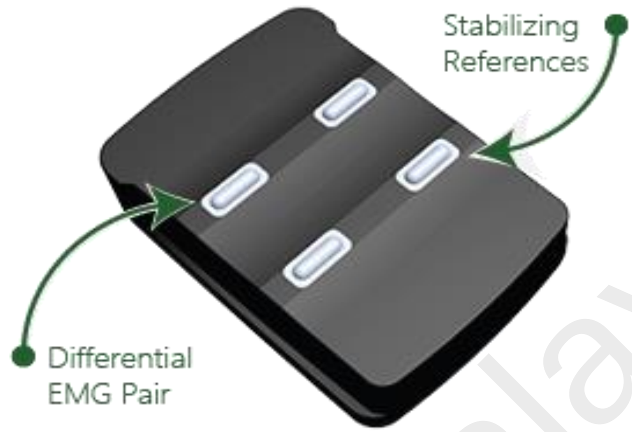


Figure 3.5: Bottom view of wireless EMG 4-channel sensor (delsys.com, 2018)

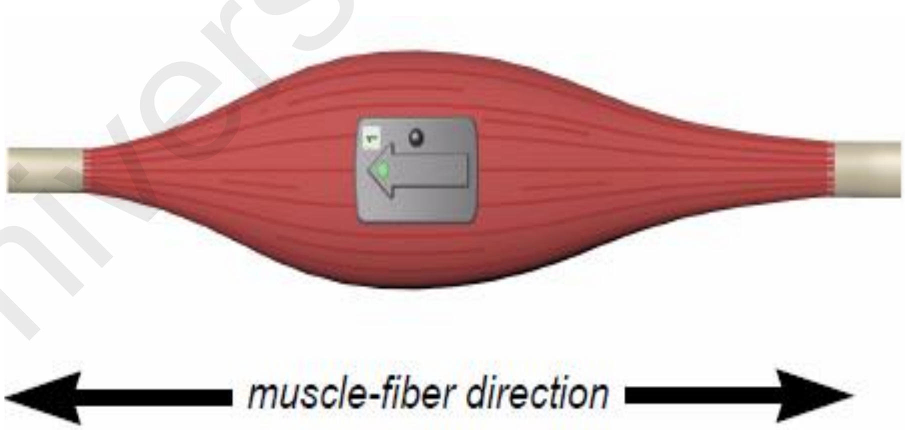


Figure 3.6: Direction of the EMG sensors on the skin (delsys.com, 2018)

3.3. Demographic data

3.3.1. Ethical Approval

This study was approved by the University Malaya Medical Center (UMMC) ethics committee (37912). The research has been done under the supervision of Certified Prosthetic and Orthotic CAT1.

3.3.2. Subjects

The surface electromyography signals were recorded from two below knee muscles; tibialis anterior (TA) and gastrocnemius lateral head (LG), and two above knee muscles; rectus femoris (RF) and biceps femoris (BF), of ten non-amputee subjects and two unilateral transtibial amputee subjects with different age, height, and weight during the five activities identified as simulating the daily activities of subjects, especially amputees subject. Activities conducted were as follows:

1- Strength of Muscles.
2- Flexion and Extension of Knee.
3- Gait cycle (normal walking).
4- Ascent Stairs.
5- Descent Stairs.

Subjects were divided as follows:

1. Ten non-amputees subjects: Five subjects from male category and five subjects from female category. One of these females was pregnant in her twenty-eighth weeks, and another female suffered from a very slight curvature of the spine which was not serious and did not affect the results of measurements. The subjects had no history of muscle pain,

trauma, discomfort, or a sequela relevant to the lower extremities. Participants were postgraduate students in Biomedical Engineering Department.

2- Two unilateral transtibial amputee (TTAmp) subjects:

TTAmp subject 1: 29 years old, male, energetic and independent person who practices his daily life as usual but with little difficulty because of his current situation of health as a unilateral transtibial amputee with the left leg and a transradial amputee with both left and right hands. He currently runs his own small business. In 2010 he was subjected to a 33-kV electric shock, causing third-degree burns on the body, and five days after the incident, the doctor decided to amputate both hands below the elbow and his left leg below the knee because of gangrene in his limbs, and five operations were performed. It took more than eleven months after the operation to experience the first prosthetic limb. Until now, two prostheses were used for 7 years, the most recent was a month ago or less and he is now using a pin lock prosthetic.

TTAmp subject 2: 26 years old, male, likes doing many activities. The subject is an independent person who practices his daily life as usual but with a lot of difficulties because of his current situation of health as a unilateral transtibial amputee at his left leg. He currently works in a call center. He suffered a motorcycle accident, and 46 days after the accident, the doctor decided to amputate his left leg below the knee because of infection in his limb and he was assured that the muscles of his leg below the knee were not active at all, and five operations were performed after that. It took one year after the operation to experience the first prosthetic limb. Until now, two prostheses were used for 6 years, the most recent was a month ago or less and he is using now a pelite prosthetic.

Table 3.2: TTAmp subject's measurements

Participants	G	Age (y)	Weight (kg)	Height (m)	BMI (kg/m^2)	Status	Left knee width (cm)	Length of left tibial (cm)	Length of left femoral (cm)
TTAmp S1	M	29	70	1.75	22.86	N	10	14	40
TTAmp S2	M	26	51	1.69	17.86	N	9.22	12	38

TTAmp S1,2= Transtibial Amputees Subjects. G= Gender. BMI = Body Mass Index.

M= Male. N= Normal.

Table 3.3: Non-amputees subject's measurements

Participants	G	Age (y)	Weight (kg)	Height (m)	BMI (kg/m^2)	Status	Other if any
S1	F	27	49	1.54	20.66	N	Pregnant in week 28, fetus weight is 1 kg
S2	F	28	49	1.52	21.20	N	N/A
S3	F	25	55	1.56	22.60	N	N/A
S4	F	29	63	1.64	23.42	N	A slight deviation in the spine
S5	F	28	58	1.55	24.14	N	N/A
S6	M	28	128	1.86	36.99	O	N/A
S7	M	28	78	1.72	26.36	OW	N/A
S8	M	27	84	1.76	27.11	OW	N/A
S9	M	25	83	1.74	27.41	OW	N/A
S10	M	23	65	1.70	22.49	N	N/A

Note: N= Normal. BMI = Body Mass Index. S= Non-amputee subject. O= Obesity. OW= Overweight. M= Male. F= Female. N/A= Not available.

3.4. The activities

Experiments were collected for five types of movement: 1- Strength muscles, 2- Flexion and extension muscles, 3- Gait (normal walking), 4- Ascending the stairs and 5- Descending the stairs. These activities were selected because they include the most important activities in daily life that are of particular interest to the TTAmp. Two tests were performed for each activity, test 1 (above the knee) for rectus femoris (RF) and biceps femoris (BF) muscles and test 2 (below the knee) for tibialis anterior (TA) and gastrocnemius lateral head (LG). Before starting data recording, the subjects were asked to perform some simple exercises to stimulate the target muscles to ensure satisfactory performance of the EMG signals. For each activity, normal subjects completed three successful trials, and the best trial was adopted and five trials for each amputee subject.

3.4.1. Strength muscles

This activity shows the maximum amount of force that muscles can generate. During test 1, the muscles targeted were above the knee rectus femoris (RF) muscle in anterior view and biceps femoris (BF) muscle in posterior view as shown in Figure 3.7. The strength muscles activity was required from all participants, including both the non-amputees and amputees. Three successful trials were recorded for each non-amputee subjects and five trials for each amputee subject to make sure to get the best possible EMG signal, because during the first or second recording the muscles may be unprepared.

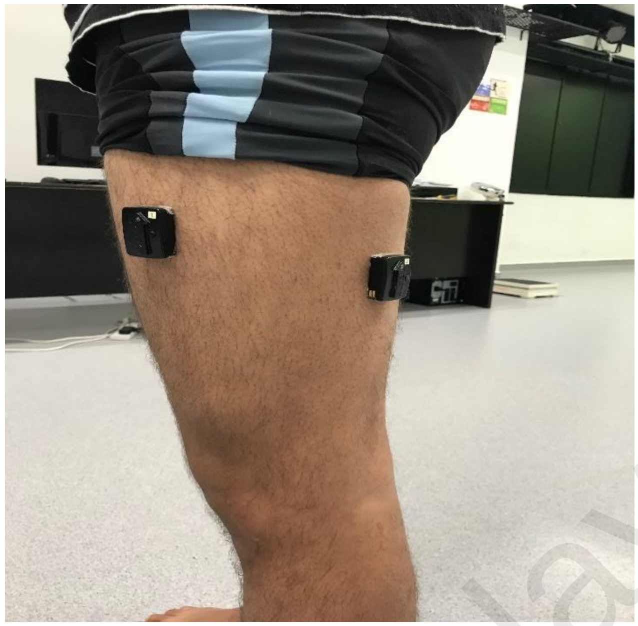


Figure 3.7: Muscles that were targeted above the knee (RF, BF) with male subject during strength muscles

During test 2, the muscles targeted were below the knee; tibialis anterior (TA) in anterior view and gastrocnemius lateral head (LG) muscle in posterior view as shown in Figure 3.8. All participants did the same activity.

Figure 3.8: Muscles that were targeted below the knee (TA, LG) with male subject during strength muscles

3.4.2. Flexion and Extension muscles (F&E)

During test 1, the muscles targeted were above the knee; rectus femoris (RF) muscle in anterior view and biceps femoris (BF) muscle in posterior view. Figure 3.9 shows the position of EMG electrodes and the participants. The flexion and extension activity of the knee was required from all participants, including both non-amputees and amputees' subjects. Three successful trials were recorded for each non-amputee subject and five trials for each amputee subject.

Figure 3.9: Muscles that were targeted above the knee (RF, BF) with (TTAmp S2) during (F&E)

During test 2, all participants did the same activity, but EMG electrodes were located on different muscles and for amputee subjects they did this activity without the prosthetic socket because the researcher couldn't put EMG sensor inside the socket due to it was too tight on the leg. The muscles targeted were below the knee as shown in Figure 3.10; tibialis anterior (TA) in anterior view and gastrocnemius lateral head (LG) muscle in posterior view.

Figure 3.10: Muscles that were targeted below the knee (TA, LG) with (TTAmp S2) during (F&E)

3.4.3. Gait (normal walking)

During test 1, the muscles targeted were above the knee; rectus femoris (RF) muscle in anterior view and biceps femoris (BF) muscle in posterior view. Figure 3.11 shows the position of EMG electrodes and the participants doing the gait (normal walking) activity with unspecified speed required from all, including both non-amputees and amputees' subjects. Three successful trials were recorded for each non-amputee subject and five trials for each amputee subject.

Figure 3.11: Muscles that were targeted above the knee (RF, BF) with TTAmp S2 during normal walking

During test 2, not all participants did the activity, but only the non-amputees subject because amputee subjects couldn't do this activity for two reasons, firstly because they couldn't put EMG sensor inside the socket during walking, due to it's too tight on the leg and the second one, they couldn't walk without their prosthetics. EMG electrodes were located on different muscles only for those who did the activity (non-amputees subjects). The muscles targeted were below the knee as shown in Figure 3.12; tibialis anterior (TA) in anterior view and gastrocnemius lateral head (LG) muscle in posterior view.

Figure 3.12: Muscles that were targeted below the knee (TA, LG) with male subject during normal walking

3.4.4. Ascending the stairs

In this activity too, amputees subject did not complete all trials, especially below the knee trials for the same reasons mentioned previously in gait (normal walking) activity.

During test 1, the muscles targeted were above the knee; rectus femoris (RF) muscle in anterior view and biceps femoris (BF) muscle in posterior view. Figure 3.13 shows the position of EMG electrodes and the participants doing the stair ascending activity with the unspecified speed with a height of 15.5cm and depth of 31cm. This activity was required from all, including both non-amputees and amputees subject. Three successful trials were recorded for each non-amputee subject and five trials for each amputee subject.

Figure 3.13: Muscles that were targeted above the knee (RF, BF) with (TTAmp S1 & TTAmp S2) during stairs ascending activity

During test 2, not all participants did the activity, only non-amputees subject did this activity because amputee subjects couldn't do this activity for two reasons as mentioned before. EMG electrodes were located on different muscles only for those who did the activity (non-amputees subjects). The muscles targeted were below the knee as shown in Figure 3.14; tibialis anterior (TA) in anterior view and gastrocnemius lateral head (LG) muscle in posterior view.

Figure 3.14: Muscles that were targeted below the knee (TA, LG) with male subject during ascending the stairs

3.4.5. Descending the stairs

In this activity too, amputees did not complete all trials, especially below the knee for the same reasons mentioned before in previous activities.

During test 1, Figure 3.15 shows the position of EMG electrodes and the participants doing the stair descending activity with the unspecified speed at the height of 15.5cm and depth of 31cm. This activity was required from all, including both non-amputees and amputees subject. The muscles targeted were above the knee; rectus femoris (RF) muscle in anterior view and biceps femoris (BF) muscle in posterior view. Three successful trials were recorded for each non-amputee subject and five trials for each amputee subject.

Figure 3.15: Muscles that were targeted above the knee (RF, BF) with (TTAmp S1 & TTAmp S2) during descending the stairs

During test 2, not all participants did the activity, just non-amputees subject did this activity because amputees subjects couldn’t do this activity for two reasons as mentioned before. EMG electrodes were located on different muscles only for those who did the activity (non-amputees subjects). The muscles targeted were below the knee as shown in Figure 3.16; tibialis anterior (TA) in anterior view and gastrocnemius lateral head (LG) muscle in posterior view.

Figure 3.16: Muscles that were targeted below the knee (TA, LG) with male subject during descent stairs

CHAPTER 4: RESULT AND DISCUSSION

4.1. Strength muscles

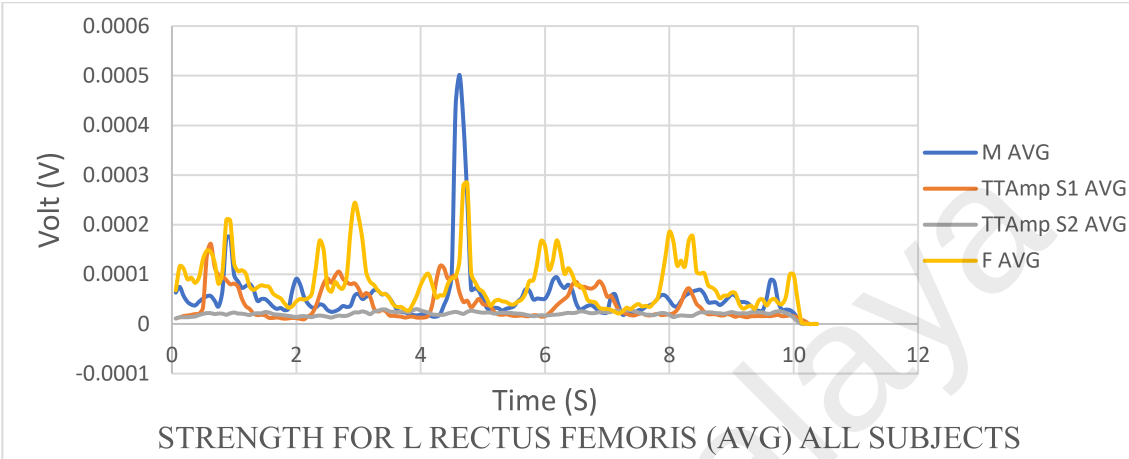


Figure 4.1: The average (AVG) of strength muscle activity for rectus femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

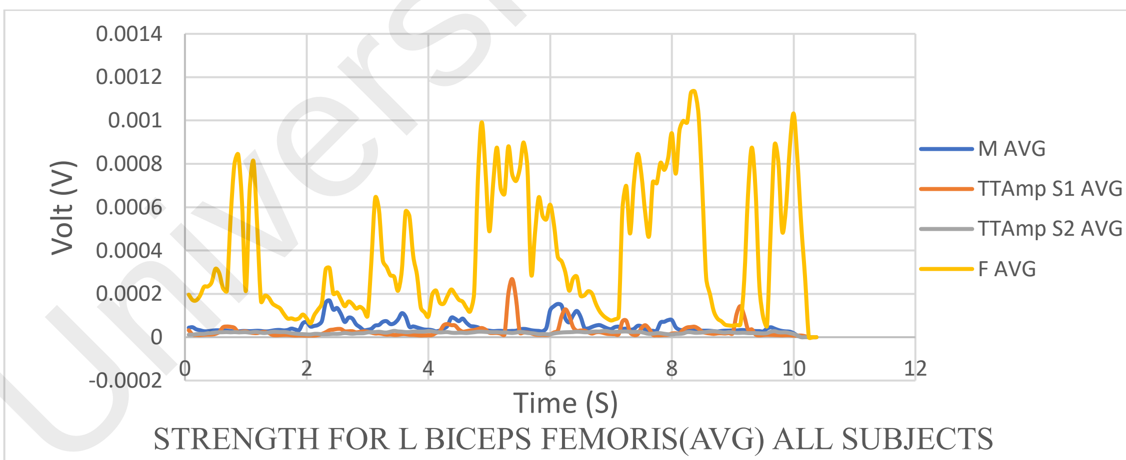


Figure 4.2: The average (AVG) of strength muscle activity for biceps femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

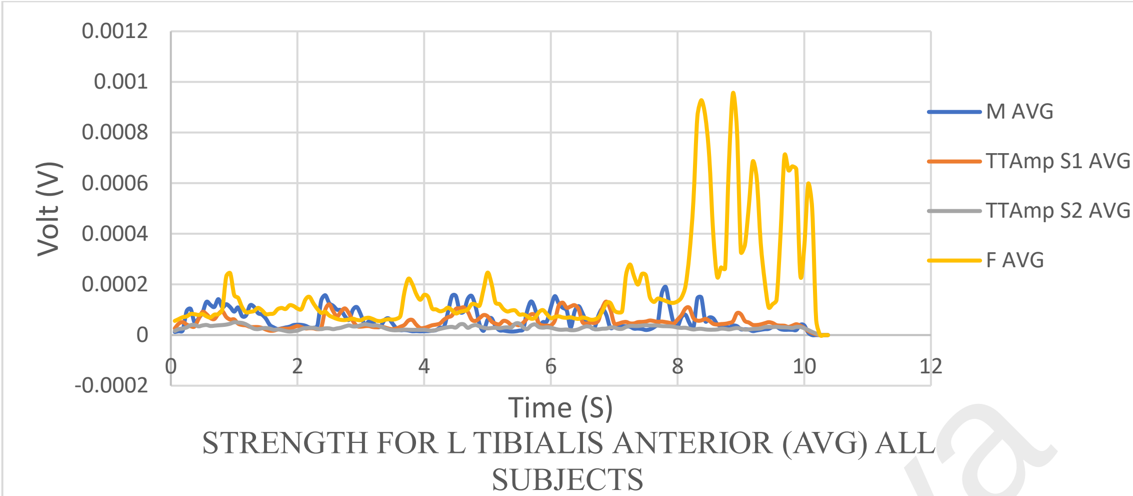


Figure 4.3: The average (AVG) of strength muscle activity for tibialis anterior muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

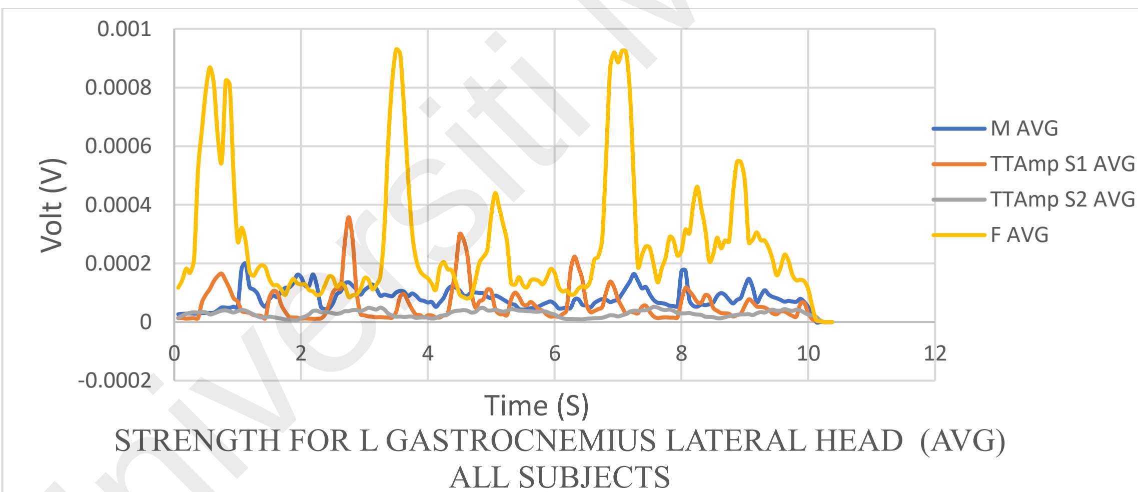


Figure 4.4: The average (AVG) of strength muscle activity for gastrocnemius lateral head muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

From Figure 4.1 until Figure 4.4 describe the first activity of the study which is the strength of muscles. Figure 4.1 demonstrates the differences of the average of rectus femoris muscles that were taken from five male (M) and five female (F) participants and two transtibial amputees (TTAmp S1), and (TTAmp S2) during muscles strength activity, while in another study by Stephanie Huang and He (Helen) Huang, ten (TTAmp) subjects were included (Huang & Huang, 2018), while by N.A. Abd Razak and N.A. Abu Osman, one subject was included in their study (Razak et al., 2015). The duration of the experiment to record EMG signals for each activity was ten seconds. In the figure, the average measurement for both male (M) and female (F) subjects of the rectus femoris muscle is shown for five males and five females respectively. In return, the average strength activity for rectus femoris muscle for amputee subjects (TTAmp S1), and (TTAmp S2) represents five trials for each one. The amputee subjects had same starting point of the action which was nearly to zero volts (V), but male and female subjects have different starting point of the action because they started earlier. Almost all participants observed a similar pattern, while the transtibial amputee S2 (TTAmp S2) showed the lowest value during the strength of rectus muscles. Male (M) subjects got the maximum value of average for strength activity of rectus femoris muscle. However, male and female signal subjects were higher than those of amputees (TTAmp S1) and (TTAmp S2).

In Figure 4.2, it focuses on the biceps femoris muscles, in which female (F) participants have the maximum value of strength which compared to the other participants, and also has better value than rectus femoris muscles. Transtibial amputee s1 (TTAmp S1), showed a slight improvement in muscle response compared to rectus muscle. There was no improvement in the transtibial amputee s2 (TTAmp S2) signal, so was in rectus femoris muscle where the signal was very weak. Male (M) participants signal wasn't better in biceps femoris muscle, same as the signal in rectus femoris muscle.

Based on Figure 4.3, almost all the signals expressed by male (M), transtibial s1 (TTAmp S1) and transtibial s2 (TTAmp S2) described as a similar average signal of the strength activity for tibialis anterior muscles with small differences between them. The average of female (F) signal value was the maximum value in this figure.

Based on Figure 4.4, the female (F) subjects once again showed the maximum average value at strength activity of gastrocnemius lateral head muscle. For male (M) subjects, almost all the average for strength activity of the above and below knee muscles (biceps femoris, tibialis anterior and gastrocnemius lateral head) were in the same range except in rectus muscle. There was a marked improvement in the signal in the muscle of transtibial s1 (TTAmp S1), while the signal of the second subject in all of the muscle signal was closer to zero volt (V). Female (F) participants presented the highest values for all EMG signals of muscles due to the less fat between the skin and the surface of the muscles for female subjects that facilitated to detect the sensor accurately, while male (M) subjects and amputees showed between medium and weak EMG signals value.

4.2. Flexion & Extension

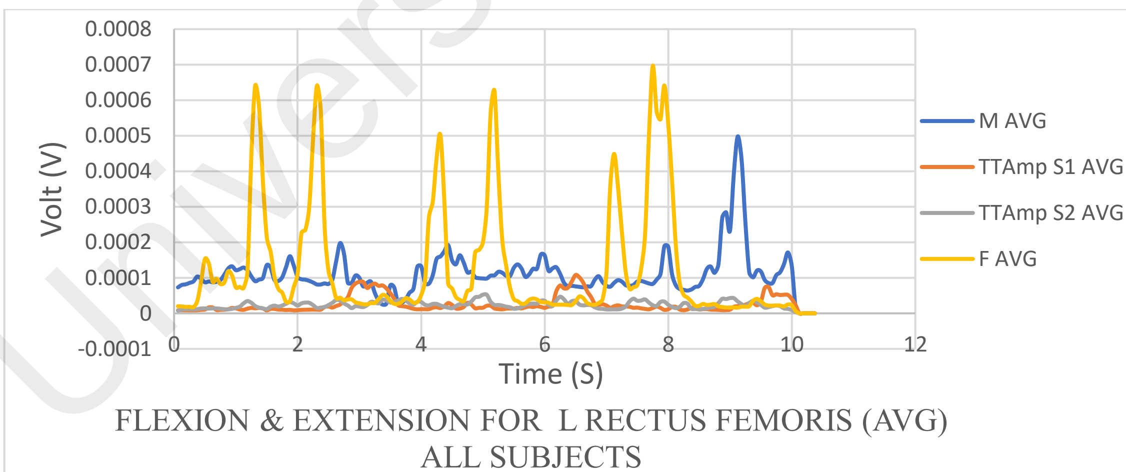


Figure 4.5: The average (AVG) of flexion and extension muscle activity for rectus femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

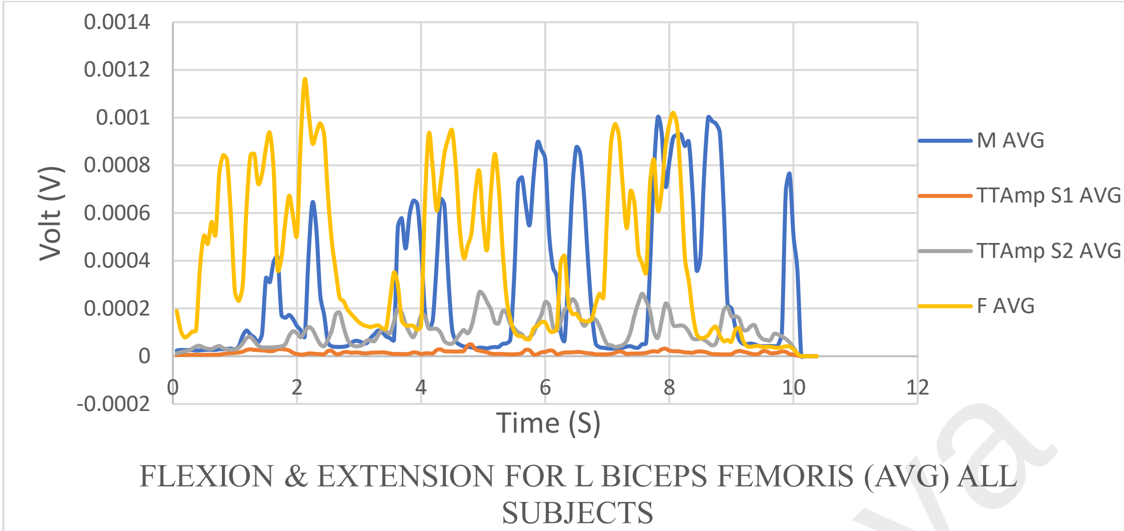


Figure 4.6: The average (AVG) of flexion and extension muscle activity for biceps femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

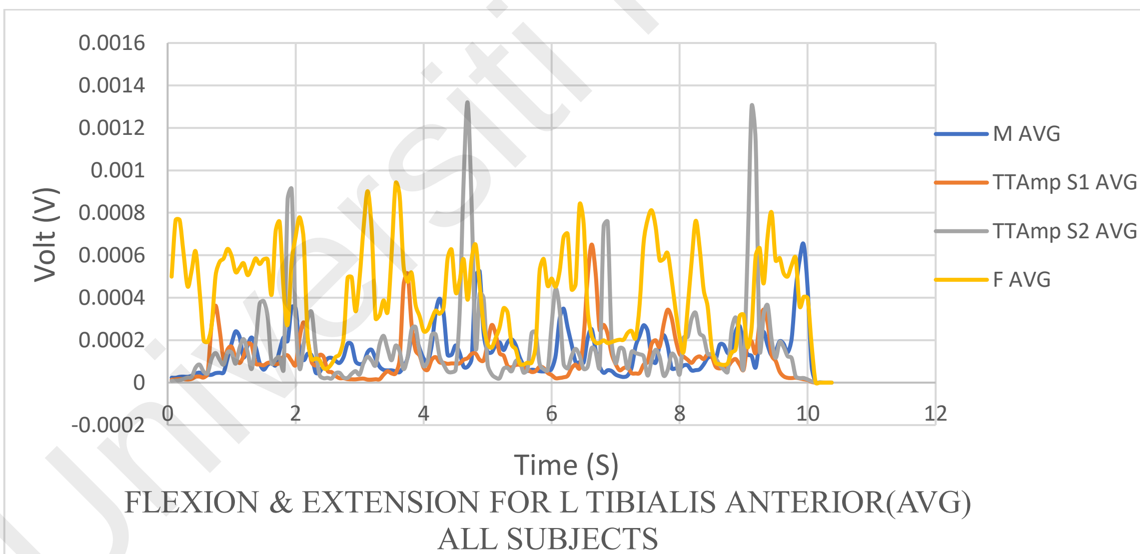


Figure 4.7: The average (AVG) of flexion and extension muscle activity for tibialis anterior muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

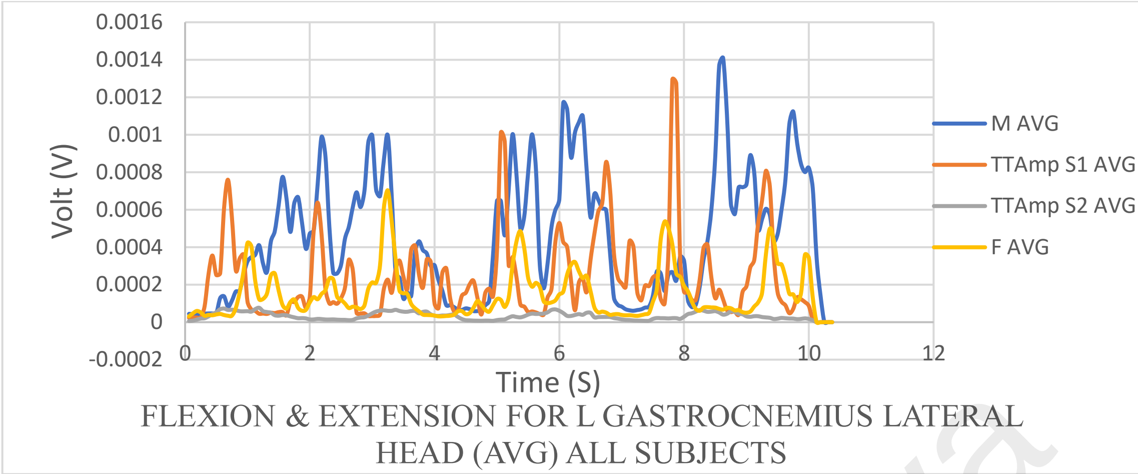


Figure 4.8: The average (AVG) of flexion and extension muscle activity for gastrocnemius lateral head muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

Figure 4.5 until Figure 4.8 presented the second activity of the study that is flexion and extension of the knee joint. Based on Figure 4.5, the signals of average for flexion and extinction muscle activity for rectus femoris from female (F) and male (M) participants were better than amputee subjects (TTAmp S1) and (TTAmp S2) signals, in which the female (F) signal was the maximum value. Until now, there were no improvements in (TTAmp S2) signals, which showed the same result as in previous activity.

Figure 4.6 explains that, it was the first time for transtibial amputee s2 (TTAmp S2) to produce clear signal, while transtibial amputee S1 (TTAmp S1) signal was very weak for the average of flexion and extension muscle activity for biceps femoris muscle. Female (F) and male (M) participants were better than amputee subjects (TTAmp S1) and (TTAmp S2) signals, in which female (F) signal was the maximum value. Apart from that, the signals for (M) and (F) subjects were better in biceps femoris compared to rectus femoris.

Based on Figure 4.7, unlike previous activities, transtibial amputee s2 (TTAmp S2) had the maximum value of the average of flexion in extension muscle activity for tibialis anterior muscle, while, the female (F) value was the second. Male (M) and transtibial S1 (TTAmp S1) subjects showed almost the same range value.

In Figure 4.8, the average of flexion in extension muscle activity for gastrocnemius lateral head muscles from male (M) and transtibial s1 (TTAmp S1) subjects were the highest signals, while, the female (F) signals were observed as good signals too. Unfortunately, transtibial s2 (TTAmp S2) signal was very week comparing with his signal in tibialis anterior muscle.

4.3. Gait (normal walking)

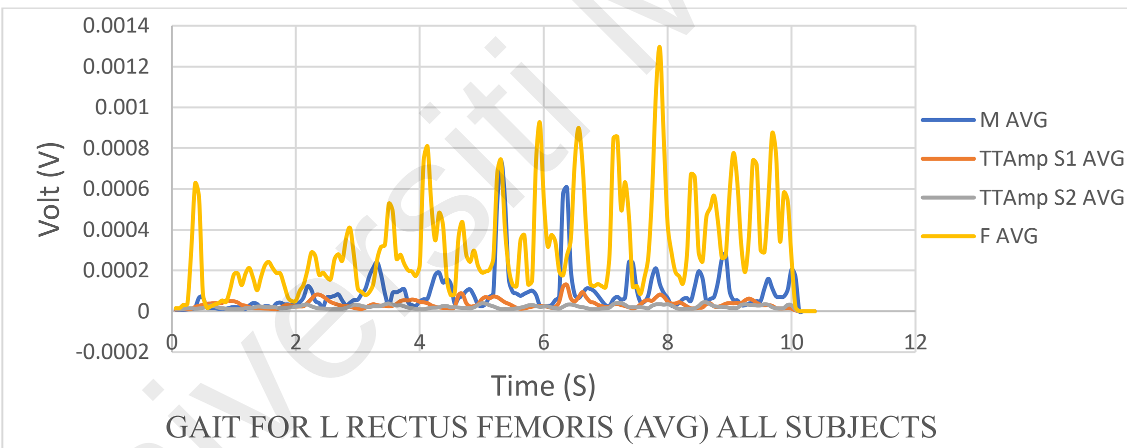


Figure 4.9: The average (AVG) of gait (normal walking) activity for rectus femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

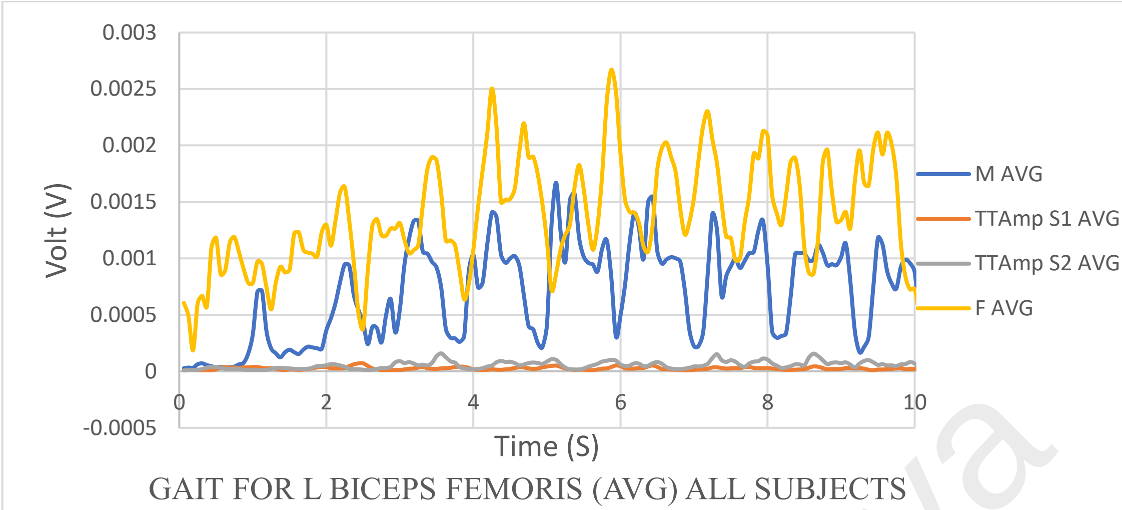


Figure 4.10: The average (AVG) of gait (normal walking) activity for biceps femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

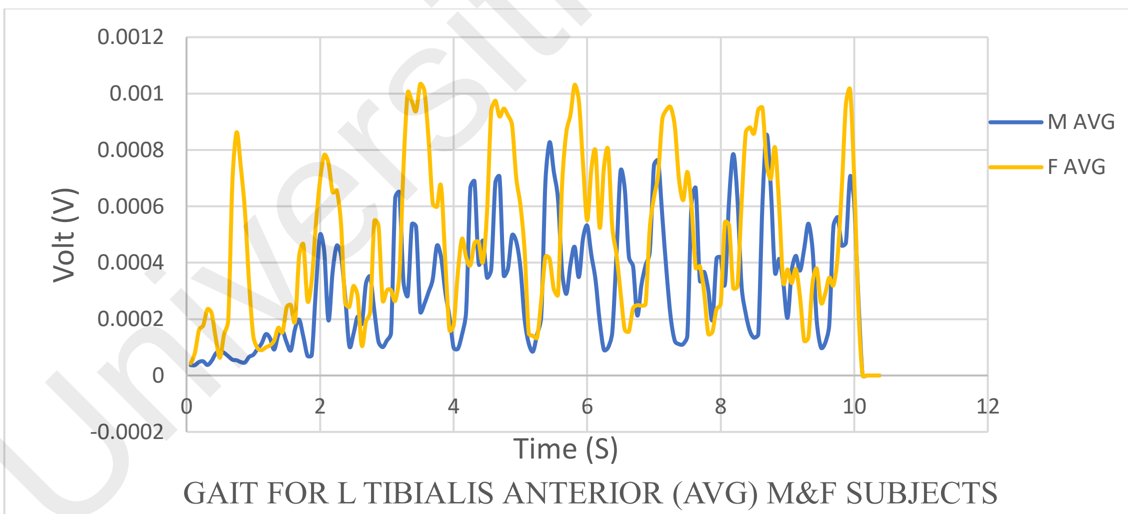


Figure 4.11: The average (AVG) of gait (normal walking) activity for tibialis anterior muscles from male subjects (M) and female subjects (F)

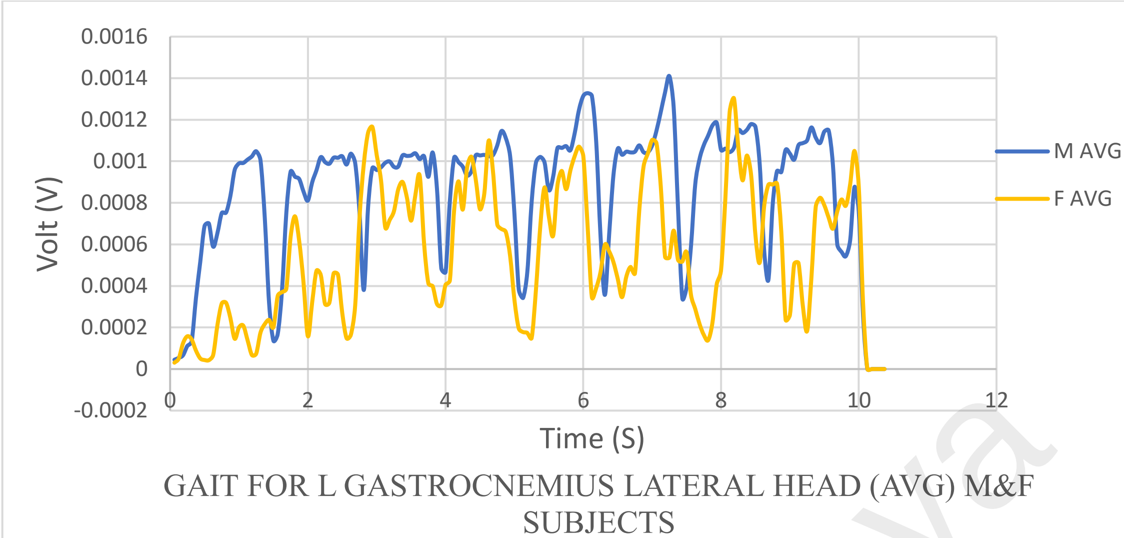


Figure 4.12: The average (AVG) of gait (normal walking) activity for gastrocnemius lateral head from male subjects (M) and female subjects (F)

Figure 4.9 until Figure 4.12 presented the third activity of the study that is gait cycle (normal walking). In Figure 4.9, it showed that an average amputee subjects (TTAmp S1 & S2) signal for normal waking activity for rectus femoris muscle, which were very low EMG signals. The signals for male (M) and female (F) subjects were better than other subjects.

Based on Figure 4.10, the average amputee subjects (TTAmp S1 & S2) signal for normal waking activity for biceps muscle was similar as rectus muscle. While the signals for male (M) and female (F) subjects were better than other subjects. Also, there was a marked improvement on the EMG signal for the non-amputee subjects. In other study, they recorded the EMG signals from three muscles at below knee; tibialis anterior, gastrocnemius medial head, gastrocnemius lateral head and four above knee muscles; vastus lateralis, rectus femoris, biceps femoris, and gluteus medius. During treadmill walking activity in a certain condition, EMG signals were recorded from the interior surface of the prosthetic socket for the muscles below the knee and for above knee. The result of this study was that muscles in the residual limb for amputee subjects gave more reliable signals than non-amputees (Huang & Ferris, 2012). For the muscles below the knee, this activity, ascending and descending the stairs were applied only on to non-amputee subjects, due to the fact that amputees subject couldn't do this activity for two reasons, firstly because EMG sensor couldn't be placed inside the socket during walking as it was too tight on the leg and the second reason was because they couldn't walk without their prosthetics. So, the comparison was only between male (M) and female (F) subjects. Based on the Figures 4.11 & 4.12, they showed that average of gait (normal walking) activity for tibialis anterior and gastrocnemius lateral head muscles for male (M) and female (F) participants have similar peak values. Female (F) subjects have the maximum values amongst all subjects.

4.4. Ascending the stairs

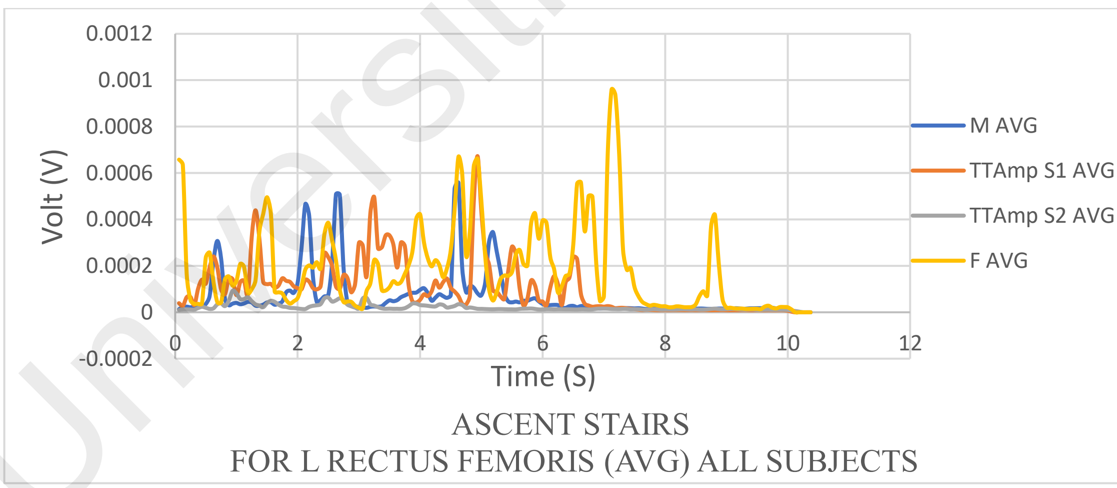


Figure 4.13: The average (AVG) of ascending the stairs activity for rectus femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

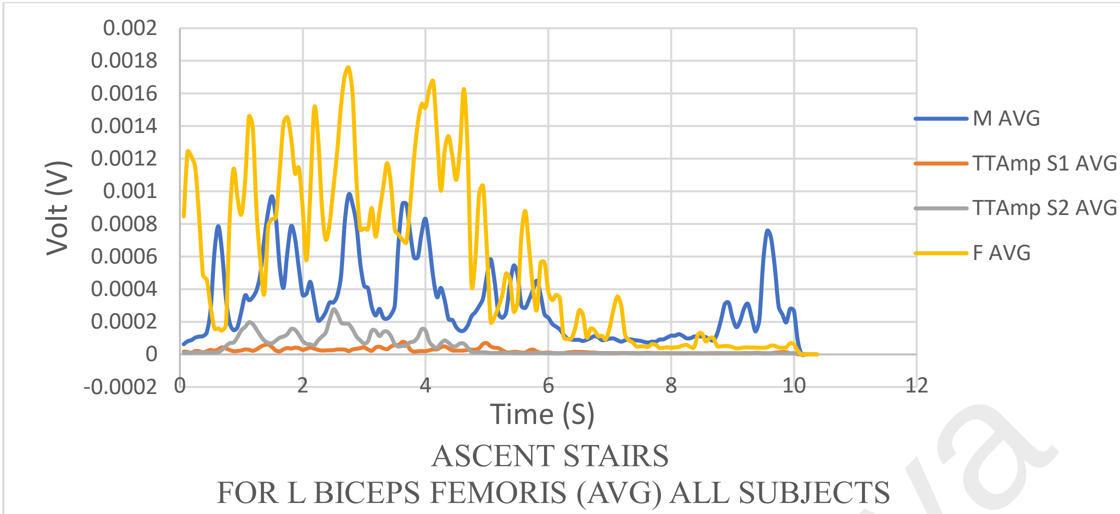


Figure 4.14: The average (AVG) of ascending the stairs activity for biceps femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

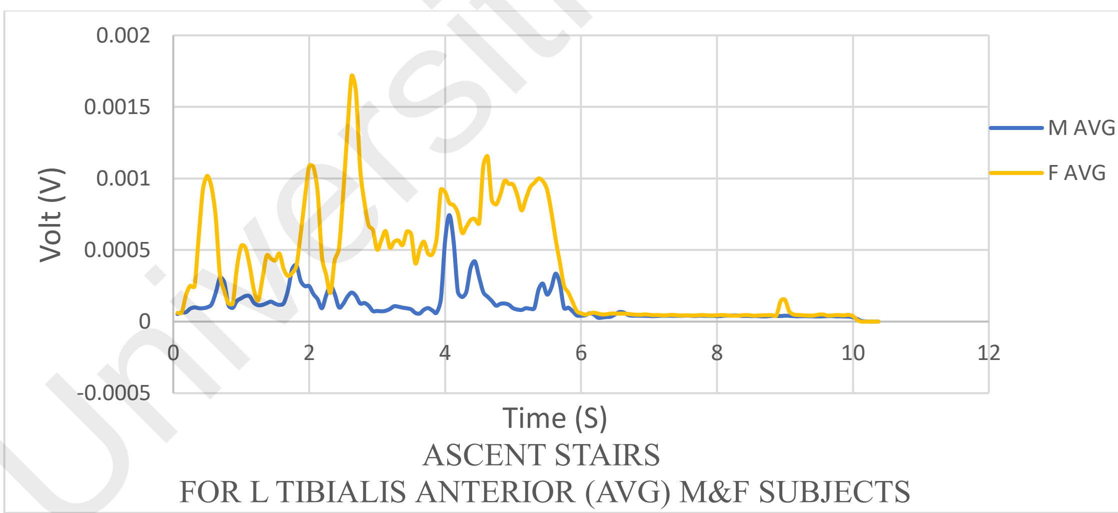


Figure 4.15: The average (AVG) of ascending the stairs activity for tibialis anterior muscles from male subjects (M) and female subjects (F)

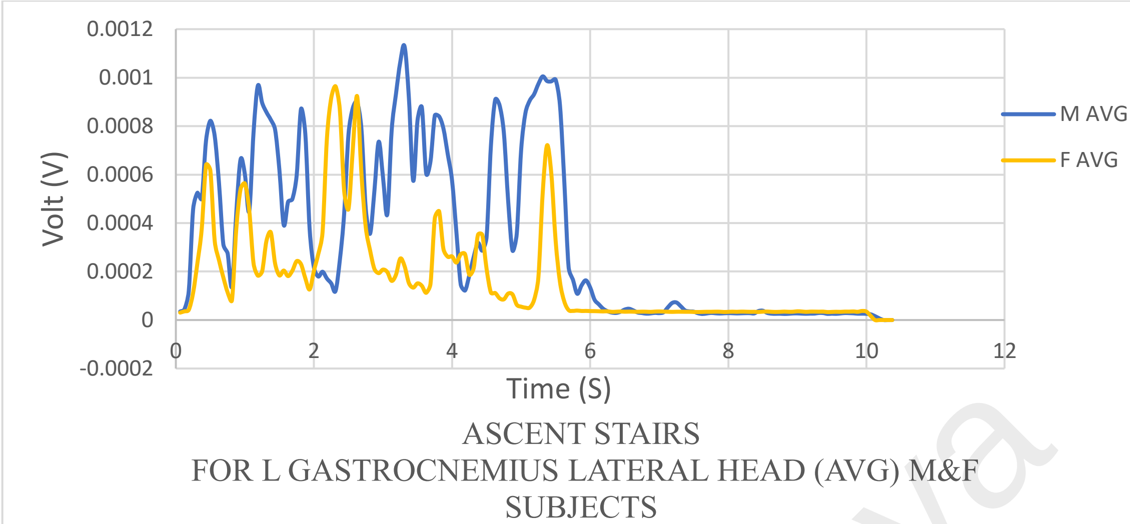


Figure 4.16: The average (AVG) of ascending the stairs activity for gastrocnemius lateral head muscles from male subjects (M) and female subjects (F)

In agreement with other study by Nicole G. Harper, it was said that this activity is very important as it is a daily activity that may be associated with everyone. That six-point walk in ascending the stairs is illustrated here as (1) weight approval, (2) pull-up, (3) forward continuance, (4) push-up, and others (Harper, Wilken, & Neptune, 2018).

Figure 4.13 until Figure 4.16 presented the fourth activity of the study that is ascending the stairs activity. Based on Figure 4.13, female (F) subject showed the maximum value of the average of ascending stairs activity for rectus femoris muscle. Transtibial amputee s1 (TTAmp S1) and male (M) participants showed similar pattern. Transtibial amputee s2 (TTAmp S2) had very small value comparing to other subjects.

Figure 4.14 illustrates the average of ascending the stairs activity for biceps femoris muscle. Transtibial amputee s2 (TTAmp S2)'s signal was very weak and almost close to zero, but transtibial amputee s1 (TTAmp S1)'s signal was better. Male (M) and female (F) subjects signal were better than amputees signal.

As mention before, there was no data for below knee muscles with this activity. Based on Figure 4.15 and 4.16, female (F) and male (M) subjects signal were similar, in Figure 4.15, female (F) subject signal was better than male (M), but in Figure 4.16, male (M) signal was better.

4.5. Descending the stairs

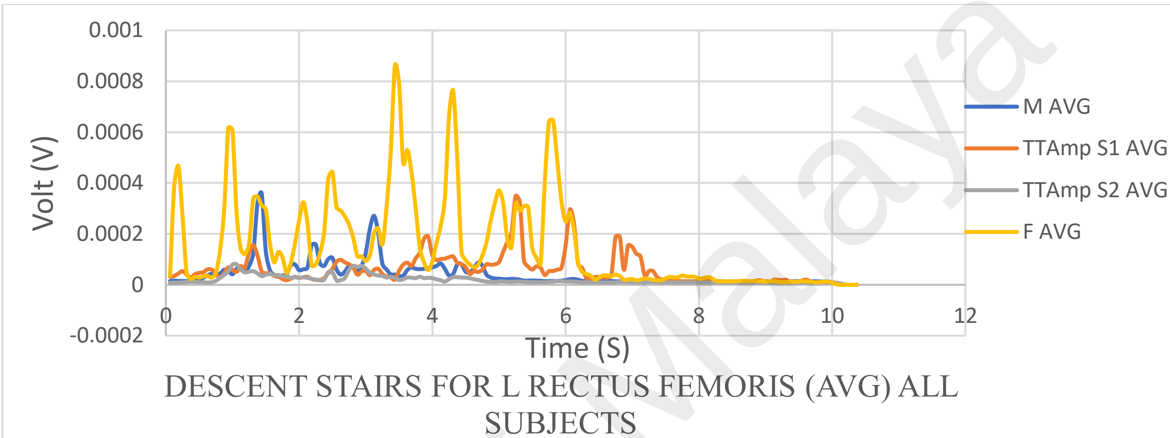


Figure 4.17: The average (AVG) of descending the stairs activity for rectus femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

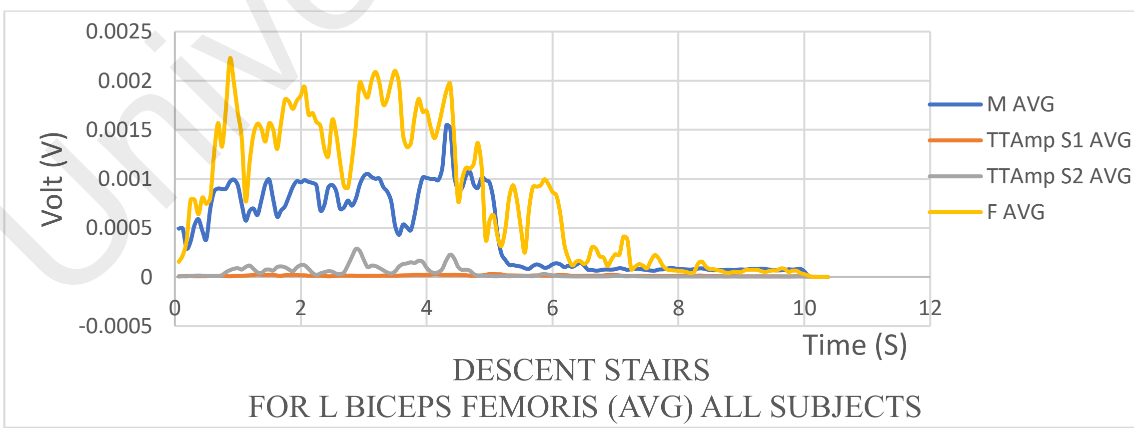


Figure 4.18: The average (AVG) of descending the stairs activity for biceps femoris muscles from male subjects (M), female subjects (F), and two transtibial amputee subjects (TTAmp s1) and (TTAmp s2)

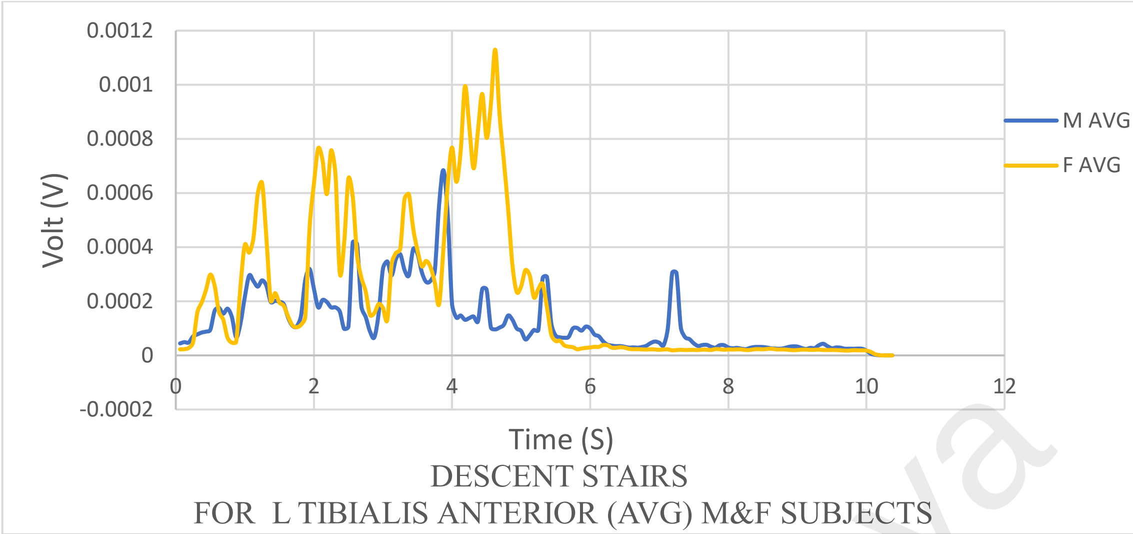


Figure 4.19: The average (AVG) of descending the stairs activity for tibialis anterior muscles from male subjects (M) and female subjects (F)

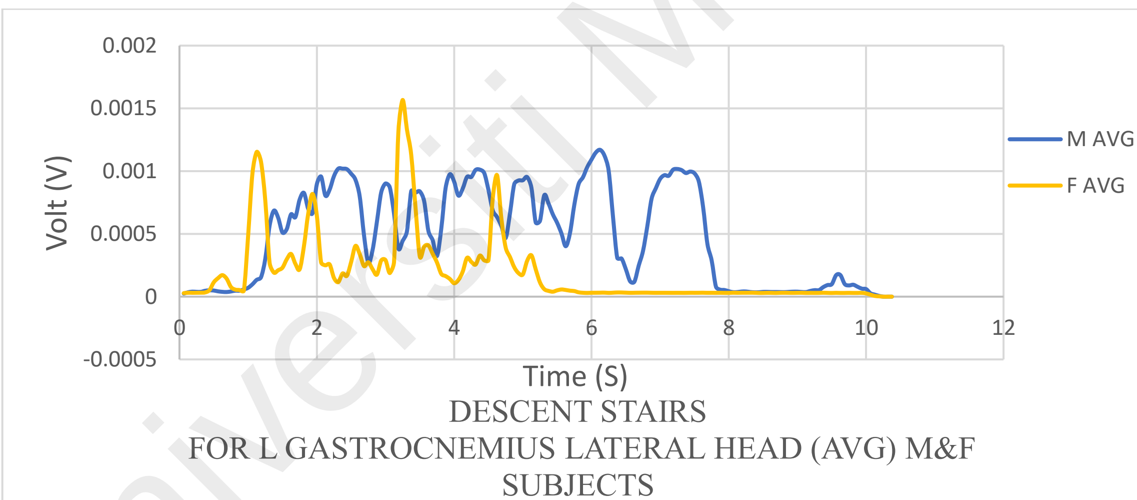


Figure 4.20: The average (AVG) of descending the stairs activity for gastrocnemius lateral head muscles from male subjects (M) and female subjects (F)

No specific speed was fixed for these activities, but it was determined by the abilities of each subject. In previous study, measurements were also taken while subjects were walking at self-selected speed. The number of amputees were ten people, and more than ten trials were made to secure five of them for the residual limb and five for the other normal limb (the other foot) (Nakajima, Yamamoto, & Katsuhira, 2018). While in this study there were only five trials for amputees and three trials for the non-amputee subjects, where one trial was chosen as the strongest signal.

Figure 4.17 until Figure 4.20 presented the last activity of the study that is descending the stairs activity. Figure 4.17 illustrates the average of descending the stairs activity for rectus femoris muscles. Transtibial s1 (TTAmp S1) and male (M) subjects had similar value. Transtibial s2 (TTAmp S2) had the lowest value comparing to other subjects. Female (F) subject had the maximum value amongst all subjects in above and below the knee in Figure 4.17, 4.18, 4.19 and 4.20.

Based on Figure 4.18, it shows that the average of descending the stairs activity for biceps femoris muscle. Transtibial s1 (TTAmp S1) signal was close to zero-volt, while transtibial s2 (TTAmp S2) had a good signal but still lower than male (M) and female (F) subjects.

Figure 4.19 and 4.20 show the average of descending the stairs activity for tibialis anterior and gastrocnemius lateral head muscles for male (M) and female (F) subjects only. Female (F) subject had the maximum values for both figures.

CHAPTER 5: CONCLUSION

5.1. Conclusion

The project was set out to investigate the best positional for EMG parameter for transtibial prosthetic and place out the socket for lower limb amputees, with the recent powered lower limb prosthesis that includes myoelectric sensors within the socket. In this study, the surface electromyography (EMG) signals were recorded from two below knee muscles; tibialis anterior (TA) and gastrocnemius lateral head (LG), and two above knee muscles; rectus femoris (RF) and biceps femoris (BF), during the conduct of 5 activities; strength muscles, flexion and extension, gait cycle (normal walking), descending the stairs and ascending the stairs. The study found that during all activities, below knee muscles were better with EMG activity than above knee muscles for the transtibial amputee, while, the biceps femoris muscle has been highly efficient in most activities for normal subjects. For example, it was found that some muscles are good at some activities and are not useful in others, such as strength muscles activity for rectus and biceps femoris muscles which is more useful for normal subjects, while, the tibialis anterior and gastrocnemius lateral head are more active for amputee subjects. During flexion and extension activities for rectus and biceps femoris muscles, it is found to be more useful for normal subjects, while the tibialis anterior and gastrocnemius lateral head are more active for amputee subjects. Also, during gait (normal walking) activity for rectus and biceps femoris muscles, it is more useful for normal subjects, while these muscles were found to be useless for amputee subjects. During ascending and descending the stairs activities for rectus and biceps femoris muscles it is useful for normal subjects. Hence, because of these differences in muscle efficiency to perform activities, it is more useful if the amputee is able to control the power prosthetic with EMG sensor outside the socket by placing it on the useful muscle for the user.

5.2. Study limitations

The main drawbacks of this study were limited to several things. This study intended to increase the number of amputees compared to other previous studies. Apart from that, the number of activities selected for this study also needed to be increased to obtain more accurate results that is hoped to achieve the objectives and purpose of this study more efficiently. It should be borne in mind that there is a need to synchronize the amputation criteria from one truncated subject to another. The most important criteria that must be taken care of are stump size, stump length, level of amputation and others.

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