THE STUDY OF EMG PARAMETERS OF TRANS-TIBIAL AMPUTEES FOR WALKING WITH DIFFERENT SPEEDS

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**FACULTY OF ENGINEERING
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THE STUDY OF EMG PARAMETERS OF TRANS-TIBIAL AMPUTEES FOR WALKING WITH DIFFERENT SPEEDS

ABSTRACT

The chief goal of the rehabilitation treatment is to ascertain the trans-tibial amputee can walk on top smoothly. The study aim was to determine the effects of the treadmill walking with three different speeds, on EMG parameters for the trans-tibial amputee and healthy-bodied. Wireless EMG sensors and treadmill instrument had used to fulfil the aim of this study. The investigation mission was to walk along the treadmill with three different speeds {2, 3 and 4 km/h}. Twelve subjects were contributory in this study, ten healthy-bodied and two unilateral trans-tibial amputees. EMG parameters had utilised to record EMG patterns of the above-knee muscles; rectus femoris muscle and biceps femoris muscle, during the walking activity on the treadmill at three different speeds. The results of EMG patterns had compared between the amputated limb and a sound limb. Healthy-bodied subjects demonstrated asymmetry EMG patterns in rectus femoris muscle and biceps femoris muscle during the walking speeds. While the trans-tibial amputee subjects had displayed symmetry EMG patterns amongst a sound leg and an amputated leg with little differences. Moreover, the results indicate the muscle activity was highly affected due to walking along the treadmill at three different speeds. EMG peak amplitude; wrists and biceps femoris muscles have demonstrated a highly notable impact across three different velocities. Due to subjects' conditions, since amputations, medication, stress and overweight considered factors affected the EMG patterns. Consequently, as the walking level in the trans-tibial amputee considers a significant functional requirement. We might employ the outcomes of this investigation to assist in the rehabilitation treatment of the trans-tibial amputee, by considering the distance and maximum speed while using the prosthesis.

Keywords: Walking; treadmill; unilateral trans-tibial amputee; electromyographic.

THE STUDY OF EMG PARAMETERS OF TRANS-TIBIAL AMPUTEES FOR WALKING WITH DIFFERENT SPEEDS

ABSTRAK

Matlamat utama rawatan rehabilitasi adalah untuk memastikan amputasi trans-tibial dapat berjalan seperti sedia kala. Tujuan kajian ini dijalankan adalah untuk menentukan hubungan antara kesan berjalan di atas treadmill pada kelajuan berbeza terhadap parameter EMG untuk amputees trans-tibial dan subjek yang sihat. Sensor EMG tanpa wayar dan instrumen treadmill digunakan untuk memenuhi tujuan kajian ini. Misi penyelidikan adalah berjalan kaki di atas treadmill dengan tiga kelajuan berbeza iaitu {2km /j, 3km / j dan 4km / j}. Sebanyak dua belas subjek telah terlibat dalam kajian ini, sepuluh daripadanya merupakan kategori subjek yang sihat, manakala dua lagi subjek mempunyai trans-tibial amputasi unilateral .Parameter EMG telah digunakan untuk merakam pola EMG otot bahagian peha aktiviti berjalan kaki di atas treadmill pada tiga kelajuan yang berbeza, iaitu ; otot rectus femoris dan otot biceps femoris. Keputusan corak EMG telah dibandingkan antara anggota yang dipotong dan yang normal. Subjek yang sihat menunjukkan corak EMG yang tidak sekata pada kedua-dua otot peha, Manakala, subjek trans tibial amputee menunjukkan corak EMG simetri pada kaki yang normal dan hanya terdapat sedikit perbezaan pada bahagian yang dipotong. Selain itu, keputusan menunjukkan bahawa aktiviti otot sangat terjejas apabila berjalan di atas treadmill pada tiga kelajuan yang berbeza. Keputusan mendapati amplitud puncak EMG pada otot bahagian peha telah menunjukkan kesan yang sangat ketara pada kelajuan yang perlahan dan pantas,. Hal ini disebabkan oleh faktor ubat, tekanan dan berat badan berlebihan yang boleh mempengaruhi corak EMG. Oleh hal yang demikian, hasil kajian ini memainkan peranan yang penting dalam merancang pembuatan prostesis yang baharu.

Kata kunci: Berjalan; treadmill; amputasi trans-tibial; elektromyografik.

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LIST OF SYMBOLS AND ABBREVIATIONS

TTA	Trans-Tibial Amputee
HB	Healthy-Bodied
EMG	Electromyography
BFM	Biceps Femoris Muscle
RFM	Rectus Femoris Muscle
GRF	Ground Reaction Force
COG	Centre of Gravity
SOL	Soleus Muscle
PTB	Patella Tendon Bearing
TSB	Total Surface-Bearing
M	Male
F	Female
ICF	International Classification of Functioning
ISO	International Standard Organization
TF	Trans-femoral
TS	Trans-tibial
AVG	Average

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Trans-tibial amputation (TTA) is conceived as a form of physical disability. According to the rating of the International Classification of Functioning (ICF), TTA impairs the body structures which lead to the participation restriction and the activity limitation (WHO, 2011). There are two cases of limb loss: first represents an acquired amputation, which occurs due to the surgery, injury or disease. The second represents congenital amputation, which appears at birth (Bello et al., 2013). According to the WHO (2011) the percentage of trans-tibial amputations from the total amputations account for approximately 84%, while the trans-femoral amputations around 16% (Figure 1.1). The trans-tibial amputations in the Western countries account for around 80% - 90% of vascular-diseases like uncontrolled diabetes (Ash et al., 2013). Diabetes patient is likely exposed to the significant risk of trans-tibial amputation 10 - 30 times more than the intact people (Grimmer et al., 2017). According to Atri et al. (2017) the diabetes amputees for around 20% - 50% will probably call for the second amputation within 1-3 years. While the 50% amputees have to undergo another amputation within 5 years.

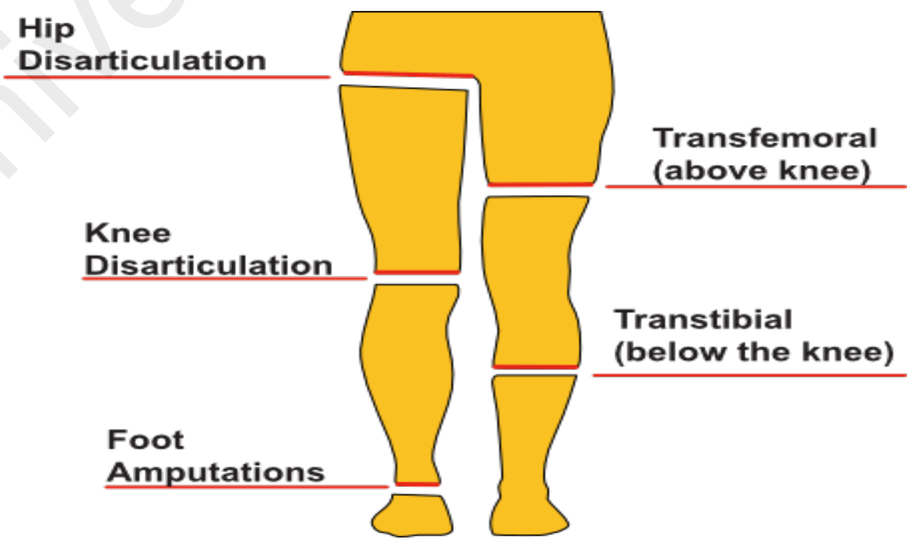


Figure 1.1: Amputation Classification (Prosthetics, 2017).

Amputation was considered a society significant challenge, as well as the psychological influence and physical impact affected the amputees (Bello et al., 2013). In addition, the worldwide healthcare sectors encounter a significant challenge due to the massive cost increases in amputations. It was recorded in the United States the annual cost for amputations around 4.3 billion USD (Duval, 2011). Post amputations, the primary target of the amputees' rehabilitation treatment is to retrieve the daily life activities, by enhancing their independence and mobility. Therefore, the trans-tibial amputee is prescribed the prosthetic limb to recover the mobility. The prosthesis is "externally applied device consisting of a single component or an assembly of components used to replace completely, or in part, an absent or deficient lower or upper-limb segment" (ISO, 1989). Frequently, the trans-femoral prosthesis substitutes the missing above-knee limb (Figure 1.2). While the trans-tibial prosthesis surrogate the missing below-knee limb (Figure 1.3). Broadly, the prosthesis components contain a socket, interface systems, pylon, joints, foot and terminal devices. The prosthesis limb should suit the necessities of the amputees refer to their amputation level and daily activities. Social integration and independence of amputees remain the crucial priority of providing a high-quality prosthetic (Arifin et al., 2017).

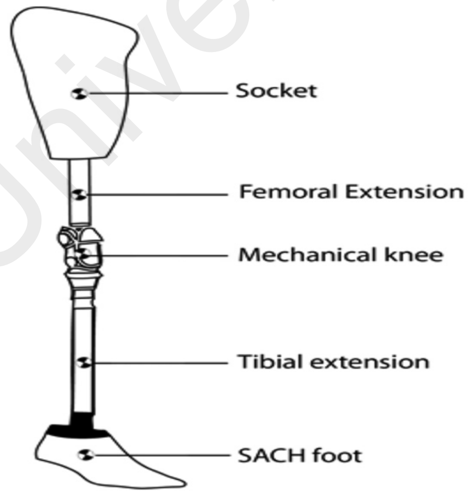


Figure 1.2: TF prosthesis components (Emmanuel, 2012).

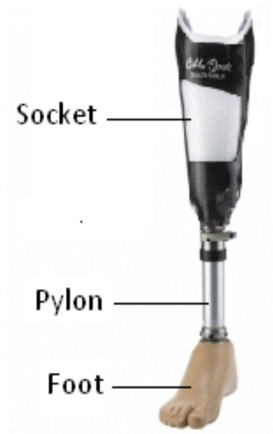


Figure 1.3: TS prosthesis components (Physiopedia, 2017).

When the trans-tibial amputation occurs, the nearest joints and muscles will play the role of compensatory mechanisms in order to amend the loss of the below knee anatomical structures. Through the daily activities, the muscles around the knee and hip will play the efficient, functional role to complete the tasks. After the surgery, the amputee undergoes the post-operative rehabilitation by rebuilding the muscle strength for both sound leg and an amputated leg. The training exercise has a significant role to reduce the negative effects of post-operative such as the muscle immobilisation. As a result of the normal daily activities, the amputee acquired the experienced of wearing the prosthesis which leads the amputated leg to become like the same strength level of the sound leg (Jung et al., 2016).

The major task for the thigh muscle is the strength, which is important for the HB to fulfil the mobility function. Quadriceps muscles give the steadiness to practising the daily ambulatory activities. Additionally, the muscle strength is significant for the TTA to achieve the best favourable control to the lower limb prosthesis (Fukuchi et al., 2018).

There are many health benefits of walking exercises such as enhance the growth of bone, increase the balance of stability, improve the mobility, decrease the risk of falling and avert contractures (Duval, 2011). Walking is the collective function that demands a special collaboration from various muscles (Mazaheri et al., 2016). Organised actions of below knee muscles are required for many purposes as body balance and body movement, in addition, conservation of dynamic settlement of joints (Firminger et al., 2018).

Walking over the ground is considered as the natural daily walking, but the walking on the treadmill is used for a specific purpose from various health status of people (Sloot et al., 2014). Nowadays, the treadmill is frequently used as a device in hospitals for rehabilitation purpose and assessment of walking ability (Assogba et al., 2018). People who have suffered from the various orthopaedic or neurological disease, for instance, knee osteoarthritis (Roper et al., 2013), cerebral palsy (Grecco et al., 2013) and Parkinson

(Lalanza et al., 2012), which caused them gait disorders are advised to utilise a treadmill walking for rehabilitation and recovery program.

The benefits of treadmill exercise are the numerous steps which are taken, the exercise is carried out within a small space; the subject is stable, a therapist has a proper place to assist and the treadmill speed is controlled (Hollman et al., 2016).

Several papers have studied the kinetics and kinematics of walking through a treadmill, which presented the foot during the exercise of walking on a treadmill is automatically pulled back when the foot touches the belt of the device (Kannape et al., 2016; Plotnik et al., 2015). In addition, the studies prove that if we want to change the pattern of the movement during the walking cycle and the period when the foot touches the belt surface, in this case, we have to stimulate the sensory receptors (Kalantari et al., 2011). The energy consumption and heart rate are higher during walking exercises on the treadmill than a walking exercise on the over-ground. (Kannape et al., 2016). Kinetics and kinematics vary while doing the walking exercise on a treadmill compared to the walking exercise on the over-ground, consequently, the activity of the muscles can be various, as well as the pattern of the muscle activity.

While this study is about the walking exercise on the treadmill, taking into account the dynamic stability of the muscles, it is important to grasp the activity of muscle and its pattern specific in the above knee muscles during walking on a treadmill. The articulations of the lower limb are bearing the highest load overall the body through the walking exercise at the stance phase (Alvim et al., 2015), while the knee exists in the critical area, between two immense levers of the tibia and femur, the knee at this situation count at risk, due to the huge role that applying to support the articulations, so it needs sturdy muscles to produce and distribute the force in the joint (Starholm et al., 2016). Consequently, the current paper compares the muscle activity of the lower limb and its patterns through the walking exercise on the treadmill focusing especially on the hamstrings and quadriceps muscles. So, we can apply the outcomes of this paper with the previous studies of walking on the treadmill to make conclusions whether the treadmill walking is appropriate to enhance the muscular strength and performance for various people with various health circumstances.

1.2 Problem Statement

People who have lost one of their lower limbs become unilateral trans-tibial amputees, which has associated with the prosthesis for walking assistance. An ability to walk after the amputation is often a main goal of rehabilitation in individuals with unilateral trans-tibial amputation. The study investigates if increasing the walk speeds would have the effects of the muscle activities in the amputees' people. The study demonstrates the findings and changes in the muscle activity for unilateral trans-tibial amputee and non-amputee subjects during walking on the treadmill at three different speeds.

Whereas the unilateral trans-tibial amputees miss the foot, ankle and below knee muscles which produce the force to walk and causes significant power asymmetry between the limbs during walking movement. The treadmill was used to imitate the natural walking environment, but the previous studies presented various views on whether the treadmill can copy the natural over-ground environment. The nominated experiment work intends to investigate the three different speeds (2, 3 and 4 km/h) by walking on the treadmill and highlight the highest speed which the amputees can perform.

I analysed the obtained data and gait variables using EMGworks analysis system. Also, I analysed the data for each subject separately, comparing the left thigh limb muscle with the right thigh limb muscle. After that, the amputees' data have compared with the intact subjects. Eventually, I compared the data of healthy-bodied in one group. I have found the considerable variation comparable between the healthy-bodied individuals and the amputee subjects during the treadmill walking exercise.

1.2.1 Hypothesis

The change in the muscles activities and muscle patterns during treadmill walking with three different speeds has investigated during this study. The daily routine contains several activities throughout the day, which practised by amputee people and healthy-bodied people. During walking on the ground noticed that it is very rare to find the variations in the muscle activation. But I suppose it to show the variations in the patterns of the muscle activation during the treadmill walking through the three different speeds (2, 3 and 4 km/h). In addition, I hypothesise it to maintain the normal strength of the involved muscles during the treadmill walking speeds.

The effects in the trans-tibial amputees during the walking exercise through the three different speeds are highly notable. Through the daily routine activities, the amputee's muscle activation had shown different patterns in healthy-bodied subjects. The variation of the activities has an influence on the muscles by increasing the activation to maintain muscle strength. However, during the treadmill walking exercise, it's hypothesised to observe differences between the sound leg and an amputated leg and expected to be greater than the variations in the healthy-bodied normal limbs.

The experimental work hypotheses involve that the hamstrings and quadriceps muscles activities for trans-tibial amputee and healthy-bodied subjects for both limbs, whether sound limb or amputated limb has comparatively identical muscles patterns of EMG during the treadmill walking on the speeds (2 and 3 km/h). Moreover, through the speed (4 km/k), EMG muscle patterns is hypothesised to change, since the muscle activity on the amputated limb will be reduced, while the sound limb will be increased. In addition, the muscle activities of the healthy-bodied subjects for both limbs stay similar, and unobservable variations compared to the trans-tibial amputees.

1.3 Research Questions

1. How do the unilateral trans-tibial amputees achieve the maximum speed during the treadmill walking?
2. What are the effects upon the thigh muscles during the training on the treadmill walking for the TTA and HB subjects?
3. How do the TTA rebuild their muscles and become sturdy and functional?

1.4 Objectives and Aims of Study

The study aim is to determine the effects of the treadmill walking with three different speeds (2, 3 and 4 km/h), on EMG parameters for the unilateral trans-tibial amputees.

The specific objectives of the study are:

1. To investigate the maximum speed that the trans-tibial amputees could be achieved during the treadmill walking.
2. To measure the variations in EMG patterns of the hamstrings and quadriceps muscles of the trans-tibial amputees and healthy-bodied subjects, under three different treadmill walking speeds (2, 3 and 4 km/h).

1.5 Scope of Study

The investigation has conducted upon the ten intact subjects, three males and seven females. In addition, two unilateral trans-tibial amputee male subjects, dressing their own prosthesis. The subjects investigated via Wireless EMG Sensors, to measure the patterns of the hamstrings (biceps femoris muscle) and quadriceps (rectus femoris muscle) muscles activities for right and left limbs, during the treadmill walking exercise, with three different speeds (2, 3 and 4 km/h). Through the activity, the comparison between the RFM and BFM usage in the sound leg and amputated leg are obtained with regard the EMG parameters and muscle activities patterns. Treadmill walking exercise trial applied to the individuals in one condition (Treadmill).

Subjects attended the trials at gait and motion analysis laboratory only for one session within the duration of 3-months. The session duration of the experiment is exactly around two hours for each subject. Participants underwent the required measurements of weight, height and the thigh circumference. Subjects completed the treadmill walking exercise: level walking along a 2.2-kilometre walking on the treadmill; for three different speeds (2, 3 and 4 km/h). They performed the walking activity 5-times to obtain the average level of the muscle activity. Between each trial, 5 minutes rest period is encouraged. Moreover, the participants have the right to end the session at any time due to fatigue or any other inconvenience caused.

1.6 Significance of Study

The paper is focusing on rebuilding the muscle strength for the unilateral trans-tibial amputees through the walking exercise on the treadmill with three different speeds, starting by warming up for one minute then move to speeds (2, 3 and 4 km/h). This process will assist the unilateral trans-tibial amputees to gain the muscles strengthening for the rehabilitation treatment process. Moreover, the process will help the amputees to react and engage easily with the daily routine activities.

The outcomes of the investigation will aid to investigate the maximum speed the unilateral trans-tibial amputees can perform and achieve. Therefore, when the relationship between the maximum speed and the change of the muscle patterns through the daily walking activity is identified, might have implications and collaborations in the training's future techniques and improving the prosthesis design to provide the economic and functional independence for the trans-tibial amputees.

CHAPTER 2: LITERATURE REVIEW

2.1 Unilateral Trans-tibial Amputees

According to Papegaaij et al. (2017) had reported that 82% of the whole number of amputations in the US are trans-tibial amputees. The amputations happen for several factors such as diabetes, dysvascular disease, Charcot, trauma and cancer. The trans-tibial is the wide common type of the amputation, also called below-knee or lower-limb amputation. Trans-tibial means that the amputation happens between the ankle and the knee joint. Called also below-knee (B-K) amputation. While the unilateral means the amputation happened only for one limb (Figure 2.1). The trans-tibial amputation remained the knee joint intact, which considers easier to deal with compared to a transfemoral amputation. In addition, the residual knee joint assists the trans-tibial amputees to address the prosthetic limb and their usage consider more practical, convenient and economical (Papegaaij et al., 2017).

Moreover, the trans-tibial prosthesis limb comprises the four essential components sorted from top to bottom; 1. The socket has a role of transmitting the forces amongst the prosthesis limb and the residual limb; 2. The suspension system has the role of supporting the prosthesis limb through the swing period at the walking cycle; 3. A pylon has a role of the median which transfers the forces amongst the prosthesis foot and the socket, also recompenses the limb length that lost; and 4. A prosthetic foot, which attaches onto the end of the pylon bottom, it shapes from different and several designs such as the woodblock and the carbon fibre foot (Koyama et al., 2012).

According to Bello et al. (2013) had described techniques for using the lower-limb management for the amputees which included the temporary prosthesis fitting straightway post-operation. Therefore, the rigid dressings are provided instantly for the amputees' people post-operation, also they supplied by the definitive prosthesis within a month of the surgery. As a result, the significant amount decreases in training and hospital treatment costs.

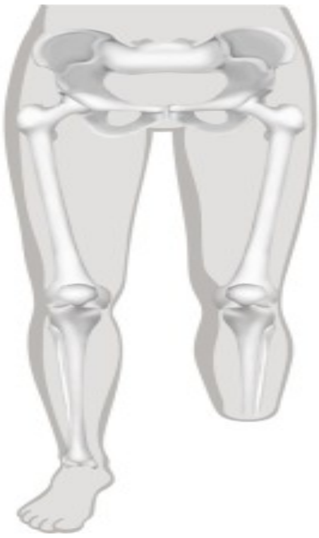


Figure 2.1: Unilateral trans-tibial amputee (Ottobock, 2013).

2.1.1 Lower-Limb Prosthetics

Figure 2.2: Lower-limb prosthetics (Indiamart, 2014).

2.1.1.1 Sockets

Following foot, the socket considers the second fundamental component for the trans-tibial prosthetic limb. GRFs are transmitted through the residuum, which transfers the forces from the prosthetic foot to the socket, after that in residual parts of the body. The user's entire weight is transmitted to the socket during a stance period in the walking cycle. The common misconception about the user's entire weight borne via a distal end of a socket, the bone bridging cannot carry the heavy loads. As a result, the prosthesis is distributing the loads and stresses among the tissues of the socket. Several options of the residuum are available to distribute the pressure around the socket such as the (PTB) patella tendon-bearing, had designed and used since the 1960s; also (TSB) total surface-bearing, had introduced since the 1980s (Nessler et al., 2013).

The previous studies analysed the difficulties that the trans-tibial amputees faced, as a result, found the patellar tendon-bearing (PTB) prosthesis which connects the socket with the stump (Figure 2.2). Furthermore, the prevailing feature of using PTB that is the amputees are less depending on the seat and more depending on the prosthesis. Nowadays, the sockets are widely used with a good understanding of the principles (Mazaheri et al., 2016).

2.1.1.2 Fabrication Materials

The fabrication of the lower-limb prosthesis, in the beginning, was constructed by the aggregate of two types of materials especially the leather and wood. This combination of materials has special properties which affect the perfections of the prosthesis. For instance, the leather could be a good choice for the perspiration absorbing, but it is very hard to clean it. The wood demands special skills of shaping and carving the model. The usage of natural resources like wood and leather has deficiencies, overcome that by presenting the thermosetting resins used for laminating tubular stockinette over the plastic, which consider as a reproduction of the stump for the purpose of forming the sockets and below knee prosthesis components (Muqatach et al., 2016).

Nowadays, the prosthetics are encouraged to change the trend toward the plastic. Whereas, the techniques of laminating plastic had created the sockets with total-contact, which considers as a globally used technique, the prosthesis made by thermoformed plastic as well as by the plastic laminate. The transparent sockets had developed by the process of vacuum-forming a polypropylene sheet across the positive stump model. The polypropylene sockets considered as the appropriate definitive usage for the prosthesis (Firminger et al., 2018).

2.2 Trans-tibial Amputees Gait

Actually, the increasing of the muscle strength seems that not affects the walking patterns in trans-tibial amputees. Also, demonstrated that the decrease in the strength might be related to the muscle disuse. Moreover, the walking deviations in the trans-tibial amputees consider as a factor of the muscle atrophy.

Several papers had studied the trans-tibial amputees walking patterns, besides the walking characteristics. In parallel with the healthy-bodied subjects, trans-tibial amputees indicate that the normal walking, reducing the rhythm and the velocity, with an increasing the expenditure of the energy through the matched velocity (Powelson et al., 2018). In the TTA demonstrated that the step length of the sound limb had decreased due to the musculature lack of the ankle, also the ability to push the prosthetic limb had reduced too. Regarding Arch et al. (2015) had noticed that the prosthetic limb had a long swing period, which regarding the stability of the sound limb, and oscillation period had decreased since the prosthesis has a lighter mass (Mongon et al., 2010). Therefore, the supporting time of a prosthetic limb had decreased parallel to a sound leg.

According to Robadey et al. (2013) had mentioned that the mechanism of an anatomical knee unaffected through the trans-tibial amputation, So the amputees with the normal walk by the knee action are reasonable. Meanwhile, The patterns of the trans-tibial amputees for the prosthetic leg do not present normal due to the knee forces and motion.

Regarding Gjovaag et al. (2018) had reported that during the stance period the knee flexion had reduced compared to the healthy-bodied. However, the amputated leg demonstrated that through the stance period had mainly an extension. Sloot et al. (2014) had mentioned that the knee extensor displayed through the stance stage while had reduced in the prosthetic limb. The knee flexion had reduced due to the required force of the quadriceps muscles. Therefore, Duval (2011) had reported full extension knee, in addition to quadriceps muscle forces with zero active. Regarding Version et al. (2018) had mentioned the continuous appearance of knee flexor moment through the gait in trans-tibial amputees.

2.2.1 Muscle Activity in Amputees Gait

Walking analysis of the unilateral trans-tibial amputees expose asymmetries in the walking patterns amongst the sound limb and an amputated limb. The treadmill walking exercise of 15 volunteer subjects was analysed via wireless EMG system portable. The appropriateness of the trans-tibial amputees' prosthesis substantially could allow them to ambulate easily and comfortably through practising the daily activities routine. Nevertheless, walking patterns have shown the distinguished asymmetry between both limbs, which has mentioned in the previous study of the walking parameters measurements (Ferryanto et al., 2017). The walking analysis of the HB subjects has shown the conspicuous the high stage of both limb symmetry (Oliveira et al., 2016).

Whereas, the unilateral trans-tibial amputees have observed that the amputated limb has resulted in the minimal active in the walking functions. The evaluation of the balance activities showed that the force reactive via the foot-ground for the amputated leg consider small in parallel with the sound leg (Jansen et al., 2014). Thigh muscles had reduced their activity for the amputated leg through the muscle strength and circumference measurements (Assogba et al., 2018).

According to Esposito et al. (2017) had investigated the EMG duration of the walking activity in trans-tibial amputees. By the comparison between the sound leg and the amputated leg revealed a modicum variation of the muscle action in the walking duration. Starholm et al. (2016) had mentioned about the trans-tibial amputees had the capability to preserve the activity of the quadriceps and increase the activity of hamstrings in the amputated leg compare to a sound leg. However, a restricted number of trans-tibial amputees had shown the decrease in the activity of muscle through the walking exercise in both RFM and BFM in the amputated leg. Moreover, the authors suggested that the number of amputees had not functionally used their knee joint, RFM and BFM conserved for the full potential.

According to Yeung et al. (2012) had mentioned that the activity of the sound leg in the trans-tibial amputees was like the healthy-bodied subjects. Moreover, the activity of the muscle in an amputated leg revealed to be extended in RFM quadriceps and BFM hamstrings compare to a sound leg. The extension activity in RFM quadriceps and BFM hamstrings groups through the stance phase is reasoning in the restraining effect absence of an indirect Soleus acting of a knee joint. In addition, in the healthy-bodied subjects, the action line of GRF passes in front of the hip and knee due to the negative prolongation of the joints. Therefore, extended the action of the muscle might demand to prolong the activation of the hip and knee. As a result of the dorsiflexion lack which might cause the resistance toward the natural body forward progression. Otherwise, the rise of the heel in an early stage is considered as an additional factor of decreasing the stability which leads to lengthy muscle activity.

Regarding Weinert-Aplin et al. (2017) had published an investigation paper about an asymmetry gait and changed motor patterns of the trans-tibial amputees. EMG and kinetic outcomes reveal an activity change in the residual muscle in comparison of the normal results. Related to the EMG graph activity, which presented a considerably increased in the duration and levels of the activity in the thigh muscle. In addition, had stated that through the mid stance and early stance phase, the hip extensions were hyperactive, which partially recompensed, due to the energy generation lack via plantar flexors during the push off. Therefore, the normal activity of hamstrings results in the immoderate moment of knee flexor. Additionally, the knee becomes hyperactive extensors to invalidate the consequent moment. Throughout the stance phase, the knee moment remains approach the zero which results in the co-contraction of the RFM quadriceps and BFM hamstrings muscle groups. Moreover, the case of the RFM quadriceps and BFM hamstrings hyperactive with similar outcomes had not replicated, or neither reported somewhere in the literature.

According to Sokhangoei et al. (2013) had reported that the EMG patterns of the activity duration in the thigh muscle had increased due to the ankle motion lack and the energy generation lack during the push off. Moreover, had investigated the dynamic elastic influence to the prosthetic feet response on the proximal joints and muscles. In addition, Liu et al. (2017) had mentioned that during the investigation of the prosthetic feet on six different types had shown no considerable differences. Moreover, the study of the phasing and the intensity of the EMG activity of the prosthetic feet on five different types had demonstrated no considerable differences too.

The indication of the previous studies, the activity of the thigh muscle in the trans-tibial amputees demonstrated an extended duration of the muscular activity in the amputated leg, which takes place in both BFM hamstrings and RFM quadriceps muscle groups compared into the sound leg. The co-contraction had announced in the amputated limb due to the stability increase, also recompense the activity of the plantar flexor of the loss of the ankle. Kaur et al. (2016) had mentioned in their investigation the activity of the EMG with the excessive levels. Moreover, Hollman et al. (2016) had demonstrated that through the gait round in the trans-tibial amputees had revealed a little activity reduction in the muscular peak at the amputated leg in comparison with sound leg.

In trans-tibial amputees had demonstrated deviations in a gait cycle, which might be due to the disuse for a prolonged time with an amputated leg. In addition, the previous studies had reported slight differences in the EMG levels between the sound limb and the amputated limb. Moreover, the activity duration of the muscles had been increased in the trans-tibial amputees. The alteration in patterns of EMG had appeared through the gait cycle in the trans-tibial amputees remain unclear to an explanation where the changes are due to the disuse of the muscles or overuse the muscles. Moreover, several prior-studies had mentioned the investigation about the level ambulation. However, in the trans-tibial amputees had demonstrated that the muscle activation maintains normal through the walking level. While slight differences appeared between the amputated leg and the sound leg through the activities require the contractions of the thigh muscles. Furthermore, hypothesised of a decrease in the muscle activation during the daily activities is a factor of the disuse observed.

2.3 Normal Subjects Gait

The gait considered as a unique walking style which depends on many factors such as; nervous system, joints and muscles. Gait cycle defined as a motion sequence of consecutive contacts of one foot during the stance and the swing period. Gait cycle divided into two periods; first is a stance phase, which occupied 60% from the gait cycle while the second period is the swing phase which occupied 40% (Table 2.1). The stance phase happens when a foot bearing the weight and contacts the ground. While the swing phase happens when a foot moving forward and not bearing the weight (Figure 2.3). Moreover, when one foot in a heel-strike phase during the initial contact, directly the second foot exists in the toe-off phase. So, during this phase, both feet remain on the ground as a double support for the gait cycle. While at a fast walking, the double support period will disappear, due to the reducing of the stance phase time (Ghazwan et al., 2017).

Table 2.1: Normal Gait Cycle.

Stance phase:	**Push off:**	**Swing phase:**
A. Heel strike, it is an initial contact. **B**. Foot flat, it is a load response. **C**. Mid-stance, it is a stance of a single leg.	**D**. Heel off, it is a terminal stance. **E**. Toe off, it is a pre-swing.	**F**. Initial swing, it is an acceleration. **F**. Mid-swing **G**. Terminal swing, it is a deceleration.

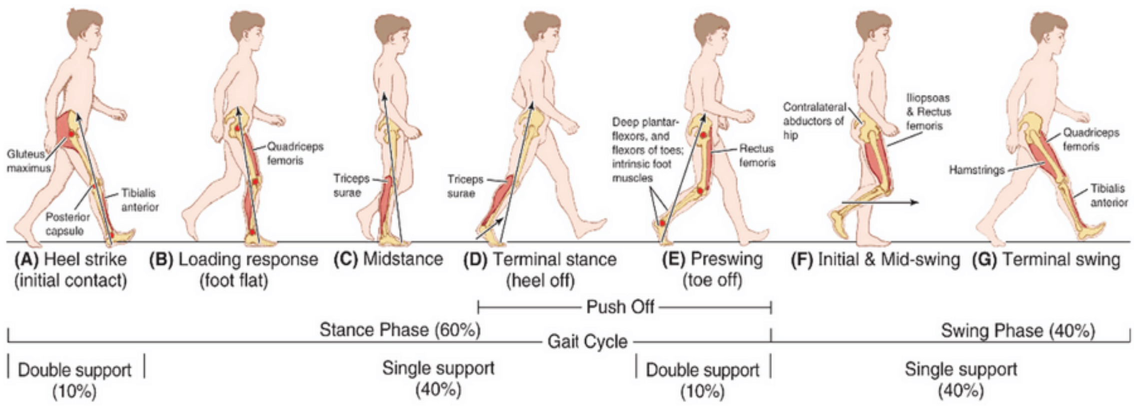


Figure 2.3: Normal Gait Cycle (epomedicine, 2014).

2.3.1 Muscle Activity During Walking

There are documented studies covered the muscle activities for the healthy-bodied through a normal walking (Wong et al., 2015; Scholes et al., 2014). Overall, the most active muscle is the lower limb muscles quite when the foot contacts the surface. The pretibial muscles are activated in the closing swing phase and through the starting of the acceleration at the same phase, also, during the beginning of heel touch to the surface. The highest activity in lower limb muscles (plantar flexor) occurred at push off period. Also, the highest activity in lower limb muscles (knee flexor) occurred in the deceleration period during the swing phase and at the onset of the ground connection. The muscles of the knee extensor contain activity patterns of biphasic. The first activity phase happened at the swing period transition to the stance period which has a clear peak. A second activity phase happened through the terminal of push off period and at the beginning of the swing phase which shows the small peak (Kostraba et al. 2018).

2.3.2 Muscle Activity in Normal Gait

The knee action based on the muscles through the walking which surrounds the knee joint. In a case to evaluate the muscle patterns of an amputated leg, knowledge and comprehension of the muscle action are required in the healthy subjects. Hamstrings muscle before the first contact to the ground is active and maintain active during the early stance phase. The knee is rapidly flexed during the heel contact due to GRF, which pass the rear knee axis. Moreover, the magnitude of the hamstring muscle activity decreased, but the activity continues. The quadriceps muscle developed a rapid eccentric contraction. Which considers significant due to the knee restrain flexion and maintain the stability (Khademi et al., 2017).

In the mid-stance phase, the knee continues flexion with a maximum of 20% gait cycle. After the admission of the weight, the quadriceps muscle activity had shown decreased. When the momentum holds forward a body over a settled tibia, line action of GRF moved into the front of the knee joint which leads to the negative knee extension. Therefore, the knee is no longer required the quadriceps muscle for stabilization (Hof et al., 2010). Moreover, the muscle around the knee had a minimum activity throughout the stance stage. In addition, the limb through the swing period behaves similarly to the negative pendulum. During the end of the swing phase, the limb starts active decelerating through the muscle hamstring contraction. As a result, the knee extension and the hip flexion immediately slow due to the deceleration action. Later on, the knee standby for the acceptance of the weight through the early activity of the quadriceps muscle.

According to Fergason et al. (2010) had reported that the COG during the gait should follow the proper and smooth pathway through the mechanisms and control patterns. Which required lower energy expenditure for the normal subject walking. Therefore, Iosa et al. (2014) had mentioned that the pathological gait considers as the attempts to maintain reducing the consumption of energy by replacing the motions in an unaffected stage. In addition, Yeung et al. (2012) had reported that the adaptations of the system for the residual neuromuscular had taken place.

2.3.3 Walking Symmetry

According to Mehryar et al. (2017) had reported that the human normal gait reflects the loading patterns of the symmetrical lower foot. Also, the symmetrical gait considers the preferable for walking with a freely selected step rate (Smith et al., 2018). Therefore, Mehryar et al. (2017) had mentioned that no variations found in Fy and Fz parameters amongst the right and left legs through the walking exercise. In addition, Lin et al. (2014) had displayed that the patterns of the plantar pressure are bilaterally symmetrical. However, the ground reaction force parameters toward the mediolateral had described massive asymmetries, because of the extreme variations had found along the axis (Huang et al., 2012). Moreover, the measurement of the Fx considers not reliable which is not a critical measure for the assessment of the walking cycle.

EMG outcomes reported in the literature in several studies, Fey et al. (2010) had mentioned that no asymmetry appeared in EMG patterns average in the healthy participants for the muscle activities of the six knees during the walking with three different speeds: fast, slow and free. Moreover, during walking at a fast speed, bilateral symmetry had become more repeatable. In addition, Lu et al. (2017) had demonstrated that no asymmetries had found in the profiles of EMG amplitude specifically for the (RFM) rectus femoris muscle and (SOL) Soleus muscle. Furthermore, the biarticular rectus femoris muscle displayed an enormous variation compared to the Soleus muscle. However, Göktepe et al. (2010) had mentioned that EMG activity had symmetrical results in 7 selected muscles which recorded at the same time through the walking cycle, excluding the Soleus muscle.

Moreover, the majority (6 to 7) of the tested muscles had revealed that the dominant side activity was higher than the activity non-dominant. However, in the human gait must emphasise that the EMG activity of extensor muscles in the leg considers massive sensitive towards the spacious loading differences which coming from the GRFs (Stephenson, 2016). According to Murley et al. (2014) had reported that walking asymmetry appears to reflect the difference of natural functional amongst the limbs. Probably, the functional differences are due to the limbs' contribution in performing the missions of control and propulsion during the healthy-bodied walking. In addition, we might consider the limb laterality the demonstration of the presence of the limb functional differences.

2.4 Muscle Wastage

Muscle atrophy defined as the muscles' tissue losses which make the muscles become weak. They can lose the muscles for whole or part due to the atrophy. Muscle atrophy happens to older people and those with medical conditions such as liver failure, renal failure, burns, and cancer. The muscles become weaker when the muscles have not used for a long time due to the long illness or wearing the cast. Also, could happen as a result of the starvation. The muscles atrophy can happen to the trans-tibial amputee especially to the amputated limb. The accurate reason for the causes of the atrophy is still unclear. In addition, the effects of the muscle atrophy on the gait and muscle fatigue had studied by the (Watt et al., 2010).

They can assess the muscles atrophy through the CT. The thigh cross-sectional space covered 86 percent from an amputated limb which related to the investigation of groups of trans-tibial amputee groups. Muscles atrophy occurred as a majority in the quadriceps muscle. A cross-sectional area has indicated to 66 percent muscles from sound limb. While hamstring muscle involves 80 percent at a sound limb (Yeung et al., 2013). Therefore, Huang et al. (2012) had investigated about the disuse and the immobilisation, which reported that the musculature of knee extensor had a greater reduction compared to the musculature of knee flexor.

CT can assess the cross-sectional region of the thigh muscles reveals that the amputated leg has 76 percent from the sound leg (Gates et al., 2012). The circumference of thigh considers not a precise measure for atrophy, probably there are some hidden differences in the cross-sectional section due to the tissue thickness. The thigh cross-sectional differences between the sound leg and an amputated leg had shown minimal variations (Sloot et al., 2014). Moreover, Huang et al. (2012) had reported that the main cause of the muscle atrophy is the changes in the muscle's volume due to the fibre size reduction.

After the operation, the amputee suffered from the immobilisation amputated limb caused to the pain and recovery. Once the treatment started, the distribution of the muscle fibre approaches the level of the muscle before the amputation. However, the walking of an amputee with the prosthesis shown an obvious alter of the walking pattern (Sloot et al., 2014). The amended walking pattern might affect the muscle function, which caused an influence upon afferent impulses from the joints and muscles (Yang et al., 2016). Post the treatment period, the fibre distribution might be changed. The fatigue rate of nominated muscles is might be affected (Tesio et al., 2010).

2.5 Muscle Strength

According to Ghazwan et al. (2017) had performed a paper about the trans-tibial amputees and their muscle strength, focused on the thigh muscle. They found that the flexion strength and the knee extension (isometric and isokinetic) at an amputated limb had remarkably lower than the sound limb (Sanjaya et al., 2016). Additionally, at an amputated limb there is an association amongst the length of the residual limb and the highest strength available into the thigh musculature (Sloot et al., 2014).

The non-amputated limb has exhibited comparable values of the muscle strength amongst the normal and amputee people at the identical ages. Healthy-bodied participants exhibited the muscle strength of the quadriceps muscle were double strongest than hamstring muscle. Regarding Ferryanto et al. (2017) had mentioned that the identical magnitude found amongst the flexion strength and knee extension at an amputated leg. Which appeared that the strength of knee extension had been comparatively less than the strength of knee flexion in a trans-tibial amputee.

They can enhance the muscle strength accompany to the EMG increasing of participatory muscle (Ghazwan et al., 2017). The increasing of the hypertrophic factors reduced the EMG activity (Tesio et al., 2010). It might cause an initial strength reduction related to the decrease in the level of neural activity, besides the progressively increasing of the muscle atrophy (Ferryanto et al., 2017).

The muscles become sturdy and functional by functional training ideal to the strengthening muscles and joints. Functional training prepares the muscles to function the daily activity missions all together as one group.

After amputation the lower muscle loss the strength, in this case, the residual limb must have the training of strengthening and stretch, so that can assist to prevent the joints tightening and muscle shortening. The trans-tibial amputees must keep their residual limb flexible and strong for a prosthetic limb use purpose. With the help of the physical therapist, the trans-tibial amputees start their rehabilitation session with the exercises of strengthening the above knee muscles. After surgery, the physical therapist's advice the trans-tibial amputees to keep the exercises of muscle strength practising at once they back home. Taking the physical therapist's instructions carefully and closely.

The muscle strength exercises should practice on a comfortable surface such as the treadmill. Standing straight, the residual limb with the prosthetic limb, walking on the treadmill around 1 minute. The subjects supporting them self by holding the edge of the treadmill. The position of the residual limb and sound limb during the training must move forward and backward continuously, not moving up and down, taking into account the backbone to be straight all over the exercising session. Hold the training for five minutes. Thereafter, continue with 2 km/h speed for one minute, rest five minutes again. Repeat the training 5 times. After that, pass to 3 km/h then to 4 km/h. Each day must practice only a constant speed.

2.6 Strength Training

According to Gholizadeh et al. (2018) had reported that the thigh muscle strength reduction caused related to the gait deviations in below-knee amputee. Quadriceps muscle weakness causes the stance knee compensative locking during the Hyperextension, besides the various patterns related to the pathological gait. Sousa et al. (2012) had mentioned that the amputee subject with the prosthesis in an amputated limb showed that the flexion strength and the knee extension is associated with the greater speed of walking and the length of the stride.

Regarding Khademi et al. (2017) had designed a special program for the muscle strength, strength training, developed for the trans-tibial amputees by employing the training of the isokinetic of the knee muscle whether flexion or extension, utilised in sound and amputated limbs. Post-training approximately twenty sessions noted that the muscle strength of the thigh had an increased ratio between 50% to 60% for both sound and amputated limbs. The muscle strength reported that had increased considerably in the muscles of knee extensor rather than the muscles of the knee flexor. Consequently, it seems that the examination has been failed to achieve the objective of the investigation to improve the functional ability of muscles strength post-training, where the results of the walking speed at the ground surface level and stairs level had been matching the predicted hypothesis.

The strengthening quadriceps examination had been designed by Plotnik et al. (2015) for the trans-tibial amputees. The investigation applied on a single participant which suffered from the weakness thigh muscle, the program held around 6 weeks, during that period the subject attended the isokinetic training sessions for both the sound limb and the amputated limb. Post-training, the amputated leg showed that the muscle strength values approached to the sound leg. However, the increase in the muscle strength had scored no variation in the kinetics and kinematics gait.

The authors explained that the walking patterns obtained were customary, and the subjects need extra walking training to increase the strength in RFM and BFM.

Furthermore, the authors said the weakness in the RFM and BFM had observed is related to the disuse (Koyama et al., 2012). The strength is organized through the muscle contractions, which contributed during the daily activities, but sometimes might not enough to keep the strength in a constant level. Also, the muscle strength decrease of 5% per day when the contractions' absence. Moreover, to prevent the decrease of the muscle strength one contraction required per day. Therefore, Roper et al. (2013) had reported ten repetitions contractions per day will produce an increase of the strength. However, the muscle disuse for a prolonged time might cause atrophy for the useful muscles. The strength is decreased In TT amputees as a result for one-side activity which becomes a practice in their daily life (Murley et al., 2014).

The essential purpose of functional training is the core stability of the whole body. In addition, during the functional training, the chance of the muscles and joints to engage together quite high which lead to building the muscle strength and enhance the motion scope. Also, by taking into account the proper process to fulfil the functional training, also by considering the priority of the safety training exercise can facilitate the daily life routine by making them easier, enhance the life quality and decrease the injury risk.

2.7 EMG during Walking at Different Speeds

During treadmill walking, tibialis anterior, gastrocnemius medial head, and gastrocnemius lateral head activation patterns in amputee subjects had a much higher inter-subject variability and were substantially different from the patterns of the control subjects. The high inter-subject variability in amputee EMG patterns has demonstrated by a significant difference (ANOVA, $p < 0.001$) in EMG pattern cross-correlation between the amputee individual data vs. amputee mean, compared to the control individual data vs. the control mean (Huang et al., 2012).

During the investigation, they assessed the subject's ability to differentiate plantar flexor and dorsiflexor muscle activation. Subjects performed maximum voluntary activation trials where they tried to isolate the activation of their tibialis anterior (dorsiflexion trial) and gastrocnemii (plantar flexion trial) muscles. Subjects were seated upright on a raised platform so that their feet did not contact the ground during the maximum voluntary activation trials. To obtain maximal activation of the tibialis anterior, we instructed subjects to point their feet and toes towards the ceiling as hard as possible and sustain muscle activation at maximum dorsiflexion. To obtain maximal activation of the gastrocnemii, we instructed subjects to point their feet and toes towards the ground as hard as possible and sustain muscle activation at maximum plantar flexion. All ankle movements were performed bilaterally. We instructed amputee subjects to activate their lower leg muscles as if they had an intact ankle and foot. During practice trials, we displayed real-time EMG signals to amputee subjects to provide feedback on the level of muscle activation. Once the EMG signals appeared consistent, we recorded three repetitions for each maximum voluntary activation task. For each repetition, we asked the subjects to sustain the maximum voluntary activation for five seconds then rest with muscles fully relaxed for five seconds (Huang et al., 2012).

Moreover, they assessed muscle activation patterns during walking. Subjects walked on a treadmill at four speeds (0.7, 1.0, 1.3, and 1.6 m/s) for two minutes at each speed. Not all subjects could walk at the two faster speeds. To determine the fastest walking trial that subjects could complete safely, we asked each subject to practice walking on the treadmill starting at the slowest speed. If they could walk comfortably at the given speed, we increased the treadmill speed gradually to the next level. We continued this until they reached the fastest treadmill speed or until the subject could no longer maintain walking speed. All subjects completed the 0.7 and 1.0 m/s trials. Eight of the twelve amputee subjects and eleven of the twelve control subjects completed the 1.3 m/s trial. Seven of the twelve amputee subjects and eleven of the twelve control subjects completed the 1.6 m/s trial (Huang et al., 2012).

2.8 Literature Review Summary

Table 2.2: Summary of a literature review of HB and TTA subjects walking in the treadmill.

	Authors	Title	Project details	Pros	Cons	Subjects	Remarks
1	Khosro Khademi - Kalantari , et al., 2016	Lower limb muscular activity during walking at different speeds: Over-ground versus treadmill walking: A voluntary response evaluation.	The study was conducted on 25 healthy young females. Surface EMG was recorded from gastrocnemius, hamstrings, vasti and gluteus medius muscles during walking over-ground and treadmill at 3 different speeds (comfortable, slow and fast). The pattern of muscle activity was compared between two walking conditions at different speeds.	Patients with gait disorders caused by different neurological or orthopaedic disease such as cerebral palsy, Parkinson and knee osteoarthritis have been advised to use treadmill walking as a part of their rehabilitation program. Treadmill exercises have many benefits: exercise is done in a small space, steps taken are abundant, walking speed can be controlled, the individual is stationary and the therapist is in a more appropriate position to help.	Heart rate and energy consumption are higher during walking on the treadmill as compared with those over-ground. Several studies have shown that treadmill walking can lead to a postural disorder (especially in the elderly).	25 healthy young females.	The pattern of muscular activity during walking on treadmill and over-ground was similar but walking on treadmill induced higher muscular activity in the lower limb musculature.
2	F. Alton, et al., 1996	A kinematic comparison of over-ground and treadmill walking	A total of 17 uninjured subjects walked over-ground at their preferred velocity. The treadmill was then set at the average velocity obtained in over-ground walking. Gait temporal variables and leg joint kinematics were analysed using the three dimensional (3D) Kinemetrix Motion Analysis System. The data were analysed separately for the two gender groups and for the groups combined.	There are only significant differences between the kinematic variables of stance time, cadence and hip joint angular motion when comparing over-ground and treadmill ambulation for all subjects. There were significant differences in one of the two gender subgroups for maximum hip flexion angle (females) and cadence (males) between the two walking conditions.	Confidence in the hip kinematic results of this study is limited by the method of assessing hip joint angles. Error is possible in calculating hip angles when using a marker placed on the shoulder. This error can result when hip joint angular motion is falsely detected during movement of the shoulder marker, which results from movements such as trunk rotation or scapulothoracic motion.	Eight male and nine female uninjured physiotherapy student.	Statistically, significant differences exist between over-ground and treadmill walking in healthy subjects for some joint kinematic and temporal variables.
3	George S. Murley, et al., 2013	Electromyographic patterns of tibialis posterior and related muscles when walking at different speeds	The study was to characterise the electromyographic timing and amplitude of selected lower limb muscles across five walking speeds. Thirty young adults were instructed to walk barefoot while electromyographic activity was recorded from tibialis posterior and peroneus longus via intramuscular electrodes, and medial gastrocnemius and tibialis anterior via surface electrodes.	The data presented are from predominantly younger adults with normal-arched foot posture – this may serve as a reference for comparing similarly matched individuals with a foot deformity and or pathological gait. Also, the new data for TP serves to inform researchers investigating individuals with pathological gait about the potential confounding effects of walking speed as individuals with pain and/or disability may walk slower to relieve pain, or because of a functional impairment or poor balance.	They did not collect kinematic or kinetic data from participants. Therefore, can only speculate about the specific functions of the muscles tested during different walking speeds. Also, as the MVICs were conducted manually (i.e. without using an isokinetic dynamometer), some random variability may be attributed to the tester resisting the MVICs (e.g. medial gastrocnemius is a powerful muscle that is difficult to resist with manual testing).	Thirty young adults (female / male) 15/15.	The muscle activity was strongly affected by walking speed. Peak EMG amplitude for TP, PL and MG were similar across very slow to slow walking speeds, presumably to assist with medio-lateral foot stability and to compensate for reduced forward momentum at very slow speeds.
4	Tateo Warabi,	Treadmill walking and	To clarify the differences of the treadmill from over-ground locomotion,	The data obtained from the male subjects and those from the female	The ratio of rearfoot phase over stance phase is larger on the treadmill	10 adults without	The experimental data confirmed the previous

	et al., 2005	over-ground walking of human subjects compared by recording sole-floor reaction force	experiments were carried out on 10 volunteers (five males and five females). The sole-floor reaction force was recorded from five anatomically discrete points with strain gauge transducers of 14 mm diameter attached firmly to the sole of bare-foot.	subjects were statistically compared by t-test on each item (e.g. stance period, contact time of 5 points, cadence) found that the preferred walking velocities were 3.5 km/h for two subjects, 3.6 km/h for one subject, 4.0 km/h for five subjects and 4.5 km/h for two subjects.	locomotion, contrary to the other eight subjects. A plausible explanation for this discrepancy is not available at this time. Patterns of medial-lateral balance (x-vector) are fairly different in these two cases as compared to other eight subjects; therefore, further investigation on the direction of weight movement is warranted.	known neurologic al disorders (five males; five females).	works that stance period is decreased and cadence is increased on the treadmill walking.
5	L.H. Sloot, et al., 2013	Self-paced versus fixed speed treadmill walking	This study had investigated possible differences between SP and fixed speed (FS) treadmill walking, in terms of spatiotemporal, kinematic and kinetic gait parameters, for both the average stride pattern as well as the within-subject stride-to-stride variability. To assess the relevance of a specific control mechanism, three different SP modes with varying gains were also compared.	One of the suggested advantages of SP walking is that it would offer a natural way of controlling and varying walking speed, leading to a more natural gait and possibly better resembling over ground gait compared to FS treadmill walking. We did find some indication that the variation of walking speed indeed seems to better resemble over-ground walking, in terms of increased fluctuations over multiple strides.	The long-term components of walking speed variability increased during SP walking, suggesting to assess whether or not SP walking could be an effective alternative to over-ground walking in gait analysis.	Nineteen healthy subjects (12 male, 7 female)	SP walking can be considered similar to FS treadmill walking for clinical gait analysis, in the absence of any clinically relevant differences in gait patterns. The resembling FS and SP gait patterns seem to indicate that interactions with the treadmill during SP walking do not notably affect the kinematics and kinetics.
6	Reza Mazaheri , et al., 2016	The Activation Pattern of Trunk and Lower Limb Muscles in an Electromyogr aphic Assessment; Comparison Between Ground and Treadmill Walking	This study in order to assess the activity of trunk as well as lower limb muscles; the following muscles were chosen: rectus abdominus, external oblique, longissimus, multifidus as well as vastus medialis, vastus lateralis and hamstrings, all from the right side of the subjects' body. The electromyographic data were recorded by the electromyogram for every person, and then the subjects walked over the treadmill (Technogym model) for 5 minutes with the same speed.	The amplitude of the electromyographic activity of trunk and lower limb muscles was greater in walking on the treadmill than over-ground walking. The duration of electromyographic activity of trunk and lower limb muscles during over-ground and treadmill walking are generally similar.	As a result, The patterns of the trunk and lower limb muscle activity on both treadmill and over-ground walking are generally very similar. The study has to be applied upon unisex for more accurate outcomes.	19 sedentary healthy men within the age range of 20 - 40.	Due to the stabilizing role of the lower limb muscles during walking, these muscles seem to be active throughout the entire gait cycle.
7	A.L. Hof, et al., 2001	Speed dependence of averaged EMG profiles in walking	EMG data were collected from 14 muscles in two groups of healthy young. Subjects walked on a 10 m indoor walkway at speeds of 0.75, 1.00, 1.25, 1.50, and 1.75 ± 0.05 ms−1. Average walking speed was assessed from the interval between passing two infrared beams at both ends of the walkway, 7 m apart. After each round, the measured speed was compared with the specified speed and the subjects were instructed to adjust their walking speed accordingly. The walking was repeated	Foot contacts were recorded by aluminium strips taped on heel and toe of the shoes that could make contact with the aluminium walkway.	To avoid the difficulty of including effects due to stature or age, the group of subjects has been chosen as homogeneously as possible. Differences in stature also complicate a comparison of speeds in between subjects.	Two groups of nine and 11 healthy young men	The paper was to present a set of normal EMG profiles, covering the usual range of walking speeds for use in clinical studies.

			until at least ten steps had been recorded at each of the five speeds within ± 0.05 ms−1.				
8	L.H. Sloot, et al., 2014	Energy exchange between subject and belt during treadmill walking	Eighteen subjects walked on a dual-belt instrumented treadmill (R-Mill) in a speed-matched virtual environment (GRAIL). Subjects were given six minutes to habituate to both modes and instructed to walk at preferred walking speed. Subjects first walked at SP mode for three minutes, of which the average speed was used for the subsequent 3 min FS trial. Subjects got off the treadmill in between trials and were given several minutes rest if appreciated. The belt speed was adjusted 60 times per second, using a 4.5 kW motor per belt. Force sensors underneath each belt (50 200 cm) recorded the ground reaction forces. Motion of the COM was tracked by a cluster marker on a pelvic belt using an active motion capture system (Optotrak). The last minute of each trial was recorded and all data, i.e. force, motion and belt speed, were sampled at 100 Hz.	Both belts of the treadmill used in this study were independently controlled for belt speed by a separate motor. Therefore, the interaction with the treadmill was isolated for the left and right leg, whereas in a single belt the deceleration due to foot impact is more or less cancelled by acceleration due to the push-off of the other foot.	Treadmill walking aims to simulate over-ground walking, but intra-stride belt speed variations of treadmills result in some interaction between treadmill and subject, possibly obstructing this aim. Especially in self-paced treadmill walking, in which the belt speed constantly adjusts to the subject, these interactions might affect the gait pattern significantly.	Eighteen Subjects Walked on a dual-belt instrument ed treadmill at both modes.	The study was to quantify the energy exchange between subject and treadmill, during the fixed speed (FS) and self-paced (SP) modes of treadmill walking.
9	A.R. den Otter, et al., 2003	Speed related changes in muscle activity from normal to very slow walking speeds	Subjects walked on a motor-driven treadmill (2.0×0.7 m) at seven different walking speeds (1.39, 0.83, 0.28, 0.22, 0.17, 0.11, and 0.06 m s−1) while EMG was recorded from eight lower extremity muscles. Two 40-s registrations were completed at each walking speed in two quasi-randomised series of seven trials. The order of each series was the same for all subjects.	Walking on the treadmill, both cadence and step length are imposed on the subject by the moving walking surface. These studies did not extend to the very low-speed range it is unlikely that major differences would appear.	Walking on a solid surface, extremely slow speeds may be realised by sequencing of more or less 'static' postures. The limited number of EMG studies that have compared treadmill walking and floor walking failed to show clear differences in the underlying patterns of muscle activity, other than minor changes in the amplitude of muscle activity.	Nine healthy young adults (five females, four males).	The aim of the present study was to investigate patterns of lower limb muscle activity during very slow walking (<0.28 m s−1), and to study the neuromuscular gain functions that reflect the phase-dependent effects of walking speed on (EMG) amplitude.
10	Jennifer R., et al., 2005	Electromyogr aphic and kinematic nondisabled gait differences at extremely slow over-ground and treadmill walking speeds	The study compared the kinematic and electromyographic (EMG) gait patterns of able-bodied adults at natural speed in contrast to extremely slow over-ground and treadmill walking speeds. Kinematic and EMG data were collected at three speeds (self-selected, 0.30 m/s, and 0.20 m/s). Subjects were evaluated for trunk and lower-limb motion and EMG of five lower-limb muscles. Subjects wore dark shorts, shirt, and shoes. Reflective markers were placed on the acromion, greater trochanter, lateral tibial plateau, lateral	The patterns of motion also agreed with past research, which mainly reported on speeds ranging from 0.60 to 0.80 m/s. EMG results generally agree with the literature, demonstrating a substantial decrease in EMG amplitude of selected muscles with slower walking speed.	Subjects in the present study reported that more conscious effort was required to maintain balance at these slower walking speeds. Patients with balance and sensorimotor deficits may be further challenged by the fact that walking speed is substantially slower. Thus, slow walking may be even more difficult for some patients than a more rapid gait.	18 able-bodied volunteers (13 females, 5 males).	There are revealed minimal differences between over-ground and treadmill walking at natural speeds. At extremely slow walking speeds, over-ground and treadmill conditions showed similar and substantial reductions in kinematic and EMG patterns.

			malleolus, posterior aspect of the calcaneus, fifth metatarsal, and toe of the right side of the body. The two-dimensional motion was obtained by one Panasonic video camcorder located perpendicular to the line of progression as subjects walked along the 10 m walkway and on the treadmill.				
11	Richard Shiavi, et al., 1987	Electromyographic gait assessment, part 1: Adult EMG profiles and walking speed	The profiles of the linear envelopes of surface electromyograms of seven major muscles in adults were studied as a function of walking speed. The ensemble statistical properties of average and standard deviation were used to quantitate the characteristics of the electromyographic patterns. The participated asked to walk at self-selected speeds of free, fast, slow, and very-slow on a level 12-meter walkway. Bilateral foot-contact and EMG measurements were made while they traversed the middle 5 meters. The start and end of a measurement run were triggered by the subject passing through and interrupting a light beam being sensed by photoelectric cells.	The ensemble statistical properties were used to quantitate the characteristics of the patterns. Two general types of pattern changes were observed: one was that the fundamental phasing of muscle activity never changed but that relative amplitude of the phases was modulated as speed increased; the second was that different phases of activity existed for different walking speeds. The timing of most phases as expressed in percentage of the stride decreased as speed increased. This suggests that the time base should be further normalized by stance and swing phases.	Several muscles displayed additional or fewer phases of activity at different walking speeds. At slower speeds, the medial hamstring and vastus lateralis had another phase of activity during the stance-to-swing transition and early swing, respectively. Perhaps the reason this phase of activity is not always observed is that most investigators concentrate on activities at free and fast walking speeds.	Thirty normal adults, (20 males and 10 females).	The profiles of the linear envelopes of electromyographic patterns of seven major muscles were studied as a function of walking speed. All subjects were adults and the electromyograms were measured with surface electrodes. The speeds ranged from 0.34 to 2.13 meters per second.
12	Manvinder Kaur, et al., 2016	Influence of Gender on Muscle Activity Patterns During Normal and Fast Walking	EMG activity was recorded from the selected muscles of both the left and right lower limbs of all subjects during barefoot gait. The skin was rubbed with cotton containing alcohol to minimize the skin impedance, thereby improving signal acquisition. Disposable Circular electrodes (44 x 32 x 1 mm) were placed on the subjects for the above muscles, with respect to the longitudinal location of the sensor on the muscle and halfway the distal motor endplate zone and the distal tendo the transversal location of the electrode.	The statistical analysis showed no significant changes in gender differences were found during normal walking but when the speed of walking changed from normal to fast, gender differences were found to be significant for all the studied muscles. Overall, the propensity of males is found to be superior over females for muscle activity patterns of gluteus, Soleus, rectus femoris and biceps femoris.	The lack of kinematic and kinetic data means that confounding variables may be present. The group of participants observed here consisted of young participants and these findings may not be generalized to older populations. Despite these issues, this would also help to identify the normal ranges of EMG variations for a local adult population under study for developing EMG based controls in a wide range of clinical applications.	Twenty healthy adult volunteers were recruited. 10 male, 10 Female.	This paper was to evaluate possible gender-related differences in the EMG activity of four significant lower limb muscles Gluteus Maximus, Soleus, Quadriceps (rectus femoris) and Hamstring (biceps femoris) for both the legs.
13	Kadek Heri Sanjaya, et al., 2016	The biomechanics of walking symmetry during gait cycle in various walking condition.	This study investigated the effects of laterality and walking speed on gait symmetry during three conditions of walking on a treadmill, namely pushing while walking, walking with arm-swing, and walking while holding on a handlebar. All conditions were performed at three speeds: 1.5, 3, and 4 km/h. Symmetry was measured from bilateral gait cycle duration	Walking holding condition in general produced the greatest symmetry, confirmed the importance of this posture in gait therapy for improving symmetry among hemiparetic patients.	Left-handers showed different characteristics from right-handers in various variables measured and not in mirror characteristics.	Participants were 17 healthy young adult males that were Chiba University students.	Walking holding condition resulted in greater symmetry than manual pushing and walking with arm swing. This probably confirms the importance of this condition in rehabilitation therapy of stroke survivors.

			and cross-correlation function analysis performed in one gait cycle.				
14	Oliver A. Kannape, et al., 2016	Split-belt adaptation and gait symmetry in trans-tibial amputees walking with a hybrid EMG controlled ankle-foot prosthesis	The main focus of this research has been on short-term adaptation, such as in response to a terrain transition or a sudden change in the environment. The current exploratory study about investigated adaptation, sensorimotor learning, and gait symmetry in a group of trans-tibial amputees walking with a hybrid-EMG controlled powered prosthesis and matched controls. Participants were asked to perform a split-belt walking trial during which the belt on the affected side ran at twice the speed of the contralateral belt (1.0m/s and 0.5m/s respectively).	All amputees were able to recruit their muscle and thereby control the torque generated by the prosthesis before ankle push-off. Trans-tibial amputees adjust their residual limb muscle EMG according to treadmill velocity and adapt to the split-belt walking condition by normalizing temporal gait characteristics.	In the long term, adaptation and with it sensorimotor learning are further important to optimize gait and adjust walking patterns predictively, when faced with persistent perturbations. Long term not including in this study.	Three trans-tibial amputees and three matched non-amputees.	The trans-tibial amputees were able to use the hybrid controller for the powered ankle-foot prosthesis during treadmill walking by modulating their EMG power. All participants adapted to the split-belt condition by adjusting the spatiotemporal parameters of their gait.
15	Stephanie Huang, et al., 2012	Muscle activation patterns during walking from trans-tibial amputees recorded within the residual limb-prosthetic interface	The study had recorded surface electromyography from three lower leg muscles (tibialis anterior, gastrocnemius medial head, gastrocnemius lateral head) and four upper leg muscles (vastus lateralis, rectus femoris, biceps femoris, and gluteus medius) of 12 unilateral trans-tibial amputee subjects and 12 non-amputee subjects during treadmill walking at 0.7, 1.0, 1.3, and 1.6 m/s. Muscle signals were recorded from the amputated leg of amputee subjects and the right leg of control subjects.	An advantage of prosthetics that rely on kinetic and kinematic sensing to infer user intent is that all of the sensors and associated computational hardware are built directly into the prosthetic. The interface with the human is purely mechanical, which simplifies socket design. These prosthetics generally have low step-to-step variability due to the robustness of the finite state controllers and the low sensor noise. Controllers based on intrinsic sensing tend to work well for stereotyped or cyclical tasks, such as gait.	One of the inherent drawbacks of these devices is that control based on intrinsic sensing is not very good at aperiodic or highly variable motor tasks. For example, going up on the toes to reach a higher shelf would be very difficult for a state-based controller to perform using intrinsic sensing. Similarly, tasks with highly variable step-to-step kinematics such as traversing obstacles in the terrain, traversing unstable terrain, or negotiating through a crowd of people, or dealing with a variety of natural surfaces like sand and rocks would be difficult to deal with using intrinsic sensing alone.	Twelve unilateral trans-tibial amputee subjects (10 male, 2 female) and twelve non-amputee subjects (8 male, 4 female).	It is possible to record artefact-free muscle activation patterns from residual limb muscles within the prosthetic socket-limb interface with surface electromyography electrodes. There is high inter-subject variability in recruitment patterns in amputees, but for each subject EMG patterns are consistent from stride to stride.
16	Sven Grevsten, et al., 1975	Electromyographic Study of Muscular Activity in the Amputation Stump While Walking with PTB and PTB-suction Prosthesis	The present electromyographic investigation was undertaken with the aim of comparing activity of the stump muscles without prosthesis and when using the PTB and PTB-suction prosthesis. In the muscular pattern, three components have been separated for investigation: 1 . Voluntary contraction of the stump muscles without prosthesis. 2. Activity pattern of the antagonistic muscles while walking, and 3. Amount of muscular activity in the stump muscles while walking.	The findings suggest that "normal" EMG-pattern in the PTB-suction prosthesis with high amplitude is associated with improved adaptation to this prosthesis. The EMG investigations can be of assistance when selecting the most desirable prosthesis for the individual patient.	The observed differences between the muscular activity for amputees and normal subjects may be due to differing afferent input in the amputation stump from that in normal subjects.	Nine healthy men and BK amputation (unilateral in 8 and bilateral in 1)	When the EMG pattern is more "normal" and the amplitude higher with the PTB-suction prosthesis, it is probably the more suitable prosthesis. These EMG investigations can thus be a possible adjunct in the selection between the PTB-suction prosthesis and PTB prosthesis.
17	Benjamin J. Darter,	Home-Based Treadmill Training to	Home-based treadmill walking for a total of 30 minutes a day, 3 days per week for 8 weeks. Each 30-minute training session	The training effect was significant for the step length symmetry ratio within the first 4 weeks of the program.	Research investigating the effectiveness of treadmill-based training is lacking in persons with	Individuals with a TFA (N=8) who	Home-based treadmill walking is an effective method to improve gait

	et al., 2013	Improve Gait Performance in Persons With a Chronic Transfemoral Amputation	involved 5 cycles of walking for 2 minutes at 3 speeds.	Energy expenditure decreased progressively during the training with nearly 10% improvement observed across the range of walking speeds.	bilateral LEA. Only 2 case reports describe the exclusive use of a walking program.	had undergone a unilateral amputation at least 3 years prior as a result of limb trauma or cancer.	performance in persons with TFA.
18	A.H. Vrieling, et al., 2007	Balance control on a moving platform in unilateral lower limb amputees	Subjects stood erect on the moving platform with their hands alongside their bodies. For reasons of safety, subjects were provided with a safety belt that was connected to the ceiling. The feet were placed in a self-selected position, one on each force plate. Balance control on a platform that moved in the anteroposterior direction was tested with eyes open, blindfolded and while performing a dual task.	The study indicate that experienced unilateral amputees with a high activity level compensate for the loss of ankle strategy by increasing movements and loading in the non-affected limb.	The ability to cope with balance perturbations is limited in the prosthetic limb. To enable amputees to manage all possible balance disturbances in real life in a safe manner, we recommend to improve muscle strength and control in the non-affected limb and to train complex balance tasks in challenging environments during rehabilitation.	Unilateral amputees subjects (n = 8) three transfemoral, five trans-tibial, and Able-bodied subjects (n = 9).	Most adjustments strategies in amputees occurred in the non-affected limb, whereas the requirements on the prosthetic limb during balance perturbations were only limited.
19	J. B. Dingwell, et al., 1996	Use of an instrumented treadmill for real-time gait symmetry evaluation and feedback in normal and trans-tibial amputee subjects	The purpose of this research was to evaluate a newly developed system for assessing and providing feedback on gait symmetry information in real time to subjects walking on a motorised treadmill (the CCF Treadmill). Gait asymmetries of six normal and six unilateral trans-tibial amputee subjects were quantified. The amputee group was the re-evaluated after receiving five minutes of training with each of three different types of real-time visual feedback (RTVF). Asymmetries in the measured parameters before feedback were 4.6 times greater in the amputee population than in the normal group. Significant decreases in gait asymmetry were demonstrated for all forms of feedback after amputees received feedback training.	The advantages of the system are that it allows the rapid collection and comparison of temporal and kinetic parameters of gait for multiple successive strides, at a constant known speed, without forcing subjects to target their footsteps.	Results indicate that gait asymmetries for different variables are not necessarily related and that more work needs to be done to identify those variables for which attaining a more symmetrical gait pattern is most beneficial.	Six normal (mean age 42.7 years) and six unilateral trans-tibial amputee subjects (mean age 41.7, and average 6.0 years using a prosthesis)	Further work also needs to be done to determine the long-term effects of such RTVF training.
20	E. Isakov, et al., 2000	Trans-tibial amputee gait: time-distance parameters and EMG activity	Gait analysis of trans-tibial (TT) amputees discloses asymmetries in gait parameters between the amputated and sound legs. The present study aimed at outlining differences between both legs with regard to kinematic parameters and activity of the muscles controlling the knees. The gait of 14 traumatic TT amputees, walking at a mean speed of 74.96 m/min, was analysed	Evaluation of standing balance activity of both limbs in TT amputees showed that the foot ground reactive forces generated by the amputated limb are smaller when compared to the sound leg.	The parameters of swing time, step time and step lengths are significantly shorter in the sound leg. This short step length of the sound leg is most probably due to the exclusive use of the SACH foot in this study. Indeed, it has been shown (Snyder et al., 1995) that the step length of the sound leg can be significantly improved by	Fourteen (14) males, 5 with left and 9 with right trans-tibial traumatic amputation volunteere	Significant differences in time-distance parameters between the amputated and sound leg were found for most parameters.

			by means of an electronic walkway, video camera, and portable electromyography system.		providing the amputee with a prosthetic foot design different from the SACH foot.	d to participate in this study.	
21	N.P. Fey, et al., 2009	The influence of increasing steady-state walking speed on muscle activity in below-knee amputees	Kinematic marker data were measured (120 Hz) using a motion capture system (Vicon, Oxford Metrics, Inc.) as each subject walked along a 10 m walkway. Each subject walked along the entire walkway at four randomly ordered, steady-state speeds of 0.6, 0.9, 1.2 and 1.5 m/s. Average speed was verified using two infrared timing gates. Trials were repeated until a minimum of five gait cycles per foot were measured at each speed ±0.06 m/s. EMG data were collected at 1200 Hz using surface EMG electrodes (2, 12-mm disk sensor contacts, 18-mm interelectrode distance, medical grade stainless steel; Motion Lab Systems, Inc.) from eight intact leg muscles.	Each amputee used his or her own prosthesis, with its alignment and fit verified prior to testing by a licensed prosthetist. The data used in this analysis were part of a larger data set collected in Silverman et al. (2008) that had not been analysed.	There were significant differences in the muscle activation patterns between the residual and intact leg muscles during specific regions of the gait cycle.	14 unilateral, below knee amputees (13 males, 1 female; 11 traumatic, 3 vascular) and 10 non-amputee, control subjects (7 males, 3 females).	The goal of this study was to identify changes in muscle activity in below-knee amputees in response to increasing steady-state walking speeds.
22	LF Yeung, et al., 2012	Effects of heel lifting on transtibial amputee gait before and after treadmill walking: a case study	Prosthetic alignment is usually unchanged once optimized. However, a previous study indicated that long-distance walking significantly altered gait patterns, suggesting some alignment adjustments after walking are required. This study investigated the effects of alignment changes (by inserting a heel lift) on gait of a transtibial amputee before and after treadmill walking.	The subject walked, without heel lifts, on a treadmill until perception of fatigue. Gait changes upon heel lifting at the prosthetic side were studied before and after the treadmill walking	Heel lifting induced drop-off with increased prosthetic-side knee flexion at mid-stance and pre-swing. The sound limb outreached to stabilize the gait. After the treadmill walking, the same heel lift did not induce drop-off. It reduced the plantar flexor power generation, potentially delaying its fatigue.	A male right-sided transtibial amputee. He was 47 years old (height = 1.7 m, weight = 74.6 kg).	After walking prosthetic-side heel lifting could be beneficial.
23	Deborah R. Vickers, et al., 2007	Elderly unilateral transtibial amputee gait on an inclined walkway: A biomechanica l analysis	The aim of this study was to analyse the gait characteristics of elderly amputees walking on an incline, through quantitative three-dimensional biomechanical analysis, by comparing them to agematched controls. Participants walked up and down an inclined (58) instrumented walkway at a self-selected pace. A ViconTM System 370 was used to acquire gait data, including temporo-spatial characteristics, ground reaction forces (GRF), electromyography (EMG), kinematics, and kinetics of the lower limb.	Compared to the age-matched controls, the amputees demonstrated reduced speed, knee and hip range of motion, hip moments, vertical GRF, along with increased amplitude and periods of muscle activation. The residual limb also had shorter single support stance phase, small stance phase knee moments, and the smallest moments and powers.	The differences demonstrate instability in stance of the residual limb. The sources of this instability include the prosthesis' limited range of ankle motion and ankle power generation, coupled with the residual limb's limited proprioception and tolerance of force.	Five male and 3 female elderly subjects with unilateral transtibial amputation s. Eight able-bodied subjects.	Prosthesis design and rehabilitation training should also improve the proprioception of their residual limb and increase their tolerance of force through the residual limb.

CHAPTER 3: METHODOLOGY

3.1 Study Design

At the beginning of the investigation, the subjects have invited to sign the consent statement before attending the investigation (Appendix 1). Thereafter, the subjects underwent for the required measurements (Table 3.1) (Table 3.2). The subjects had invited to the lab experiment for approximately a week before. The healthy participant called first to perform 30 minutes walking exercise on the treadmill for (2.2 km) distance, the trial repeated 5 times, starting with warming up for one minute, then performing the three different speeds (2, 3 and 4 km/h). After an accomplishing of the HB, the amputee participants have called to perform the walking exercise on the treadmill for the same distance and same measured speeds.

3.2 Ethics

This research was conducted with the approval of permission by National Medical Research Register Secretariat 37912 and under the guidance of Certified Prosthetist and Orthotist (CPO) of the International Society of Prosthetics and Orthotics (ISPO) Category-2.

3.3 Participants

The investigation was conducted of the ten healthy-bodied subjects (three males and seven females) and two trans-tibial amputee subjects (two males). Trans-tibial amputees have associated with their personal prosthesis to investigate the highest speed can achieve and perform it, which compare with the non-amputees, during the walking on the treadmill. The investigation was conducted by the wireless electromyographic sensors, to capture the changes in the hamstrings (BFM) and quadriceps (RFM) muscles activities. The study was conducted on a lower limb for healthy and unhealthy males and females (age 19   20 years, weighed 50   80 kg, height 150   35 cm). Further information about healthy-bodied and amputee subjects have shown in (Table 3.1) (Table 3.2).

3.3.1 Healthy Subjects

Seven healthy-bodied subjects are physically normal, with no medical history background, free from chronic diseases, with no regular medication. But, healthy subject number 6 has a chronic mental disease, with a regular medication specifically; Lithium and Aripiprazole. With respect, she refused to mention her situation disease and diagnosis. While healthy subject number 7 had a motorcycle accident before three days of the lab experiment. In addition, healthy subject number 5 has badly strong stress and extreme anxiety due to her study challenges and English Language deficiency. These circumstances were affected the measurement results as observed.

All participants consented to perform the experiment after the given information about the test procedure. The healthy subjects had shown no visible cardiac, musculoskeletal, lung and nerve disorders. Also, no walking abnormalities, no falling history as well as no lower limb pain. According to the information collected from the subjects at the investigation time, the majority of the healthy-bodied participants had no medical treatment such as the painkillers, antispasmodic medications, sleeping pills. Except for two subjects, one subject has a mental regular medication, and another subject has taken painkillers before 3 days of the lab session. Also, most of them had not suffered from the medication effects on blood pressure and heart rate. The healthy subjects free from rheumatologic diseases. In addition, none of them had faced the balance or cardiac problems. The subjects with the history of heart disease, blood pressure, and chest pain had been excluded from the experiment.

3.3.2 Amputee Subjects

At the time of the investigation, two unilateral trans-tibial amputees shown no medical problems could affect the gait experiment. The two amputees considered as independent ambulators. Also, none of them suffered from lower limb pain during the session. Amputee subjects wore their personal prosthesis during the treadmill walking exercise throughout the session experiment. The amputees have declared that their prosthesis had been used for more than two months before the investigation. The amputee subject number 1 had suffered from the amputation due to the electric shock. While amputee subject number 2 have an amputation caused by the motorcycle accident. Further details have shown in (Table 3.1).

The amputee subject number 1 (AS1); is a male with 29 years old, considered as an independent and energetic man operating his own business and practising his daily routine activities normally with slight difficulties. AS1 is suffering from the multi amputation, he is a trans-tibial amputee, below the knee of his left leg and trans-radial amputee, below the elbow of his left and right hands. The amputation occurred due to the 33-kV electric shock which caused burns at the third-degree level. Later on, the physician determined after five days of the accident to amputate his limbs due to gangrene. The physician performed him five operations to amputate the affected limbs. He owned a prosthesis limb within the eleven months post-operation. He declared that during the seven years of the amputation, had used only two prosthesis limbs. Recently, he has been using the pin lock prosthesis.

The amputee subject number 2 (AS2); is a male with 26 years old, deemed as a vital and independent man who's performed his activities life smoothly with some difficulties. Nowadays, he is a call centre employee. AS2 is suffering from the amputation, he is a trans-tibial amputee, below the knee of his left leg. When he was twenty years old exposed to a motorcycle accident, the physician decided after 46 days of an incident to amputate his below-knee left limb due to a limb infection and inactive below-knee muscles. AS2 underwent for five operations to amputate his affected left limb. He possessed a first prosthesis limb twelve months post-operation. He stated that during the six years of the amputation, had used only two prosthesis limbs. Currently, he is using the pelite prosthesis.

Table 3.1: The information about the trans-tibial amputee subjects.

DETAILS OF TRANSTIBIAL AMPUTEE SUBJECTS							
Subject No.	**Sex**	**Age (yrs)**	**Weight (kg)**	**Height (cm)**	**Time post - amp. (yrs)**	**Cause of amputation**	**Prosthesis type**
AS 1	M	29	72	171	21	Electric shock	Pin lock prosthetic
AS 2	M	26	51	169	20	Motorcycle accident	Pelite prosthetic

TTA Subject No.	Right knee width (cm)	Left knee width (cm)	Right Tibial Length (cm)	Left Tibial Length (cm)	Right Femoral Length (cm)	Left Femoral Length (cm)
AS1	10	10	33.8	14	40	40
AS2	9.22	9.22	23.9	12	38	38

Table 3.2: The information about the healthy-bodied subjects.

DETAILS OF HEALTHY-BODIED SUBJECTS				
Subject No.	**Sex**	**Age (yrs)**	**Weight (kg)**	**Height (cm)**
HS1	F	24	55	157
HS 2	F	25	56	151
HS 3	F	23	50	153
HS 4	F	25	60	156
HS 5	F	25	56	162
HS 6	F	27	60	154
HS 7	F	19	55	158
HS 8	M	28	79	170
HS 9	M	26	84	174
HS 10	M	28	128	186

3.4 Instruments

3.4.1 DELSYS Surface EMG System

The EMG system device is TRIGNO^{TM} Wireless which considers the high-performing system (Figure 3.1). The instrument intended to detect the EMG signal easily and reliably. EMG sensors are integrated the triaxial accelerometer, rechargeable battery with around 7 hours as a minimum and the transmission scope around 20 m. EMG system used the software for the Acquisition and Analysis data which streaming via wireless to the EMG work system. Also, generates the analog channels for acquisition systems for the third-party data and their captured motions, the channels around 48 accelerometers and 16 EMG. The triggering features can integrate into extra measurement technology (Figure 3.2) (DELSYS Incorporated, 2018).

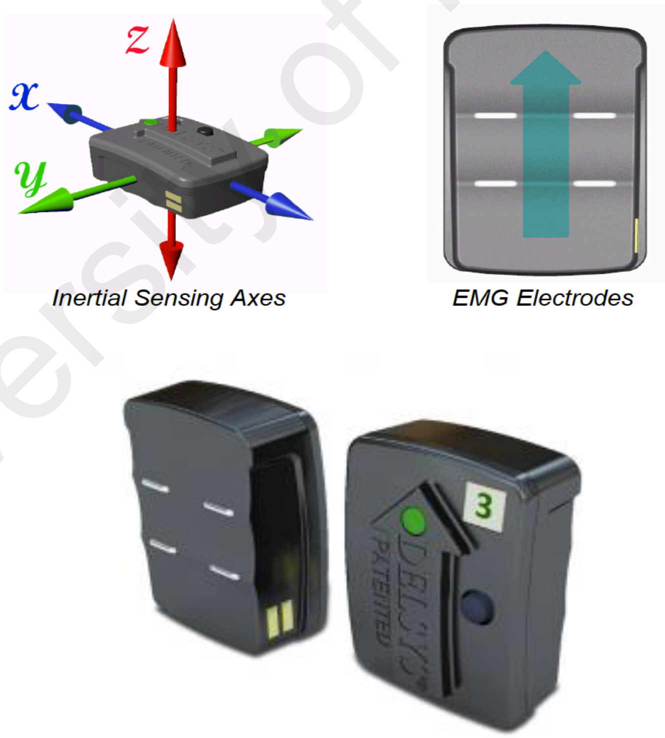


Figure 3.1: TRIGNO^{TM} Wireless 4-channels sensor (DELSYS Incorporated, 2018).

Wireless EMG Sensor (SP-W01D)

Each Trigno Sensor is equipped with the following features:

- transmission range of 20m
- inter-sensor latency < 500us (< 1 sample period)
- self-contained rechargeable battery
- EMG signal bandwidth 20- 450 Hz
- EMG signal sampling rate of 2000 samples/sec
- EMG baseline noise of <750 nV RMS
- CMRR > 80dB
- 16-bit EMG signal resolution
- integrated triaxial accelerometer
- software selectable accelerometer sensitivity of ±1.5g, ±4g, ±6g, or ±9g
- LED User feedback
- battery charge monitoring and status indicator
- environmentally sealed device
- proven parallel bar electrode technology
- contoured sensor-skin interface for maximum signal stability
- auto shutoff

Figure 3.2: TRIGNO™ sensor features (DELSYS Incorporated, 2018).

Figure 3.3: TRIGNO™ Base Station (DELSYS Incorporated, 2018).

Table 3.3: DELSYS 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

3.4.1.1 Software Installation

Through software, the PC controlled the wireless EMG system via the USB port. The systems contain an Analysis Software, Control Utility, Signal Acquisition and DELSYS Software. The Base Station has to install to connect to the PC for data acquisition via 3rd party. When EMG installation completed correctly, PC directly will detect the Base Station via the USB port which connects to the PC (DELSYS Incorporated, 2018).

3.4.1.2 Powering the Base Station

The power supply should connect to the jack circular DC on Base Station (Figure 3.4). The power supply has to connect to the isolation transformer or the Mains outlet for energizing. Base Station and the PC should be connected via an isolation transformer (Figure 3.3) (Table 3.3). At Base Station when the LED power applies the power, its directly illuminate. In addition, the antenna of Base Station should firmly be attached by the connector (DELSYS Incorporated, 2018).

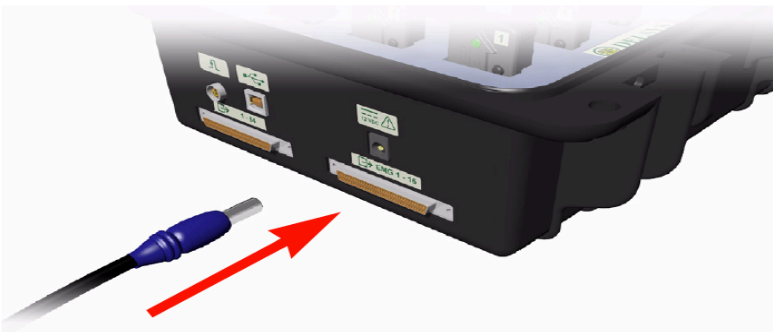


Figure 3.4: Connecting TRIGNO™ Base Station power supply (DELSYS Incorporated, 2018).

3.4.1.3 Charging the Sensors

EMG sensors must charge before conducting the experiment, the charging done by cradle slots of the Base Station. During the experiment, the LED power must illuminate green and powering the Base Station (Figure 3.5). Through the process of the charging, the LED sensor supposed to show the amber colour during recharge. When the LED sensor has totally charged, the LED will illuminate green. The process of charging the battery will take approximately two hours and a half to finish the full cycle of charging (DELSYS Incorporated, 2018).

Figure 3.5: Sensor LED feedback for battery charging status (DELSYS Incorporated, 2018).

3.4.1.4 EMG Sensors Aligning

EMG Sensors contain four silver bars which connect to disclose EMG signal on the surface of the skin. The sensor bars have to be in the vertical direction of muscle fibres to obtain the largest signal capacity. An upper part of the sensor contains the arrow-shaped to assist the user to figure out the orientation. The location of the arrow-shaped must be parallel to the muscle fibres which located underneath the sensor. TRIGNO^{TM} EMG Sensors have to set in the muscles' centre away from the muscles' edge. The EMG sensors can effortlessly be attached to the skin surface. I simply stick TRIGNO^{TM} EMG Sensors to the skin (DELSYS Incorporated, 2018).

EMG sensors must clean before attaching to the skin surface, for removing skin oils and dry dermis from the sensor's surface. In addition, the skin has to wipe via alcohol before the affixing the sensors into the skin, to acquire good quality signals. Also, it recommended shaving the excessive hair from the skin. Might use the medical tape to remove the dry cells from the skin if it is extremely dry. Before applying the EMG sensors, the skin must be dry from alcohol. EMG Sensors should be oriented properly with the muscle fibres (Figure 3.6) (DELSYS Incorporated, 2018).

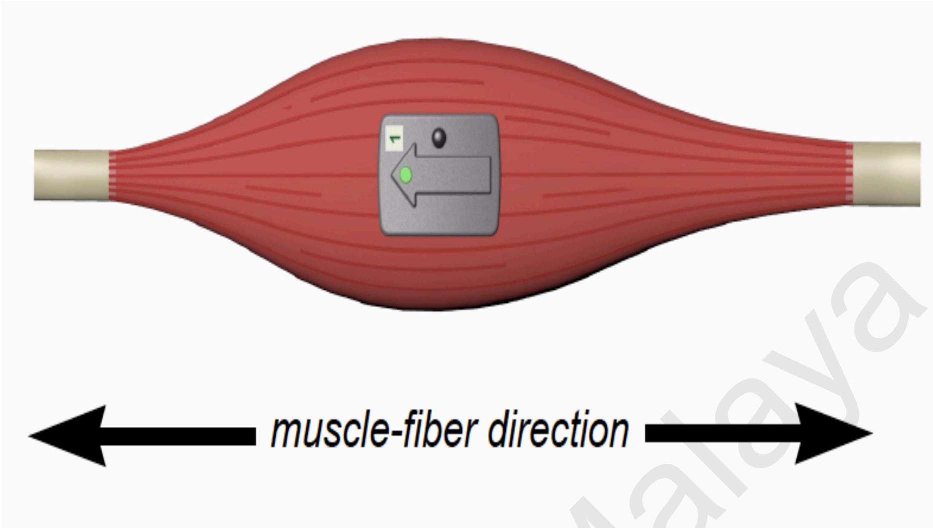


Figure 3.6: Align the sensor's arrow with the direction of the underlying muscle fibers (DELSYS Incorporated, 2018).

3.4.1.5 EMG Sensors On

When the EMG sensors have affixed into the skin's surface and before the signal and data acquisition, the sensor has to turn on (Figure 3.7). The LED sensor will flash green and looking for the nearest Base Station within the scope. If the sensor not within the range of the Base Station, the LED sensor will flash amber. Since the communication link has been established and the LED sensor is flashing a green every one second, which indicates that the signal transmitting and the data acquiring are streaming to the EMG system (DELSYS Incorporated, 2018).

Figure 3.7: Turning the TRIGNO™ Sensor "ON" (DELSYS Incorporated, 2018).

3.4.2 Treadmill

3.4.2.1 Kistler Gaitway Treadmill

The treadmill instrumented for walking training and gait way analysis with reliable outcomes. Treadmill used as a physical tool for the practice-oriented to collect the data and report the results. Also, it is useful for rebuilding the muscle performance after the recovery from an injury. Kistler treadmill is quite assisting in the clinical research and sports activities. Due to the results' accuracy of the treadmill has become a measurement standard worldwide. Kistler treadmill has developed several kinds of instruments such as the gait-way and a force plates treadmill (h-p-cosmos, 2015).

Treadmill machine is a stationary device for walking exercise (Figure 3.8). They use it for training and rehabilitation treatment. The device can perform different adjustable speeds and inclination. The instrument contains a dynamic platform which has the electric motor and conveyor broad belt. Treadmill belt is moving forward and backward, which allow the trainee to walk equally, to control velocity and direction as necessary (h-p-cosmos, 2015).

Figure 3.8: h/p/cosmos® running machines (h-p-cosmos.com, 2015).

During the rehabilitation treatment, the patients are demanded to concentrate on the treadmill walking exercise, watch their steps carefully a moment on the belt, and follow the provided speed. Also, the subject's position has to be preserved within the deck. I analyse the patient physical condition during the walking exercise via the EMG system. Through the physiotherapy treatment, the subject is strictly secure and obtained a body harness support. In addition, the treadmill apparatus provides the analysis of gaits under safe conditions (h-p-cosmos, 2015).

The treadmill walking benefits are obvious, for instance, the subject performs a task of steps measurement with a certain number, which demands subject to walk all over the room forwards and backwards to cover the scope. While performing a task on a treadmill is simply easier and faster. The subject demands to walk on the treadmill with a stable position of the body during a task to avoid the falling down. Consecutive strides can be measured as desired. However, the treadmill procedure makes the pattern acquisition and data analysis of the regular daily subjects complete quickly and simply. Treadmill helps to follow up with the patients preoperative and postoperative (Figure 3.9). Also, the treadmill plays a massive role in the rehabilitation treatment by a functional assessment, re-educates the walking post-operation, and follows up the physical results. Treadmill aids sports medicine by monitoring the changes at walking and running, control the training sessions and post-injury rehabilitation. In addition, the treadmill device provides opportunities for the researchers to measure the variable and nominated speeds for the purpose of studying the gait pattern transitions. Also, data acquisition from uphill and downhill walking (h-p-cosmos, 2015).

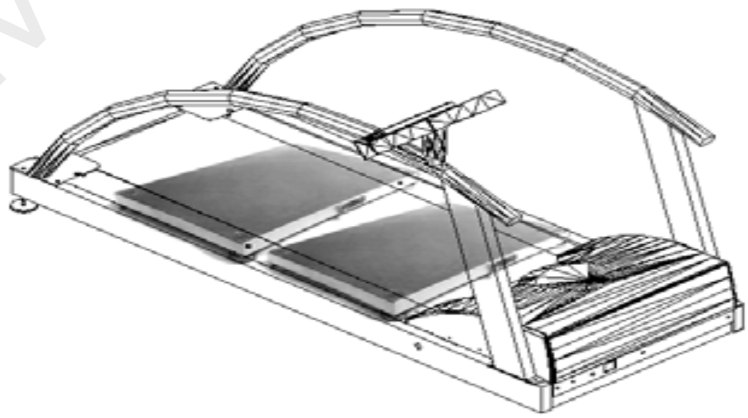


Figure 3.9: h/p/cosmos® running machines (h-p-cosmos.com, 2015).

The technical data of the treadmill apparatus is the belt surface areas scope from 150 x 50 cm, with handrails for both treadmill sides. Treadmill contains on 6 keys, 6 LCD displays and displays unit and mode with LED. AC power supply 100 V ~ / 110 V ~ / 200 V ~ / 208 V ~ / 230 V ~. Fuse C 16 A at 230 V ~. Power input (long time) 1500 VA and power input (momentary) 3400 VA. The capacity of drive motor 3300 VA. The treadmill has a mode of continuous operation with intermittent loading. Treadmill speed from 0.0 to 22.0 km/h with an accuracy speed +/- 5%. The dimension of the walking surface is length 1500 mm x width 500 mm. Dimension frame is length 2100 mm x width 800 mm x height 1370 mm. The track access height from the floor 180 mm. The treadmill weight is 200 kg. Maximum permissible user weight is 300 kg. Treadmill environmental conditions involve the humidity which about 30 to 70% - without condensation, the temperature around +10 to +50 °C, the barometric pressure approximately 700 to 1060 hPa (h-p-cosmos, 2015).

3.5 Procedure

3.5.1 Anthropometric Measurements

Overall, the data acquisition process passes through several steps, subject selection, anthropometric data, recording the signals, data processing. Anthropometric data involves body height and body weight. Anthropometric data consider the first step to the walking exercise experiment since each subject has to undergo the required measurements for data collection purpose. The measurement process is simple and quick approximately 5 minutes. For amputee subjects, I measure anthropometric data for the sound and amputated limbs. Further information about anthropometric measurements of healthy-bodied and trans-tibial amputee subjects have shown in (Table 3.1) (Table 3.2).

3.5.2 Circumference of Thigh Measurements

Amputee subjects require additional information, for instance, mid-thigh circumference, amputation causes are trauma or electric shock, amputation level, prosthetic and socket types. The thigh circumference has measured for both limbs, an amputated leg and sound leg. The amputees have selected with unilateral trans-tibial amputation level. Further details about thigh circumference of healthy-bodied and trans-tibial amputee subjects have shown in (Appendix 2).

3.5.3 DELSYS Wireless EMG Sensors

Post-starting the investigation, the subjects have to clean the nominated area, by removing the dead skin and oils produced by the skin. Also, they have to shave the skin from unwanted hair. In addition, the area must be swabbed via alcohol to ensure the clear results with a highly precise. After the skin preparation, the EMG sensors take place on the skin surface via the four silver strips (Figure 3.10). The silver strips have the function of detecting the EMG signals (Garikayi et al., 2018).

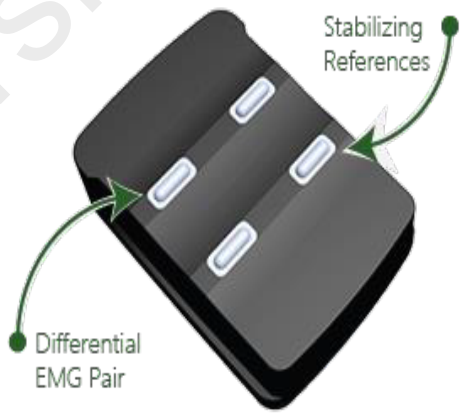


Figure 3.10: Wireless EMG 4-channel sensor (Delsys Incorporated, 2018).

Parallel to the treadmill walking process, Delsys Wireless EMG Sensors attached into the hamstrings (BFM) (Figure 3.13) and quadriceps (RFM) muscles (Figure 3.12). EMG sensors play the role of the connector between subject and Base Station. EMG sensors collect the signals acquired from the subject's muscles from the last 10 seconds of one minute walking exercise. The EMG sensors transfer the signals to the Base Station, which captured via an antenna. Base Station transfers the signals to the EMGworks Analysis program on the PC for the data analysis. The EMGworks Analysis program provides a fast, simple and reliable analysis.

Measuring the muscle activity of hamstrings (BFM) and quadriceps (RFM), recording muscle signals, for this purpose, the surface wireless EMG sensors take a place over the skin at the nominated muscles (Figure 3.11). Therefore, small piece and position where EMG sensors attach and tape on the limbs have to shave, in order to obtain an accurate result. Moreover, no risk upon the participants during this procedure, no pain neither discomfort. Also, the Laboratory personnel in charge are attending the whole session trials to ensure the subjects' safety and assist during the experiment.

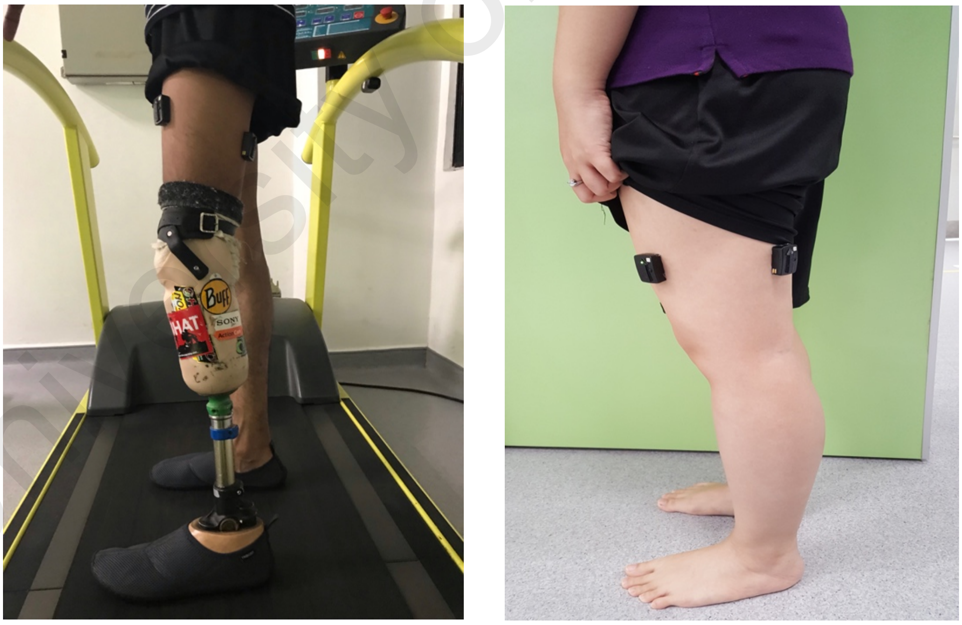


Figure 3.11: TTA and HB subjects with DELSYS Wireless EMG Sensors.

Figure 3.12: The Rectus Femoris Muscle (Dreamstime.Com, 2018).

Figure 3.13: The Biceps Femoris Muscle (Fitness Oriented, 2015).

3.5.4 Treadmill Walking Analysis

In the beginning, the subjects are demanded to warming-up for one minute before recording the data, to stimulate the RFM and BFM muscles, for the purpose of EMG signals performance (Figure 3.14). The subject has to ride the treadmill barefoot, with the aids of the operator, the subject starts the walking exercise at speed (2 km/h), the walking process performs for one minute. Subject has the chance to grip on the handrail during the training as a procedure for ensuring the safety. After completing one-minute walking, the subject has to take rest for 5-minutes. Thus, the subject has to repeat the process for 1-minute walking on (2 km/h) and has to take rest for 5-minutes, they will repeat the process for 5 times with the same steps.

When speed (2 km/h) completed, they moved on to speed (3 km/h), the subject will continue the walking exercise at speed (3 km/h), the walking exercise will perform for 1-minute. After completing 1-minute walking, the subject has to take rest for 5-minutes. Therefore, the subject has to repeat the process for 1-minute walking on the same speed and has to take rest for 5-minutes, they will repeat the walking process for 5 times with the same steps.

Moreover, when the walking process of speed (3 km/h) has completed, they moved on to speed (4 km/h), the subject will continue the walking training at speed (4 km/h), the walking training will carry out for 1-minute. After fulfilling the 1-minute walking, the subject has to take rest for 5-minutes. Thus, the subject has to repeat the process for 1-minute walking on the same speed and has to take rest for 5-minutes, they will repeat the walking process for 5 times with the same steps. The subject predicts to accomplish the whole walking exercise on the treadmill within 2 hours. All HB and amputee participants had completed five successful trials.

Figure 3.14: TTA and HB subjects walking on the treadmill.

3.5.5 Level Walking

The hamstrings (BFM) and quadriceps (RFM) muscles activity had recorded during the treadmill walking exercise, since the participant walked along 2.2 km, for around 30 minutes, 15 minutes for left leg and 15 minutes for right leg, in the gait and motion analysis laboratory. The subjects have walked on three different speeds after warming-up for 1-minute. Through the 1-minute walking, the data had collected from the last ten seconds during each trial. Each subject had obtained 5 successful trials. According to Kalantari et al. (2017) post-elimination of deceleration and acceleration, approximately ten strides had obtained from each subject to be analysed. Which considered as a credible indication of the muscle activity during the walking exercise (Kalantari et al., 2017).

Initially, the subjects have arrived at gait and motion analysis laboratory within an appointment time. The experiment has started by taking the required anthropometric measurements such as; weight and height. Also, had recorded the subject's information such as; age and medical history background. Next, the subjects have prepared for the walking exercise by wearing a suitable outfit like shorts. Moreover, the subjects have attached the wireless EMG sensors on the nominated muscles, which are the hamstrings (BFM) and quadriceps (RFM) after switch-on the EMG sensors.

Furthermore, the subjects took place on the treadmill warming-up for 1-minute. Then the 1st trial started by fixing the velocity on speed (2 km/h). The subject has conducted the trial for 1-minute, while the data had acquired from the last ten seconds via the wireless EMG sensors. After completing the 1st trial, the subject rested for 5-minutes. Then the subject proceeded to the second trial, by walking for 1-minute and record the last 10 seconds, using EMGworks analysis program. The process of the 3rd, 4th and 5th trials had performed with the same procedures and steps.

Later on, the subject moved on to the 2nd level of speed (3 km/h); the subject took place on the treadmill by warming-up for 1-minute. After that, the subject underwent the 1st trial for 1-minute; the signal passed from the muscles to wireless EMG sensors, then to Base Station, which its transfer to the EMGworks program. When the trial process completed, the subject claimed to take the 5-minutes rest. Subsequently, the subject performs the 2nd, 3rd, 4th and 5th trials by following the exact methods.

Moreover, the subject got the idea about the last stage and nominated speed (4 km/h); the subject has moved back to the treadmill and fulfilled 1-minute warming-up. As former, the subject carried out the 1st trial for 1-minute. However, the data had captured by the wireless EMG sensors to analyses via EMGworks program. The subject induced to get 5-minutes rest, then the subject has implemented the 3rd, 4th and 5th trials.

3.6 Flowchart of Research Activities

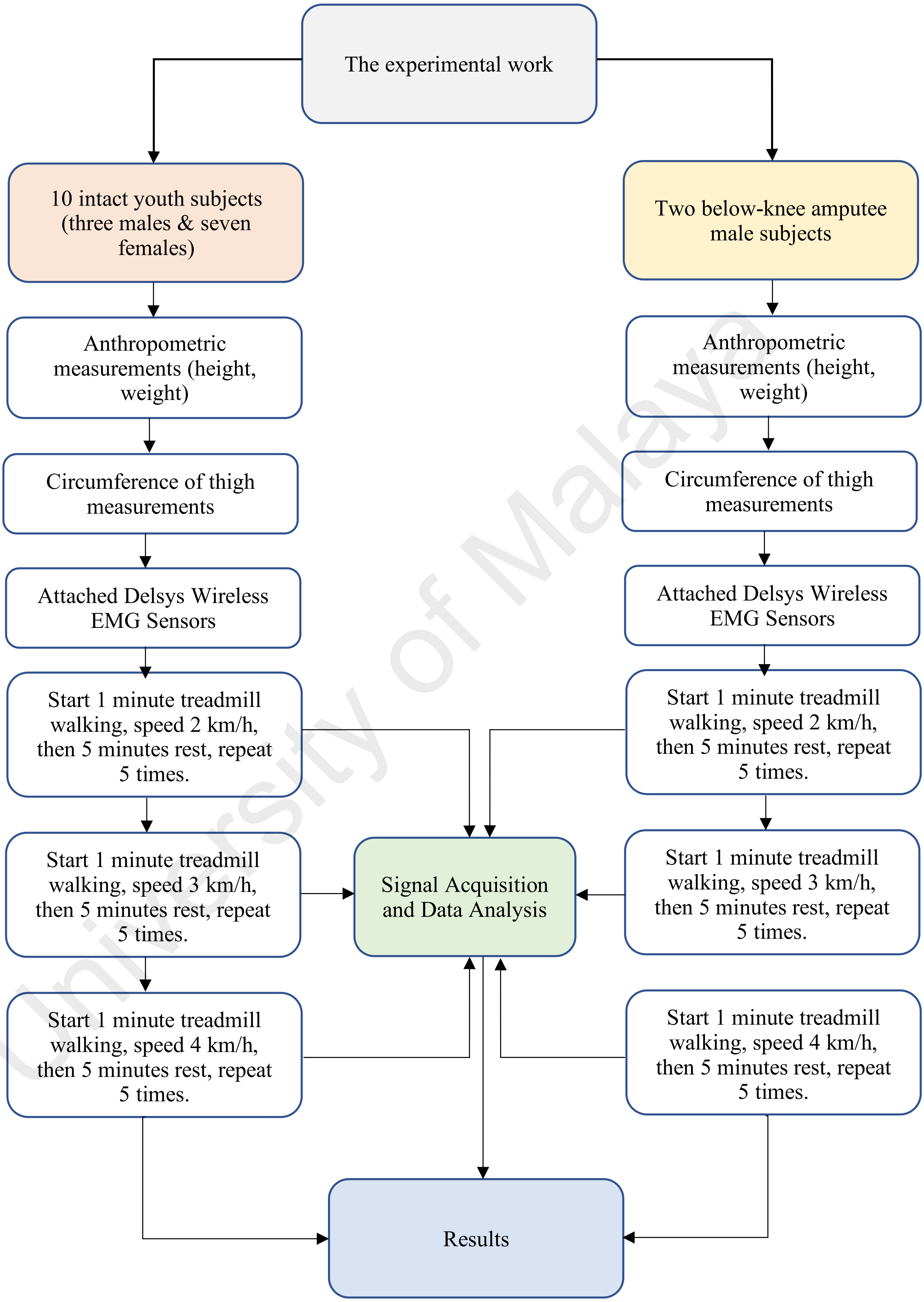
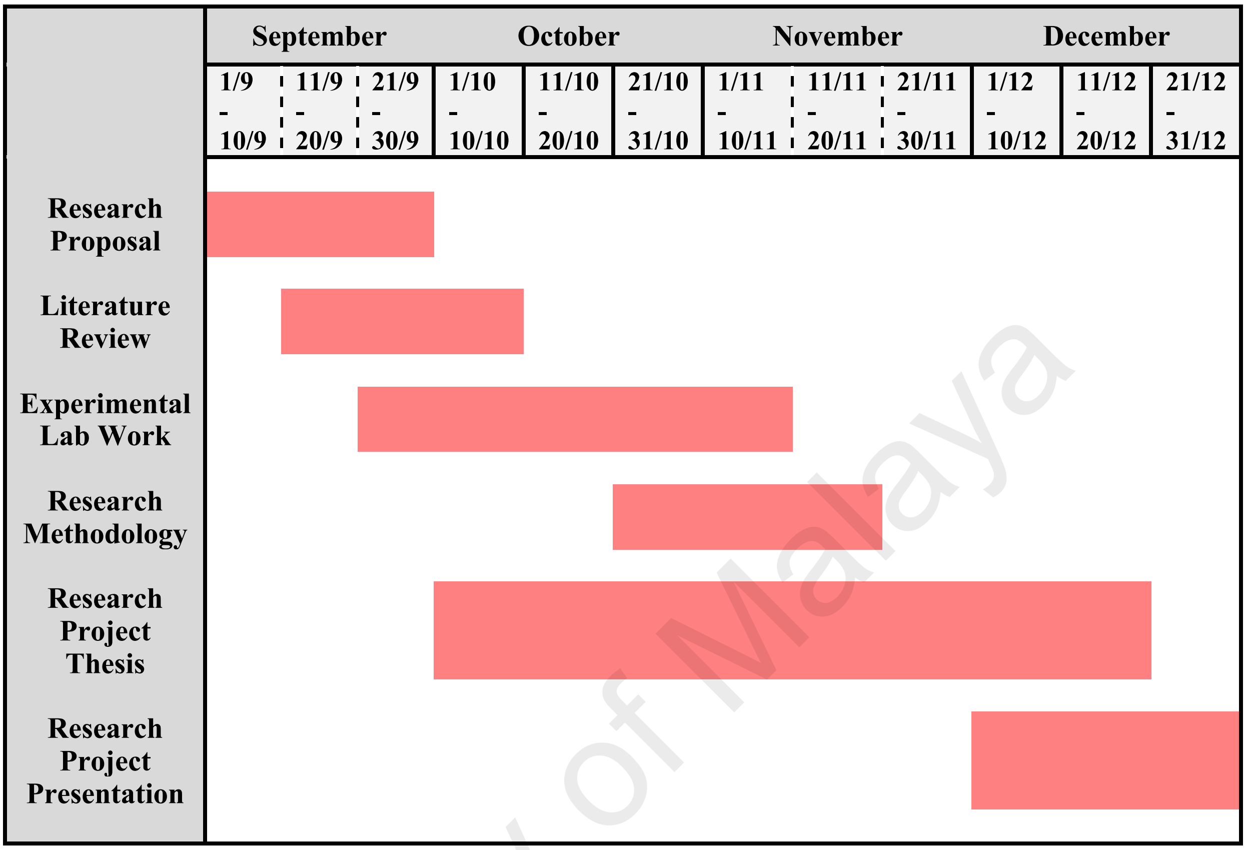


Figure 3.15: Flowchart of Research Activities.

3.7 Gantt Chart

3.7.1 Schedule of Activities



3.8 Data Handling and Statistical Analysis

I used a descriptive statistical test to analyse the data in this study. DelSys EMGworks Analysis system was performed on a computer to read the statistical results had taken. I handled the data from the first group (TTA) and from the second group (HB). Also, from the dominant limb and non-dominant limb of healthy-bodied subjects. In addition, the sound limb and amputated limb of the trans-tibial amputees. The data had collected during the specific task (walk activity on the treadmill with three different speeds). EMG was analysed, on quadriceps (BFM) and hamstrings (RFM) muscle. The obtained data have exported from DelSys EMGworks Analysis to MS Excel for building the graphs. The obtained data underwent to filtration processes such as filter IIR and Root mean square via the EMGworks Analysis program.

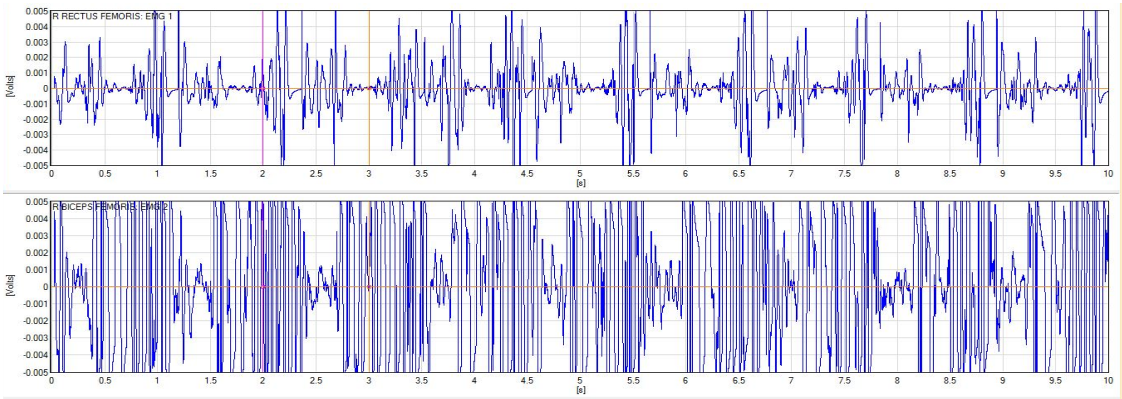


Figure 3.16: Right Rectus and Biceps Femoris Muscles before filtration.

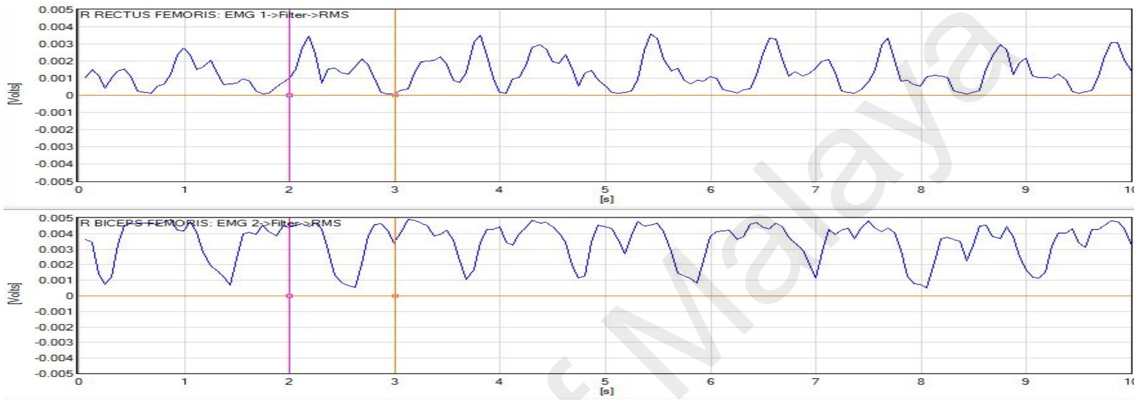


Figure 3.17: Right Rectus and Biceps Femoris Muscles after filtration.

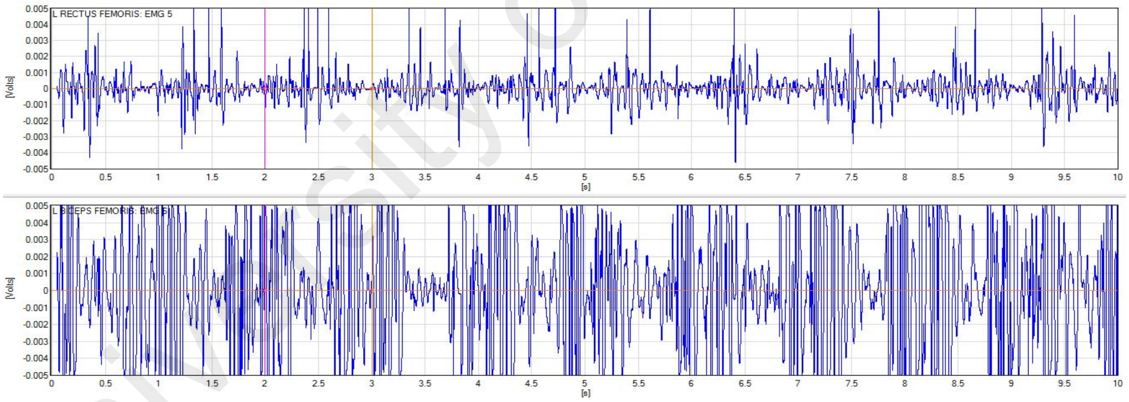


Figure 3.18: Left Rectus and Biceps Femoris Muscles before filtration.

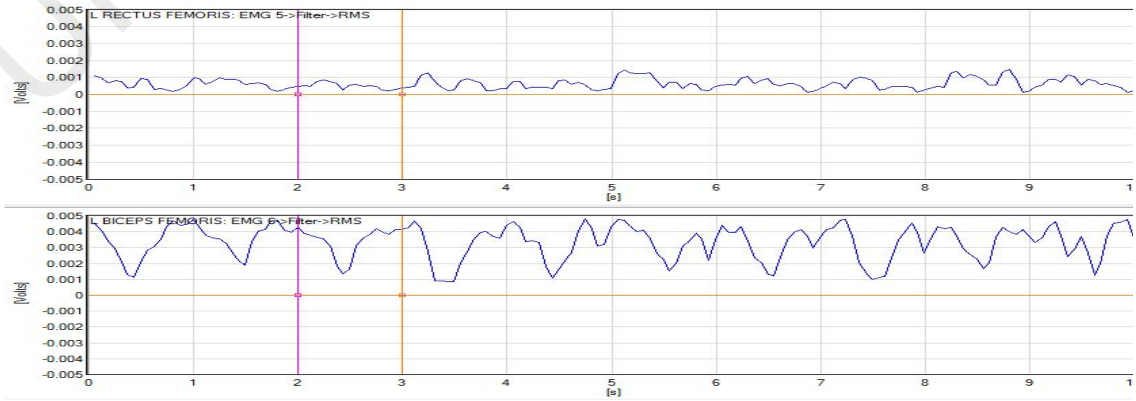


Figure 3.19: Left Rectus and Biceps Femoris Muscles after filtration.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 EMG Parameters for Treadmill Walking Analysis

I observed the main effects of walking on the treadmill with three different speeds on the magnitude of RFM and BFM muscles activity to be highly notable (Table 4.1). During treadmill walking variations of muscle activity magnitude has highly observed in the healthy-bodied subjects more than the trans-tibial amputees. As hypothesised, variations of muscle activity magnitude have shown the highest value during speed (4 km/h). While the lowest value has shown for all HB and TTA similarly between speeds (2 and 3 km/h). The right biceps femoris muscle has shown the highest value at speed (4 km/h). Also, the dominant limb has a highly notable reading during the three different speeds. As a result, the right biceps femoris muscle considers as the dominant limb. Whereas, the left rectus femoris muscle has shown the lowest value at speed (2 km/h) during the one minute of walking. Moreover, the magnitude of the BFM muscle activity for the right leg has observed a highly notable mean value (75.9) at speed (4 km/h), whereas the mean value at speed (3 km/h) is (52.7) and speed (2 km/h) is (61.3) have shown notable differences.

Table 4.1: The mean value and standard deviation of the healthy-bodied subjects during treadmill walking at three different speeds.

Mean value and standard deviations of BFM and RFM						
	2 km/h		**3 km/h**		**4 km/h**	
	AVG	**SD**	**AVG**	**SD**	**AVG**	**SD**
Left BFM	44.4	0.0004	36.1	0.00038	67.5	0.00044
Left RFM	18.5	0.0002	28.1	0.00032	44.8	0.00042
Right BFM	61.3	0.0004	52.7	0.00065	75.9	0.0006
Right RFM	28.9	0.95	27.3	0.00035	37.7	0.00036
TOTAL	**153.1**	**0.951**	**144.2**	**0.0017**	**225.9**	**0.00182**
MEAN	**38.28**	**0.2378**	**36.05**	**0.00043**	**56.48**	**0.00046**
SD	18.68	0.47	11.79	0.00	18.14	0.00

4.1.1 Healthy-Bodied (HB)

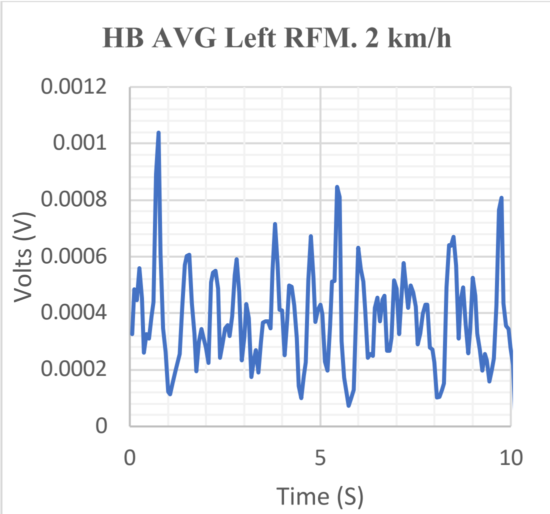


Figure 4.1: AVG of treadmill walking for Left RFM, of HB subjects with 2km/h.

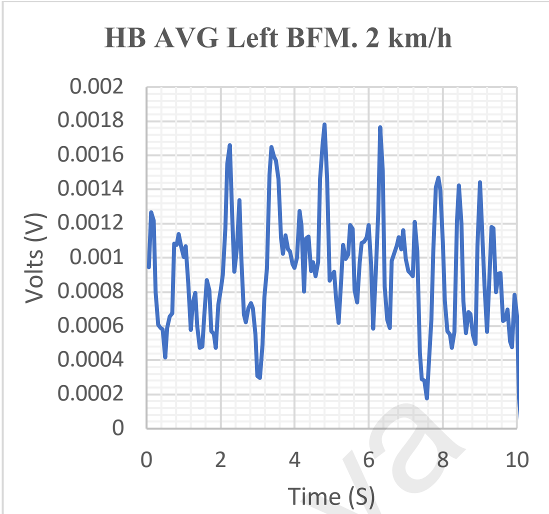


Figure 4.2: AVG of treadmill walking for Left BFM, of HB subjects with 2km/h.

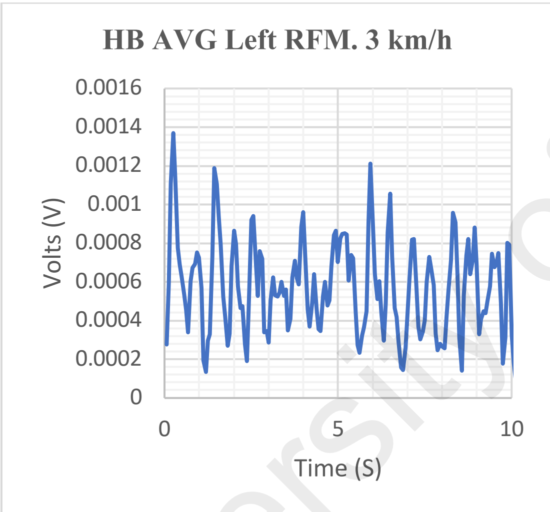


Figure 4.3: AVG of treadmill walking for Left RFM, of HB subjects with 3km/h.

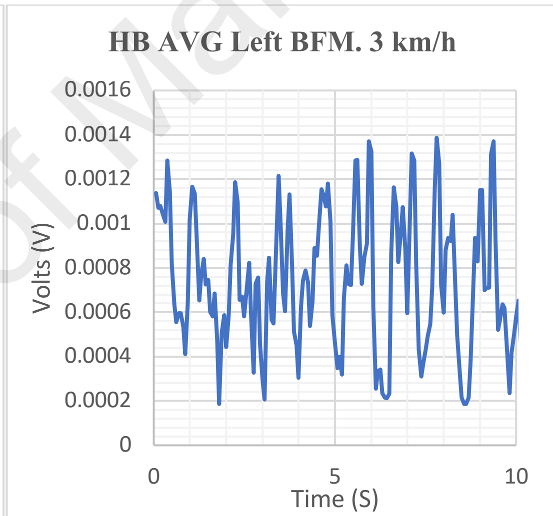


Figure 4.4: AVG of treadmill walking for Left BFM, of HB subjects with 3km/h.

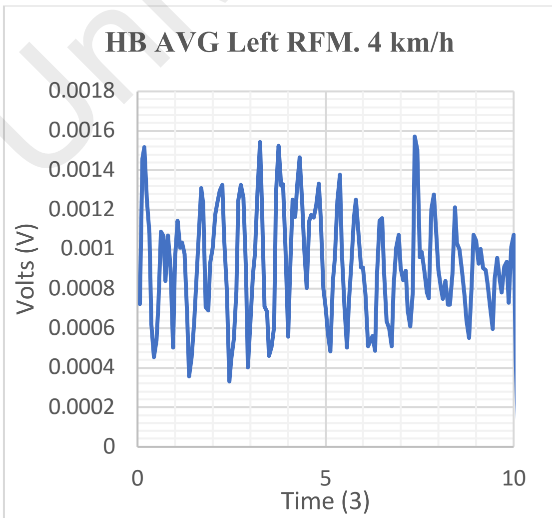


Figure 4.5: AVG of treadmill walking for Left RFM, of HB subjects with 4km/h.

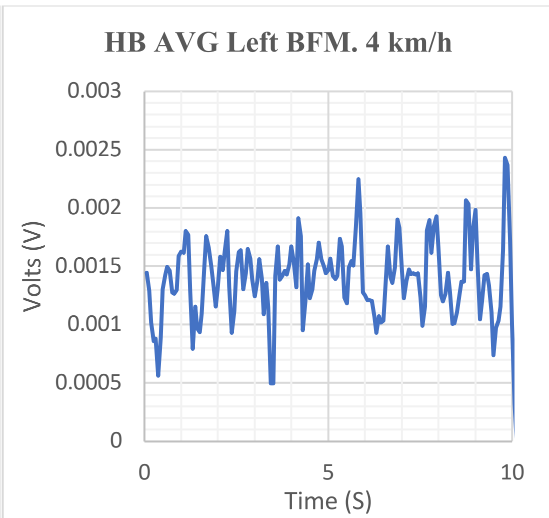


Figure 4.6: AVG of treadmill walking for Left BFM, of HB subjects with 4km/h.

At speed (2 km/h), has observed the peak of the left biceps femoris muscle activity at (0.0018 V), while the minimum value at (0.0002 V), during the last 10 seconds of 1-minute walking on the treadmill performed by the healthy subject (Figure 4.1). At speed (3 km/h), the peak of the left biceps femoris muscle activity at (0.0014 V), whereas the lowest value at (0.0002 V), through last 10 seconds walking (Figure 4.2). At speed (4 km/h), the beak of the left biceps femoris muscle activity has reached a highly notable value at (0.0025 V) comparing with other speeds within the same left BFM, while the bottom value record at (0.0005 V) during the last 10 seconds walking (Figure 4.3).

During the left rectus femoris muscle activity, at speed (2 km/h), has observed the peak at (0.001 V), and the lowest value at (0.0001 V), during the last 10 seconds of treadmill walking carried out by the healthy-bodied subjects (Figure 4.4). At speed (3 km/h), the peak of the left rectus femoris muscle activity at (0.0014 V), while the minimum value at (0.0001 V), during the last 10 seconds of treadmill walking (Figure 4.5). At speed (4 km/h), the beak of the left RFM activity has reached (0.0016 V), shown slightly change compared with speed (3 km/h), while the minimal value observes at (0.0003 V) during the last 10 seconds walking (Figure 4.6) (Khademi et al., 2017).

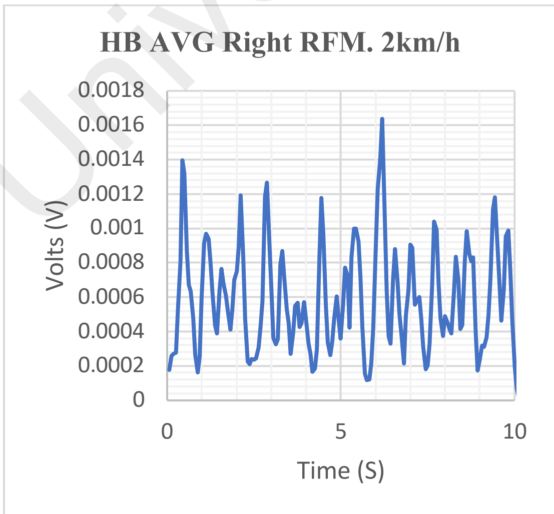


Figure 4.7: AVG of treadmill walking activity for Right RFM, of HB subjects with 2km/h.

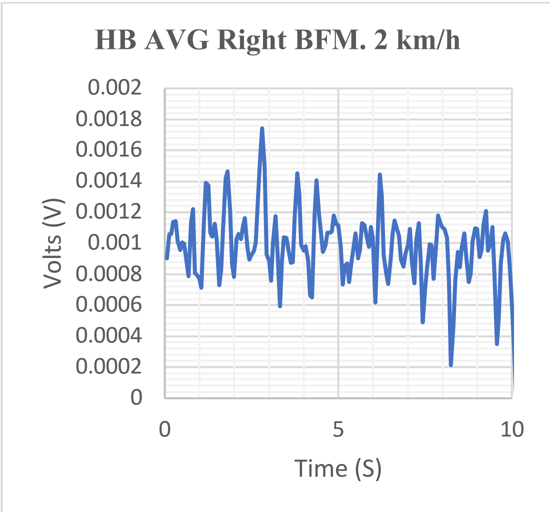


Figure 4.8: AVG of treadmill walking activity for Right BFM, of HB subjects with 2km/h.

During the right biceps femoris muscle activity, at speed (2 km/h), has recorded the peak at (0.0018 V), while the bottom value has shown at (0.0002 V), through the last 10 seconds walking achieved by the healthy-bodied subjects (Figure 4.7). At speed (3 km/h), the right biceps femoris muscle activity peak has observed at (0.0018 V), whereas the lowest value at (0.0001 V), during the last 10 seconds of the treadmill walking (Figure 4.8). At speed (4 km/h), the beak of the right BFM activity has shown value at (0.0025 V), while the minimum value record at (0.0004 V), shown slightly change compared with speed (3 km/h) (Figure 4.9) (Yeung et al., 2013).

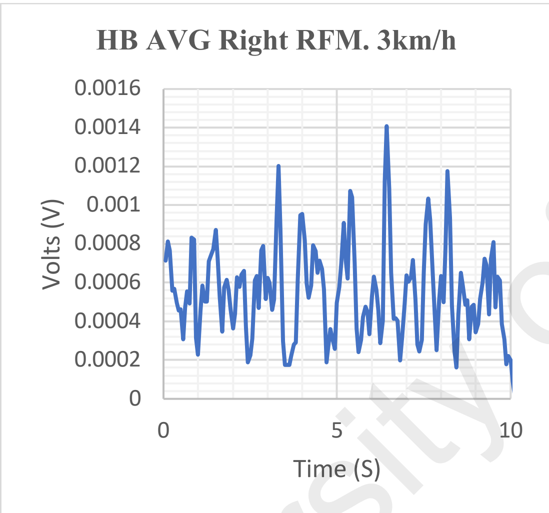


Figure 4.9: AVG of treadmill walking activity for Right RFM, of HB subjects with 3km/h.

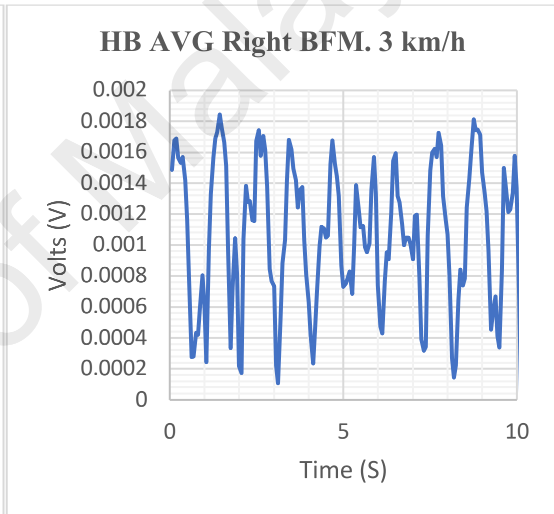


Figure 4.10: AVG of treadmill walking activity for Right BFM, of HB subjects with 3km/h.

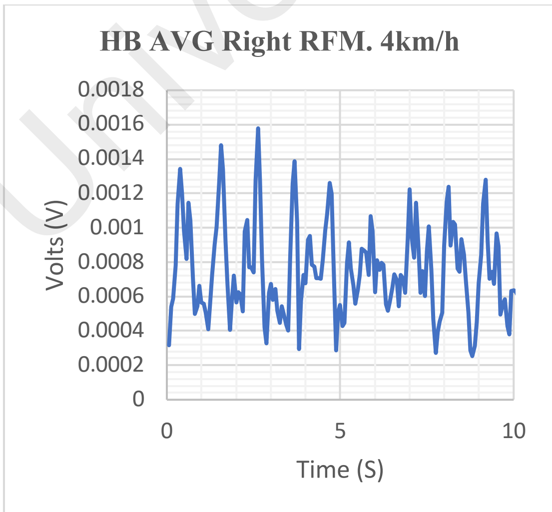


Figure 4.11: AVG of treadmill walking activity for Right RFM, of HB subjects with 4km/h.

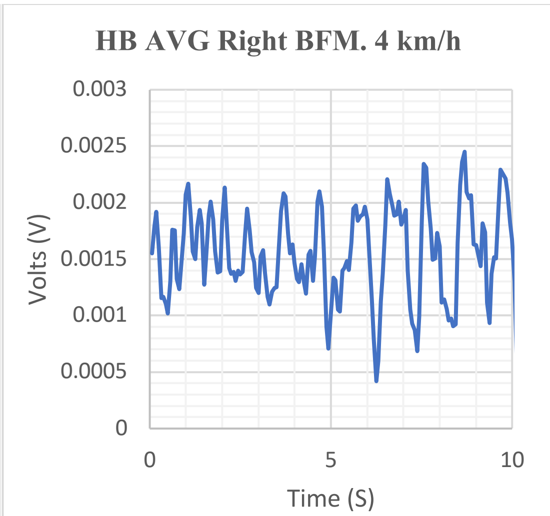


Figure 4.12: AVG of treadmill walking activity for Right BFM, of HB subjects with 4km/h.

During the right rectus femoris muscle activity, at speed (2 km/h), the peak has reached (0.0016 V), whereas the minimum value has recorded at (0.0001 V), during the last 10 seconds walking which performed by the healthy subject (Figure 4.10). At speed (3 km/h), the peak of right rectus femoris muscle activity has shown at (0.0014 V), while the bottom value at (0.0002 V), through the last 10 seconds walking on the treadmill (Figure 4.11). At speed (4 km/h), the beak of right RFM activity has shown value at (0.0016 V), whereas the minimal value observed at (0.0002 V), has shown slightly change compared with speeds (2 and 3 km/h) (Figure 4.12) (Khademi et al., 2017).

4.1.2 Trans-tibial Amputees (TTA)

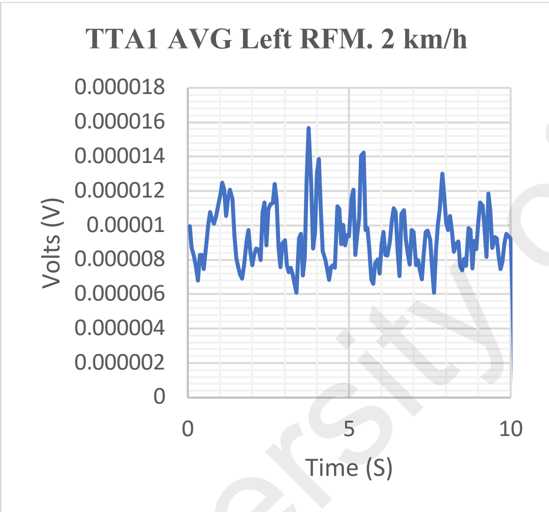


Figure 4.13: AVG of treadmill walking activity for Left RFM, of TTA1 subject with 2km/h.

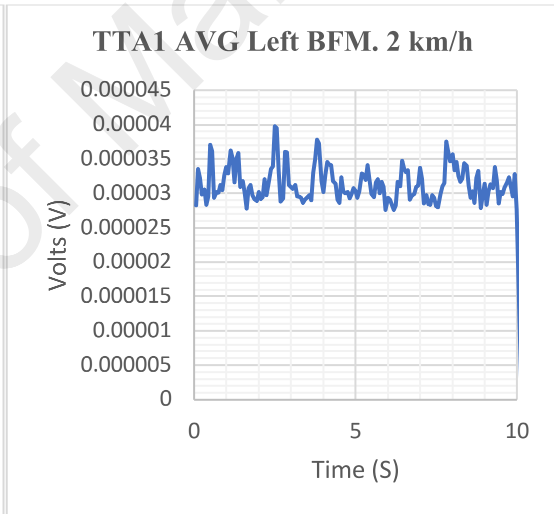


Figure 4.14: AVG of treadmill walking activity for Left BFM, of TTA1 subject with 2km/h.

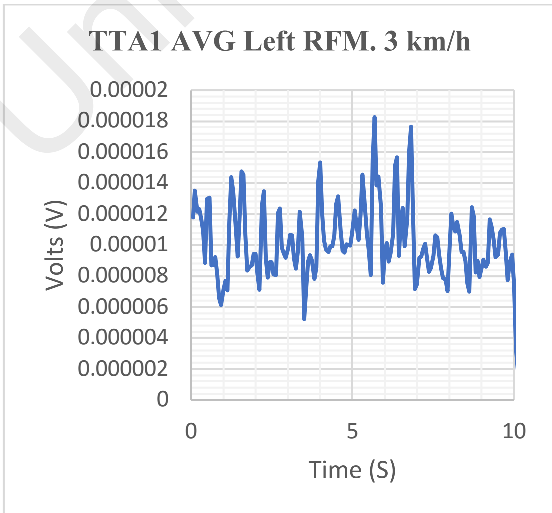


Figure 4.15: AVG of treadmill walking activity for Left RFM, of TTA1 subject with 3km/h.

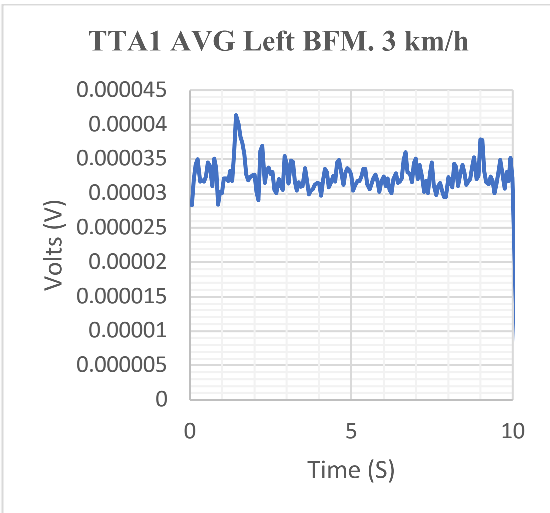


Figure 4.16: AVG of treadmill walking activity for Left BFM, of TTA1 subject with 3km/h.

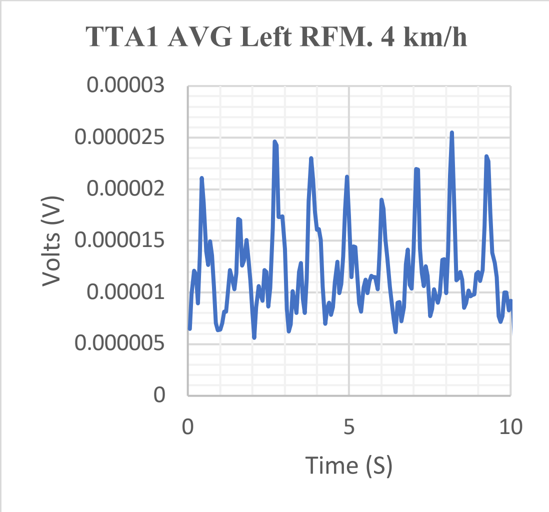


Figure 4.17: AVG of treadmill walking activity for Left RFM, of TTA1 subject with 4km/h.

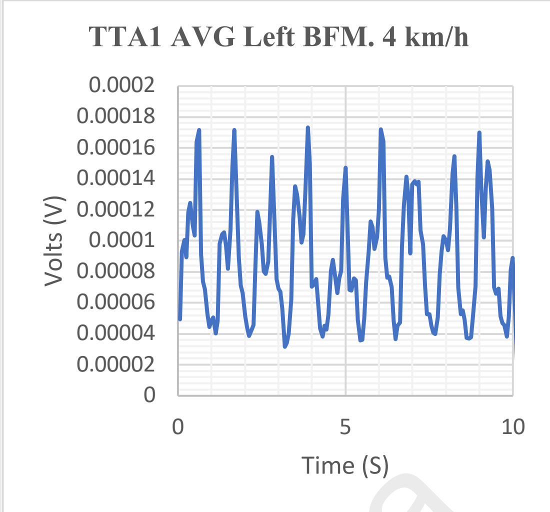


Figure 4.18: AVG of treadmill walking activity for Left BFM, of TTA1 subject with 4km/h.

Amputee subject 1, comparing the left rectus and biceps femoris muscles activity, at speed (2 km/h), RFM peak has reached (0.000016 V), while the minimum value has recorded at (0.000006 V). But, BFM peak has reached (0.00004 V), whereas the bottom value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.13; Figure 4.14). At speed (3 km/h), RFM peak has reached (0.000018 V), while the minimum value has recorded at (0.000005 V). But, BFM peak has reached (0.00004 V), whereas the bottom value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.15; Figure 4.16). At speed (4 km/h), RFM peak has reached (0.000025 V), whereas the bottom value has recorded at (0.000005 V). But, BFM peak has reached (0.00018 V), while the minimum value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.17; Figure 4.18). Based on the results, has shown a highly notable change, left BFM on the amputated limb considers as dominant muscle and more active than the RFM (Huang et al., 2012).

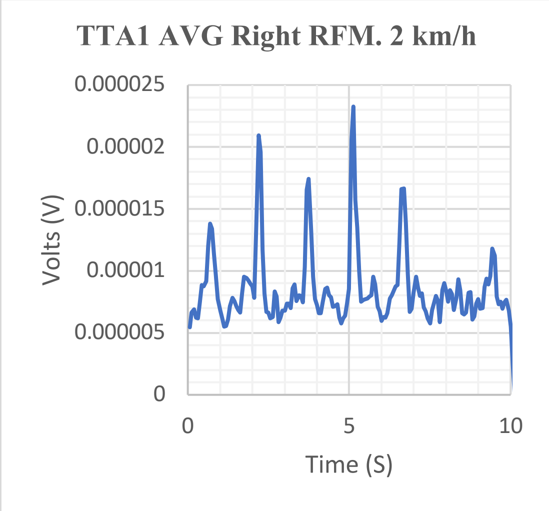


Figure 4.19: AVG of treadmill walking activity for Right RFM, of TTA1 subject with 2km/h.

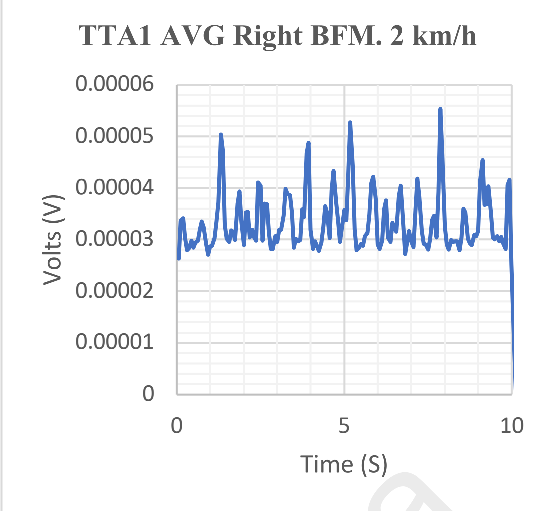


Figure 4.20: AVG of treadmill walking activity for Right BFM, of TTA1 subject with 2km/h.

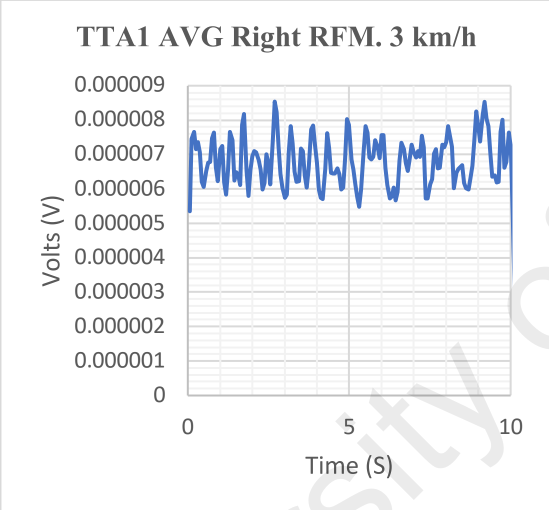


Figure 4.21: AVG of treadmill walking activity for Right RFM, of TTA1 subject with 3km/h.

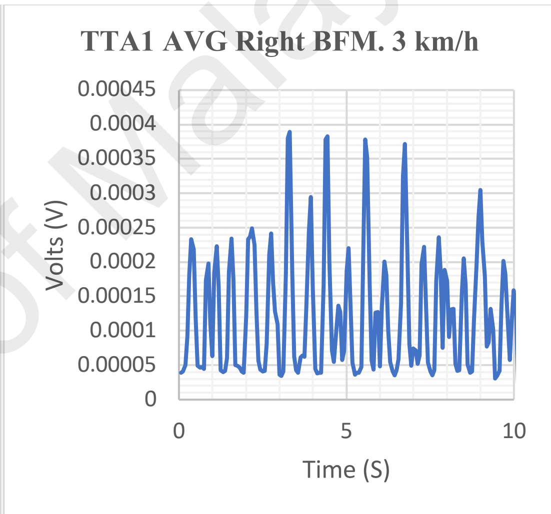


Figure 4.22: AVG of treadmill walking activity for Right BFM, of TTA1 subject with 3km/h.

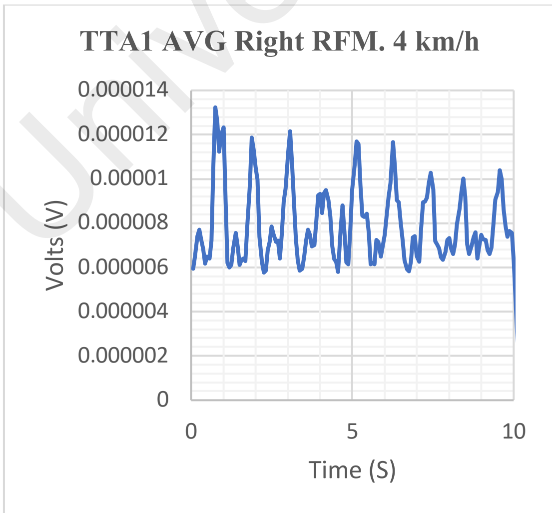


Figure 4.23: AVG of treadmill walking activity for Right RFM, of TTA1 subject with 4km/h.

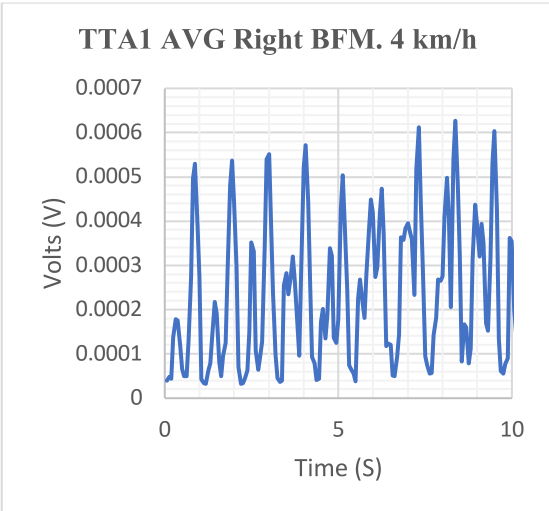


Figure 4.24: AVG of treadmill walking activity for Right BFM, of TTA1 subject with 4km/h.

Amputee subject 1, comparing the right rectus and biceps femoris muscles activity, at speed (2 km/h), RFM peak has observed at (0.000025 V), while the minimum value has recorded at (0.000005 V). But, BFM peak has observed at (0.00006 V), whereas the bottom value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.19; Figure 4.20). At speed (3 km/h), RFM peak has reached (0.000009 V), while the minimum value has recorded at (0.000005 V). But, BFM peak has reached (0.0004 V), whereas the bottom value has recorded at (0.00005 V), during the last 10 seconds walking on the treadmill (Figure 4.21; Figure 4.22). At speed (4 km/h), RFM peak has reached (0.000014 V), whereas the bottom value has recorded at (0.000006 V). But, BFM peak has reached (0.0006 V), while the minimum value has recorded at (0.0001 V), during the last 10 seconds walking on the treadmill (Figure 4.23; Figure 4.24). Based on the results, has shown a highly notable change, right biceps femoris muscle on the sound limb considers as dominant muscle and more active than the right rectus femoris muscle (Huang et al., 2012).

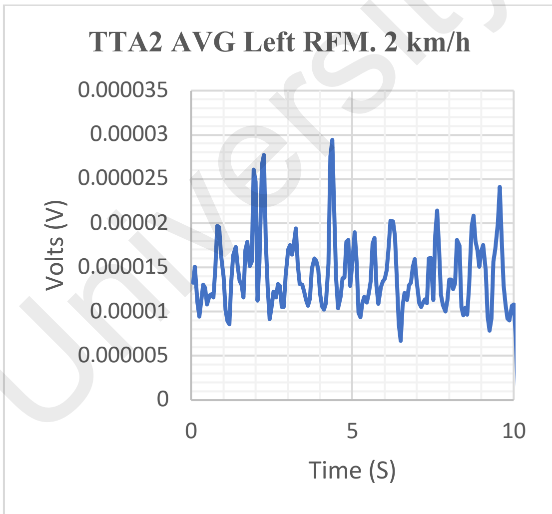


Figure 4.25: AVG of treadmill walking activity for Left RFM, of TTA2 subject with 2km/h.

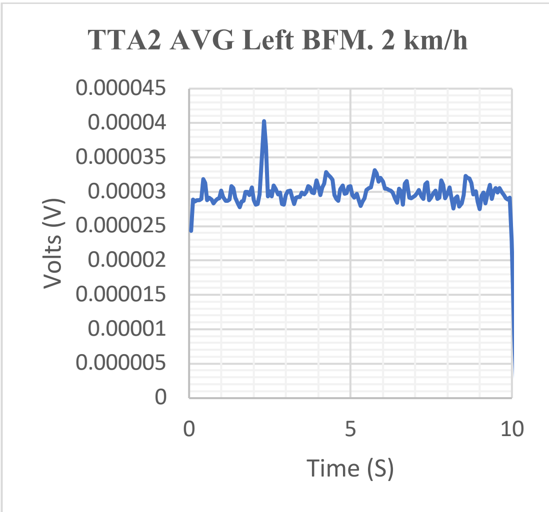


Figure 4.26: AVG of treadmill walking activity for Left BFM, of TTA2 subject with 2km/h.

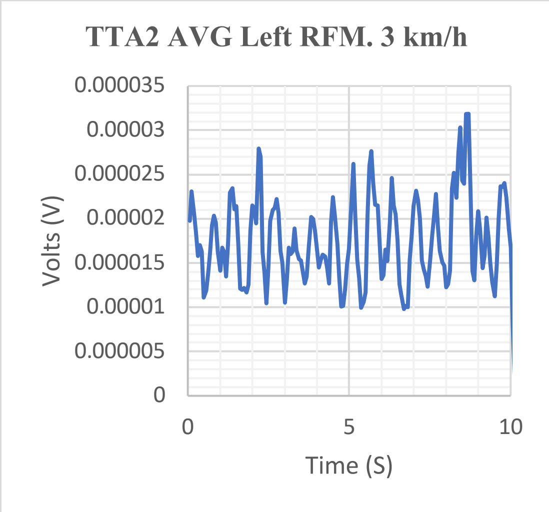


Figure 4.27: AVG of treadmill walking activity for Left RFM, of TTA2 subject with 3km/h.

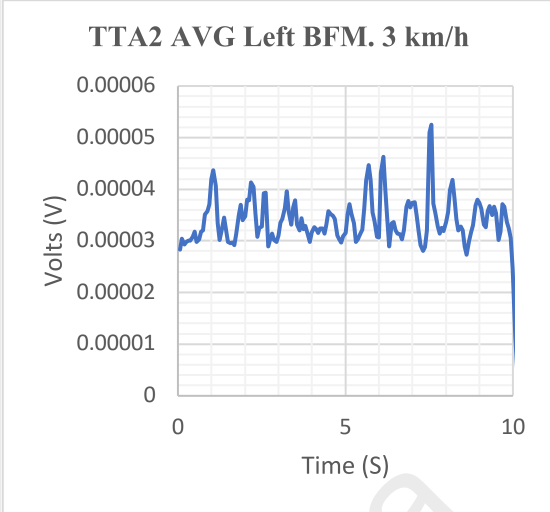


Figure 4.28: AVG of treadmill walking activity for Left BFM, of TTA2 subject with 3km/h.

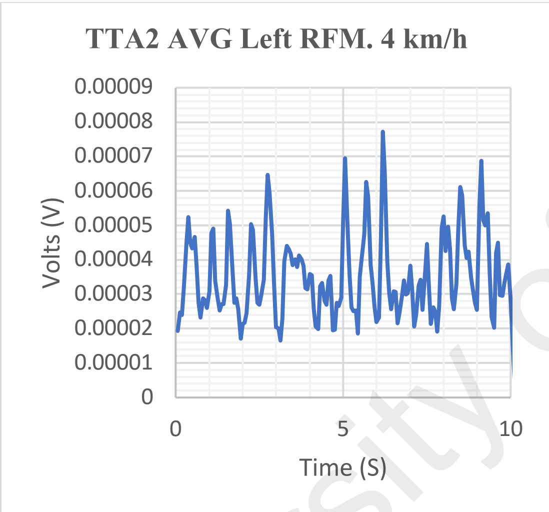


Figure 4.29: AVG of treadmill walking activity for Left RFM, of TTA2 subject with 4km/h.

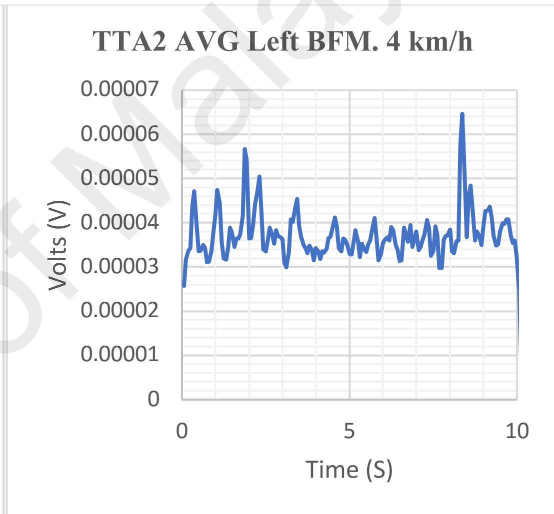


Figure 4.30: AVG of treadmill walking activity for Left BFM, of TTA2 subject with 4km/h.

Amputee subject 2, comparing the left rectus and biceps femoris muscles activity, at speed (2 km/h), RFM peak has recorded at (0.00003 V), while the minimum value has recorded at (0.000004 V). But, BFM peak has observed at (0.00004 V), whereas the bottom value has recorded at (0.000025 V), during the last 10 seconds walking on the treadmill (Figure 4.25; Figure 4.26). At speed (3 km/h), RFM peak has reached (0.00003 V), while the minimum value has recorded at (0.00001 V). But, BFM peak has reached (0.00005 V), whereas the bottom value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.27; Figure 4.28). At speed (4 km/h), RFM peak has reached (0.00008 V), whereas the bottom value has recorded at (0.00002 V).

But, BFM peak has reached (0.00006 V), while the minimum value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.29; Figure 4.30). Based on the results, has shown slightly change, left RFM on the amputated limb considers as dominant muscle and more active than the BFM (Huang et al., 2012).

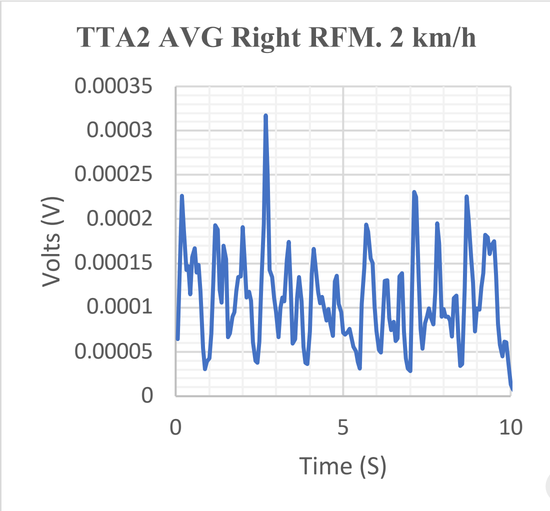


Figure 4.31: AVG of treadmill walking activity for Right RFM, of TTA2 subject with 2km/h.

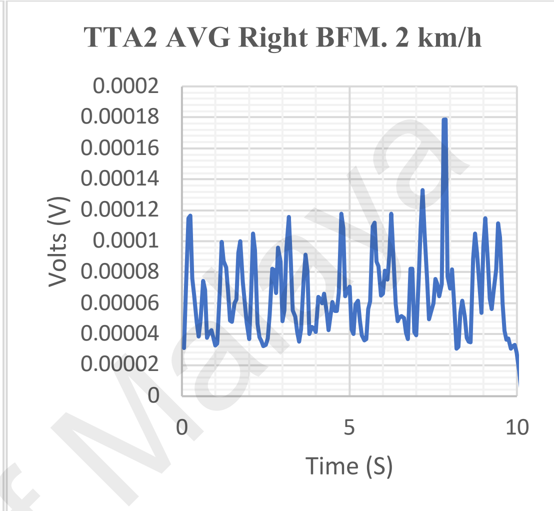


Figure 4.32: AVG of treadmill walking activity for Right BFM, of TTA2 subject with 2km/h.

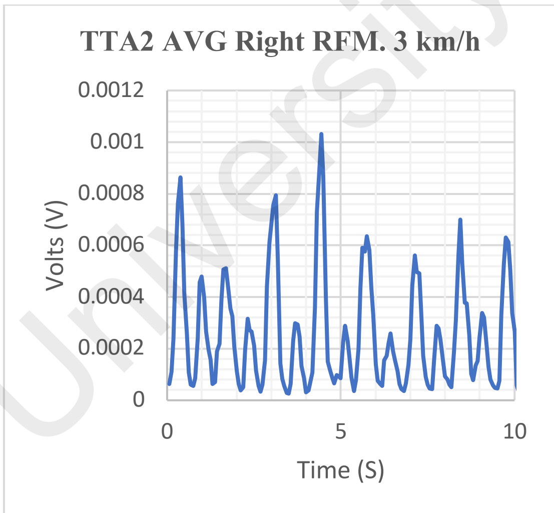


Figure 4.33: AVG of treadmill walking activity for Right RFM, of TTA2 subject with 3km/h.

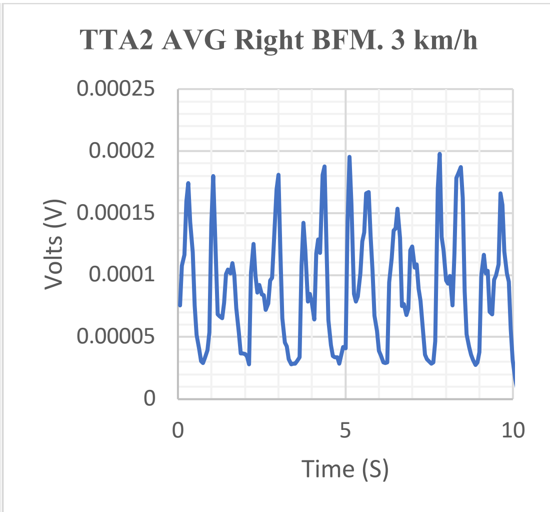


Figure 4.34: AVG of treadmill walking activity for Right BFM, of TTA2 subject with 3km/h.

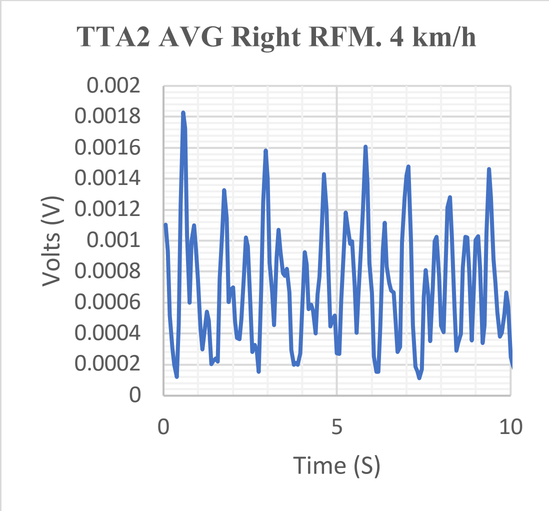


Figure 4.35: AVG of treadmill walking activity for Right RFM, of TTA2 subject with 4km/h.

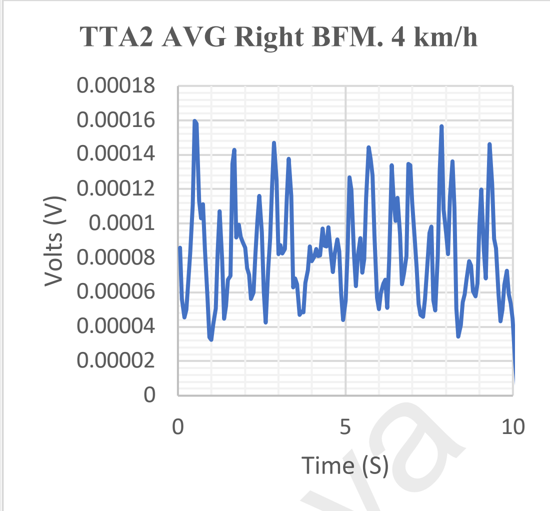


Figure 4.36: AVG of treadmill walking activity for Right BFM, of TTA2 subject with 4km/h.

Amputee subject 2, comparing the right rectus and biceps femoris muscles activity, at speed (2 km/h), RFM peak has recorded at (0.0003 V), while the minimum value has reached (0.00004 V). But, BFM peak has observed (0.00018 V), whereas the bottom value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.31; Figure 4.32). At speed (3 km/h), RFM peak has reached (0.001 V), while the minimum value has recorded at (0.0001 V). But, BFM peak has reached (0.0002 V), whereas the bottom value has recorded at (0.00004 V), during the last 10 seconds walking on the treadmill (Figure 4.33; Figure 4.34). At speed (4 km/h), RFM peak has reached (0.0018 V), whereas the bottom value has recorded at (0.0001 V). But, BFM peak has reached (0.00016 V), while the minimum value has recorded at (0.00003 V), during the last 10 seconds walking on the treadmill (Figure 4.35; Figure 4.36). Based on the results, has shown a highly notable change, right RFM on the sound limb considers as dominant muscle and more active than the BFM (Huang et al., 2012).

4.1.3 Comparing Trans-tibial Amputees with Healthy-bodied.

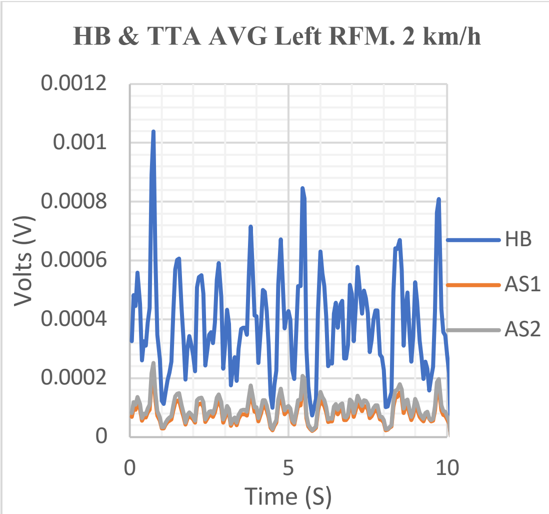


Figure 4.37: AVG of treadmill walking for Left RFM, for HB, AS1 & AS2 subjects at 2km/h.

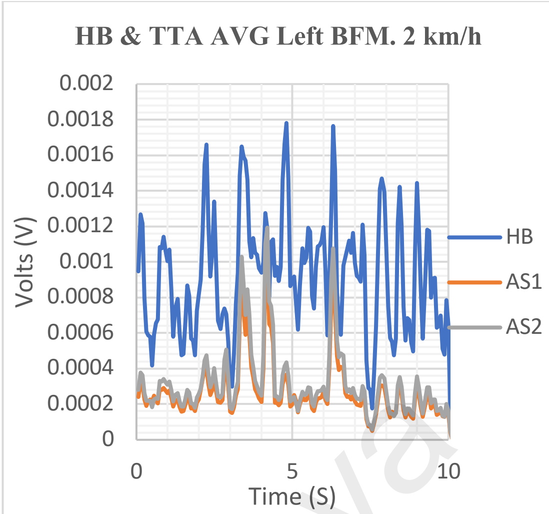


Figure 4.38: AVG of treadmill walking for Left BFM, for HB, AS1 & AS2 subjects at 2km/h.

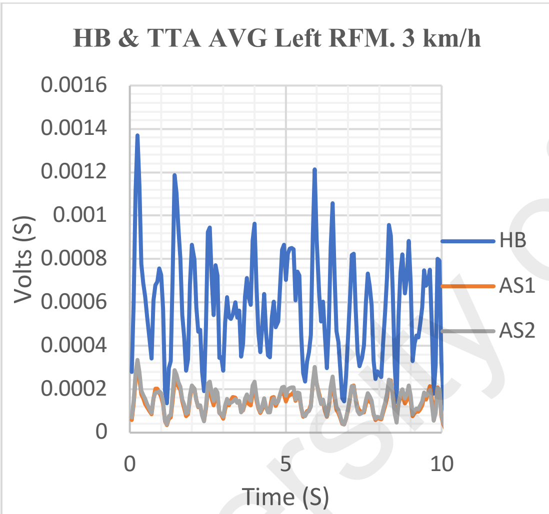


Figure 4.39: AVG of treadmill walking for Left RFM, for HB, AS1 & AS2 subjects at 3km/h.

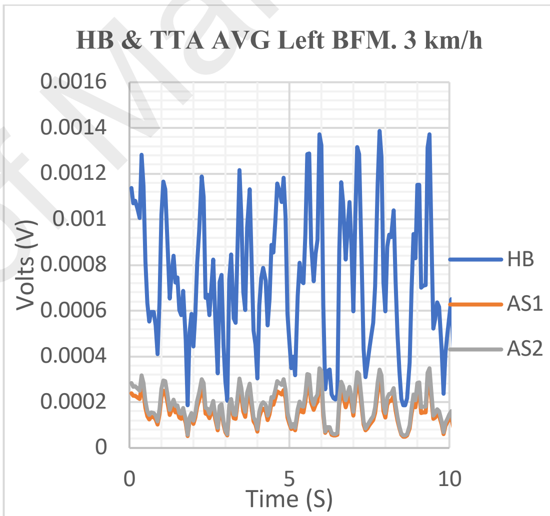


Figure 4.40: AVG of treadmill walking for Left BFM, for HB, AS1 & AS2 subjects at 3km/h.

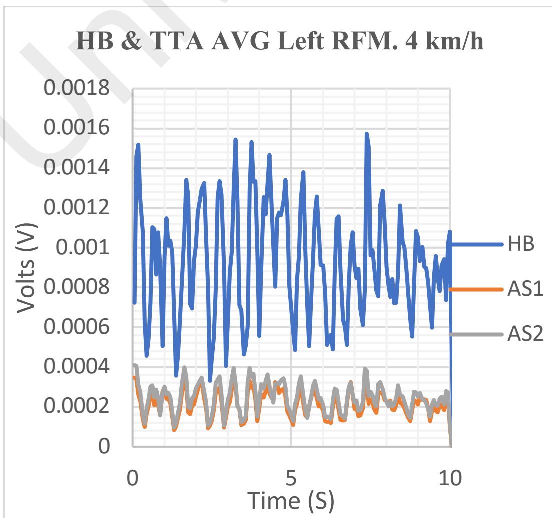


Figure 4.41: AVG of treadmill walking for Left RFM, for HB, AS1 & AS2 subjects at 4km/h.

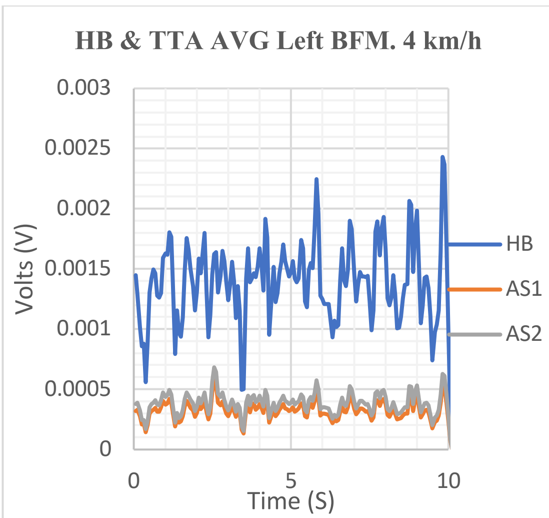
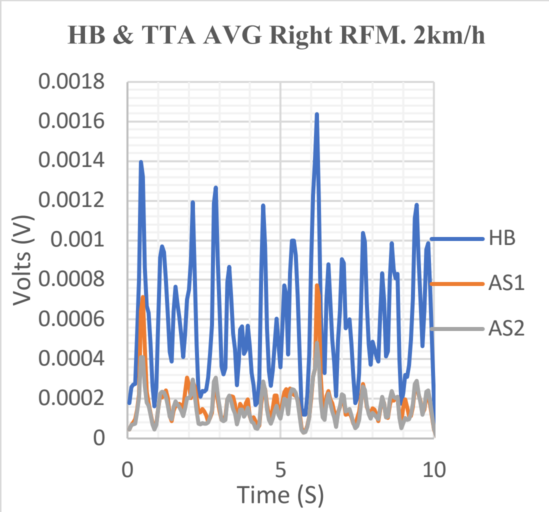


Figure 4.42: AVG of treadmill walking for Left BFM, for HB, AS1 & AS2 subjects at 4km/h.



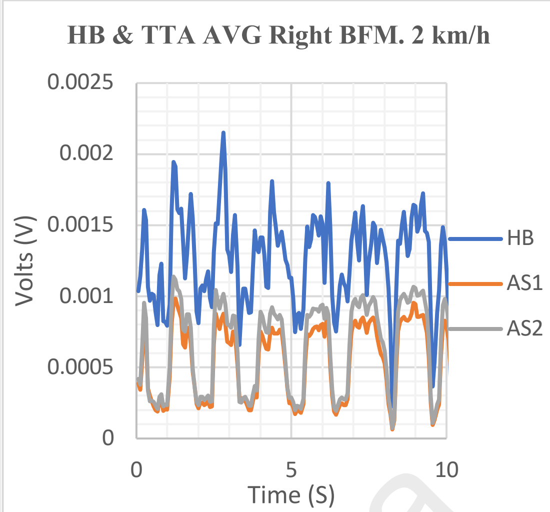
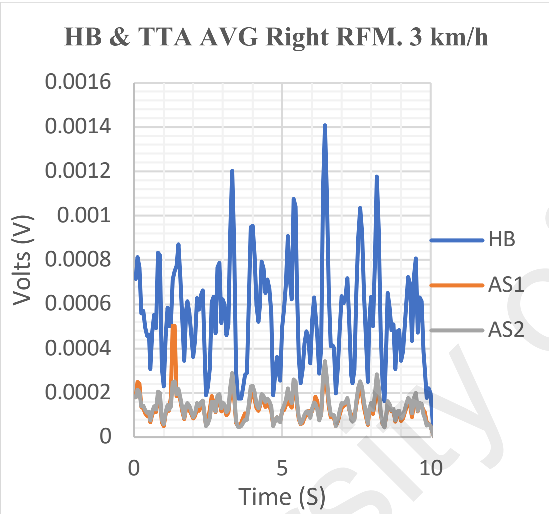


Figure 4.43: AVG of treadmill walking for Right RFM, for HB, AS1 & AS2 subjects at 2km/h.

Figure 4.44: AVG of treadmill walking for Right BFM, for HB, AS1 & AS2 subjects at 2km/h.



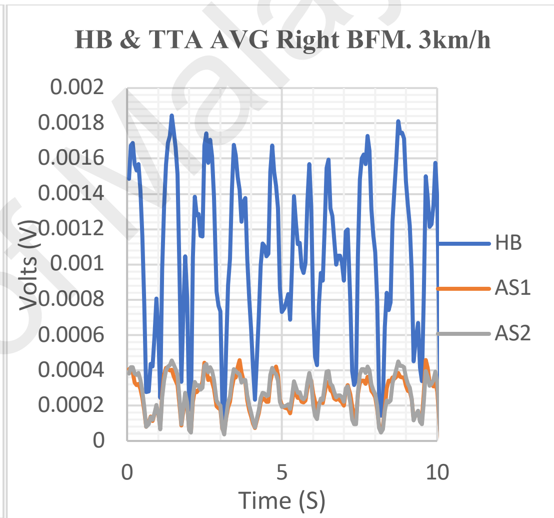
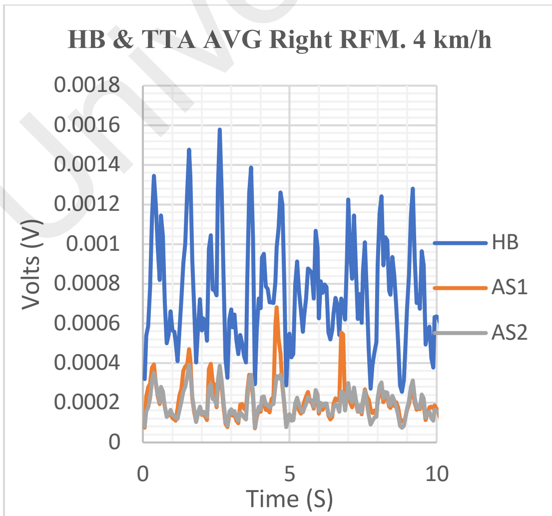


Figure 4.45: AVG of treadmill walking for Right RFM, for HB, AS1 & AS2 subjects at 3km/h.

Figure 4.46: AVG of treadmill walking for Right BFM, for HB, AS1 & AS2 subjects at 3km/h.



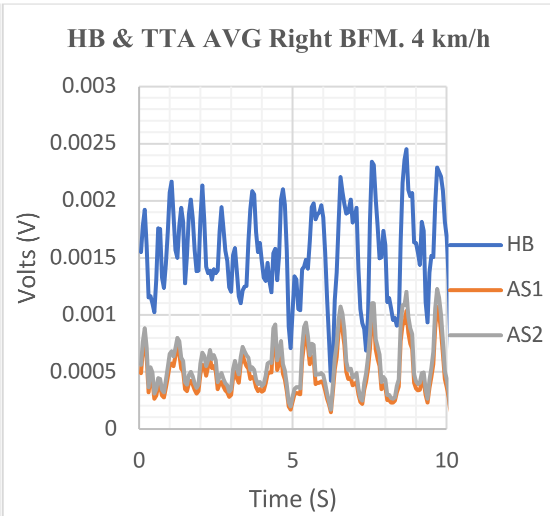


Figure 4.47: AVG of treadmill walking for Right RFM, for HB, AS1 & AS2 subjects at 4km/h.

Figure 4.48: AVG of treadmill walking for Right BFM, for HB, AS1 & AS2 subjects at 4km/h.

HB and TTA left limb results, at speed (2 km/h), patterns had shown highly notable changes. HB left biceps femoris muscle's peak has reached (0.0018), considers as dominant muscle and more active than RFM. Whereas TTA patterns had shown high differences, TTA left BFM's peak has reached (0.0012). At 3 km/h, left RFM and BFM patterns had shown symmetry. At 4 km/h, patterns had shown highly notable changes. HB left biceps femoris muscle's peak has reached (0.0025), considers as dominant muscle and more active than RFM. Whereas, TTA left BFM patterns had slightly increased. HB and TTA right limb results, at speed (2 km/h), HB patterns had shown high differences between RFM and BFM. Whereas, TTA right RFM and BFM patterns had shown an asymmetry. TTA right biceps femoris muscle's peak has reached (0.001), considers as dominant muscle and more active than RFM. At 3 km/h, HB and TTA right RFM and BFM patterns had shown slight differences, but HB right BFM's peak has reached (0.002). At 4 km/h, patterns had shown highly notable changes. HB right biceps femoris muscle's peak has reached (0.0025), considers as dominant muscle and more active than RFM. While TTA right BFM patterns had increased highly compared to RFM.

In other studies, EMG had recorded from four muscles (hamstrings, gastrocnemius, vasti and gluteus medius muscles), through walking on the treadmill and over-ground with three different speeds (slow, comfortable and fast). I had conducted the study in two walking conditions. The essential effect of the treadmill walking with two conditions at three different speeds had shown significant ($P < 0.001$) on the muscle activity magnitude (Kalantari et al., 2017). Huang et al. (2012) had recorded surface EMG from 3 below-knee muscles (gastrocnemius medial head, tibialis anterior, gastrocnemius lateral head). In addition, four above-knee muscles (rectus femoris, vastus lateralis, gluteus medius and biceps femoris), for twelve trans-tibial amputees and twelve healthy subjects, through treadmill walking with four different speeds (0.7, 1.0, 1.3, and 1.6 m/s). The signals of muscles had recorded from the right limb of healthy participants and the amputated limb of amputee participants. Moreover, had recorded above-knee muscle and below-knee muscle signals from the limb-socket interface. Therefore, the variability of muscle activation had shown higher at amputee participants more than healthy participants (Huang et al., 2012).

4.2 Limitations

The study conducted on youth subjects; unilateral trans-tibial amputee and healthy-bodied. Since sex, age and weight could affect the walking patterns. I recommend increasing the range of participants. In addition, the investigation concentrated upon two above-knee muscles, especially rectus femoris muscle and biceps femoris muscle. Also, focused on one condition, walking on the treadmill with three different speeds.

This study had focused on EMG parameters in two above-knee muscles activity. The investigation had applied only one parameter to study. Might be advantageous to add an extra parameter such as the kinetic and kinematic, in order to analyse the gained results precisely. There is a lack of the subjects kinetic and kinematic data, in this case, the muscle functions could only speculate during the treadmill walking exercise. In advanced, motion analysis video might play a good role of analysis the EMG outcomes. Walking through the trails had noted that rectus femoris muscles displayed lower activated patterns than biceps femoris. EMG activity profile might be estimated to become consistent patterns over 5-minutes warming up the muscles.

CHAPTER 5: CONCLUSION

5.1 Conclusion of the Study

The results obtained from this study might assist to develop a special training use of the treadmill walking overall the diverse people with various conditions such as amputees, osteoarthritis, a stroke patient, joint deformities and so on. Regarding the study experience, the treadmill walking should be prescribed cautiously for the people with joint instability. Since the speeds (2 and 3 km/h) pushed them back and gave them a sense of dizziness, while speed (4 km/h) possibly has the highest level of falling down risk. Moreover, I observed that the walking on the treadmill at speed (4 km/h) increased the muscle activity, in turn, had shown the symptoms of the fatigue on the participated subjects, also might increase the possibility of the injury incidences.

Furthermore, walking exercise on the treadmill might consider as a good choice for healthy-bodied people with good joint steadiness conditions, which assists to rebuild the strength of muscles and keep the muscles active. On the other hand, walking on the treadmill at speed (4 km/h) might be advised for overweight people, which is a good treatment to lose the calorie and fat. Also, is considering as an effective rehabilitation for amputee people to gain the muscle strength and rebuild their muscle again, which could aid to the speedy re-engage in the society.

Briefly, the effects of treadmill walking at different speeds (2, 3 and 4 km/h) on the EMG parameters for the unilateral trans-tibial amputees have shown a highly notable change. In addition, the maximum speed that the trans-tibial amputees achieved during the treadmill walking have observed at (4km/h). Moreover, the variations in EMG patterns of the hamstrings (BFM) and quadriceps (RFM) muscles of the TTA and HB subjects under three different treadmill speeds have highly observed. The results of this investigation might be used to assist the rehabilitation treatment of the TTA, by considering the distance and maximum speed while using the prosthesis.

5.2 Future Work

This study has concentrated upon the healthy and amputee young males and females. While the fundamental characteristic and different circumstances could affect the results and gait pattern, for instance, the age of the subjects, sex, muscle strength, skeletal alignment and anthropometric features. The recommendation is to apply this study upon unisex male and female with a various age for a large group of intact volunteers and unilateral trans-tibial amputee volunteers. Also, to study the effect of the wide variety of anthropometric features on the muscular activity pattern through the walking exercise on the treadmill compared to the walking exercise on the over-ground.

In addition, the study has to extend the number of muscles under the test, especially main muscles that play the role to make knee-joint under the dynamic stability during walking exercise on over-ground and treadmill. Furthermore, it considers a beneficial to measure BEM and RFM activity over the day. The method could assist to obtain the indication of total muscles used during the common activity. Also, I recommended expanding the time frame of the experiment through different days and months. As well as, to change the speed of treadmill walking exercise.

The relationship among the different speeds and the change of EMG activity patterns not documented, and neither reported well through the literature. It benefits to repeat the experiment over many years, which could find out the progressing on the relationship between increasing speeds and various EMG activity patterns obtained. (Robadey et al., 2013) had a study reported about following-up and covering the last ten years of the lower limb operation.

In addition, the strength training deserves to investigate the muscles which play the role of stabilisation and equilibrium in the trans-tibial amputees. Kaur et al. (2016) suggested the strength training to increase the muscles' function and performance. Moreover, thigh muscles need training for the endurance, so as a result, the endurance training of the walking activity could aid to reduce the fatigue of the appointed muscles.

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