CONCEPTUAL DESIGN OF SMART PASSIVE EXOSKELETON FOR MONITORING LOCALIZED PRESSURE AND POSTURAL ANGLE DURING SITTING/STANDING TASKS

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

AZMIRUL HYZAIN BIN AHMAD APANDI

FACULTY OF MANUFACTURING ENGINEERING

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DECLARATION

I hereby, declared this report entitled "Conceptual Design of Smart Passive Exoskeleton for Monitoring Localized Pressure and Postural Angle During Sitting/Standing Tasks" is the result of my own research except as cited in references.

Signature : ……………………………………………

Author's Name : AZMIRUL HYZAIN BIN AHMAD APANDI

Date : 24 JULY 2022

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Bachelor Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

DR. ISA BIN HALIM
Lecturer
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka

……………………………………………………

(Dr. Isa bin Halim)

ABSTRAK

Dalam industri pembuatan, ramai pekerja melaksanakan proses tugasan mereka dalam keadaan berdiri yang terlalu lama. Akibat berdiri terlalu lama, pekerja mengalami ketidakselesaan dan keletihan otot di bahagian bawah badan seperti belakang dan kaki. Kawalan kejuruteraan yang dikaitkan dengan exoskeleton duduk dan berdiri boleh dicadangkan untuk menangani masalah isu ergonomik ini. Exoslekeleton duduk berdiri komersial semasa adalah terhad kerana dia tidak boleh memanjang secara automatik apabila diperlukan disebabkan tapak tempat duduk tidak stabil untuk menstabilkan kedudukan badan untuk kegunaan jangka masa panjang, dan kekurangan sistem maklum balas ergonomik untuk memaklumkan pengguna tentang perubahan dalam kedudukan dari duduk dan berdiri, begitu juga sebaliknya. Objektif kajian ini adalah untuk menentukan keperluan pengguna dan keperluan reka bentuk exoskeleton duduk-berdiri, mencipta dan menilai kesan exoskeleton duduk dan diri yang dihasilkan pada aktiviti otot dan tekanan sentuhan, dan mengintegrasikan exoskeleton duduk dan diri dengan sensor tekanan dalam keadaan berdiri dan duduk secara berselang-seli. Tinjauan dalam talian menggunakan borang Google akan dijalankan untuk mengetahui keperluan pekerja industri berkenaan reka bentuk eksoskeleton duduk dan diri. Sepuluh orang dewasa muda Malaysia yang sihat berumur 21 – 30 tahun akan dipilih untuk mengkaji kesan exoskeleton berdiri duduk pada aktiviti otot dan tekanan di bahagian punggung. Alat elektromiografi (EMG) (Delsys, USA) akan digunakan untuk mendapatkan isyarat EMG pada otot tibialis anterior, vastus lateralis dan gastrocnemius. Sementara itu, Tikar Tekanan Badan (CONFORMat, USA) akan digunakan untuk menganalisis tekanan sentuhan antara punggung dan tempat duduk eksoskeleton. Hasil kajian, rumusan soal selidik mendapati pekerja industri mengalami gangguan muskuloskeletal akibat berdiri lama. Pekerja industri mengemukakan ciri berikut bagi eksoskeleton duduk berdiri masa hadapan: mudah alih, selesa, kos rendah, stabil, boleh laras, ringan, pergerakan kurang terhad, tampan, mudah digunakan, maklum balas

ergonomik boleh mengingatkan mereka supaya mereka boleh Duduk bergantian atau berdiri semasa anda bekerja. Keputusan EMG menunjukkan bahawa exoskeleton duduk berdiri yang dibangunkan dalam kajian ini mampu mengurangkan pengecutan otot sebanyak 75 peratus, yang mencukupi untuk mengurangkan keletihan otot. Berdasarkan keputusan, kajian ini menyimpulkan bahawa exoskeleton duduk-diri yang dibangunkan dalam kajian ini menunjukkan potensi besar dalam mengurangkan ketidakselesaan subjektif dan keletihan otot yang disebabkan oleh berdiri berpanjangan. Faedah penyelidikan ini ialah ia membuat hipotesis bahawa prototaip exoskeleton duduk akan dapat membantu jurutera industri mengurangkan risiko ergonomik yang berkaitan dengan kedudukan berpanjangan di tempat kerja.

ABSTRACT

In manufacturing industry, many workers perform their task processes in prolonged standing. Due to prolonged standing, workers experienced discomfort and muscle fatigue in the lower body parts such as back and legs. Engineering controls associated with sit-stand exoskeleton can be proposed to resolve these ergonomics issues. The limitations of the current commercial sit-stand exoskeletons are the stand is unable to extend automatically when needed, the base of the stand is not stable to stabilize the body posture for prolonged use, and lack of ergonomics feedback system to alert users in changing positions from sitting and standing, vice-versa. The objectives of this study are to determine users' needs and design requirements of sit-stand exoskeleton, fabricate and evaluate the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure, and integrate the sit-stand exoskeleton with a pressure sensor for alternating standing and sitting postures. An online survey using Google form was performed to determine the needs of industrial workers regarding design of the sit-stand exoskeleton. Ten healthy Malaysian young adults aged 21 – 30 years old were selected to study the effects of the sit-stand exoskeleton prototype on the muscle activity and the contact pressure in the buttock. Surface electromyography (EMG) instrument (Delsys, USA) was used to measured and analyzed EMG signals in the tibialis anterior, vastus lateralis, and gastrocnemius muscles. Meanwhile, Body Pressure Mat instrument (CONFORMat, USA) was applied to analyse the contact pressure between the buttock and the exoskeleton seat. As the outcome of the study, the questionnaire survey found that industrial workers suffered from musculoskeletal disorders due to prolonged standing. The industrial workers proposed the following features in the future sit-stand exoskeleton: portable, comfortable, low cost, stable, adjustable, lightweight, low movement restriction, good appearance, easy to use and having ergonomics feedback that can alert them so that they can alternately sit or stand while working. The EMG results showed that the sit-stand exoskeleton developed by this study was able to minimize muscle contraction up to 75 percent which is good

enough for reducing muscle fatigue. Based on the results, this study concluded that the sit-stand exoskeleton developed by this study has shown a great potential to reduce the subjective discomfort and muscle fatigue caused by prolonged standing. The benefit of this study is that study hypothesized that the sit-stand exoskeleton prototype would be able to assist industrial engineers to alleviate the ergonomics risk associated with prolonged standing at workplace.

DEDICATION

Special dedication my beloved mother, Roslina Binti Abd Malik
my father and my sister, Ir. Ahmad Apandi Bin Lakin and Aini Ardina Binti Ahmad Apandi for giving me moral support, encouragement and also understandings
Thank You So Much & Love You All Forever

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CHAPTER 1
INTRODUCTION

In this first chapter explains about background of study, problem statement, objective, scope of the study, the significance of the study, and the organization of the report. The background of study elaborates how the exoskeleton will benefit to the manufacturing industry. The problem statements define the issue that frequently happens in the manufacturing industry that would encourage to design of the sit-stand exoskeleton. Additionally, the problem statement highlights the limitations of the existing prototype and commercial sit-stand exoskeletons. An objective is a clear statement of the project goal to accomplish design prototype. The scope explains the focus and limitation of the study. The significance of this study shows how the exoskeleton prototype will overcome ergonomics issues on prolonged standing at the manufacturing industry. Lastly, the organization of the report demonstrates how this report is carried out in total.

1.1 Background of Study

In manufacturing industry, the workers usually practices the action of prolonged standing for their daily jobs. They did not have a choice because the working area would not allow them to rest in a short period of time because of the hazardous environment and to work right beside the machine. Due to prolonged standing, many workers have taken medical leave because of common health injuries. Thus, this can affect the company production process and their performance. Figure 1.1 shows a worker operating a lathe machine for prolong hours in standing posture.

Figure 1.1: A worker operating a lathe machine in standing posture

Prolonged standing is also common in the service sector: sales clerks, food service employees, salons employees, grocery clerks, customer service representatives, flight attendants, receptionists, and security guards. Standing for most of the working day is bad for the lower limbs; it can damage joints, cause muscular aches, and cause foot issues such as heel spurs and flat feet. The most frequent symptom of operating on feet, and generally the first to begin, is leg pain and exhaustion. Standing for two hours causes EMG signs of muscle exhaustion, severe soreness in the lower back, and edema build-up in the feet. Figure 1.2 shows the muscular aches in the leg due to prolonged standing.

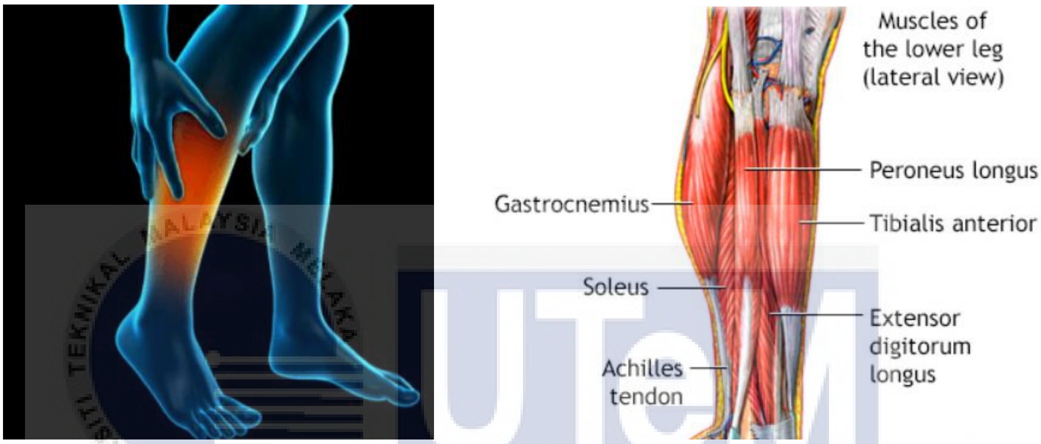


Figure 1.2: Muscular aches in the leg due to prolonged standing

Due to above mentioned issue, the primary goal of this study is to develop a device called passive sit-stand exoskeleton for workers who perform the job in prolonged standing. This passive sit stand exoskeleton can benefit them for preventing muscular aches due to prolonged standing.

1.2 Problem Statement

Prolonged standing can cause occupational injuries and physiological discomfort, muscle fatigue, pain and could also contribute to the development of severe health hazards such as Musculoskeletal Disorders (MSDs). MSDs include discomfort and pain in the back, leg, and feet. Figure 1.3 shows discomfort and muscle pain caused by standing for long period of time.

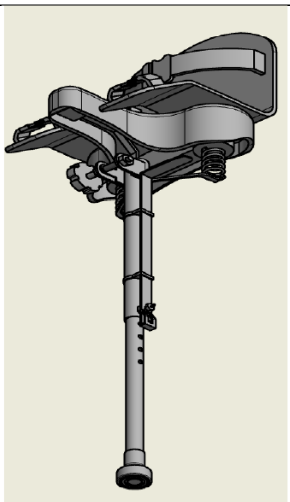

Figure 1.3: Example of discomfort and muscle pain caused by standing for long period of time

To be specific, this study identified several limitations and constraints of the existing prototype and commercial sit-stand exoskeletons through direct observation and literature review, summarized as follow:

1.2.1 Limitations of the design prototype and commercial sit-stand exoskeletons

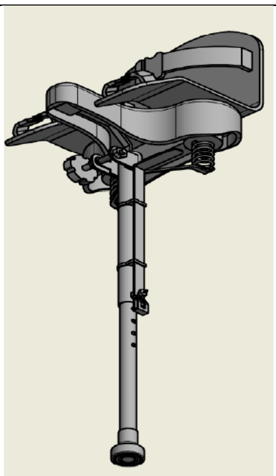
1. The stand is unable to extend automatically when needed:
   Both existing and commercial exoskeleton can adjust the height by just going down, but it cannot increase the height automatically; thus the user needs to bend to increase the height; this will put the user in the discomfort posture.

Table 1.1: The stand is unable to extend automatically.

Existing prototype of sit-stand exoskeleton	**Commercial sit-stand exoskeleton**
 Solehin, 2021	 Source: www.noonee.com

2. The base of the stand is not stable to stabilize the body posture for prolonged use: The bottom platform in the existing exoskeleton is too small same goes with the commercial exoskeleton, but the commercial has two small bottom platforms. When the base is small, it can discomfort the user because it is not stable; thus the user needs to use their leg to steady their position when used. Also, a small base has the potential to tilt backwards, and this would lead the user to fall backward.

Table 1.2: The base of the stand is not stable.

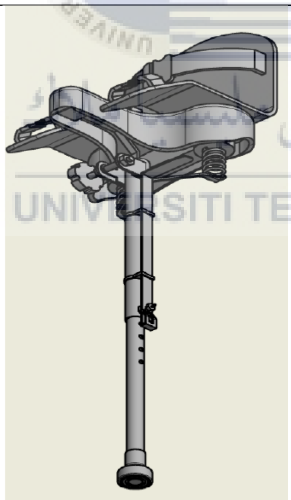
Existing prototype of sit-stand exoskeleton	**Commercial sit-stand exoskeleton**
 Solehin, 2021	 Source: www.lexbyastride.com

1.2.2 Lacking of ergonomics feedback system to alert users in changing positions from sitting and standing, vice-versa.

Abundant published literature highlighted that ergonomics interventions using a wearable sit-stand exoskeleton are helpful to minimize muscle fatigue associated with prolonged standing. However, far too little attention has been paid to studying and visualizing the trend/ pattern of data such as force and contact pressure in contact areas such as buttock and feet. Yet, information of force, contact pressure, and time workers start to feel discomfort/ numbness (onset of fatigue) is still unknown.

There are commercial products and prototypes of wearable sit-stand exoskeleton developed by manufacturers and past researchers; however, an exoskeleton that can alert the users (workers) to alternate sit/stand based on quantitative data (postural angle, contact pressure, and time) requires a further study.

Table 1.3: Lack of ergonomic feedback.

Existing prototype of sit-stand exoskeleton	**Commercial sit-stand exoskeleton**
 Solehin, 2021	 Source: www.archelis.com

1.3 Objectives

a) To determine users' needs and design requirements of sit-stand exoskeleton from Malaysian industrial workers.

b) To evaluate the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure of the users.

c) To integrate the sit-stand exoskeleton with pressure and postural angle sensors for a conceptual smart system of alternating standing and sitting postures.

1.3.1 Relationship between Problem Statement and Objective

A problem statement is a statement of a current issue or a flaw that needs to be repaired and improves. In design 1, the stand is unable to extend automatically, the user needs to bend to increase the height; this will put the user in the discomfort posture. Design 2, the base of the stand is not stable, it can discomfort the user because it is not stable; thus the users' needs to use their leg to steady their position when used. Design 3, it lack of ergonomics feedback, this is a feature must have because it can inform the worker of what positios there in. An objective is a clear statement of the project goal to accomplish design prototype. The first objective is to determine user needs, where is this study a survey would be conducted and evaluate the feedback. The second objective is to evaluate the fabricated sit-stand exoskeleton, where in this study an exoskeleton is being design and fabricated base on collected feedback. The third objective is to integrate the exoskeleton with pressure sensor, where in this study the product and its features is being testes where it would meet user expectation. Table 1.4 shows the relationship of problem statement and objective.

Table 1.4: Relationship of problem statement and objective

Problem Statement	Objective
Design issue 1: The stand is unable to extend automatically when needed	To determine user needs and design requirements of the sit-stand exoskeleton based on Malaysian industrial workers.
Design issue 2: The base of the stand is not stable to stabilize the body posture for prolonged use.	To evaluate the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure.
Design issue 3: Lack of ergonomics feedback system to alert users in changing positions from sitting and standing, vice-versa.	To integrate the sit-stand exoskeleton with pressure sensor for a conceptual smart system of alternating standing and sitting posture.

1.4 Scope

This study aims to design a prototype of a passive sit-stand exoskeleton that can benefit the manufacturing industry workers affected by prolonged standing. The project is based on continuous standing, where the workers had to stand for the whole working hour doing their daily job routine, such as operating a machine. For the data collection, Ten healthy Malaysian young adults aged 21 – 30 years old will be selected to study the effects of the developed sit-stand exoskeleton on muscle activity and pressure in the buttock. A surface electromyography (EMG) (Delsys, USA) will be used to obtain EMG signals in the tibialis anterior, vastus lateralis, and gastrocnemius muscles. Meanwhile, Body Pressure Mat (Comfortmat, USA) will be applied to analyse contact pressure between the buttock and the exoskeleton seat. To make this product new and improved, it must be different from the existing exoskeleton and the commercial exoskeleton. Based on Malaysia anthropometry, the exoskeleton design has a new ergonomics feature like adjustable height and a sensor to alert the users of their posture. The new design will be evaluated to satisfy the needs of the users and fulfil safety specifications.

1.5 Significance/Importance of Study

There are many advantages that can obtain from completing the study. It starts with the collecting data from the experiment that have been done on student and adult. This data will then be used to make a new and improve passive sit stand exoskeleton. In future this data will contribute for further studies. Also, after fabricating the product and user have satisfy with the design, the product can benefit workers by reducing the discomfort they have been experiencing so that they can work without worrying any occupational injuries.

1.6 Organization of the Report

Chapter 1 begins with a research background, problem statement, objectives, scope of study, and the significance of the study are to design a sit stand exoskeleton. The impact of the study on the manufacturing industry is also revealed. Therefore, chapter 1 will compose the introduction, problem statement, objectives, scopes, the significance of the study, and organization of the report. Chapter 2, literature review comprises previous study and research about the benefit and comparison of the sit stand exoskeleton. A literature review provides a comprehensive background and supportive material research. Then, chapter 3 describes the process flow and the methodology study.

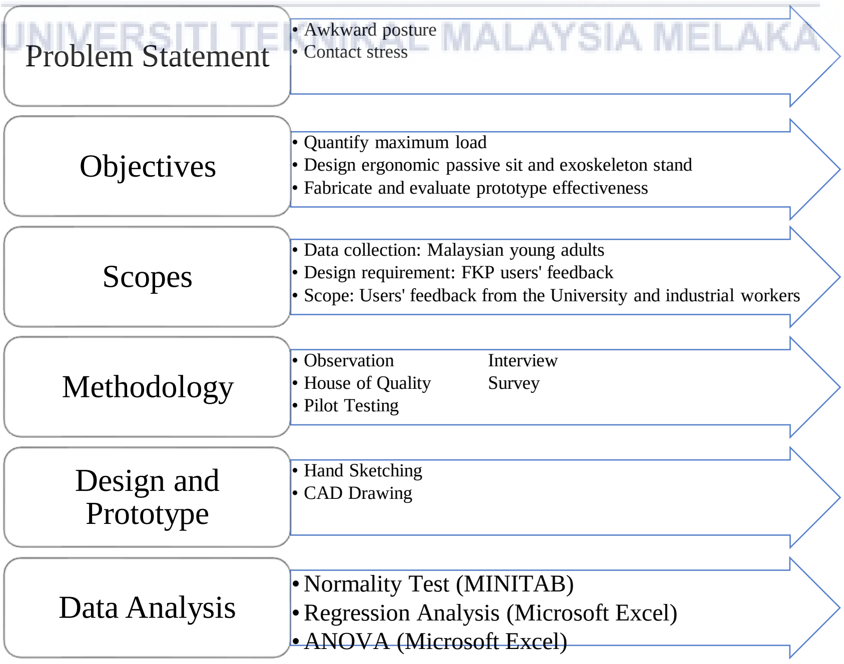


Figure 1.4: Framework of study

1.7 Summary

In a nutshell, standing posture is one of the most typical poses in the manufacturing business. Most operators will be required to stand for extended periods of time due to operational needs. Prolonged standing is defined as the operator standing for more than 50% of the work shift. Prolonged standing causes a lot of negative effects, including soreness, muscular fatigue, oedema, and varicose veins. Furthermore, prolonged standing will have an impact on the industry, resulting in poor industrial performance. Thus, to lessen the effect of extended standing, particularly muscular fatigue, this study was conducted to assess and raise the operator's awareness of the consequences of prolonged standing. Furthermore, the idea of smart passive exoskeleton is suggested and tested in order to reduce muscular fatigue caused by prolonged standing. Because of the pandemic circumstances, various online surveys are being done among manufacturing industry operators who are free of musculoskeletal problems such as back and neck discomfort.

CHAPTER 2
LITERATURE REVIEW

This chapter will discuss the literature review and substantive findings of academic knowledge in terms of theory and methodologies of previous studies and experiments. This chapter is built according to the research objectives, and all the information presented is supported with relevant journals, books, articles and other resources.

2.1 Ergonomics Issues Related to Prolonged Standing

Ergonomics is focused on the design of workplaces in which people do their tasks. Ergonomics is concerned with the fit between a person, their activities, the items they use, and the surroundings in which they work, travel, and play. People's stress levels are lessened when they achieve a good fit. They are more relaxed, can do tasks more swiftly and effortlessly, and make fewer mistakes. Ergonomics is the study of human fit, as well as the reduction of tiredness and pain through product design (Openshaw and Taylor, 2006). The goal of ergonomics is to guarantee that in the design of work systems, a human requirement for efficient working and safe are fulfilled (Bridger, 1995).

Injuries and conditions of the muscles, nerves, tendons, ligaments, joints, cartilage and spinal discs are known as musculoskeletal disorders (MSDs) (Baker. 2000). The purpose of ergonomics is to decrease work-related musculoskeletal diseases (MSDs) by modifying the task to the individual rather than pushing the individual to adapt to the task. Fatigue, soreness, and repetitive strain injuries (RSI) are caused by repeated action while doing tasks. OSHA has identified workplace risk factors that have the potential to cause MSDs, which include force, static posture, awkward posture, cold temperatures, repetition, contact stress, vibration. When identifying risks of certain employment, factor 1030 evaluates the length of time exposed to risk factors, the workstation layout and space design, the equipment used and items handled, environmental conditions, and the organisation of work (Sebesta. 2001). The expense of work-related musculoskeletal disorders such as CTDs (Cumulative Trauma Disorders) in the US sector is relatively high even when not entirely attributable to poor work design. According to the National Safety Council (1997), 15-20% of employees in vital sectors (meatpacking, poultry processing, auto assembly, and garment manufacturing) are at risk for CTD, and repeated activities are responsible for 61% of all occupational injuries (Nieble and Freivald. 1999).

2.2 Evidence of Negative Health Outcome

2.2.1 Cardiovascular Disease

Ngomo et al. (2008) investigated the influence of prolonged standing on self-reported orthostatic symptoms, heart rate, and blood pressure in employees who stand for considerable lengths of time during the workday (i.e., an average of 84–95 percent of the workday) and reported blood pressure variations. Sudol-Szopinska et al. (2007) conducted prospective research comparing the risk of chronic venous diseases (CVD) for employees who are exposed to prolonged standing against individuals who are predominantly exposed to extended sitting in the workplace. Prolonged standing did worsen CVD symptoms. The outcomes of follow-up research using the comparable technique but different employees were nearly identical (Sudol-Szopinska et al., 2011). Table 2.1 shows the Studies examining prolonged standing and cardiovascular CV.

Table 2.1: Studies examining prolonged standing and cardiovascular

Author	Study Population	Brief Summary
(Krijnen et al., 1997)	387 Dutch Male workers in a standing profession.	Age and body weight were risk factors for presence of CVI and that the number of years having a standing profession was identified as a risk factor for severity of CVI.
(Bahk et al., 2012)	2165 (1203 F, 962 M) South Koreans. Workers.	Sig. ORs for varicose veins in women (2.99, 95% CI 1.26–7.08) + men (7.93, 95% CI 3.15–19.95) with prolonged standing > 4h/d. Nocturnal leg cramps were sig. only for men (2.93, 95% CI 1.73–4.97).

(Sudol-Szopinska et al., 2007) and (Sudol-Szopinska et al., 2011)	2007-160 office + bakery workers (97 F, 63 M). 2011-126 office + laboratory workers. Poland.	Occurrence of CVD symptoms were significantly higher for workers who work in a standing position compared with workers who primarily work in a sitting position.

2.2.2 Fatigue / Discomfort

Physiological/biomechanical measurements such as muscle electromyography, postural stability utilising force platforms, or muscle surface temperatures are commonly used to detect physical tiredness. Subjective rating scales that ask people to estimate their level of pain or exhaustion using a body location diagram are frequently used to assess discomfort. Drury et al. (2008) investigated the influence of work postures on subjective tiredness in baggage security screening staff. Work posture did have an influence on evaluations of body part discomfort. Balasuabramanian et al. (2009) examined muscular fatigue and felt discomfort in employees utilising static and dynamic standing (walk between work stations) labour activities. The fatigue rate and discomfort ratings were greater in the immobile static standing posture than in the dynamic standing posture. Freitas and colleagues et al., (2005) showed gains in postural stability measurements from adults and elderly persons after 30 minutes of extended standing. Increased sway can suggest a loss of postural control, which is an indication of physical exhaustion. Table 2.2 shows the studies examining prolonged standing, fatigue & discomfort

Table 2.2: Studies examining prolonged standing, fatigue & discomfort

Author	Study Population	Brief Summary
(Flore et al., 2004)	62 F Italian Surgery room workers and 65 F Italian outpatient workers.	Workers with predominantly standing occupations increased venous pressure (before work compared to after work) was significantly higher for the standing workers compared to the controls compared to

		workers who stand less, suggesting that these workers are likely at higher risk of CVI.
(Balasuabramanian et al., 2009)	9 M volunteers performing assembly/disassembly task. India.	Fatigue rates in leg and lower back muscles were sig. higher ($p < 0.05$) in stationary standing posture as compared to dynamic standing posture, and perceived discomfort in the legs, shoulders, and overall rating of discomfort were sig. higher for static posture than for dynamic posture.
(Drury et al., 2008)	US TSA baggage screeners (7 M, 5F).	Standing posture was rated as having the highest level of discomfort, followed by sitting on a high stool, then by sitting at a desk.
(Freitas et al., 2005)	14 elderly volunteers + 14 adult volunteers. Brasil.	Postural sway was sig. greater following a prolonged standing task and the increase in sway was attributed to fatigue. Lack of mobility had greater effects on the elderly compared to the adults.

2.2.3 Low Back Pain

Several investigations have been carried out to determine whether there is evidence of enhanced gluteus medius (GM) activity after prolonged standing (Nelson-Wong et al., 2008 and Marshall et al., 2011). Using electromyography (EMG) recordings, the researchers discovered that subjects who reported low back pain had more co-activation of the left and right GM muscles during the standing task than those who did not experience LBP. Marshall et al. (2011) used EMG to investigate the endurance and strength of the GM muscles and co-activation patterns in participants without back pain. Their findings suggested that prolonged standing affected endurance and co-activation, which influenced reports of low back pain (LBP). Table 2.2 shows the Studies examining prolonged standing and LBP.

Table 2.3: Studies examining prolonged standing and LBP

Author	Study Population	Brief Summary
(Engels et al., 1996)	846 nursing staff in Netherlands	Workers who reported being "hampered by standing" at work had an increased risk of LBP (OR=3.07) and leg pain (OR=4.9) compared to those who were not hampered by standing at work.
(Marshall et al., 2011)	24 (8 M, 16 F) Canadian volunteers.	Evidence suggesting that GM endurance and co-activation were affected by prolonged standing and this influenced reports of LBP.
(Roffey et al., 2010)	Review of 2,766 citations (only18 met review criteria).	Concluded that it was unlikely that occupational standing or walking is independently causative of LBP.

2.3 Explanation of Passive Exoskeleton

2.3.1 The Chair-Less Chair

The 'chairless chair exoskeleton system' is a mechanical based exoskeletal support that is simply a 'chair' like an exoskeleton, allowing users to walk or move at a certain pace with the device while working. It is a mechanical ergonomics device developed around the structure and function of the human body, with segments and joints that correspond to those of the person with whom it is externally attached. This support allows users to relax their leg muscles by directing their body weight towards a variable damper attached to the frame and directing the weight to the ground. This exoskeleton system is intended to be a proper mechanism for the human lower extremities, and it acts in sync with the human realises.

Figure 2.1: Design exoskeleton chair-less chair (Malode et al., 2021)

2.3.2 The Lower Hip Region Support

As indicated in Figure 2.2, holes are drilled to link the straps from the rear to the user's shoulder, keeping the gadget intact. A rectangular rod is positioned parallel to the butt area to support the lower hip region. As support, two pairs of stainless steel rods are welded to the opposite end of each thigh area. The rod used measures 33 cm in length.

2.3.3 The Thigh Region Support

Two thigh areas support stainless steel rods that are slightly bent. Each rod is attached to the calf area support through a joint constructed parallel to the user's knee joint, as shown in Figure 2.2. The two thigh support rods are either joined or welded to one end of the hydraulic piston. The lengths of the two stainless steel rods are 39 cm.

Figure 2.2: Thigh region support (Delicia et al., 2020)

2.3.4 The Calf Region Support

The calf support rod is attached to the other end of the joint (47 cm). They are also two in number and longer than the thigh support rods, as shown in Figure 2.3. The hydraulic piston's opposite end is soldered to the calf rod support. This is done to keep the chair-less chair balanced on the ground.

2.3.5 The Hydraulic Piston

Hydraulic is a phrase used to describe a device that is powered or moved by a fluid, most commonly oil. One side of the piston is welded to the thigh support, while the other is welded to the calf support. Figure 2.3 shows the location of the hydraulic piston. Only when the piston is compressed can the user sit; when it is extended, the user can stand. The piston is the essential component of the design because it is responsible for the device's operation. In its extended size, it measures 50 cm.

Figure 2.3: The Hydraulic Piston (Delicia et al., 2020)

2.3.6 The Shoe and Strap

Straps link the calf support area rod's end to a pair of shoes. These straps are fastened to the shoes along with the rod using the nuts and bolts shown in Figures 2.4. This helps in keeping the rod firmly planted on the ground and within the user's control. Straps are put across the user's shoulder, hip, and chest area to keep the two devices in place. The strap measures 90 cm from hip to shoulder.

Figure 2.4: Shoe and strap (Delicia et al., 2020)

2.4 Exoskeleton for Standing at Workplace

Exoskeleton are divided into two type and that is active exoskeleton and passive exoskeleton. An active exoskeleton is made up of one or more actuators such as electrical motors that actively supply power to the human body. Active exoskeletons were created specifically for the intention of rehabilitating injured or handicapped people. Active exoskeletons with occupational or industrial applications are being developed, however they are mostly in the laboratory for now. A passive exoskeleton would not require an external power source and instead makes use of materials, springs, or dampers that can store and release energy from human motions.

2.5 Existing Design of Exoskeleton for Prolonged Standing

According to, portable smaller body robots, or exoskeletons of the low neck, have expanded fast during the recent decade (Lee et al., 2019). He defined such instruments as falling into three categories: supporting exoskeletons, rehabilitative exoskeletons, and raising exoskeletons. Exoskeletons are intended for usage in people with neurological problems or the elderly. Customers who have been consistently out of place are more likely to benefit from assistive exoskeletons. Those who ease/write the flaws of persons so that consumers may live and function as good patients with the usage of the units by performing it. He also noted that specific location commutive is an important component of such type of broad connection. It is, of course, easier to discover any with. Alternatively, exoskeletons in the rehab can be used for people with disease that can be resolved from rehabilitation and preparation and augmentation exoskeletons, mainly aids healthy users.

2.5.1 Design and Preliminary Experimentation of Passive Weight-Support Exoskeleton

PEXER IV (Passive Exoskeleton for Easy Running, Version IV) is a prototype. PEXER IV is a wearable device designed to reduce a runner's physical strain. It can produce enough force to sustain a portion of the user's upper body weight during the stance phase. It also allows the wearer to stretch or extend the user leg during the swing phase without causing friction. Furthermore, it is light and would not increase to the weight of the gravitational and inertial effects (Hasegawa & Ogura, 2013).

Figure 2.5: PEXER IV (Hasegawa & Ogura, 2013)

2.5.2 Effect of Wearable Exoskeleton Chair Based on Muscle Activities

Standing for an extended period of time elevates the health risks for workers in the manufacturing industry. Huazhong University of Science and Technology designed and developed a wearable exoskeleton chairX to minimize stress on the leg muscles of long-term workers, lowering the risk of muscular damage. They measured the surface Electromyography (EMG) of the biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) during multiple things to evaluate the effects of chairX. They conducted an experiment in which six healthy people were recruited to perform squatting activities with and without chairX at different knee bending angles. According to the results of the tests, the chairX was able to significantly lower the activation levels of the muscles at various bending angles and loads. (Li et al., 2019).

Figure 2.6: A wearable exoskeleton chair X (Li et al., 2019)

2.5.3 Chair-Less Chair for Lumbar Pain Reduction

The chair-less chair is a versatile, lightweight, contraption-like, ergonomic device that resembles an exoskeleton wrapped on the body. The exoskeleton wraps the hip and reaches all the way down the leg to the foot; straps are given around the user's shoulder to secure the exoskeleton. The model may be adjusted to fit different body sizes, and safety shoes are included. With this equipment, the user can roam about and sit anyplace. Squatting, crouching, bending, and other demanding postures should be avoided. It is an ergonomic device since it is connected to or developed for workplace productivity and comfort. Exoskeletons are used to produce medical rehabilitation and movement of the human body. (Delicia et al., 2020)

Figure 2.7: Chair-less for lumbar pain reduction (Delicia et al., 2020)

2.6 Description Mechanism and Function of Existing Design

2.6.1 ChairX

According to Figure 2.8, the mechanism for this device is to measure the surface Electromyography (EMG) of the biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM). The function is to minimize the stress on the leg muscles of long-standing employees.

Mechanism: to measure the surface Electromyography (EMG) of the biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM).

Function: to minimize the stress on the leg muscles of long-standing employees.

Figure 2.8: Design 1, a wearable exoskeleton chair X (Li et al., 2019)

2.6.2 Chair-less chair for lumbar pain

According to the Figure 2.9, the mechanism for the Chair-less device is rod stainless steel, gas spring, and thigh area support. The ability to sit anywhere, at any time, is made possible by this wearable technology, and it aids in the relief of back pain, limb discomfort, and exhaustion, as well as a boost in worker efficiency.

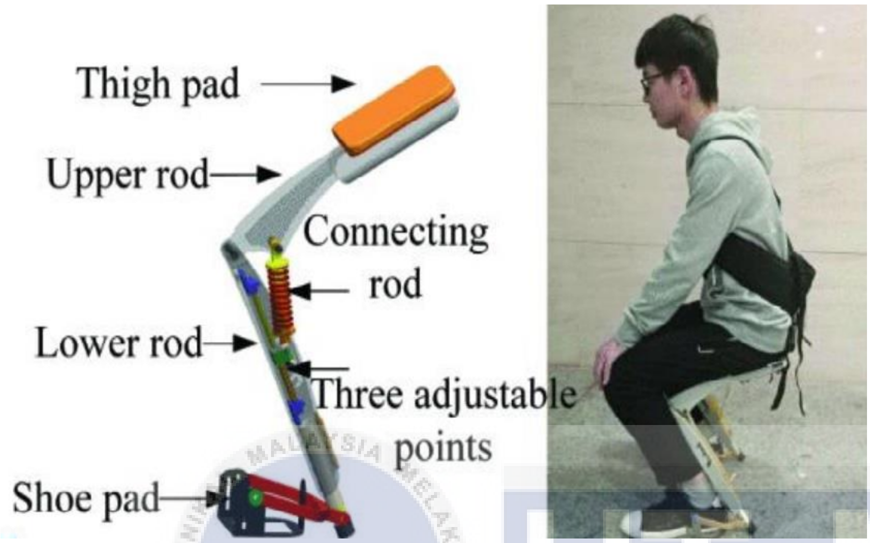
Mechanism: Rod stainless steel, gas spring and thigh region support.

Function: ability to sit anywhere, at any time, is made possible by this wearable technology, and it aids in the relief of back pain, limb discomfort, and exhaustion, as well as a boost in worker efficiency.

Figure 2.9: Design 2, the chair-less for lumbar pain reduction (Delicia et al., 2020)

2.6.3 PEXER IV

The mechanism for device PEXER IV is a spring compensation system and a shoe pad, as shown in Figure 2.10. The function is to design for changeable levels and to automatically lock the angle after sitting on the seat.



Mechanism: Shoe pad and spring compensation system
Function: adjustable height and auto lock

Figure 2.10: Design 3, PEXER IV (Hasegawa & Ogura, 2013)

2.7 Advantages and Disadvantages of Existing Design

Based on the summary table, we can assume that each current design has its own set of advantages and disadvantages. Certain designs of exoskeleton devices are not mobile, have a restricted range of motion, are heavy, and can only be utilised in specific locations. Some previous designs give a large range of motion and multiple directions, as well as being transportable and detachable, however the design is eventually not cost effective. The improvements that will be made on developing exoskeleton devices in this project are based on the disadvantages of existing designs, as shown in Table 2.4.

Table 2.4: Advantages and Disadvantages of Existing Design

Existing Design	Mechanism	Advantages	Disadvantages
ChairX	Strap support and adjustable high	- Economical - Adjustable angle - Can support the weight	- Difficult to walk freely - Heavy - Limited adjustable angle

Chair-less chair for lumbar pain	Rod stainless steel, gas spring and thigh region support	- Have back support equipment - Economical	- Difficult to walk freely - Difficult to wear - Heavy
PEXER IV	Spring compensation system and shoe pad	- Can adjustable the angle at three points	- Limited adjustable angle

2.8 Malaysian Anthropometry

A study was conducted to determine the differences between the three racial groupings. Malaysian populations based on anthropometric data (Karmegam et al., 2011). He also indicated that the data was gathered from 300 voters, 150 males and 150 females. Women between the ages of 18 and 24. There are 100 Malays, 100 Indians, and 100 Chinese among the 300 responders. The dimension of the measured anthropometric is shown in the Figure 2.11.

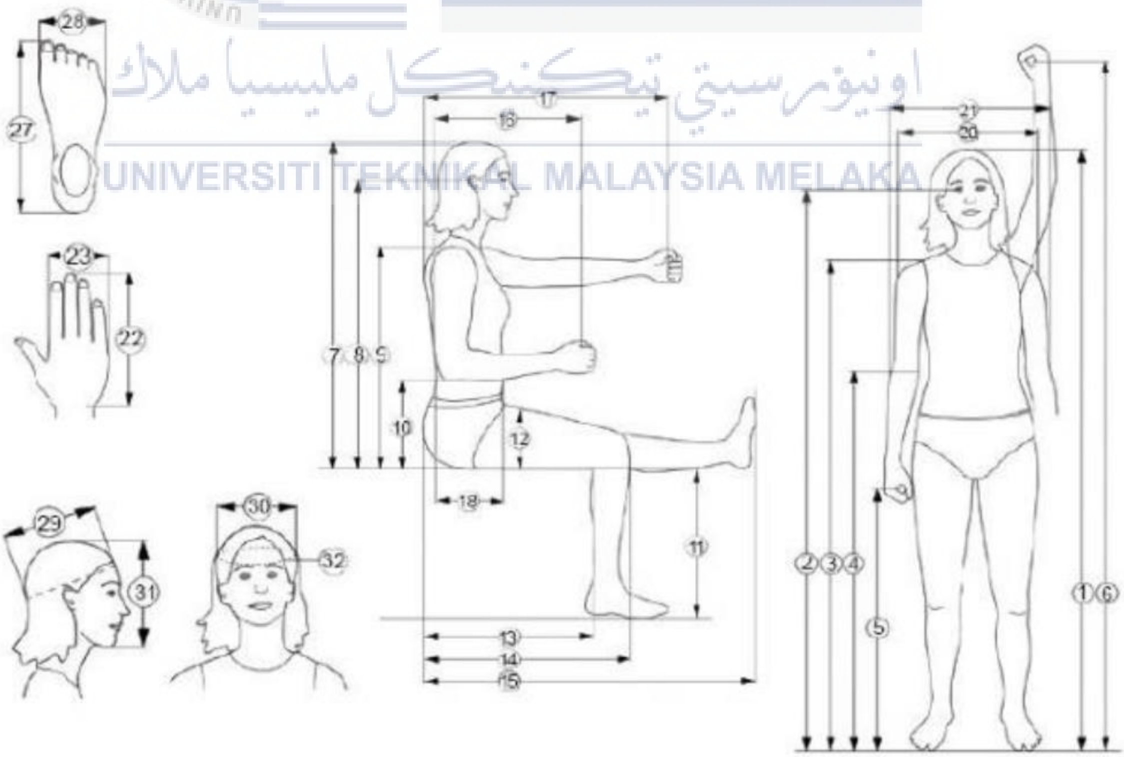


Figure 2.11: The illustration of the measured anthropometric (Karmegam et al., 2011)

Table 2.5: Table of measurement of body and labelled number (Karmegam et al., 2011)

Measurement	**Number**
Stature	1
Thigh thickness	12
Hip breadth	18
Buttock popliteal length	13
Buttock knee length	14
Buttock heel length	15
Popliteal length	11

For the different body measures that have been tabulated, the statistical test provides the mean, low, median, 5th percentile, 50th percentile, and 95th percentile. The anthropometric statistics of Malaya, both male and female, are shown in Tables below, depending on their measurement.

Table 2.6: Anthropometric of Malay's male (Karmegam et al., 2011)

Measurement	Male (n=50)					
	Mean (cm)	Min (cm)	5^{th} (cm)	50^{th} (cm)	95^{th} (cm)	Max (cm)
Stature	178.57	147.40	174.56	177.75	184.75	186.80
Thigh thickness	14.88	10.20	12.31	14.85	18.79	19.00
Hip breadth	32.62	24.90	24.96	32.45	38.10	40.30
Buttock popliteal length	52.39	49.10	49.16	52.40	55.45	57.30
Buttock knee length	63.38	52.10	56.78	63.35	67.34	67.50
Buttock heel length	115.00	107.00	111.40	115.30	121.00	121.80
Popliteal length	41.18	39.30	39.56	40.90	43.81	44.40

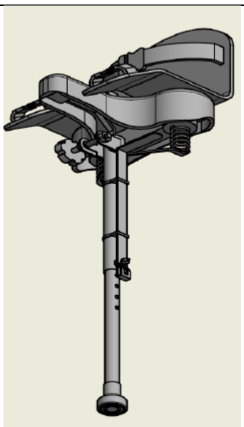
Table 2.7: Anthropometric of Malay's female (Karmegam et al., 2011)

Measurement	Female (n=50)					
	Mean (cm)	Min (cm)	5^{th} (cm)	50^{th} (cm)	95^{th} (cm)	Max (cm)
Stature	153.30	141.50	141.61	147.35	167.64	170.10
Thigh thickness	14.76	9.70	10.46	15.25	19.05	19.60
Hip breadth	33.00	13.50	26.51	31.95	41.14	41.00
Buttock popliteal length	45.26	36.30	38.90	44.80	51.45	53.20
Buttock knee length	56.66	46.60	47.16	56.75	63.84	66.40
Buttock heel length	99.98	91.40	93.61	98.45	109.19	109.40
Popliteal length	38.26	31.40	31.56	39.25	42.25	43.50

2.9 Difference Between Previous Studies and Current Study

Study	Summary
LEX	 **Name** : Lex **Material** : Aluminium **Size** : Small = below 164cm, Standard = over 165cm **Weight** : more than 1 kg **Adjustable length** : No **Portability** : High **Inclination angle** : Fixed Angle **Movement restriction** : Low **Comfortability** : Low **Price** : Rm 1668 – Rm 6684

Noonee	 **Name** : Noonee **Material** : Polymer **Size** : 160 cm – 195 cm **Weight** : 3.3 kg **Adjustable length** : Calves (4 option) & Thigh (4 option) **Portability** : High **Inclination angle** : Two angle **Movement restriction** : Low **Comfortability** : High **Price** : Rm 17 257
Archelis	 **Name** : Archelis **Material** : Polymer **Size** : Applicable user height 160cm - 185cm **Weight** : 3.2 kg **Adjustable length** : Knee (2 option) **Portability** : Low **Inclination angle** : No **Movement restriction** : High **Comfortability** : Low **Price** : Rm 11 362

Solehin	 **Name** : Passive sit stand exoskeleton **Material** : Alluminium Alloy **Size** : Follow Malaysian Anthropometry **Weight** : 5 kg **Adjustable length** : Handle adjustable height **Portability** : High **Inclination angle** : Fixed angle **Movement restriction** : Low **Comfortability** : High **Cost** : RM 100

2.10 Design on Ergonomic Passive Sit and Stand Exoskeleton

Several methods will be discussed in order to record the first objective of this project, which is to identify the requirements needs of potential users of design passive sit and exoskeleton stand. The method employed was an online questionnaire survey.

2.10.1 Determination of user needs through Questionnaire Form

For such research questions, a questionnaire survey is insufficient. Its effectiveness is determined by the sort of information needed to answer the study inquiry and the individuals from whom the researcher want to acquire information. The survey was carried out with the use of a Google form, and the questionnaire included an optional question, a scale question from 1 to 5, and open-ended responses for additional comments. The project supervisor reviewed the questionnaire survey form after the question was created. The questionnaire form is distributed if the questionnaire is accepted; otherwise, the questionnaire is repaired.

2.10.2 House of Quality

House of Quality is a technique for finding and analysing voice feedback. The House of Quality (HOQ) form will be utilised in this study to translate customer needs into design considerations in order to satisfy customer satisfaction. Technical requirements, customer needs, a planning matrix, a technical co-relationship matrix, an interrelationship matrix, competitive benchmarking, technical benchmarking, and technical priorities formed the core structure of the HOQ. The early phase in developing HOQ was to determine the customer's demands through an interview with potential users of prolonged standing. This interview will include a number of respondents. Each customer need will be assigned an importance value between 1 and 5, with 1 being the least important and 5 being the most essential. The size of the rating was determined by a customer interview. Following that, the technical requirements were acquired through interviews with the technical society and the design team. The performance of each requirement was scored by the customers on a scale of 1 to 5. Then, to connect the customer needs and technical specifications, an interrelationship matrix was created. It may be used to estimate the level of connection between the two requirements. To avoid design conflict, a co-relationship matrix has been created to determine the relation between each technical requirement. The diagrams below show the representative symbols for the interrelationship matrix and the co-relationship matrix.

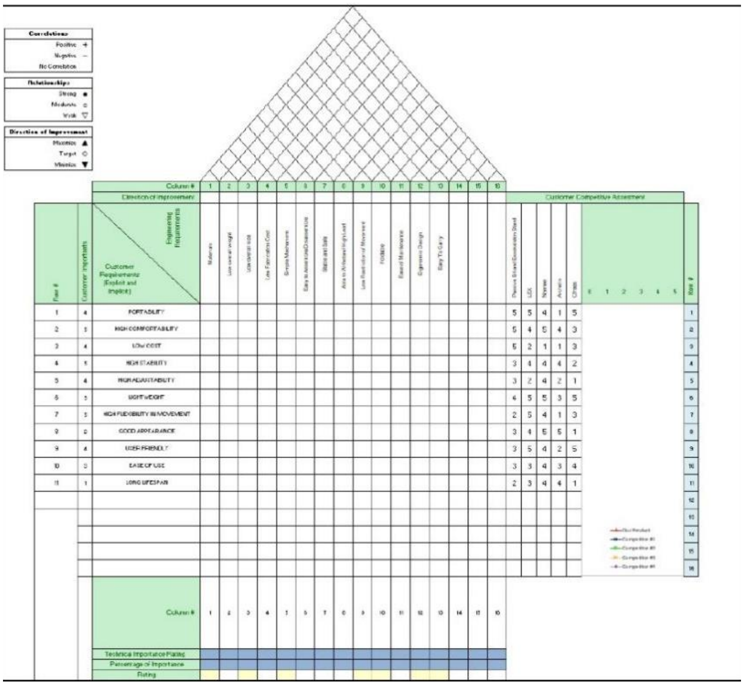


Figure 2.12: House of Quality (HOQ)

Table 2.8: Representative symbol for interrelationship matrix

Scale	Symbol	Relationship
+9	●	Strong
+3	○	Moderate
+1	∆	Weak

Table 2.9: Representative symbol for co-relationship matrix

Relative Performance	Rating
Better than	+
Worse then	-
Same as	0

2.10.3 Conceptual Design

Conceptual design is a phase in the design process in which the broad outlines of a product's functionality and shape are articulated. Designing interactions, experiences, processes, and methods are all part of it. Four types of conceptual design will be shown in this section. The five important requirements from the previous section were used to develop these designs. The design concepts were based on an exoskeleton stand patent, previous research on passive sit, and the present exoskeleton stand product. By hand drawing, four concepts will be designed. The next part used a concept screening matrix and a concept score matrix to identify the best concepts. The table 2.10 shows the conceptual design of four ideas.

Table 2.10: Concept Design

Concept	Design	Description
A		
B		
C		
D		

2.10.4 Pugh Concept Selection

Three of the four concepts in the previous section were selected through concept screening or concept selection using the Pugh method. This concept was used to compare and rank each concept based on important specifications from the QFD section. The Pugh concept screening used in this investigation is shown in the Table 2.11.

Table 2.11: Pugh Concept Screening

Selection Criteria	Concept A	Concept B	Concept C	Concept D	Reference
Criteria					
Criteria					
Criteria					
Criteria					
Criteria					
Criteria					
Criteria					
Sum of 0					
Sum of -					
Net score					
Rank					
Decision					

Before ranking the concepts, an overall number of pluses, minuses, and the same were calculated, and the net score was determined. Each of the principles have been rated according to their net ranking. For the following method, the definition with the lowest rank and net score was 35. The scores in the Table 2.12 are used for concept comparison and assessment in the screening concept.

Table 2.12: Rating used for concept comparison and evaluation

Relative Performance	Rating
Better than	+
Worse then	-
Same as	0

2.10.5 Concept of Scoring

Following the screening process, the remaining concepts were numerically evaluated. Using simple scales that are proportionate to the weighting percentage. The total score was obtained by determining the overall rating for each of the definitions. The best design with the highest rating has been selected and properly designed for the next segment. The concept scoring used in this study is shown in Table 2.13.

Table 2.13: Concept Scoring

Selection criteria	Weight	Concept A		Concept B		Concept C	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Criteria							
Criteria							
Criteria							
Criteria							
Criteria							
Criteria							
Criteria							
Total							
Rank							
Decision							

2.11 Analysis and Synthesis of Literature Review

Previous researchers have carried out a number of passive exoskeleton investigations. This research may have connections and differences that may be examined in order to provide beneficial ideas and information on the methodologies and results presentations for the current study. Table 2.14 compares the past studies to the current study in terms of subject and variables of investigation.

Table 2.14: The differences between past study and current study

Studies	Subject of study	Variable of study
(Karakolis & Callaghan 2014)	14 Articles from various countries published between 1950–2011 that met review criteria.	Sufficient evidence to conclude that sit-stand workstations are effective in reducing local discomfort in the low back. Some evidence that sit-stand workstations may increase reported discomfort in hand and wrist. No optimal sit-stand time ratio. No decrease in productivity noted.
(Robertson et al., 2013)	22 F American volunteers.	Minimal musculoskeletal and visual discomfort over a 15 day experimental period for participants who used sit-stand workstations with ergonomics training compared to participants with minimal training. 7 body region pain measures showed sig. differences ($p < 0.01$) between regions. Low back, neck, and shoulder highest reported pain areas.
(Husemann et al., 2009)	60 M German College volunteers.	Sit-stand workstation across a 1-week period reduced musculoskeletal complaints while performing a data entry task. No sig. effects noted on data entry task performance with sit-stand workstation.
(Chester et al., 2002)	18 American (7 F, 11 M) volunteers.	Found that the sit-stand chair resulted in higher leg volume changes than standing or sitting only and the most discomfort in the hips.
Current Study	10 male of healthy Malaysian young adult aged 21 – 30 years old	**Independent variables:** - The activity of the tibialis anterior, vastus lateralis, and gastrocnemius. - Maximum voluntary contraction (MVC) **Dependent variables:** pressure, EMG

2.12 Summary

The theoretical concept of passive sit and stand exoskeleton design is covered in this chapter. Various methods for acquiring qualitative feedbacks and quantitative equipment tool and ergonomics design data were referred to based on journal literature reviews. All of the information gathered in this chapter acts as a guide for the development of methodology for this study.

CHAPTER 3
METHODOLOGY

In this chapter, the methodology of the design prototype is presented. To achieve the objectives in Chapter 1, the process and equipment used to conduct the study will be mentioned and elaborated. First, the survey and questionnaire were used to achieve objective 1, which is to evaluate potential user requirements for designing passive sit-stand exoskeletons for prolonged standing tasks at workplaces. Second, the House of Quality (HOQ) and Pugh were used to fulfil objective 2 to design and fabricate a medium-fidelity prototype of a passive sit and stand exoskeleton to reduce discomfort caused by prolonged standing. Finally, many evaluations were performed to determine the maximum stress on the body structure of the passive sit-stand exoskeleton.

3.1 Users Needs of Passive Sit and Stand Exoskeleton

Several methods will be discussed in order to archive the first objective of this project, which is to determine the requirements needs of potential users of design passive sit and exoskeleton stand. The method in use was an online questionnaire survey.

3.1.1 Online questionnaire survey

To achieve objective 1, a survey and questionnaire were used to investigate the design of smart passive exoskeleton for monitoring localized pressure and postural angle during prolonged standing tasks. The survey was conducted using a google form, and the questionnaire used an optional question, scale question from 1 to 5 and open-ended responses for additional comments. The survey was voluntary and anonymous, and the questionnaires were distributed online. The completed questionnaires were returned by email.

3.1.1.1 Flow chart of questionnaire survey

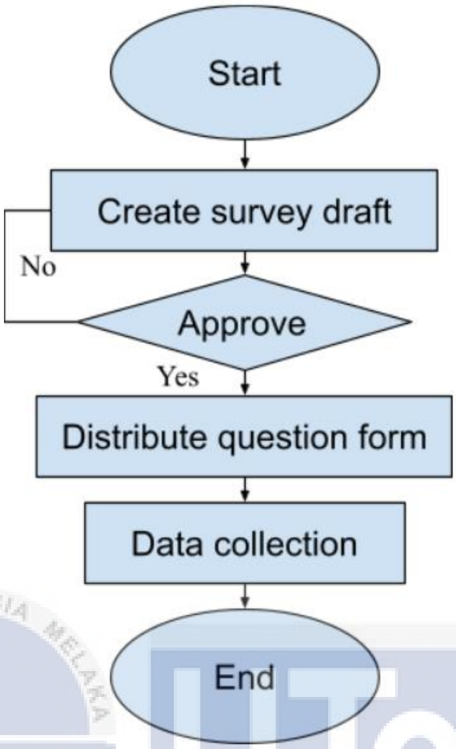


Figure 3.1: Flow chart of questionnaire survey

3.1.2 House of Quality (HOQ)

Using the House of Quality (HOQ) method, user's requirements can be determined and achieved. The questionnaire survey result was collected and evaluated. Based on the user's feedback on the product's design requirements and the product itself, HOQ was used to acquire engineering specifications for the passive sit and stand exoskeleton. The HOQ template used in this project is shown below.

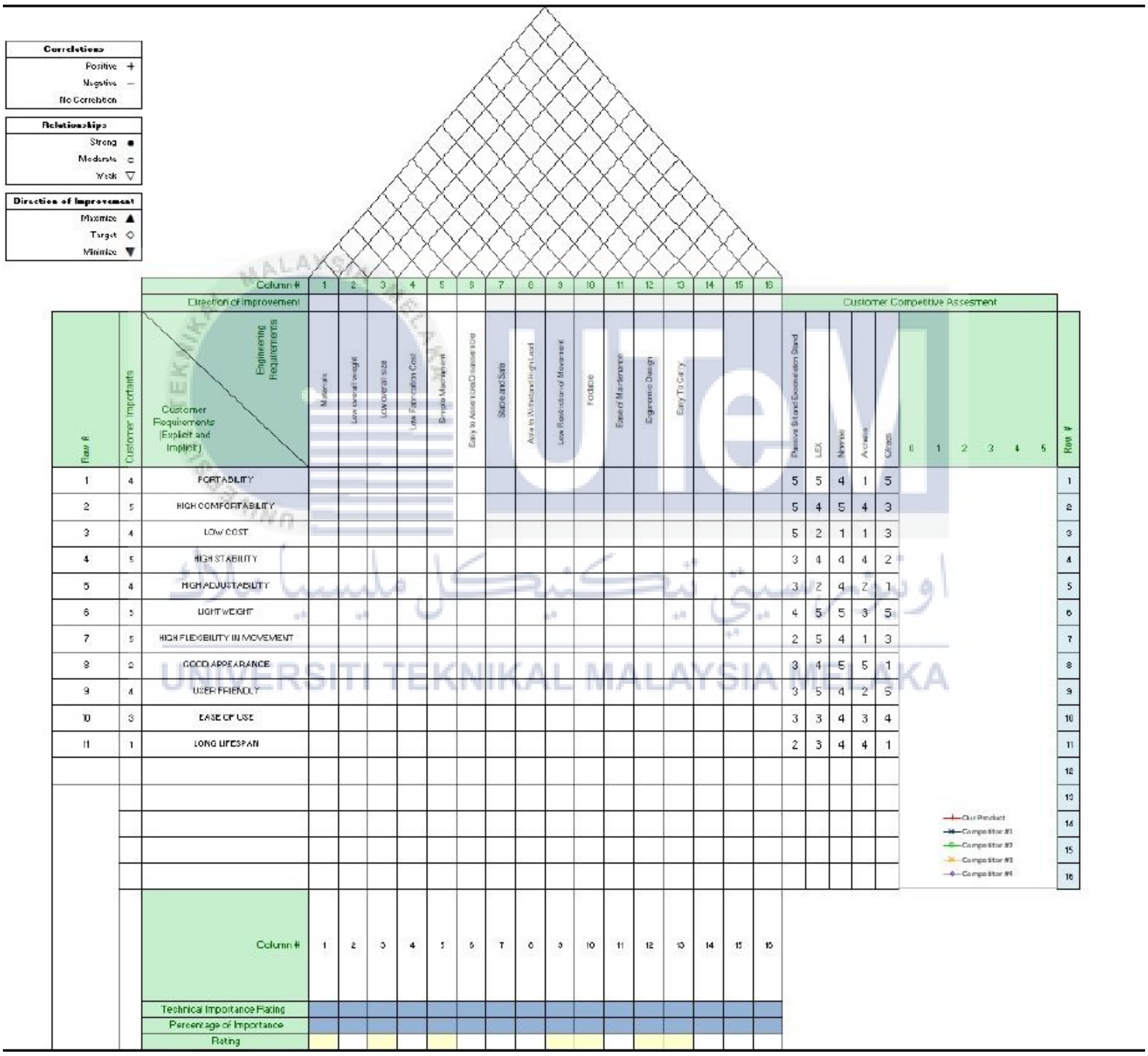


Figure 3.2: House of Quality (HOQ)

The row under the triangle in the template indicates the product's engineering standards, while the left column is used to define aspects of the customers' needs, based on the template above. The top triangle, also known as the correlation matrix, is used to evaluate the link between the product's engineering specifications. The evaluation is based on the numbers 9 (strong), 3 (moderate), and 1 (weak), and an empty column in the matrix indicates that there is no correlation between the product's engineering standards. The second row of the correlation matrix represents the engineering specifications that must be improved, minimized, or avoided. Lastly, using numbers the correlation matrix is used to rate the user's needs and the product's engineering specifications, with 9 representing strong, 3 representing moderate, 1 representing weak, and 0 representing no assignment. Table 3.1 shows the symbol for correlation matrix.

Table 3.1: Representative symbol for interrelationship matrix

Scale	Symbol	Relationship
+9	●	Strong
+3	○	Moderate
+1	Δ	Weak

3.2 Design and Fabricate Passive Sit-stand Exoskeleton

Illustrates the flowchart of fabricate and evaluate the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure using the selected design as shown as Figure 3.3. The process to develop the prototype and the efficiency of the prototype will be discussed in this section.

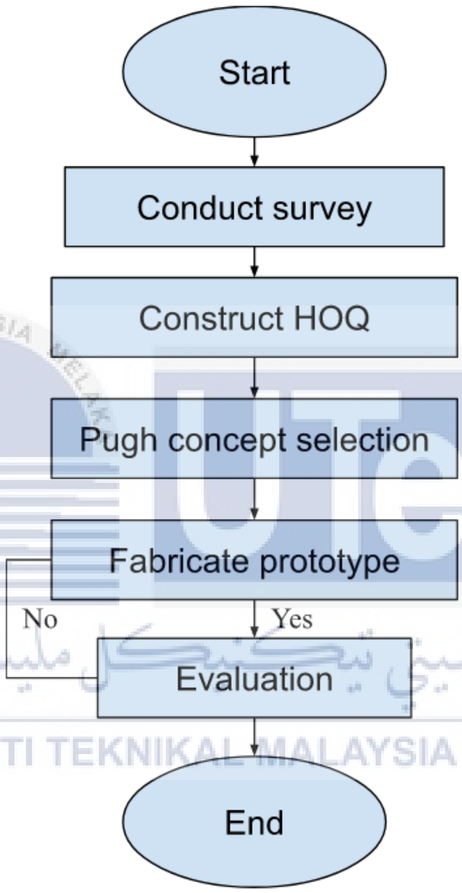


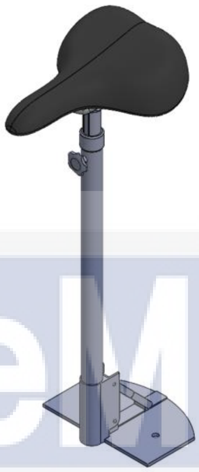
Figure 3.3: Flow chart design and fabricate exoskeleton

3.2.1 Conceptual design

Conceptual design is an early phase of the design process, in which the broad outlines of function and form of something are articulated. It includes the design of interactions, experiences, processes, and strategies. In this section, four conceptual designs will be provided. The concept of design was created based on previous products and commercial products. The four-concept design will be made by manual sketching. A concept screening matrix and concept scoring matrix have been made in the next section for the best concept design. The Table 3.2 shows the conceptual design of four concepts.

Table 3.2: Conceptual Design

Concept	Design
A : Tripod leg	
B : Office chair leg	

C : Unfoldable and wider bottom base	
D : Flat, foldable and wider bottom base	

3.2.2 Pugh Concept Selection

Three of the four concepts in the previous section were selected through concept screening or concept selection using the Pugh method. This concept was used to compare and rank each concept based on important specifications from the QFD section. Table 3.3 shows the Pugh Concept Screening.

Table 3.3: Pugh Concept Screening

Selection Criteria	Concept A	Concept B	Concept C	Concept D	Reference
Ergonomic design					
Foldable					
Easy to carry					
Simple mechanism					
Low overall size					
Low restriction movement					
Materials					
Sum of 0					
Sum of -					
Net score					
Rank					
Decision					

Before ranking the concepts, an overall number of pluses, minuses, and the same were calculated, and the net score was determined. Each of the principles have been rated according to their net ranking. For the following method, the definition with the lowest rank and net score was 35. The scores in the table below are used for concept comparison and assessment in the screening concept.

Table 3.4: Rating used for concept comparison and evaluation

Relative Performance	Rating
Better than	+
Worse then	-
Same as	0

3.2.3 Concept of Scoring

Following the screening process, the remaining concepts were numerically evaluated. Using simple scales that are proportionate to the weighting percentage. The total score was obtained by determining the overall rating for each of the definitions. The best design with the highest rating has been selected and properly designed for the next segment. The concept scoring used in this study is shown in Table 3.5.

Table 3.5: Concept Scoring

Selection criteria	Weight	Concept A		Concept B		Concept C	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Ergonomic design							
Foldable							
Easy to carry							
Simple mechanism							
Low overall size							
Low restriction movement							
Materials							
Total							
Rank							
Decision							

3.2.4 Bill of material

Bill of material illustrated the materials and cost used to fabricate the passive sit and stand exoskeleton. Table 3.6 shows the bill of material of the passive sit and stand exoskeleton.

No.	Component	Quantity	Material	Cost	Buy or Assemble
1.	 	1	Sponge + aluminium alloy	RM55.70	Buy Website link: https://3c5.com/oCHac
2.		1	Aluminium alloy	RM 70	https://shopee.com.my/product/174836171/11249499576?smtt=0.12396904-1641030187.3

3.		5	Alloy steel	RM 2	Assemble
4.		1	Stainless steel	RM 40	Assemble

3.2.5 Fabrication of Passive Sit and Exoskeleton Stand

Product prototype development happens throughout the product design process, both early on to validate the form, fit, and function of the design and later on to ensure that the design details have fulfilled technical requirements. In this context, the fabrication methods needed to produce the exoskeleton prototype will be elaborate. Sawing and drilling were two of the techniques used. The procedures used are determined by the availabilities of the machines.

3.2.5.1 Cutting

In order to get the exact high the aluminium rod has to go thru cutting process. The aluminium rod is cut using a bandsaw machine so that it could get a clean cut and clean edge. Figure below shows the cutting process of the aluminium rod.

3.2.5.2 Drilling

To attach the base to the aluminium rod, a hole needed to be drilled. The machine use to drill a hole at the rod is vertical drill vise clam. Figure below shows the driling process of the aluminium rod.

3.3 Evaluating Sit-Stand Exoskeleton on Muscle Activity and Contact Pressure.

This section discussed the experimenting on efficiency of the design sit stand exoskeleton. In order to archive the second objective of this project, which is to evaluate the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure. The method use will be elaborated.

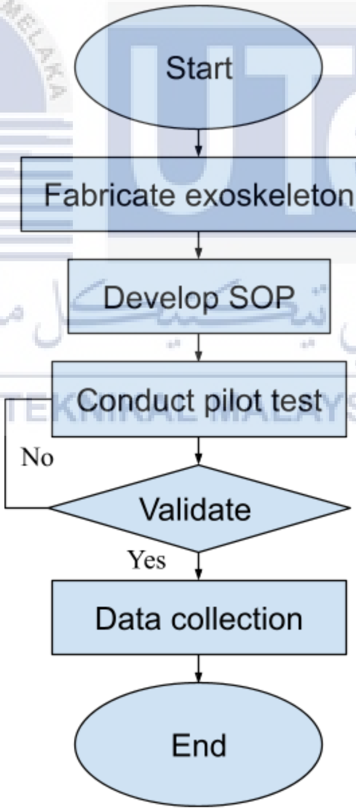


Figure 3.4: Flow chart experimenting the design product

To achieve the second objective, there are some instruments that needed to gather to evaluate the design prototype and that Electromyography (EMG), and CONFORMat. This instrument will be elaborated in the next content.

3.3.1 Electromyography (EMG)

Electromyography is the study of the electrical impulses sent by contracting muscles, as well as their detection, analysis, and application. This signal is known as an electromyographic (EMG) signal, a term that was more applicable in the past than it is now (Luca, 2006). It is a technique for obtaining, recording, and analysing myoelectric signals (Konrad, 2005). Physical responses in the condition of muscle fibre membranes generate myoelectric signals. In this experiment an EMG sensor and software DELSYS EMGworks is needed to start the experiment. Figure 3.5, 3.6 and 3.7 shows the EMG sensor, example of EMG signal and the software of EMG. Table 3.6 shows the step in operating the EMG and table 3.7 shows the step in operating MVC experiment.

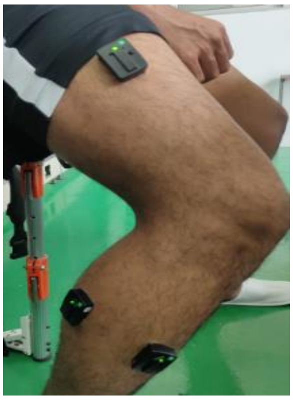
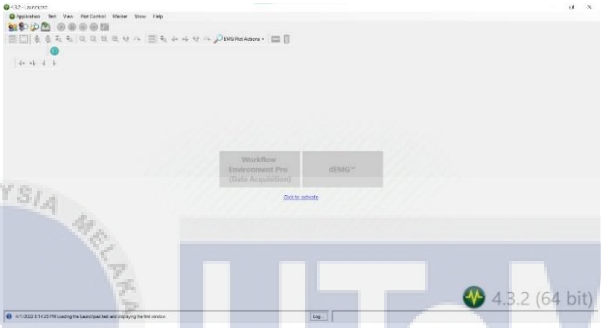
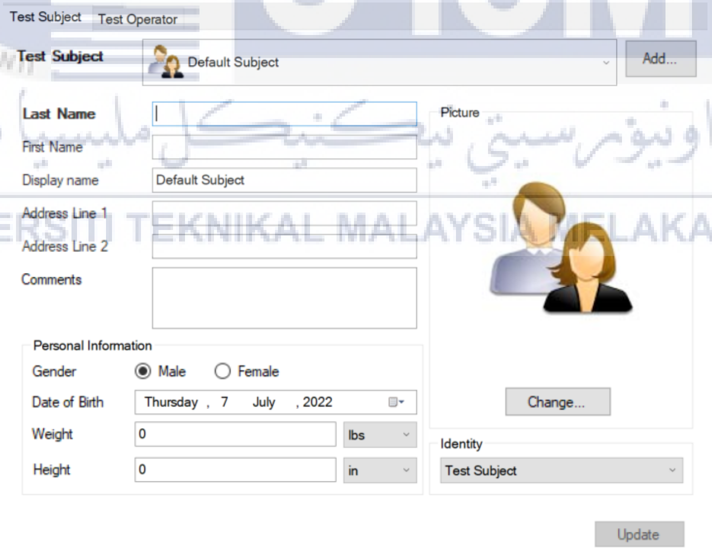
Figure 3.5: EMG sensor

Figure 3.6: DELSYS EMGworks

Figure 3.7: Example of EMG signal

Table 3.6: Steps in operating the DELSYS EMG instrument

No.	Step in operating EMG
1	Turn on the EMG sensor 

2	Attach the sensor to the test subject 
3	Open DELSYS EMGwork software 
4	In the people section, key in the detail of the test subject 

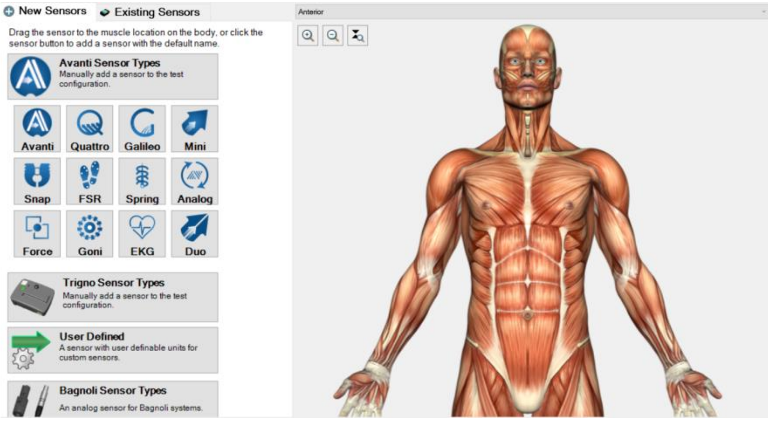
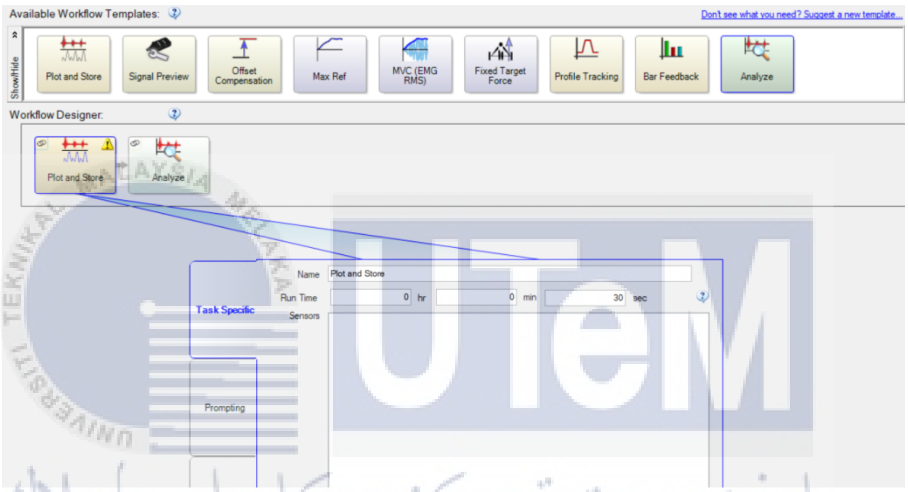
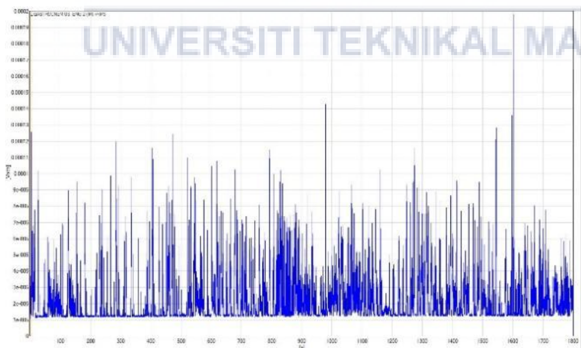
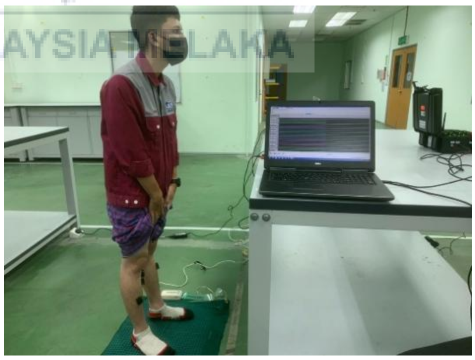
5	In the sensor section, select the muscle that needed to be tested 
6	In the experiment workflow, drag the plot store and analyze templates into workflow 
7	Start the experiment  

Table 3.7: Steps to perform maximum voluntary contraction (MVC) test

No.	Steps to perform MVC test
1	Attach the sensor to tibialis anterior muscle, vastus lateralis muscle, and gastrocnemius muscle.
2	Insert the name, weight and height of the test subject in the DELSYS EMGwork software
3	Select the MVC section in the software
4	Set time 30 second for standing MVC
5	Start the experiment
6	Save the EMG data

3.3.2 CONFORMat

In this experiment a pressure test were conducted, the equipment used was pressure mat where the test subject would step on the mat to get the reading of the pressure under the foot. The other is software CONFORMat, the function is it shows the pressure reading of the test subject that have been step on the pressure mat. Figure 3.8 and 3.9 shows the pressure mat and software of CONFORMat. Table 3.8 shows the step in operating the pressure test.

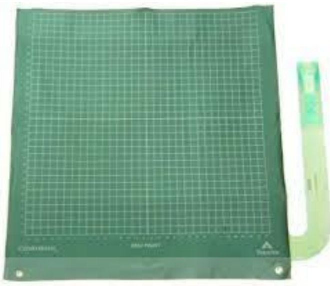


Figure 3.8: Pressure Mat

Figure 3.9: Software CONFORMat

Table 3.8: step in operating the pressure test

No.	Step in operating the pressure test
1	Put down the pressure mat
2	Connect the pressure mat to the USB compatible connector
3	Open the CONFORMat software
4	Put test subject on the pressure mat
5	Start record the capture in the software
6	Collect data

3.3.3 Compression Test

Compression testing is used to assess how a product or material reacts when compressed, squashed, crushed, or flattened by evaluating essential variables that determine the specimen performance under a compressive load. The machine use to conduct the compression test is Autograph AG-1 100kN. Figure below shows the machine use to conduct the compression test.

Figure 3.10: Autograph AG-1 100kN Compression Machine

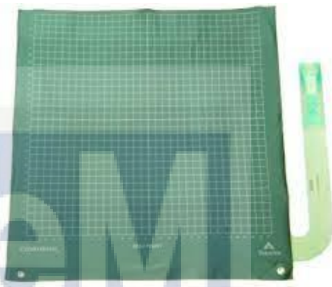
Table 3.9: step in operating the compression test

No.	Step in operating the compression test
1	Put the product at the machine
2	Lower the top platform until it clamps the product
3	In the software, at the load section, leave the value undefine
4	Start the test
5	Collect data

3.3.4 Experimental Procedures

To avoid unwanted outcome, a Standard Operation Procedure (SOP) needed to be created before starting the experiment. This to improve the efficiency of the task and compliance with quality standards, as well as standardising processes. Table 3.10 shows the experimental procedures for EMG test and pressure Test.

Table 3.10: Experimental procedures for EMG test and pressure Test

Step	Procedure
1	Power up the EMG sensor and setup the Pressure mat  
2	Attach the EMG sensor to test subject. Following the muscle map in the DELSYS EMGworks, the sensor needs to attach to the Gastrocnemius, Tibialis Anterior and Vastus Lateralis. 
3	Put test subject on the pressure mat 

4	Before running the software, make sure the setting is correct. For MVC reading, choose the MVC setting on the EMG software, and for normal reading of the muscle, make sure the time input is correct.
5	Start the experiment.
6	Repeat step 2 till step 5. Repeat the experiment until acquired MVC result, standing still result, standing with commercial exoskeleton, sitting with commercial exoskeleton, standing with design exoskeleton, and sitting with design exoskeleton.
7	After acquired all the result, open the result, from the graph extract the raw graph result.
8	Repeat step 2 till step 7 for next test subject.

CHAPTER 4
RESULTS AND DISCUSSION

This chapter presents the results and discussion of the design prototype. To execute the first objective which is to determine users' needs and design requirements of sit-stand exoskeleton from Malaysian industrial workers, a survey has been conducted and the result will be shown in this chapter. Besides, this section will also discuss the evaluation of the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure. The prototype was designed to reduce discomfort caused by prolonged standing and to assess the effects of the exoskeleton prototype on muscle activity and physical contact pressure.

4.1 Design Requirements of Sit-Stand Exoskeleton

This study provides the experimental results of the design prototype, which is based on questionnaires, Quality Function Deployment (QFD), conceptual design, Pugh concept and concept scoring.

4.1.1 Questionnaire Survey

The objective of this survey is to collect the information from respondents regarding the design requirements of sit-stand exoskeleton from Malaysian industrial workers. The data that had been collected from the survey were analysed and the passive sit and design exoskeleton stand feature were used. The data were obtained from 90 respondent whom currently working in the industrial sector. All summarized result will be interpreted using pie chart, table, and bar graph which were developed according to the question ask. The results and discussion are presented below.

The first section of the survey is section A where the question is about the respondent personal information. The data that collected from the survey will determine the design requirement for the sit-stand exoskeleton so that it would match with the objective.

Figure 4.1 shows the result of 90 respondents answered the survey whereby 51.7 percent were male, and 48.3 percent were female.

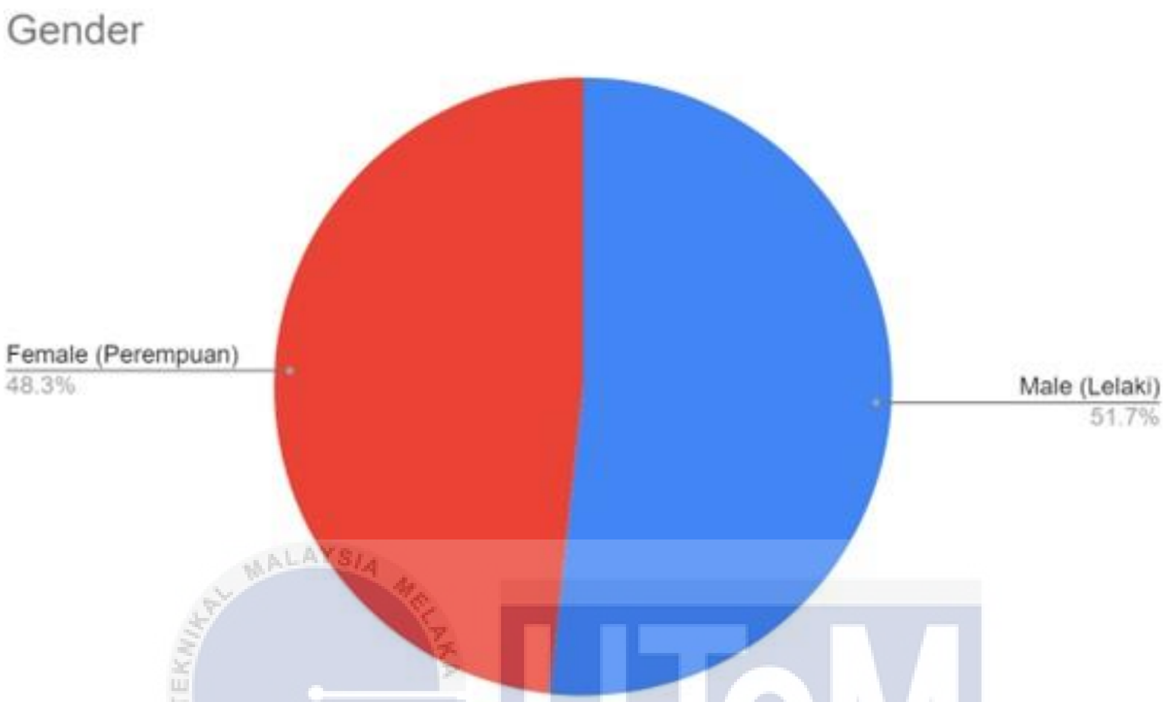


Figure 4.1: Gender of respondents

Figure 4.2 shows the result of 90 respondents where 10.3 percent age below 20 years old, 48.2 percent age between 20 to 25 years old, 6.9 percent are 25 to 30 years old, 10.3 percent are 30 to 35 years old, 3.4 percent are 35 to 40 years old, and 20.7 percent are 40 years old and above. The age of respondent would affect the study. This shows that industrial workers at the age of 20 to 25 have been exposed to prolonged standing at certain protracted time.

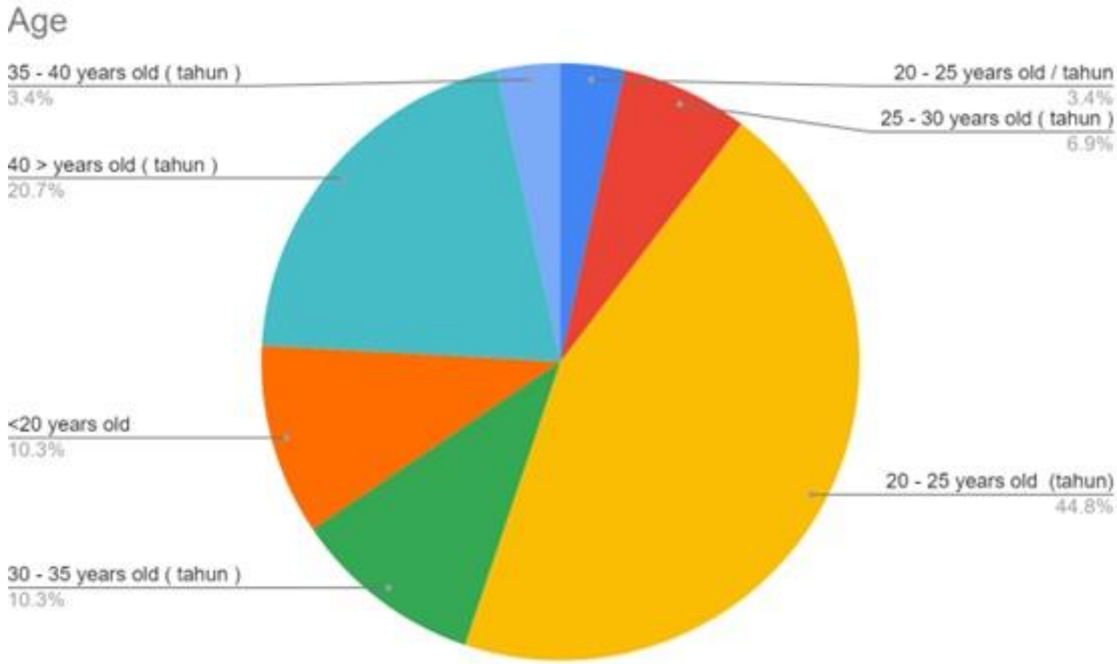


Figure 4.2: Age of respondent

Figure 4.3 show the current position of the workers in the industry. This survey found that 62.1 percent are operator, 17.2 percent are line supervisor, 10.3 percent are technician and 3.5 percent are administrator. The majority is that they work as an operator, they often stand for long periods of time during working hours. Therefore, they are required to participate in this survey to determine the design and characteristics of passive sit and exoskeleton stand.

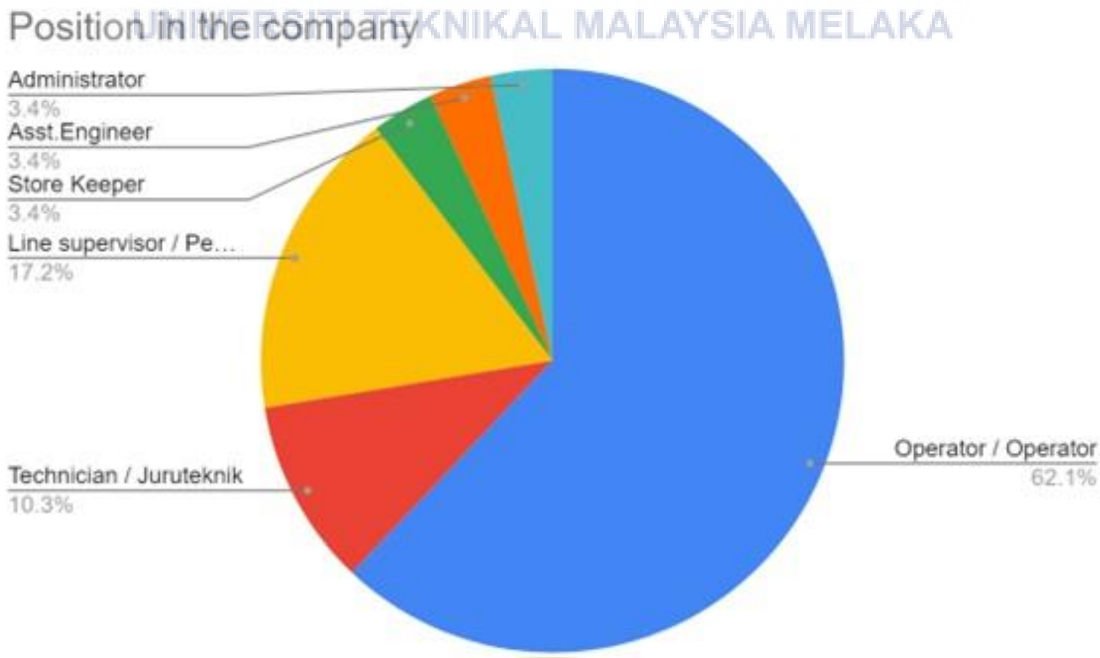


Figure 4.3: Position of the respondent

Figure 4.4 shows the result for how long they need to stand while working. 75.9 percent of them had to work more than 2 hours, 20.7 percent of them are working between 1 to 2 hours, and 3.4 percent of them working less than one hours. With this result of working hour shows they need to withstand working in the prolonged standing position.

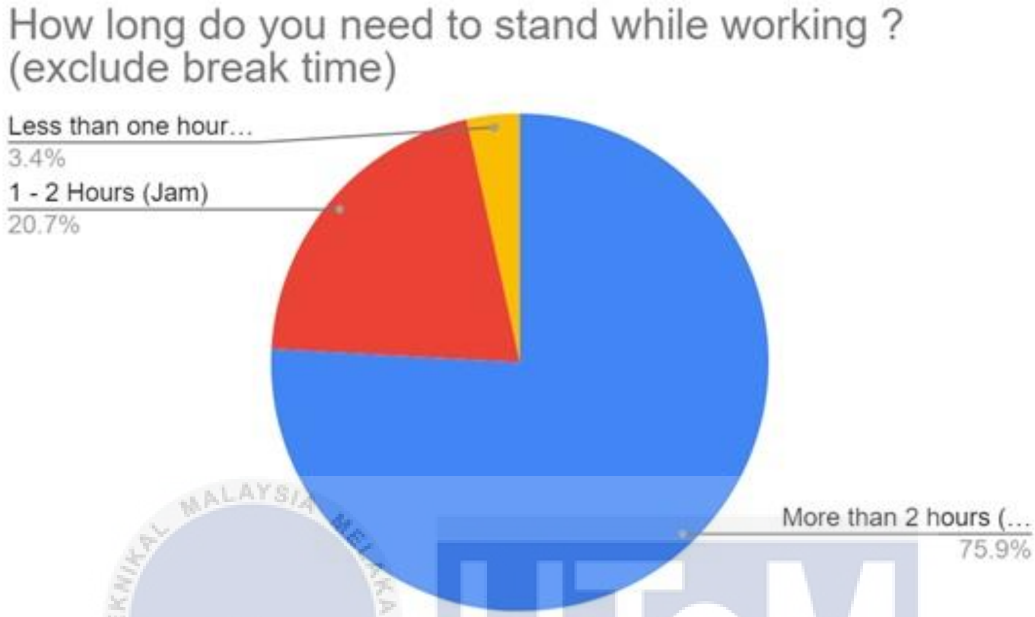


Figure 4.4: Respondent working hour needed to withstand for prolonged standing.

The second section of the survey is section B where the question is about the respondent problem analysis. The purpose of this section is to examine problems encountered and to assess the best position while working in prolonged standing. This section is a multiple answer / scaling question where 0 is not tired, 1 slightly tired, 2 moderately tired, 3 very tired and 4 too tired. Referred to the figure 4.5, 48.3 percent voted too tired at their back side followed by 20.7 percent very tired, 20.7 percent moderately tired, 6.9 percent slightly tired, and 3.4 percent not tired. Also, 55.2 percent voted very tired at their calves' side followed by 24.2 percent too tired, 17.2 percent moderately tired, and 3.4 percent slightly tired. Then, 48.3 percent voted very tired at their knee side followed by 24.2 percent too tired, 20.7 percent moderately tired, and 3.4 percent slightly tired and not tired. Next, 37.9 percent voted too tired at their front foot side followed by 34.5 percent very tired, 20.7 percent moderately tired, and 6.9 percent slightly tired. Lastly, 34.5 percent voted too tired at their heel side followed by 34.5 percent very tired, 20.7 percent moderately tired, and 10.3 percent slightly tired. This shows that they all have been expose to the musculoskeletal disorders and exhausted due to prolonged standing while working.

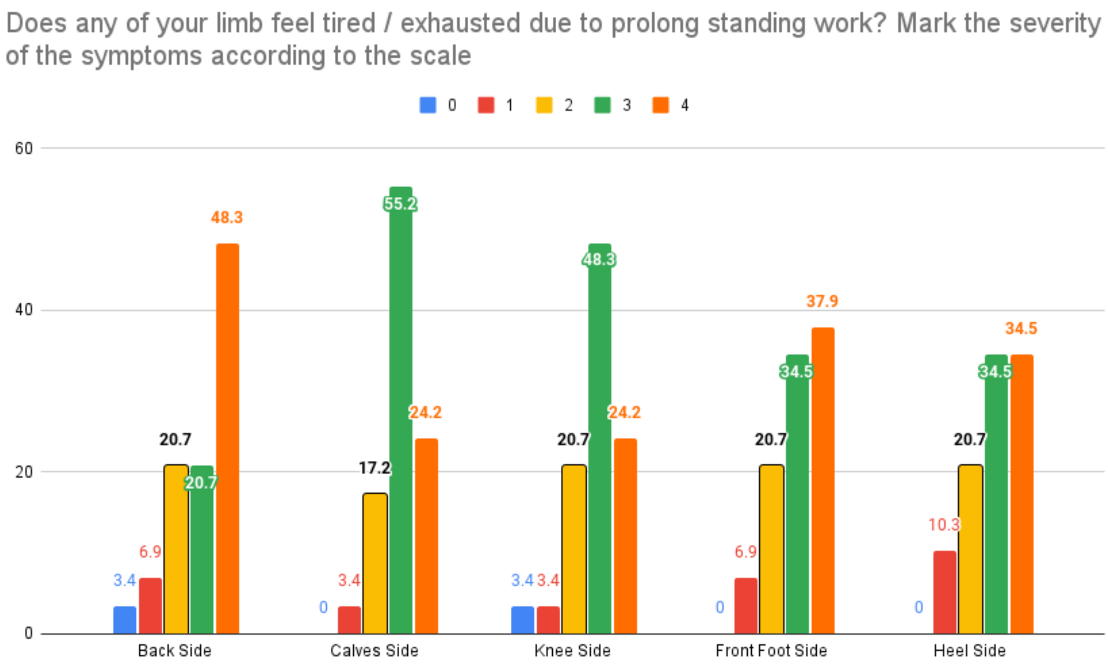


Figure 4.5: The percentage of the respondents felt tired in different body parts due to prolonged standing.

The third section of the survey is section C where the question is about the design requirement. The purpose of this section is to get the design requirement that is needed by the respondent where the improvement will help them reduce the muscle fatigue due to prolonged standing. This section is a multiple answer / scaling question where 1 is strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 strongly agree. Referred to the Figure 4.6, 48.3 percent are strongly agreed with the application of stability to passive sit stand exoskeleton design while 3.4 percent of them disagree. Based on the percentages, most respondents agreed that stability is required to create passive sitting and standing exoskeletons. The device needed to be stable so that the user would not fall easily.

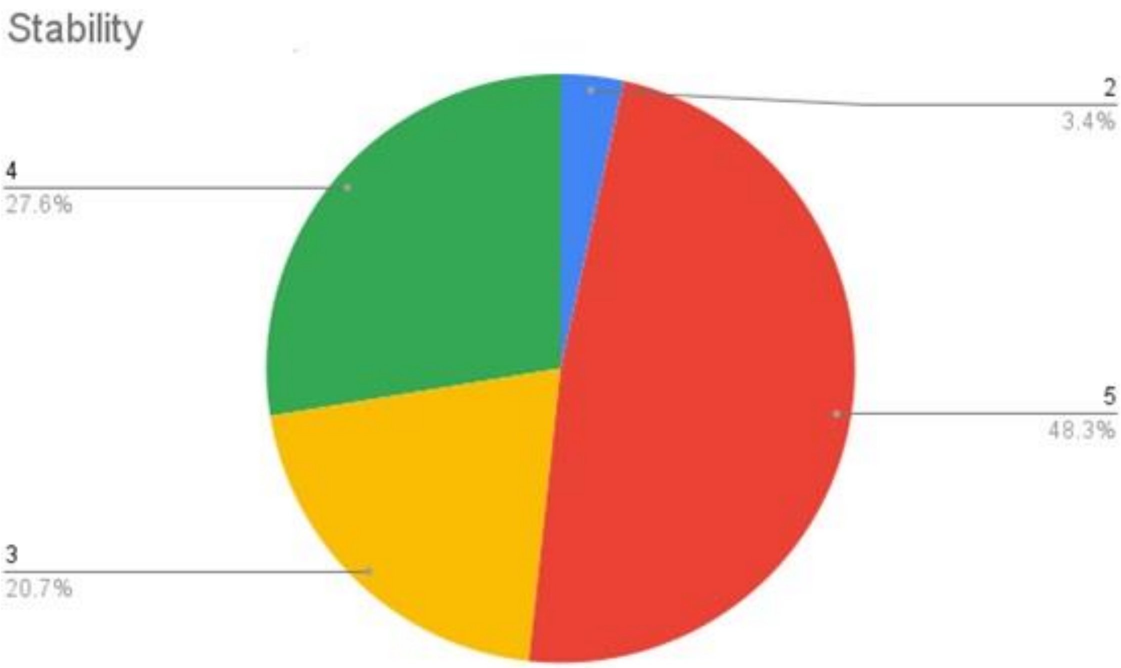


Figure 4.6: Stability

Figure 4.7 shows the design requirement for safety. 51.7 percent are strongly agreed with the application of safety to passive sit stand exoskeleton design while 10.3 percent of them were neutral but none of them disagree. Based on the percentages, most respondents agreed that safety is required to create passive sitting and standing exoskeletons. The device needed to be safe so that the device itself would not harm the user.

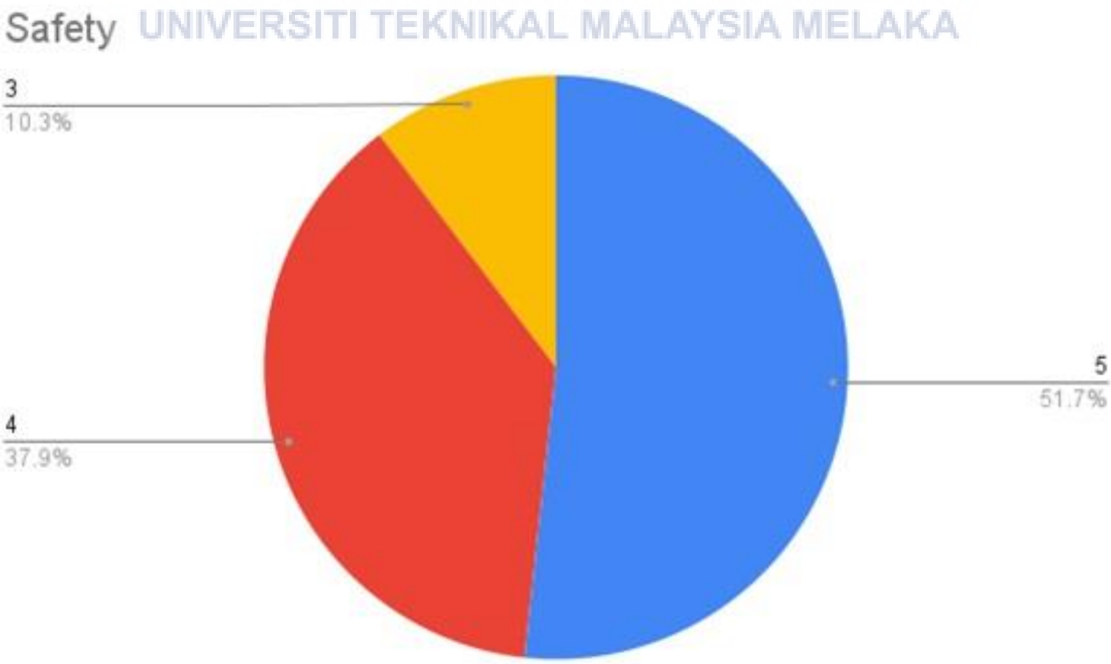


Figure 4.7: Safety

Figure 4.8 shows the design requirement for movement flexibility. 41.4 percent are agreed with the application of movement flexibility to passive sit stand exoskeleton design while 3.4 percent of them strongly disagree. Based on the percentages, most respondents agreed that movement flexibility is required to create passive sitting and standing exoskeletons. The device needed to be flexible so that the user movement would not be so strict therefore they can work easily while also wearing the device.

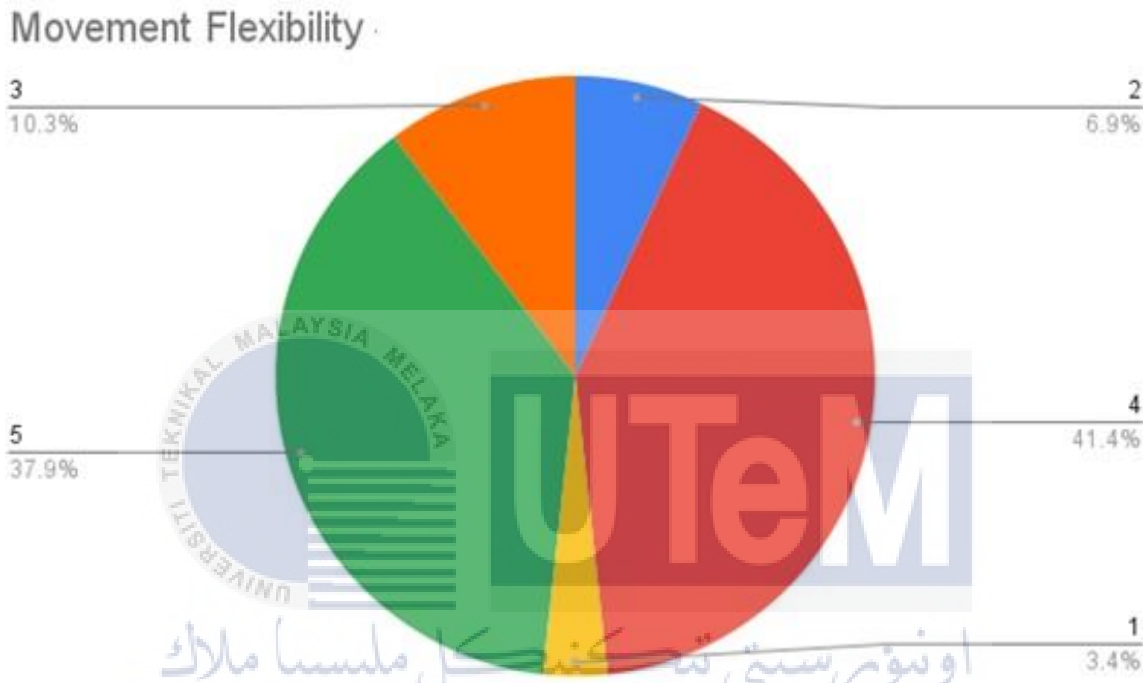


Figure 4.8: Movement Flexibility

Figure 4.9 shows the design requirement for ease of use. 62.1 percent are agreed with the application of ease of use to passive sit stand exoskeleton design while 6.9 percent of them strongly disagree. Based on the percentages, most respondents agreed that ease of use is required to create passive sitting and standing exoskeletons. The usability when wearing passive sit and exoskeleton stand tool is important. The passive sit and exoskeleton stand tool must have high usability to ease access and use.

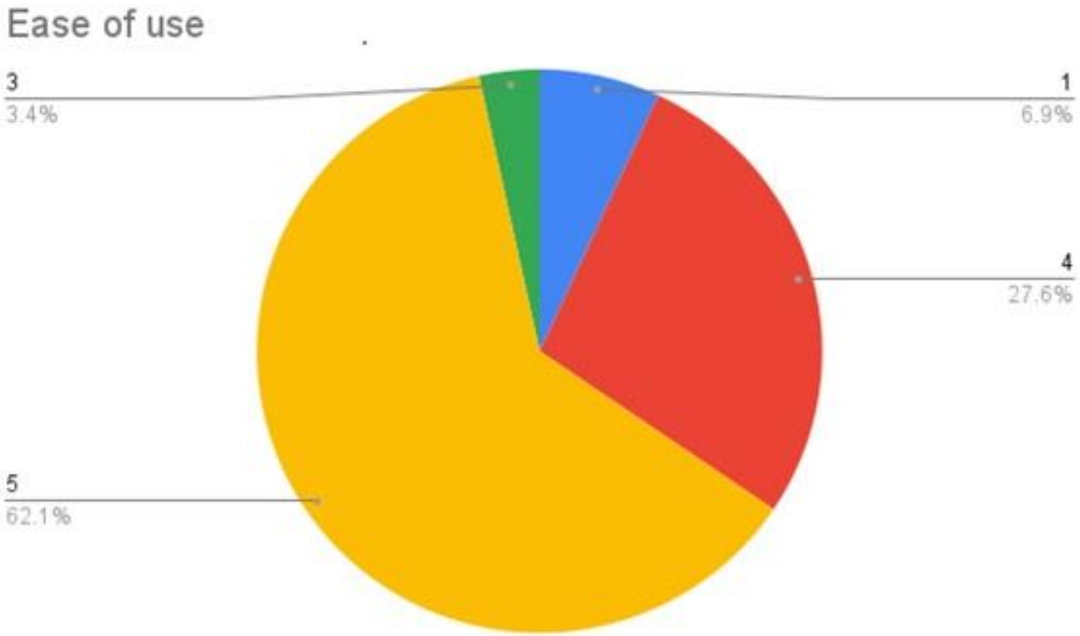


Figure 4.9: Ease of use

Figure 4.10 shows the design requirement for lightweight. 55.2 percent are strongly agreed with the application of lightweight to passive sit stand exoskeleton design while 6.9 percent of them disagree. Based on the percentages, most respondents agreed that lightweight is required to create passive sitting and standing exoskeletons. The device needed to be lightweight so that the user would not feel the extra load that have been added to them.

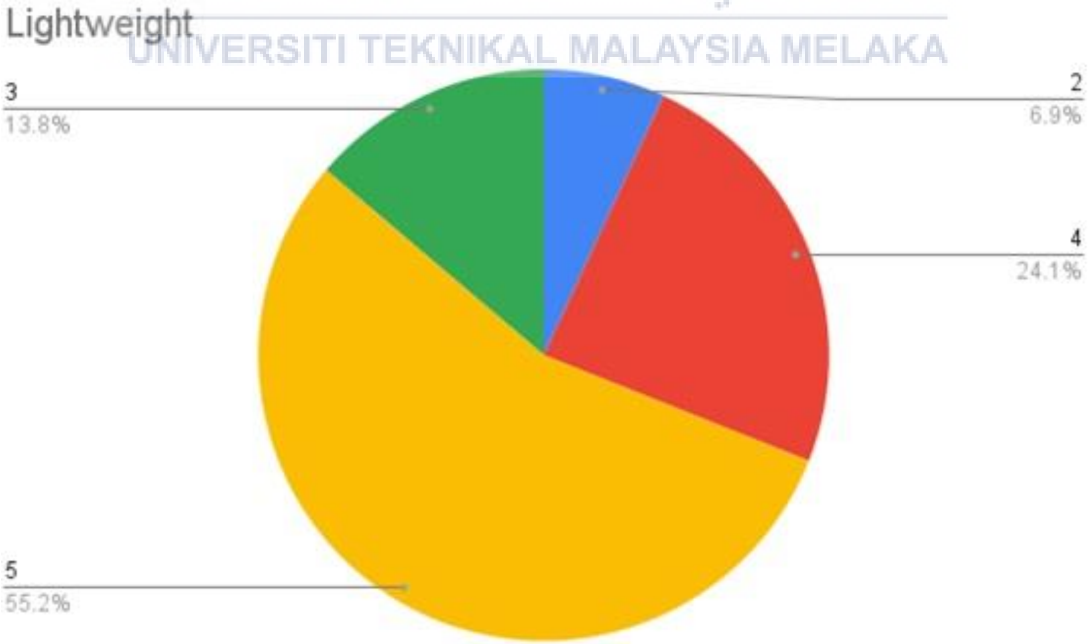


Figure 4.10: Lightweight

Figure 4.11 shows the design requirement for adjustable. 55.2 percent are strongly agreed with the application of adjustable feature to passive sit stand exoskeleton design while 6.9 percent of them disagree. Based on the percentages, most respondents agreed that adjustable feature is required to create passive sitting and standing exoskeletons. The adjustable feature is needed so that the user would not have to bend their body just to adjust their height also it could reduce the movement of the workers.

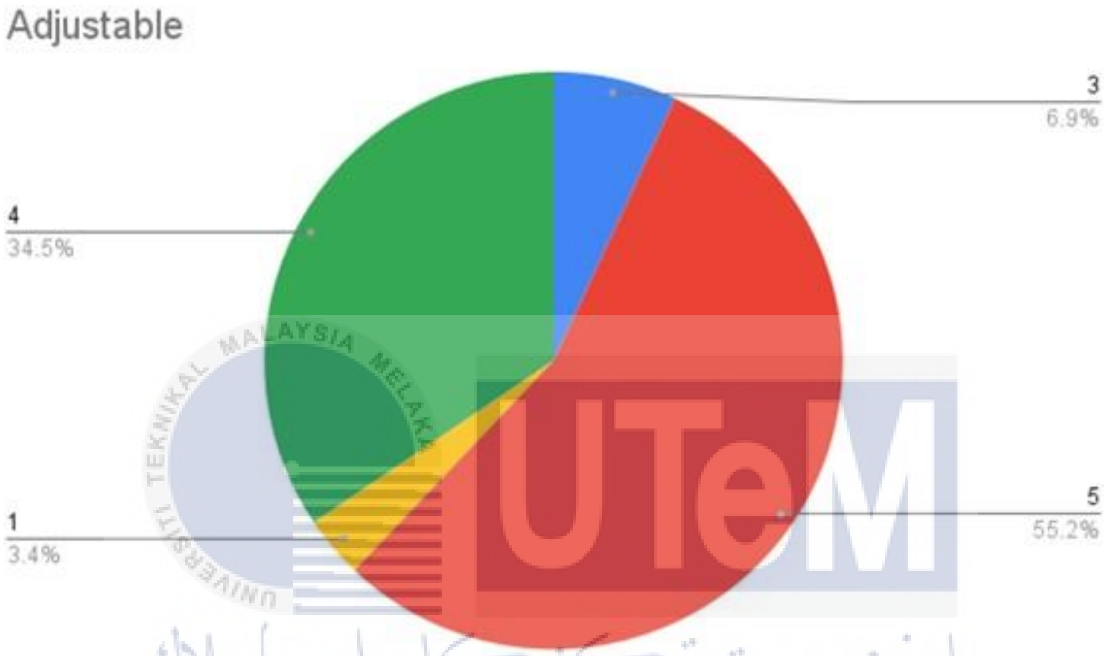


Figure 4.11: Adjustable

Figure 4.12 shows the design requirement for portable. 51.7 percent are agreed with the application of portable to passive sit stand exoskeleton design while 3.4 percent of them strongly disagree. Based on the percentages, most respondents agreed that portable feature is required to create passive sitting and standing exoskeletons. The device needed to be portable so that the user could easily carry the device anywhere.

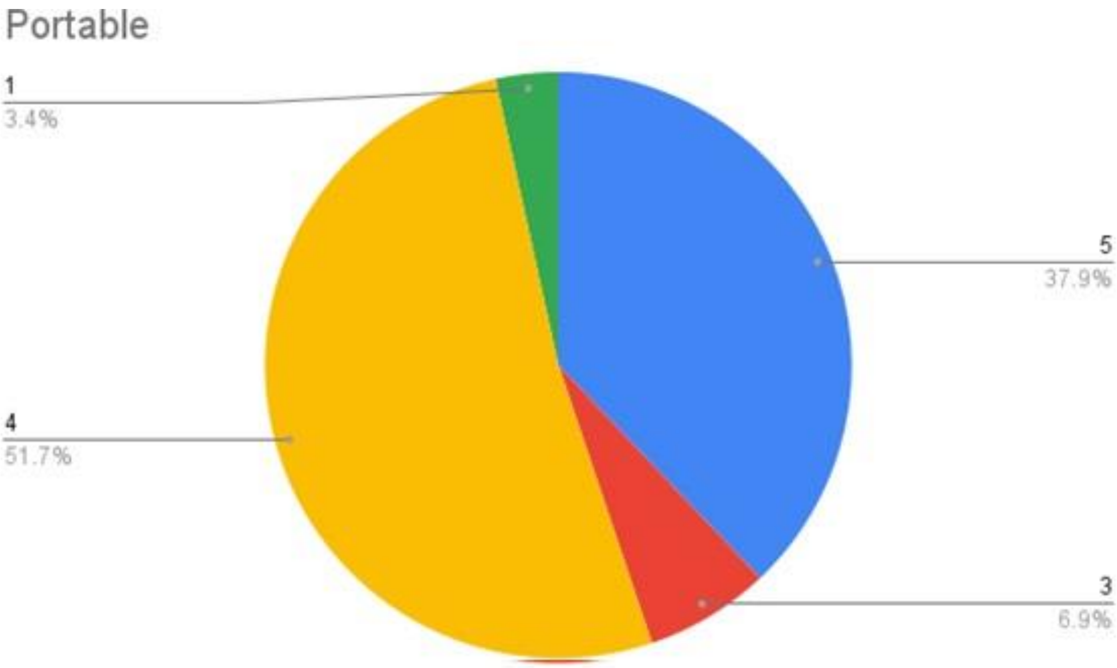


Figure 4.12: Portable

Figure 4.13 shows the design requirement for comfort. 51.7 percent are strongly agreed with the application of comfort to passive sit stand exoskeleton design while 6.9 percent of them strongly disagree. Based on the percentages, most respondents agreed that comfort is required to create passive sitting and standing exoskeletons. The device needed to be comfortable so that it would comfort the user and reduce the muscle fatigue.

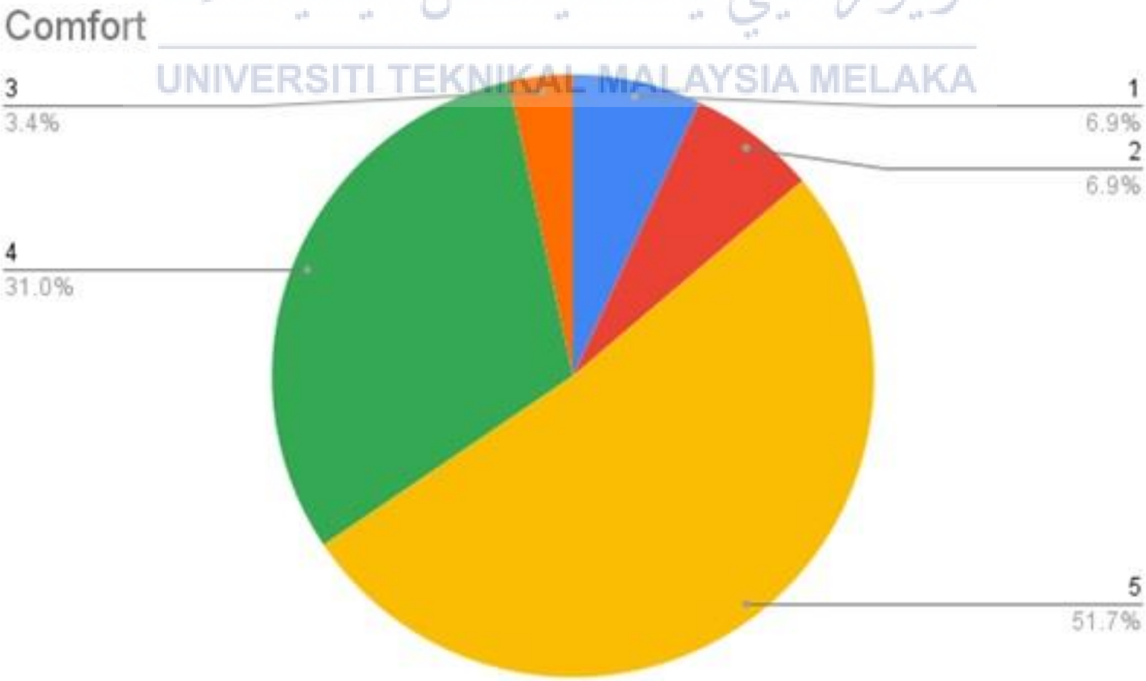


Figure 4.13: Comfort

Figure 4.14 shows the design requirement for low cost. 48.3 percent are strongly agreed with the application of low cost to passive sit stand exoskeleton design while 3.4 percent of them strongly disagree. Based on the percentages, most respondents agreed that low cost is required to create passive sitting and standing exoskeletons. The device needed to be low cost so that any user could buy the device without worrying the price.

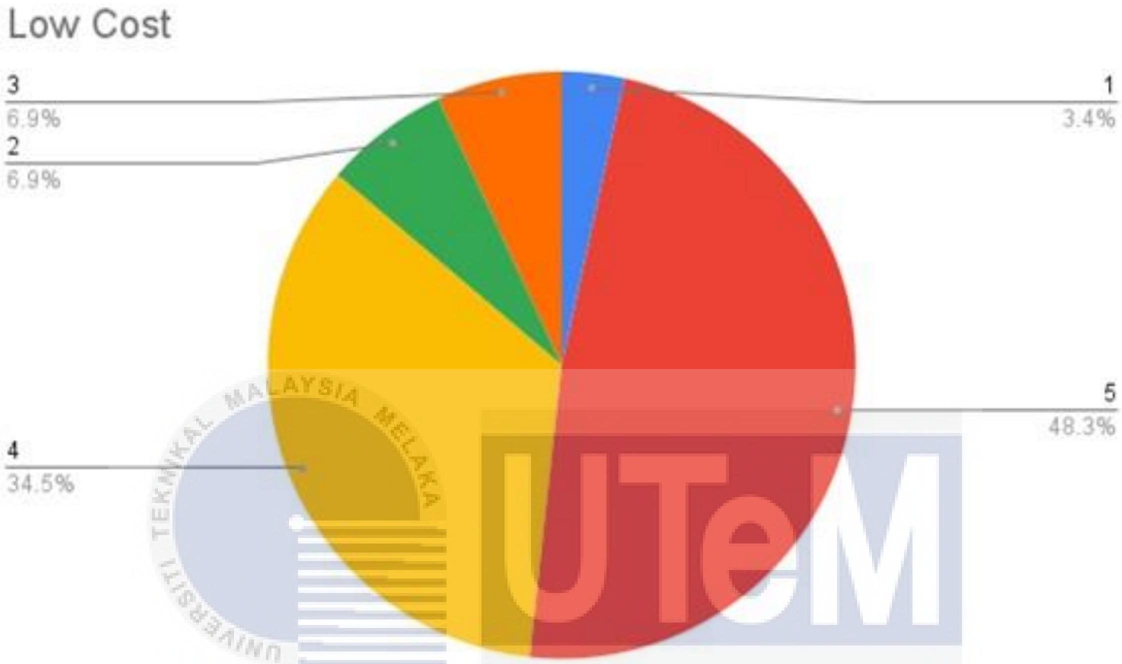


Figure 4.14: Low cost

Figure 4.15 shows the design requirement for appearance or aesthetic. 44.8 percent are strongly agreed with the application of appearance or aesthetic to passive sit stand exoskeleton design while 3.4 percent of them strongly disagree. Based on the percentages, *most respondents agreed that appearance or aesthetic is required to create passive sitting and standing exoskeletons. It can be determined that the characteristic of good appearance is not as important for designing and fabricating passive sit stand exoskeleton tool.

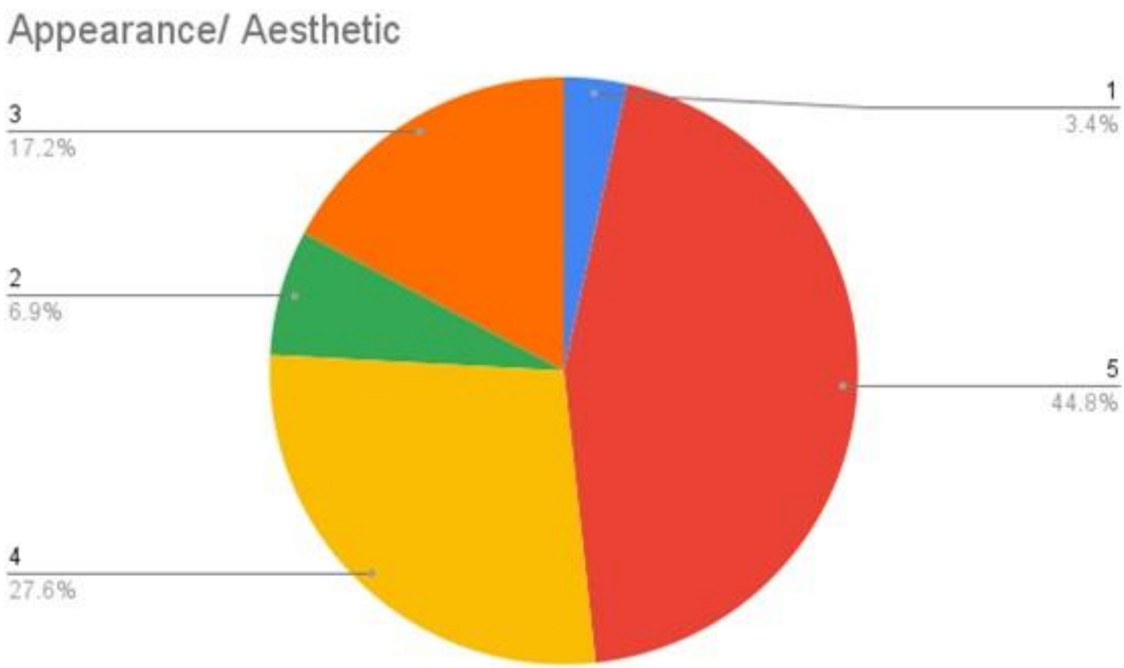


Figure 4.15: Appearance or aesthetic

4.1.2 Quality Function Deployment (QFD)

Table 4.1 presents the symbol and value of the link between functional requirements and customer requirements. A strong relationship is represented by the symbol '●' and is valued at the highest level of 10, while a moderate relationship is represented by the symbol '○' and is valued at 5. The weak link between functional requirement and customer requirement has been represented as '▽' and is value at the lowest level of 1.

Table 4.1: Relationship

Scale	Symbol	Relationship
10	●	Strong
5	○	Moderate
1	▽	Weak

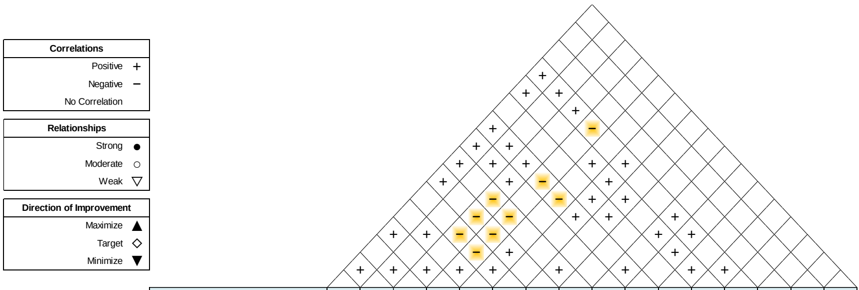
Table 4.2 shows the symbol for the correlation between functional needs. A positive correlation between functional needs was represented by the symbol "+", while the negative correlation was represented by the symbol "-". There was no connection when no symbol was used.

Table 4.2: Correlation

Scale	Symbol	Correlation
+3	+	Positive
-3	-	Negative

Figure 4.16 represents the House of Quality, one of the tools used in this study to determine the Quality Function Deployment. The user needs section has been defined using the questionnaire specification, and the user importance of the questionnaire responses. Functional requirements are defined based on the technical requirements for passive sit and exoskeleton stand. The evaluation compared specifications based on user requirements and was rated from 1 (very poor) to 5 (excellent). The specifications for passive sit-stand exoskeletons that require serious attention, it can be determined by using a cross-reference method between functional requirements and user requirements.

Ergonomic design has the highest percentage of importance at 11.8 percent, while the lowest percentage is 3 percent for high loads. According to the evaluation section, the first seven specifications are used to determine the optimal design in the next section. This case adopts ergonomic design, foldable, easy to carry, simple in mechanism, small in overall volume, and small in restrictions on movement.



Raw #	Weight	Customer Requirements (Explicit and Implicit) / Engineering Requirements	1 Material	2 Low overal weight	3 Low overal saiz	4 Low cost	5 Simple Mechanism	6 Easy to Assemble	7 Stable and Safe	8 Able to Withstand High Load	9 Low Restriction of Movement	10 Foldable	11 Ease of Maintanance	12 Ergonomic Design	13 Easy to Carry	14	15	16	Passive Exoskeleton Stand	Lex	Noonee	Archelis	Others	Row #
		Direction of Improvement		▲		▲								▲	▲									
1	4	Portable	○	●	●	▽	○		▽		○	●	▽	●	●				5	5	4	1	5	1
2	5	Comfortability	●	●	○		●	○	●	▽	○	●	○	●	●				5	4	5	4	3	2
3	4	Low Cost	●		○	●	●		▽	○	▽	▽	●	○					5	2	1	1	3	3
4	5	Stable	▽	○	○	▽			●	○		▽		○					3	4	4	4	2	4
5	4	Adjustable			●		●	○	○	▽	●	●	●	●	●				3	2	4	2	1	5
6	5	Light Weight	●	●	●	●	○			●	●	○		●	●				4	5	5	3	5	6
7	5	High Flexability in Movement	●	●	●	○	○		○		●	●	▽	●	●				2	5	4	1	3	7
8	2	Good Appearance	●				○					●		○					3	4	5	5	1	8
9	4	User Friendly	○	○	○	○	●	●	●		●	●	●	●	●				3	5	4	2	5	9
10	3	Ease of Use	▽	▽	●	○	●	●	●		●	●	●	●	●				3	3	4	3	4	10
11	1	Long LifeSpan	●					○	○	●	●			●	▽				2	3	4	4	1	11
																								12
																								13
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																								15
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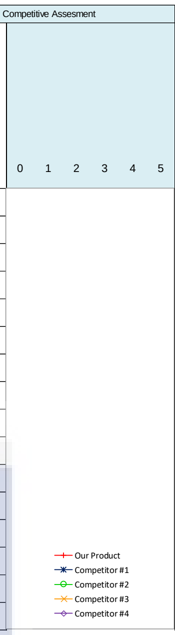


Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Technical Importance Rating	268	238	273	159	280	120	228	94	269	304	184	365	301			
Percentage of Importance	8.7	7.7	8.8	5.2	9.1	3.9	7.4	3	8.7	9.9	6	11.8	9.8			
Rating	7		5		4				6	2		1	3			

Figure 4.16: House of Quality for sit-stand Exoskeleton

4.1.3 Conceptual Design

Four conceptual designs from eight specifications from the previous study were presented in Table 4.3.

Table 4.3: Concep0tual Design

Concept	Design	Description
1		This concept shows the use of a tripod as a base for legs/support while sitting. Height is adjusted using spring balance mechanism. The seat is comfortable due to the use of bicycle saddle parts.
2		The concept shows that the base uses a wide base and rolled tyre as legs/support when sitting. Height is adjusted using spring balance mechanism. The seat is comfortable due to the use of bicycle saddle parts.

3		The concept shows that the base uses two beam bars with a form of V as legs/support when sitting. Height is adjusted using spring balance mechanism. The seat is comfortable due to the use of bicycle saddle parts.
4		The concept showed that the base uses a wide flat plate as a leg/support when sitting. Height is adjusted using spring balance mechanism. The seat is comfortable due to the use of a bicycle saddle.

4.1.4 Pugh Concept Selection

A Pugh concept selection was conducted to choose the best concept design. The method involves concept screening and concept scoring. Concept filter symbols appear in Table 4.4, and concept filter symbols appear in Table 4.5. The Noonee brand was chosen as a reference because it topped the House of Quality competition score of 42. The Selection Criteria section of the Concept Screener includes the first seven specifications selected from the previous section.

Table 4.4: Notation

Notation	
Better	+
Worse than	-
Same as	0

Table 4.5: Concept Screening

Selection Criteria	Concept 1	Concept 2	Concept 3	Concept 4
Easy to carry	0	-	0	0
Stable	-	+	-	+
Portable	+	-	+	+
Extendable	-	0	0	0
Material	0	0	0	0
Sum of '+'	1	1	1	2
Sum of '-'	2	2	1	0
Sum of 0	2	2	3	3
Net score	1	1	1	2
Rank	4	3	2	1
Continue	No	No	Yes	Yes

Concept 4 had the highest net score of 2, followed by Concepts 1, 2, and 3, each with 1. Concept 4 ranked last in the concept scoring process and did not meet the study criteria.

4.1.5 Concept Scoring

From concept screening to concept evaluation in Table 4.5, concepts 2, 3, and 4 were advanced to determine the best concept. According to the importance of the research criteria, the weight percentage of the criteria was defined.

Table 4.6: Concept scoring

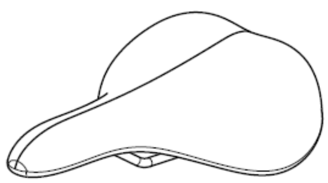
Selection criteria	Weight	Concept 2		Concept 3		Concept 4	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Easy to carry	10	1	0.1	2	0.2	4	0.4
Stable	20	3	0.6	3	0.6	5	1.0
Portable	20	2	0.4	4	0.8	4	0.8
Extendable	10	2	0.2	3	0.6	5	0.5
Material	10	2	0.2	2	0.2	2	0.2
Total		1.5		2.4		2.9	
Rank		3		2		1	
Continue		No		No		Yes	

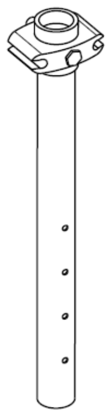
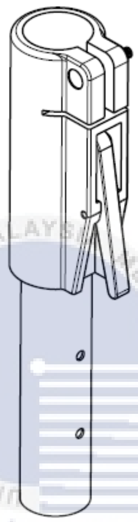
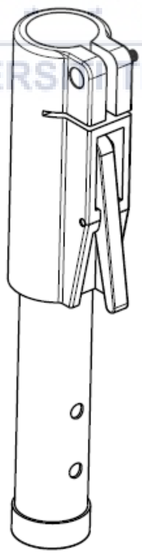
According to Table 4.6, Concept 4 has the highest overall weighted score of 2.9, followed by Concept 3 with a weight of 2.4. The lowest weighted score is Concept 2, which is only 1.5. Furthermore, Concept 4 was selected as the best concept for this study because the design satisfies with the criteria and specifications after performing the Pugh concept selection.

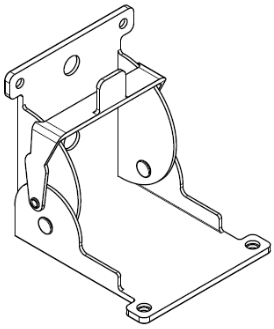
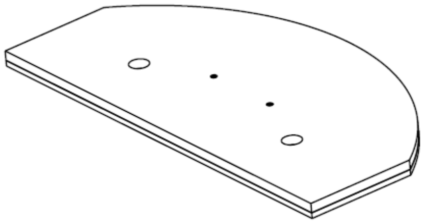
4.1.6 Detail Design

Based on shown in Table 4.8, the detail design of Concept 4.

Table 4.7: Detail Design of concept 4

No	Components	Quantity	Description
1		2	**Saddle** This product provides a lower hip seating area of a comfortable seat consisting of a sponge surface.

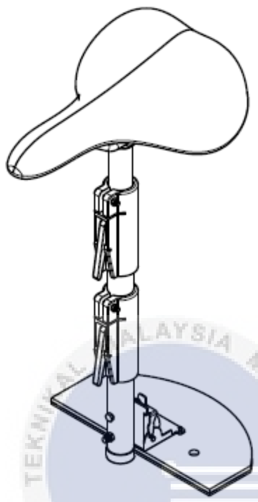
2		1	**Saddle Rod** Hold the saddle and the rod together.
3		1	**Middle Rod** Hold the top saddle rod and the bottom base rod. The assembly slides in and out of the outer hollow rod legs/posts, increasing or decreasing the length of the post for increased user comfort
4		1	**Base Rod** Hold the middle rod and the base plate. The assembly slides in and out of the outer hollow rod legs/posts, increasing or decreasing the length of the post for increased user comfort

5		1	**Foldable Bracket** Hold the bottom rod and the base plate.
6		1	**Base Plate** It provides balance so the user would not fall easily.
7		1	**Spring** Will be place in the rod so that the height of the device can be adjusted.

4.1.7 Design of 3D with Bill of Material (BOM)

Figure 4.17 and Table 4.8 show the 3D drawings of the passive sit-stand exoskeleton and the bill of materials (BOM), while the desktop display is shown on the 3D drawings with bill of materials (BOM).

Assembly



Bill of Material: Adjustable Saddle Seat

Part Number	Components	Quantity
1	Saddle	1
2	Saddle Rod	1
3	Upper Pole	1
4	Lower Pole	1
5	Base	1
6	Hinge	1
7	M6 Screw and Nut	2
8	M4 Bolt Screw	2

Figure 4.17: 3 Dimension assembly drawing and bill of material

Table 4.8: Bill of material

Part Number	Components	Quantity
1	Saddle	1
2	Saddle Rod	1
3	Upper Pole	1
4	Lower Pole	1
5	Base	1
6	Hinge	1
7	M6 screw and Nut	2
8	M4 Bolt Screw	2
9	Spring (inside)	1

4.1.8 Design of Assembly View

Figure 4.18 and Table 4.9 shows the assembly view of the 3D design of the passive sit and stand exoskeleton.

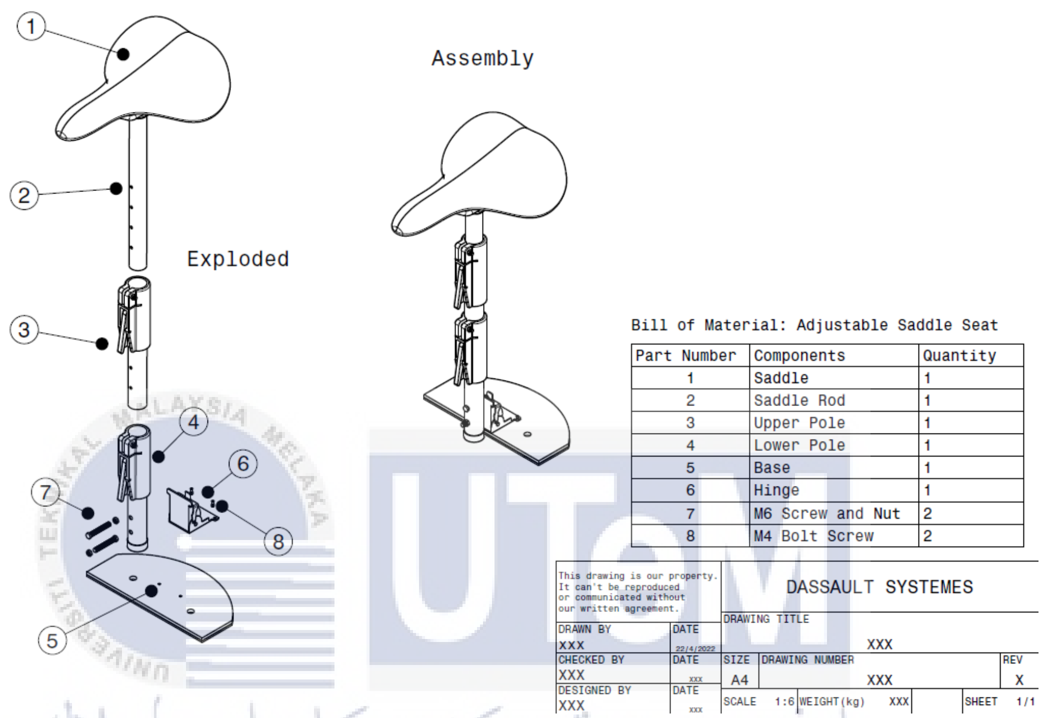


Figure 4.18: Assembly view

Table 4.9: Description of assembly view

Number	Part Name
1	Saddle
2	Saddle Rod
3	Upper Pole
4	Lower Pole
5	Base
6	Hinge
7	M6 screw and Nut
8	M4 Bolt Screw
9	Spring (inside)

4.2 Evaluate the Effects of the Fabricated Sit-Stand Exoskeleton on Muscle Activity and Contact Pressure

This study provides the test results and discussion for design passive sit-stand exoskeleton, which include the compression test result and 10 result from the test subject. This section serves to achieve the second objective.

4.2.1 Mechanical Compression Test

After finishing fabricating the product, the durability of the product needed to be tested so that it could withstand the weight of the user. Figure 4.19 shows the result of the mechanical compression test that have been tested on the design sit-stand exoskeleton. It shows that as the force increase in time, the product slowly break after it reaches at force 10.7 kN. Figure 4.20 shows the product failed at the lower end of the stand after the force of the compression test reaches 10.7 kN.

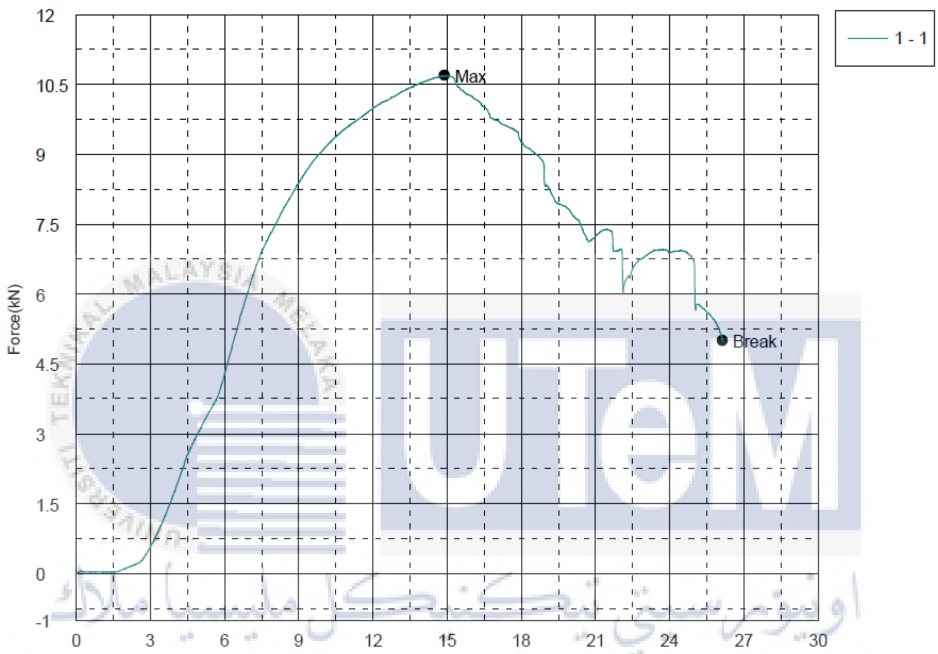


Figure 4.19: Mechanical compression test result

Figure 4.20: Structure effect from mechanical compression test – structure failed at the lower end of the stand

4.2.2 Experimental Results

In this section an experiment were conducted to test whether the design sit-stand exoskeleton have been improves with the new added features. 10 male test subjects with age between 20 to 30 years old were tested. The result obtain is being analysed between 2 phase, phase 1 is between the muscle contraction without exoskeleton versus muscle contraction with exoskeleton (design product), and phase 2 is between muscle contraction with exoskeleton (design product) versus muscle contraction with exoskeleton (commercial product). The important value is the percentage of the muscle activity. To get the percentage of the muscle activity the equation are as follows:

$$\frac{\text{maximum muscle activity}}{\text{maximum voluntary contraction}} \text{ X } 100\% \text{ ….. eqn. (1)}$$

After finish obtaining and calculating the percentage of muscle activity for 2 phase, the data is then compared between phase 1 and phase 2. Table 4.10 until Table 4.13 show all the data that have been collected for the whole experiment.

In experiment 1 where we tested the muscle fatigue between muscle contraction without exoskeleton and muscle contraction with exoskeleton, the data obatined were analysed. The summerized data in Figure 4.21 shows that subject 1 experience the highest muscle contraction in the right vastus lateralis (RVL), followed by right tibialis anterior (RTA), right gastrocnemius (RGA), left tibialis anterior (LTA), left gastrocnemius (LGA) and lastly left vastus lateralis (LVL). However, after wearing the exoskeleton, subject 1 experienced the highest muscle contraction in the LTA and came with RGA, LVA, LGA, RVL and RTA. This shows that the subject experienced the most reduction of muscle fatigue in RVL, followed by RTA, RGA, LTA, LGA, and LVL.

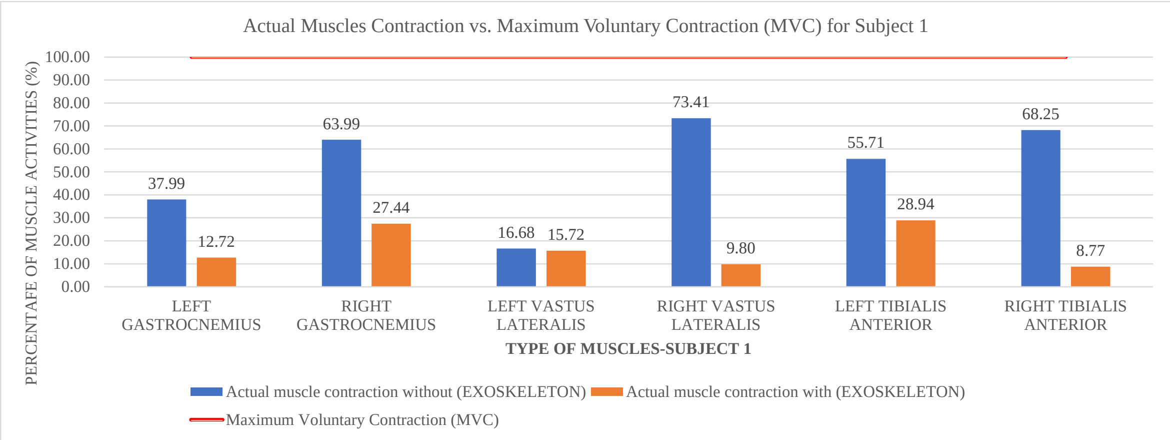


Figure 4.21: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 1

According to Figure 4.22, subject 2 experienced the highest muscle contraction in the RVL and followed by LTA, RTA, LVL, RGA and lastly LGA. After wearing exoskeleton, subject 2 experienced the highest muscle contraction in the LTA and came with RGA, LVA, RVL, RTA, and LGA. Besides, it shows that the subject experienced the most reduction of muscle fatigue in RTA, followed by RVL, LVL, LTA, RGA, RGA and lastly, LGA.

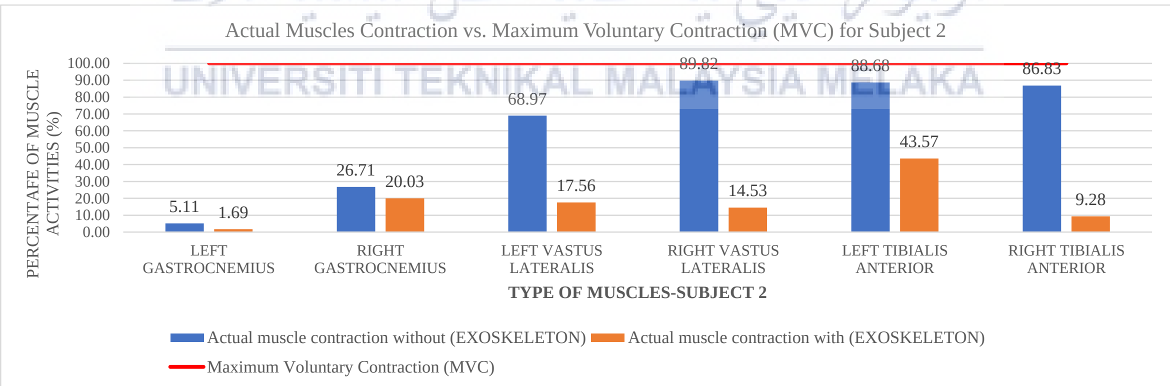


Figure 4.22: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 2

Figure 4.23 shows that subject 3 experienced the highest muscle contraction from LGA to RTA and followed by RGA, RVL, LVL and LTA. After waering exoskeleton, subject 3 experienced the highest muscle contraction in the RTA and came with LTA, RVL, LGA, LVL, and RGA. The subject experienced the most reduction of muscle fatigue in LGA, followed by RTA, RGA, RVL, LVL and lastly, LTA.

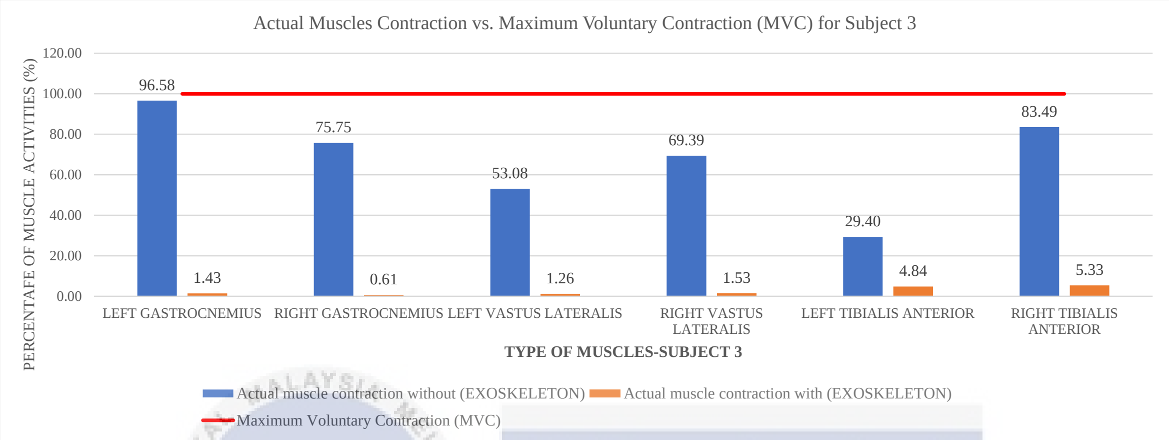


Figure 4.23: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 3

Figure 4.24 shows that subject 4 experienced the highest muscle contraction from LTA and followed by RGA, LGA, and RTA. After waering exoskeleton, subject 4 experienced the highest muscle contraction in the RVL and came with LTA, RGA, LGA, LVL, and RTA. The subject experienced the slightest reduction of muscle fatigue in LTA, followed by RTA, and RGA.

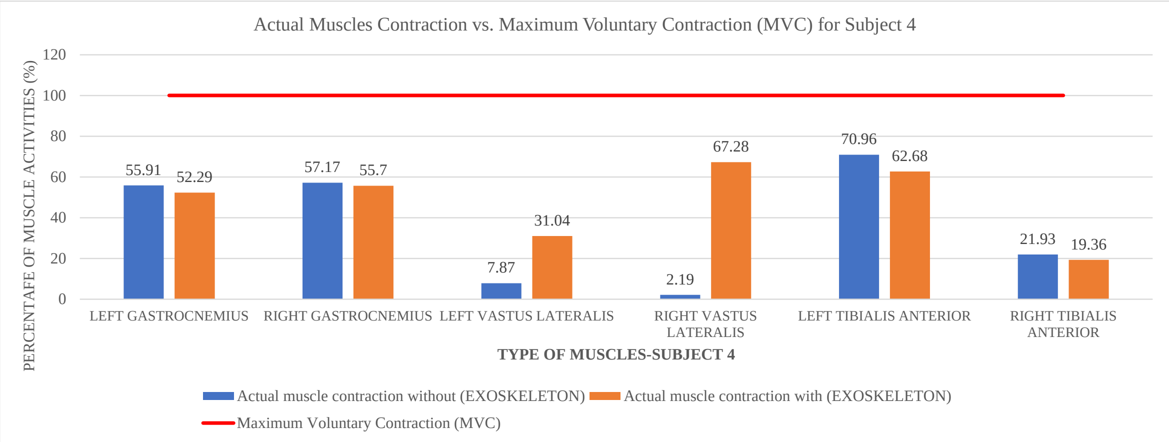


Figure 4.24: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 4

Figure 4.25 shows that subject 5 experienced the highest muscle contraction from LTA followed by LGA, RTA, RGA, RVL and LVL. After waering exoskeleton, subject 5 experienced the highest muscle contraction in the LTA and came with LGA, RTA, RGA, RVL, and LVL. The subject experienced the most reduction of muscle fatigue in LGA, followed by RTA, LTA, and RGA.

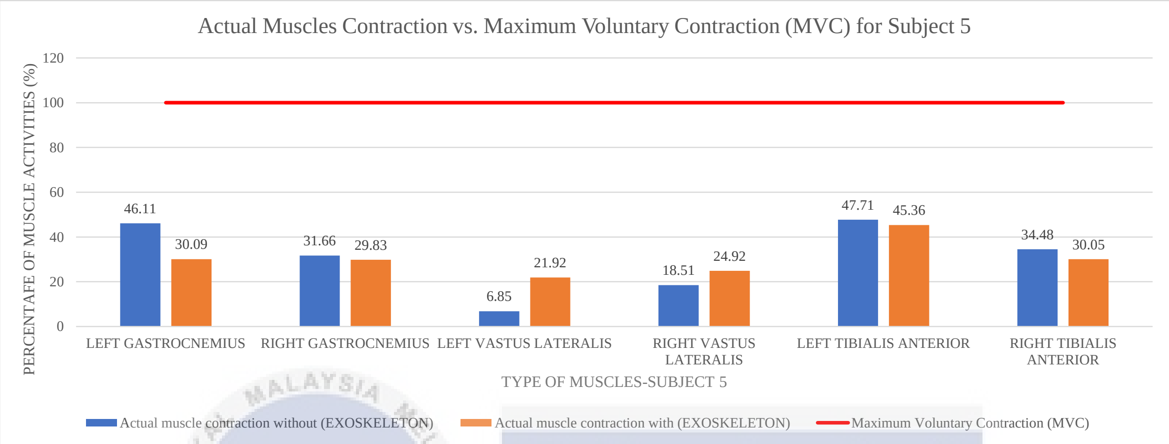


Figure 4.25: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 5

Figure 4.26 shows that subject 6 experienced the highest muscle contraction from LGA followed by RGA, LTA, LVL, RTA and RVL. After waering exoskeleton, subject 6 experienced the highest muscle contraction in the LGA and came with RGA, RVL, LVL, LTA, and RTA. The subject experienced the slightest reduction of muscle fatigue in LGA, followed by RGA, LTA, and RTA.

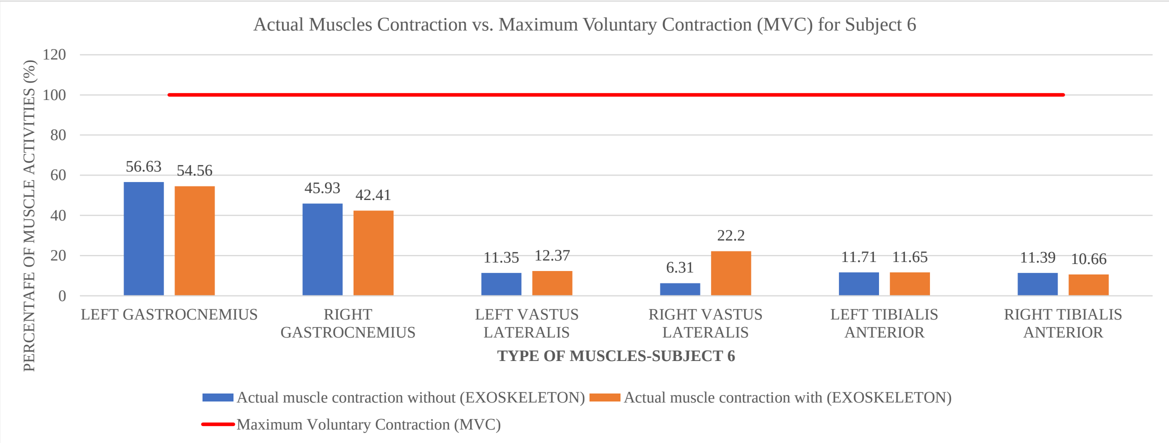


Figure 4.26: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 6

Figure 4.27 shows that subject 7 experienced the highest muscle contraction from RGA followed by LGA, RVL, LTA, RTA and LVL. After waering exoskeleton, subject 7 experienced the highest muscle contraction in the RTA and came with LVL, LTA, RGA, RVL, and LGA. The subject experienced the slightest reduction of muscle fatigue in LGA, and RGA, but increase muscle fatigue in LVL, RVL, LTA and RTA.

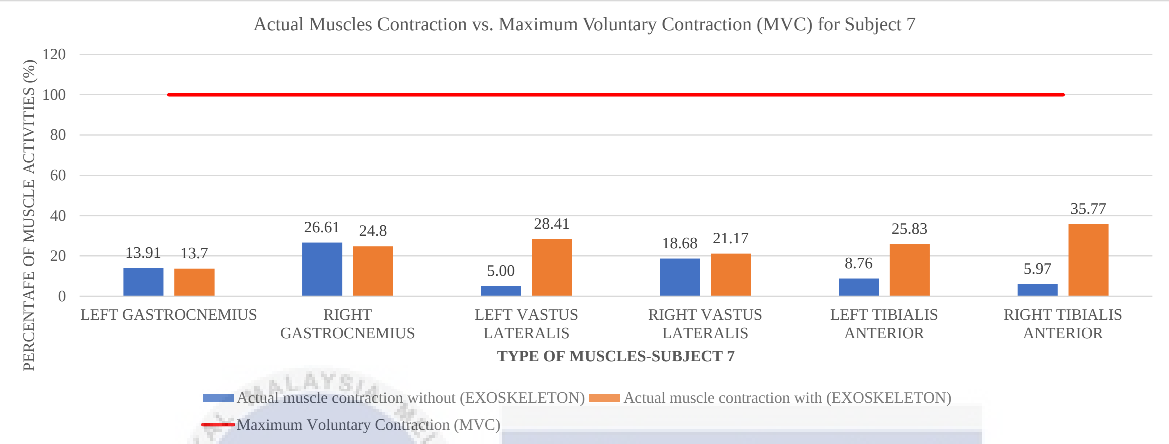


Figure 4.27: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 7

Figure 4.28 shows that subject 8 experienced the highest muscle contraction from RVL followed by LVL, RTA, RGA, LGA, and LTA. After waering exoskeleton, subject 8 experienced the highest muscle contraction in the RVL and came with LVL, RTA, RGA, LGA, and LTA. The subject experienced the increase of muscle fatigue in RVL followed by LVL, RTA, RGA, LGA, and LTA.

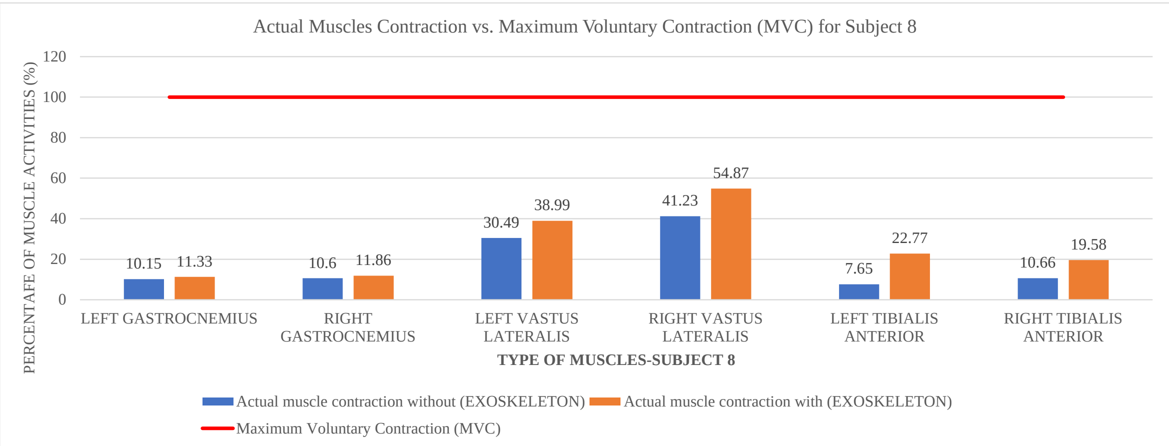


Figure 4.28: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 8

Figure 4.29 shows that subject 9 experienced the highest muscle contraction from LGA followed by LVL, RGA, RTA, LTA, and RVL. After waering exoskeleton, subject 9 experienced the highest muscle contraction in the LVL and came with RGA, RTA, LGA, RVL, and LTA. The subject experienced the most reduction of muscle fatigue in LTA, followed by LGA, RVL, RGA, and LVL.

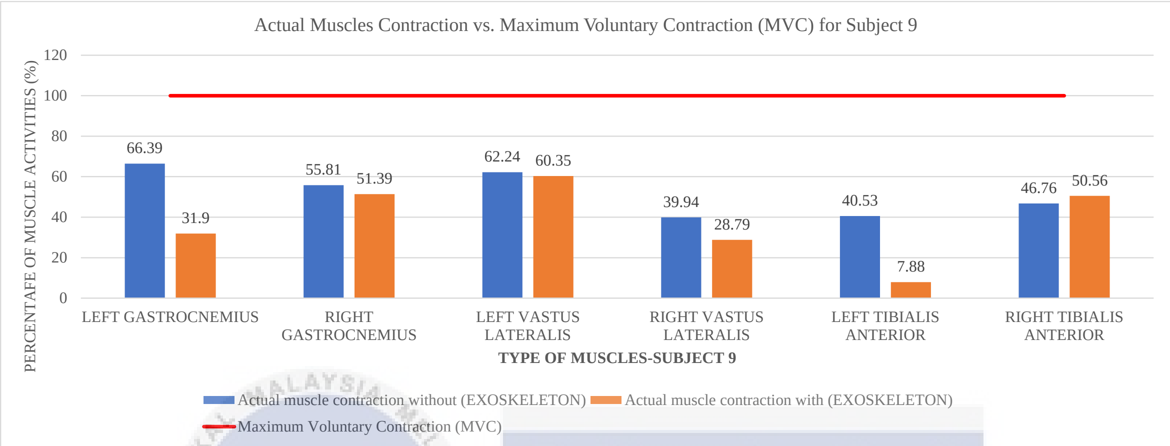


Figure 4.29: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 9

Figure 4.30 shows that subject 10 experienced the highest muscle contraction from RTA followed by LGA, RGA, LVL, LTA, and RVL. After waering exoskeleton, subject 10 experienced the highest muscle contraction in the LGA and came with RGA, LTA, LVL, RTA, and RVL. The subject experienced the most reduction of muscle fatigue in LGA, followed by RGA, LVL, RVL, LTA and RTA.

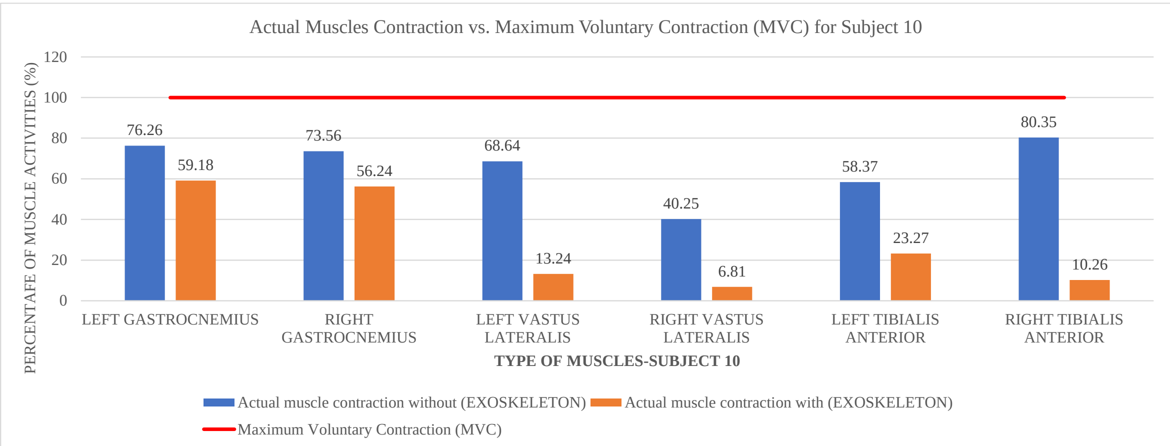


Figure 4.30: Actual muscles contraction without exoskeleton vs with exoskeleton for Subject 10

In experiment 2 where we tested the muscle fatigue between muscle contraction with commercial exoskeleton and muscle contraction with design exoskeleton, the data obatined were analysed. The summerized data in Figure 4.31 shows that subject 1 experience the highest muscle contraction in left vastus lateralis (LVL), right vastus lateralis (RVL), right tibialis anterior (RTA), left tibialis anterior (LTA), left gastrocnemius (LGA), and lastly right gastrocnemius (RGA). After waering desgin exoskeleton, subject 1 experienced the highest muscle contraction in the LTA and came with RTA, RGA, LVL, RVL, and LGA. The subject experienced the most reduction of muscle fatigue in LTA followed by RTA, RGA, LVL, RVL, and LGA.

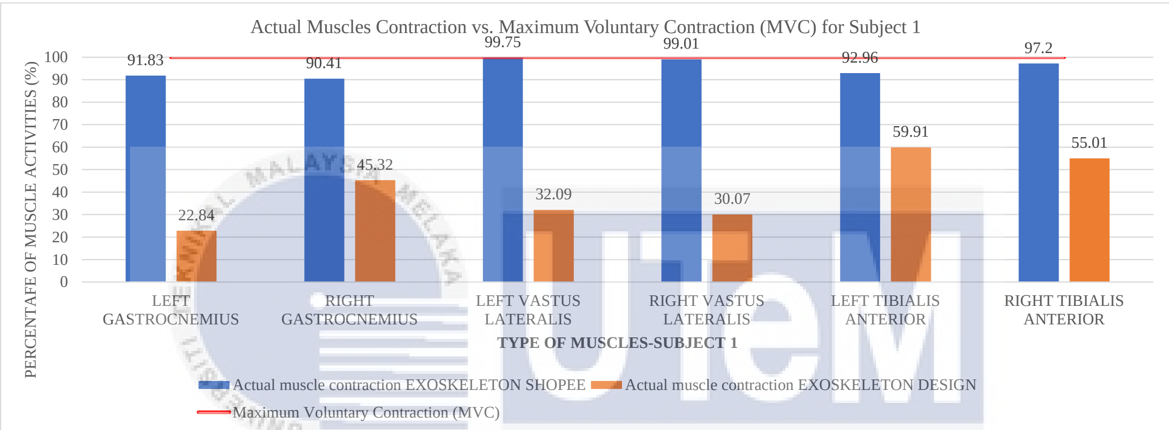


Figure 4.31: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 1

Figure 4.32 shows that subject 2 experienced the highest muscle contraction from LGA followed by RGA, RTA, LVL, RVL, and LTA. After waering design exoskeleton, subject 2 experienced the highest muscle contraction in the RTA and came with RGA, RVL, LTA, LVL, and LGA. The subject experienced the most reduction of muscle fatigue in RTA followed by RGA, RVL, LTA, LVL, and LGA.

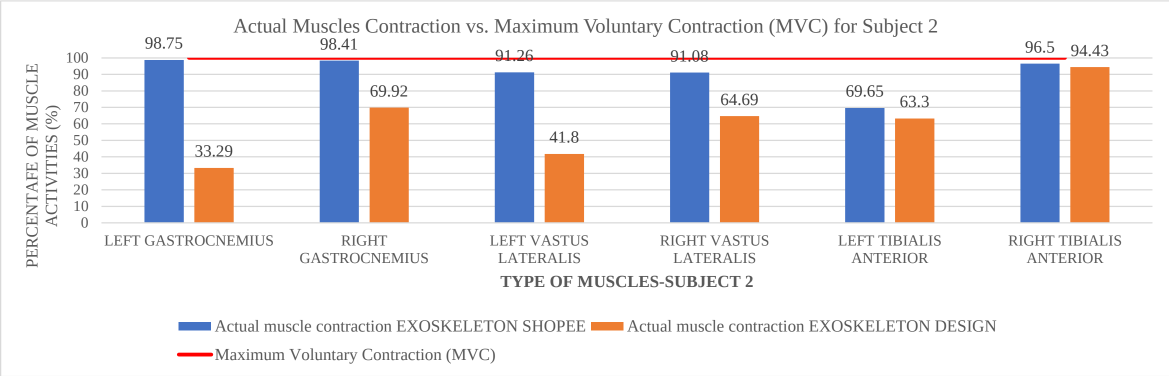


Figure 4.32: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 2

Figure 4.33 shows that subject 3 experienced the highest muscle contraction from LVL followed by RTA, RVL, LTA, RGA, and LGA. After waering design exoskeleton, subject 3 experienced the highest muscle contraction in the RTA and came with LTA, RVL, LVL, RGA, and LGA. The subject experienced the most reduction of muscle fatigue in RTA followed by LTA, RVL, LVL, RGA, and LGA.

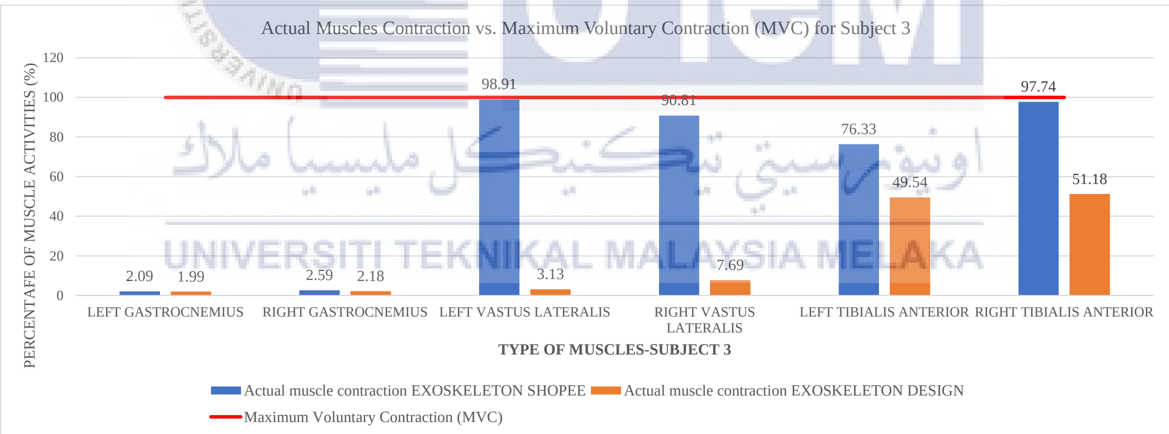


Figure 4.33: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 3

Figure 4.34 shows that subject 4 experienced the highest muscle contraction from LVL followed by RGA, RVL, LGA, RTA, and LTA. After waering design exoskeleton, subject 4 experienced the highest muscle contraction in the RGA and came with RVL, LVL, LGA, RTA, and LTA. The subject experienced the most reduction of muscle fatigue in RGA followed by RVL, LVL, LGA, RTA, and LTA.

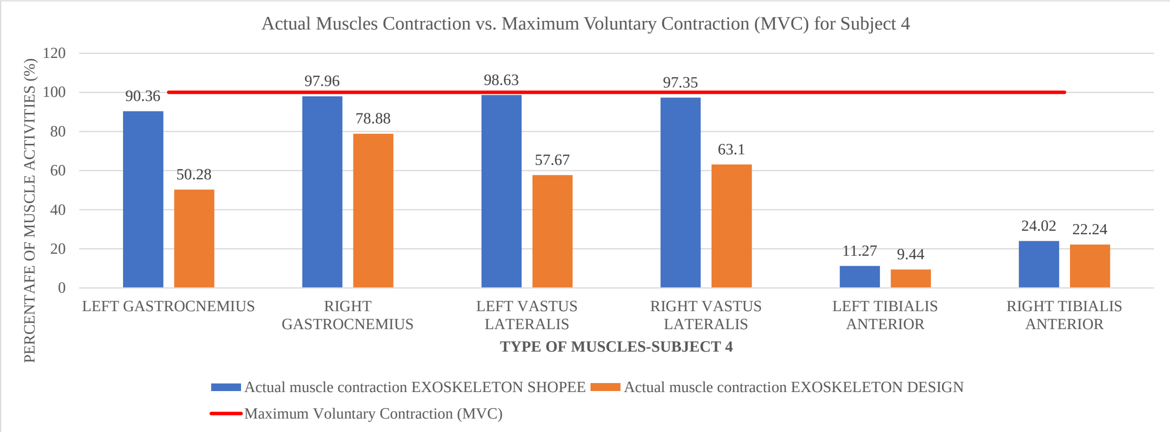


Figure 4.34: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 4

Figure 4.35 shows that subject 5 experienced the highest muscle contraction from LVL followed by RVL, RTA, RGA, LGA, and LTA. After waering design exoskeleton, subject 5 experienced the highest muscle contraction in the LVL and came with RVL, RGA, LTA, LGA, and RTA. The subject experienced the most reduction of muscle fatigue in LVL followed by RVL, RGA, LTA, LGA, and RTA.

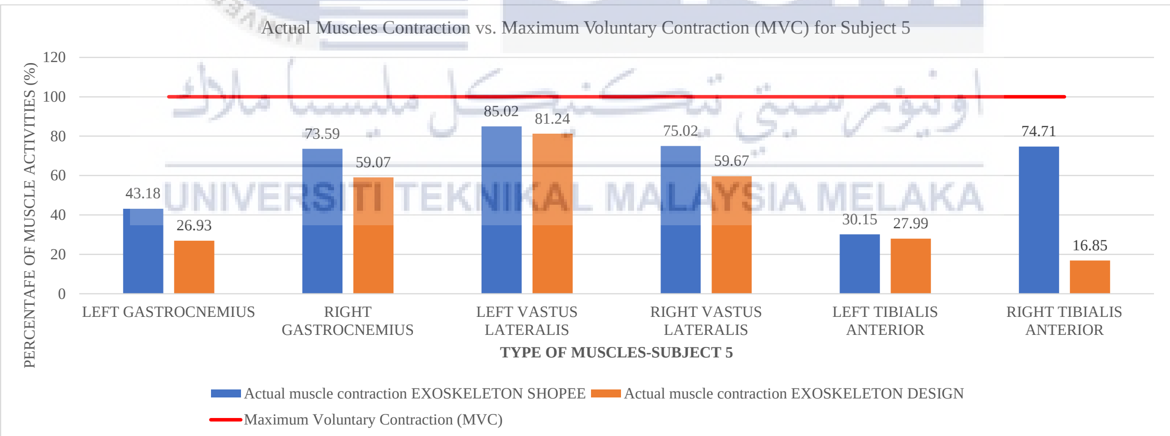


Figure 4.35: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 5

Figure 4.36 shows that subject 6 experienced the highest muscle contraction from LGA followed by RVL, RTA, LVL, LTA, and RGA. After waering design exoskeleton, subject 6 experienced the highest muscle contraction in the LGA and came with RVL, LTA, RTA, LVL, and RGA. The subject experienced the most reduction of muscle fatigue in LGA followed by RVL, LTA, RTA, LVL, and RGA.

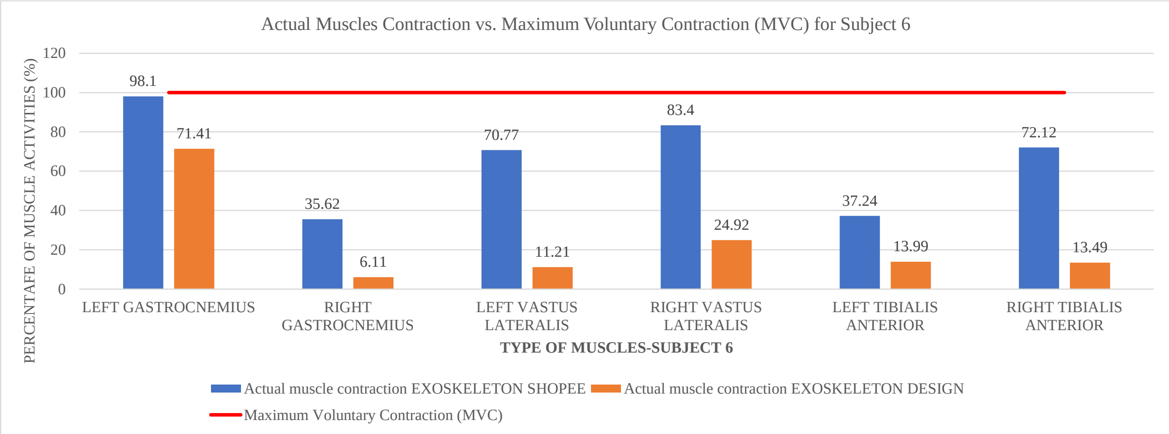


Figure 4.36: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 6

Figure 4.37 shows that subject 7 experienced the highest muscle contraction from LTA followed by RVL, LVL, LGA, RGA, and RTA. After waering design exoskeleton, subject 7 experienced the highest muscle contraction in the RTA and came with LGA, RGA, LVL, LTA, and RVL. The subject experienced the most reduction of muscle fatigue in RTA followed by LGA, RGA, LVL, LTA, and RVL.

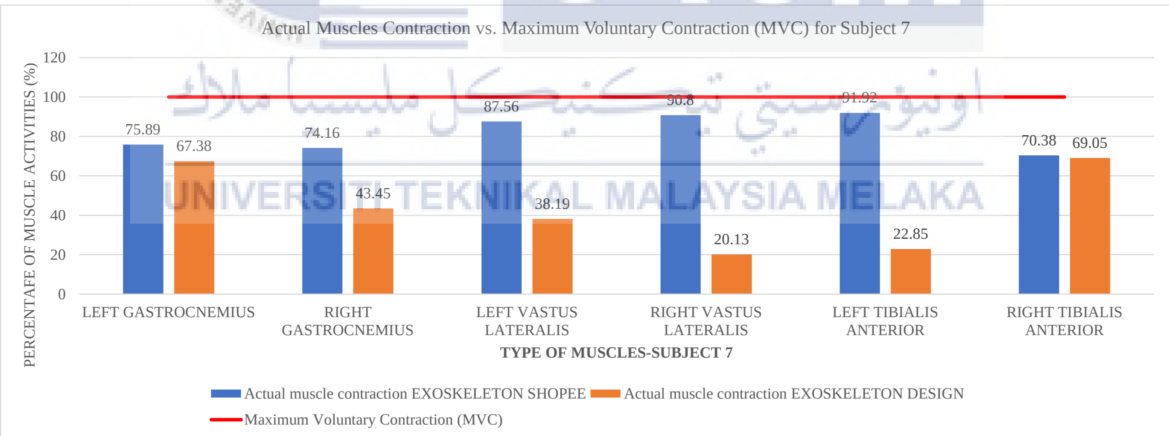


Figure 4.37: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 7

Figure 4.38 shows that subject 8 experienced the highest muscle contraction from LVL followed by RVL, RTA, RGA, LTA, and LGA. After waering design exoskeleton, subject 8 experienced the highest muscle contraction in the RVL and came with LVL, LTA, LGA, RGA, and RTA. The subject experienced the most reduction of muscle fatigue in RVL followed by LVL, LTA, LGA, RGA, and RTA.

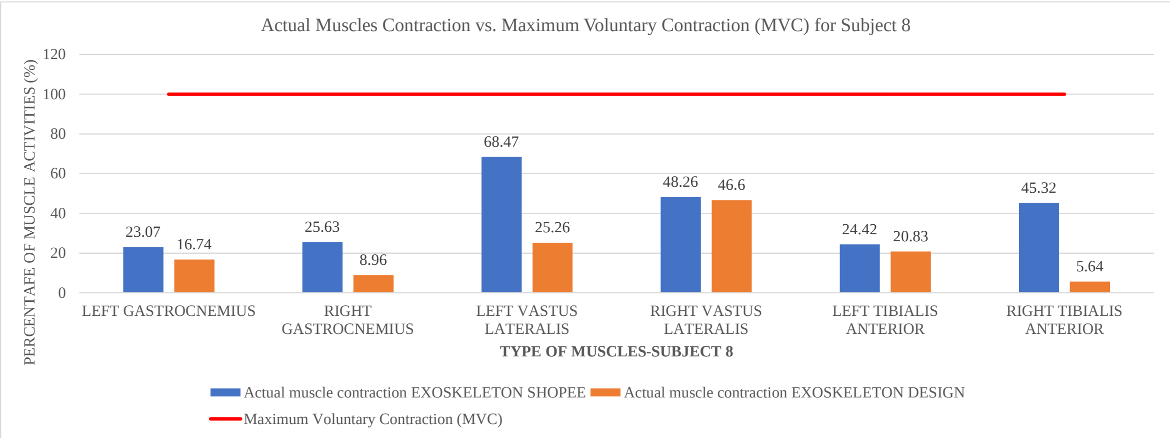


Figure 4.38: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 8

Figure 4.39 shows that subject 9 experienced the highest muscle contraction from LVL followed by RVL, LGA, RGA, RTA, and LTA. After waering design exoskeleton, subject 9 experienced the highest muscle contraction in the LVL and came with LGA, RGA, RVL, RTA, and LTA. The subject experienced the most reduction of muscle fatigue in LVL followed by LGA, RGA, RVL, RTA, and LTA.

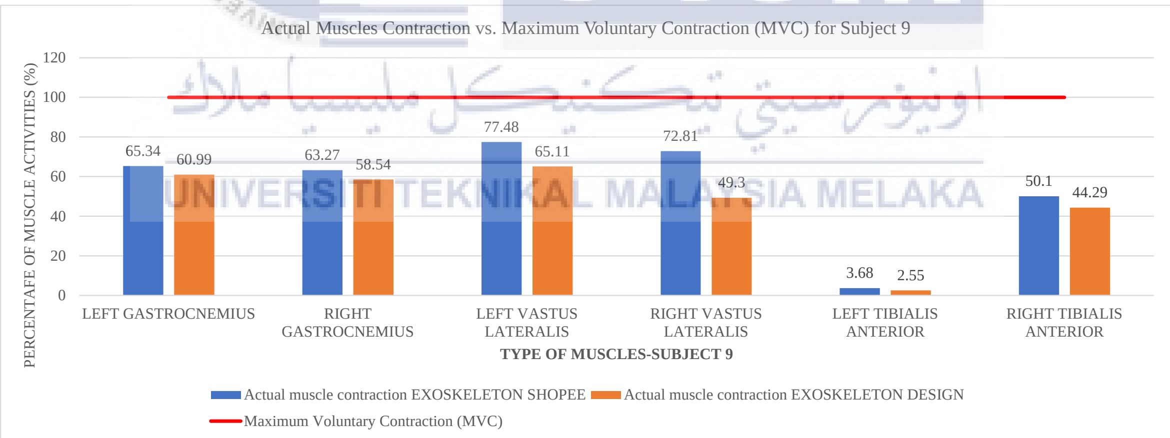


Figure 4.39: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 9

Figure 4.40 shows that subject 10 experienced the highest muscle contraction from RVL followed by RGA, RTA, LGA, LTA, and LVL. After waering design exoskeleton, subject 10 experienced the highest muscle contraction in the LVL and came with RVL, RGA, RTA, LTA, and LGA. The subject experienced the most reduction of muscle fatigue in LVL followed by RVL, RGA, RTA, LTA, and LGA.

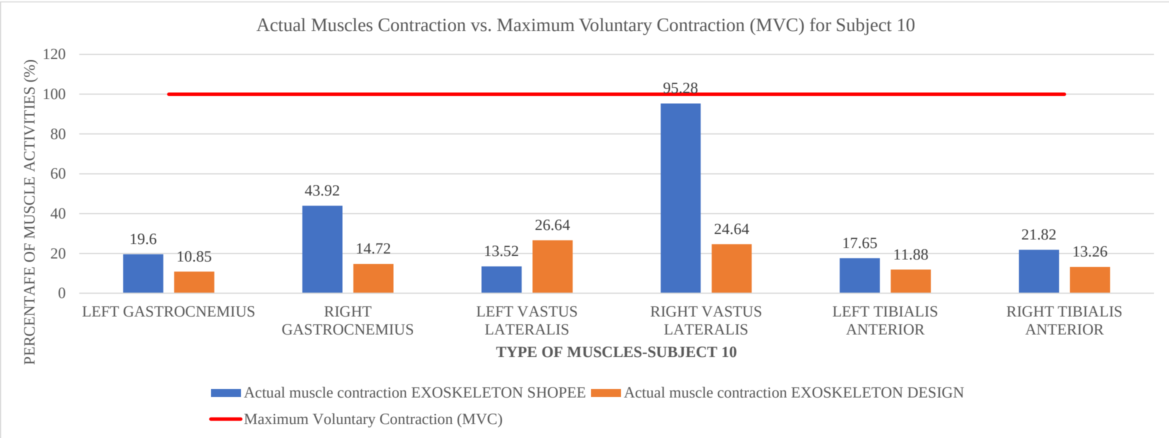


Figure 4.40: Actual muscles contraction with commercial exoskeleton vs with design exoskeleton for Subject 10

After analysing the results, it shows that the design exoskeleton helps reduce muscle fatigue. It can be concluded that the design exoskeleton helps reduce the exposure to muscle fatigue, as shown by low contraction of muscle activity as the voltage and percentage of muscle activity is reduced.

This section explain the experiment result of pressure test. The pressure test is conducted simultaneously with the EMG test. The pressure mat is place under the bottom section of test subject, this is to read the pressure between the design exoskeleton and the subject buttock. Figure 4.41 shows that subject 1 experienced the highest pressure at 88 raw followed by 85 raw, 31 raw, 21 raw. This shows that the highest pressure occur at the red area which is 88 raw.

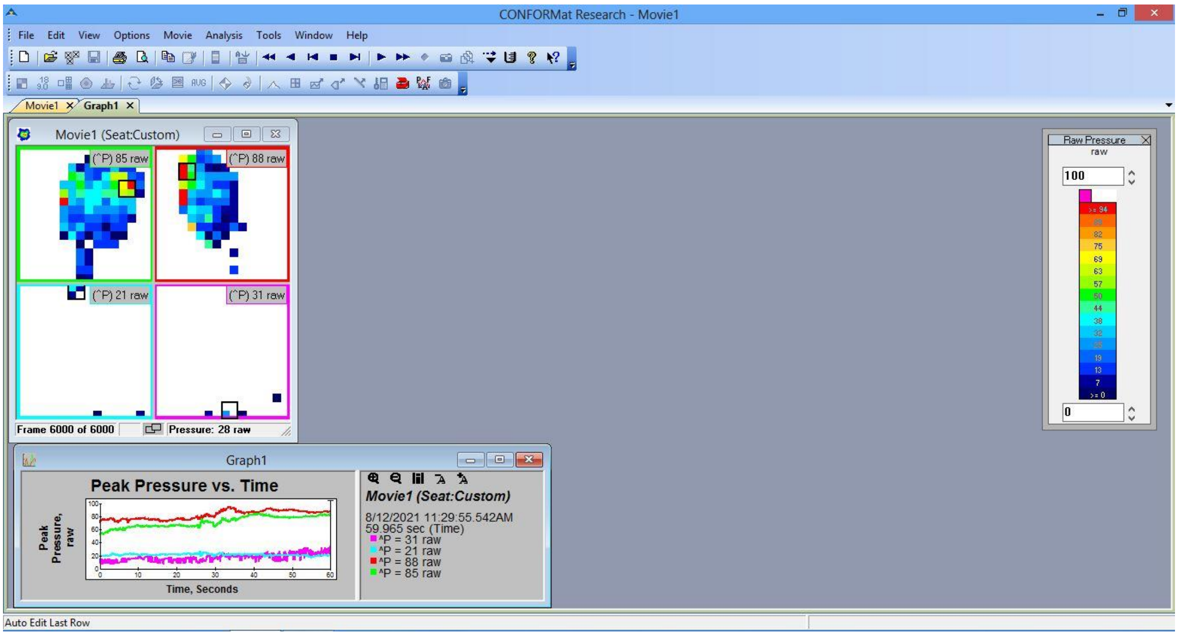


Figure 4.41: Pressure test of subject 1

Figure 4.42 shows that subject 2 experienced the highest pressure at 74 raw followed by 61 raw, 38 raw, 29 raw. This shows that the highest pressure occur at the red area which is 74 raw.

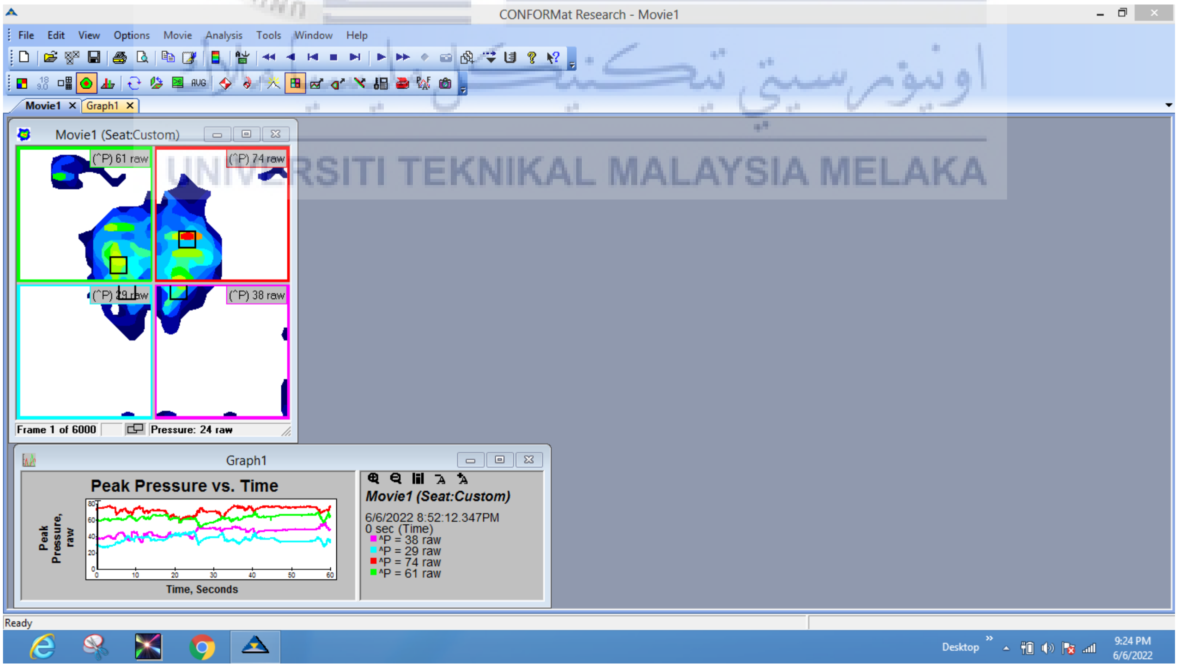


Figure 4.42: Pressure test of subject 2

Figure 4.43 shows that subject 3 experienced the highest pressure at 72 raw followed by 65 raw, 57 raw, 49 raw. This shows that the highest pressure occur at the red area which is 72 raw.

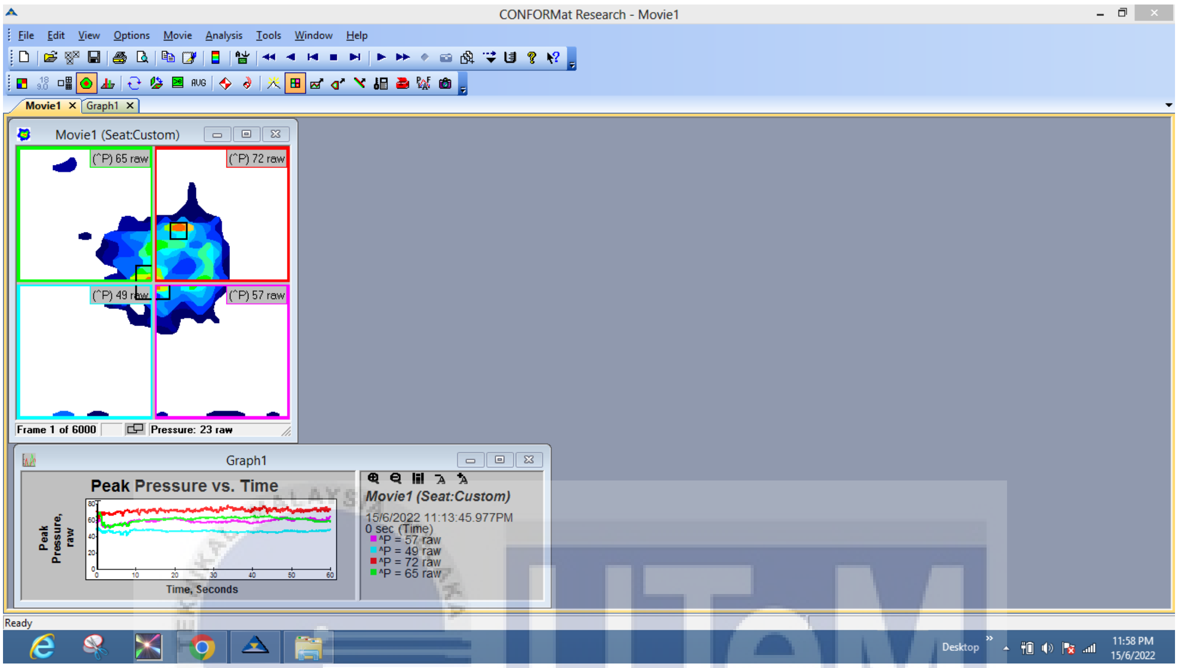


Figure 4.43: Pressure test of subject 3

Figure 4.44 shows that subject 4 experienced the highest pressure at 106 raw followed by 90 raw, 23 raw, 14 raw. This shows that the highest pressure occur at the red area which is 106 raw.

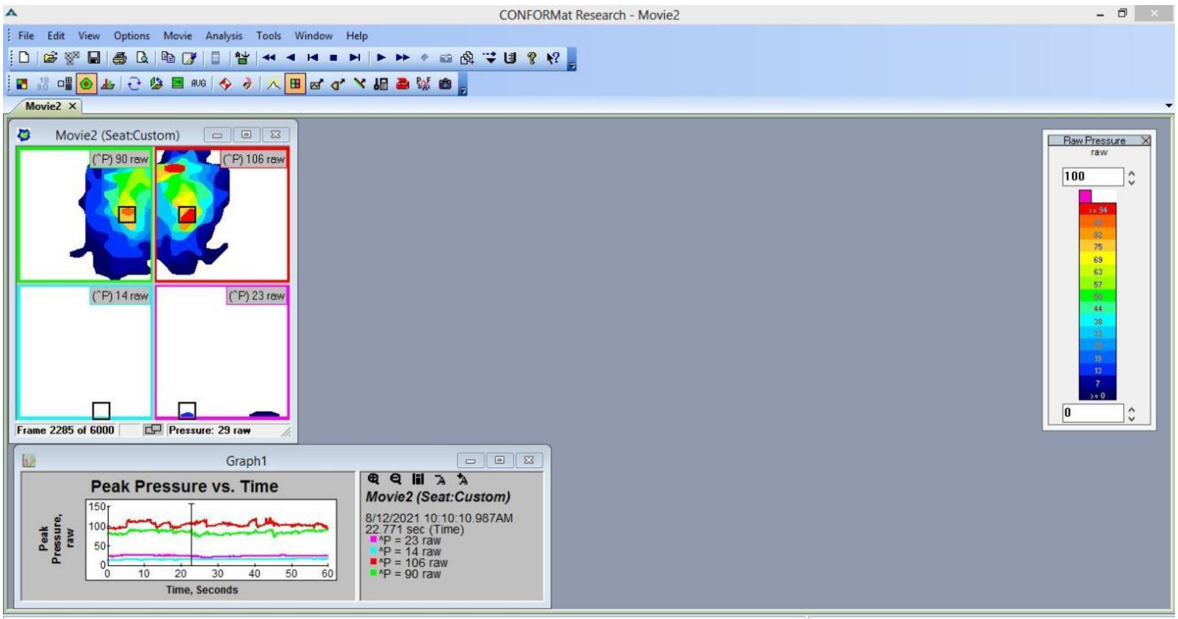


Figure 4.44: Pressure test of subject 4

Figure 4.45 shows that subject 5 experienced the highest pressure at 115 raw followed by 107 raw, 66 raw, 60 raw. This shows that the highest pressure occur at the red area which is 115 raw.

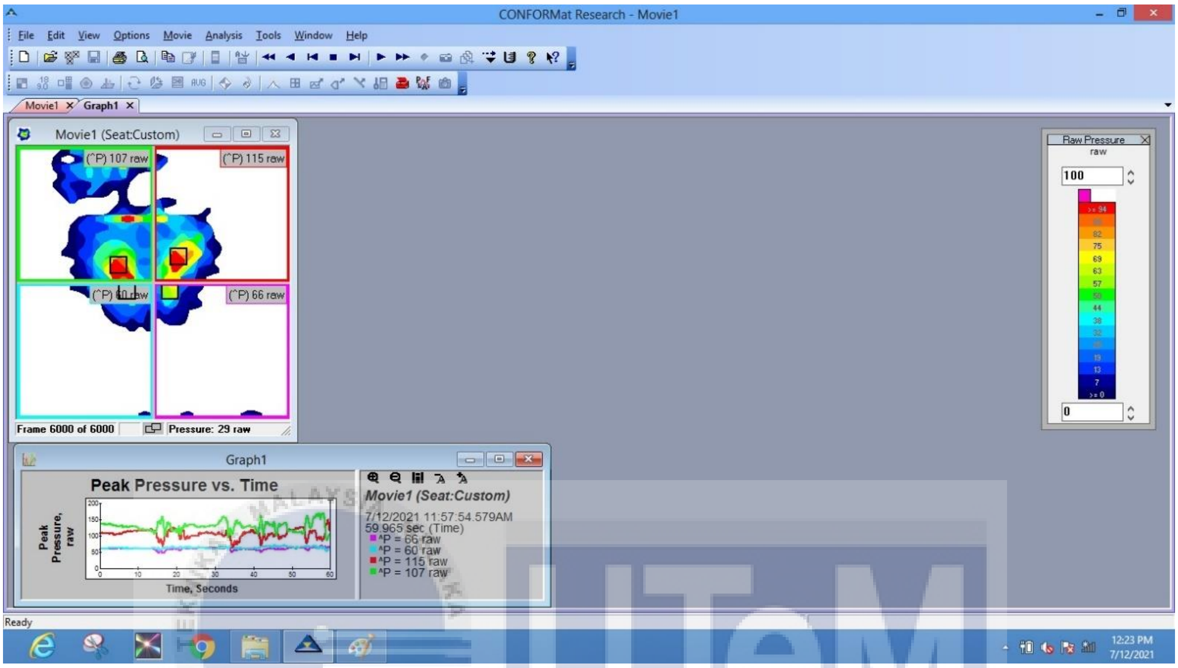


Figure 4.45: Pressure test of subject 5

Figure 4.46 shows that subject 6 experienced the highest pressure at 155 raw followed by 144 raw, 120 raw, 72 raw. This shows that the highest pressure occur at the red area which is 120 raw.

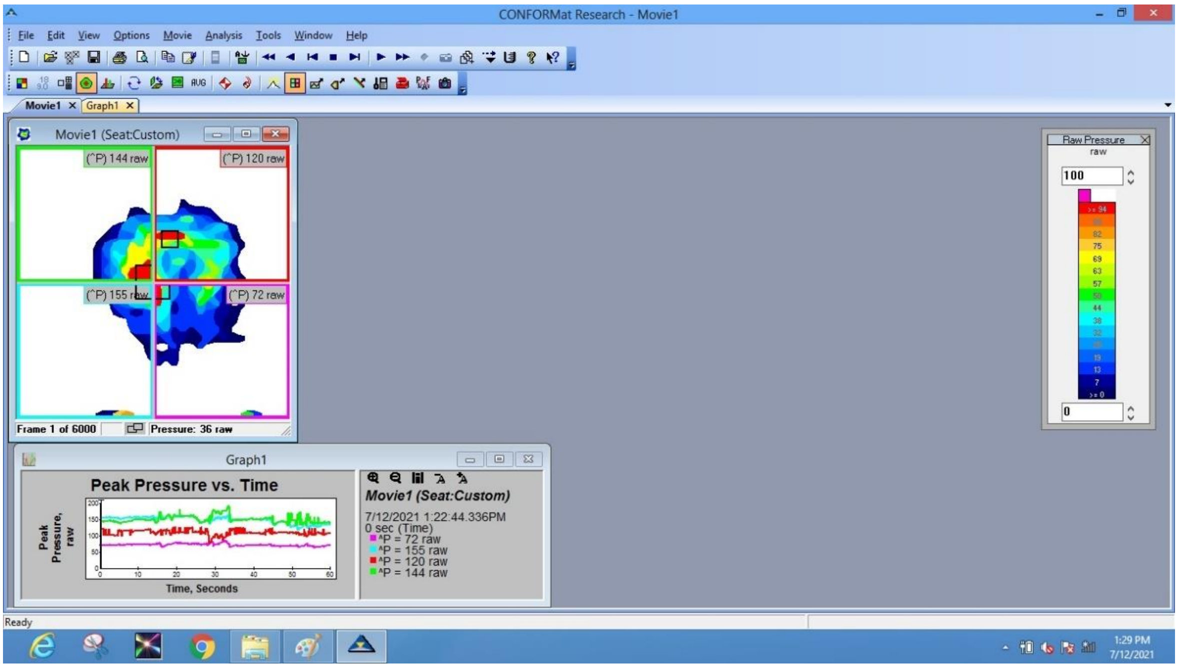


Figure 4.46: Pressure test of subject 6

Figure 4.47 shows that subject 7 experienced the highest pressure at 131 raw followed by 100 raw, 36 raw, 31 raw. This shows that the highest pressure occur at the red area which is 100 raw.

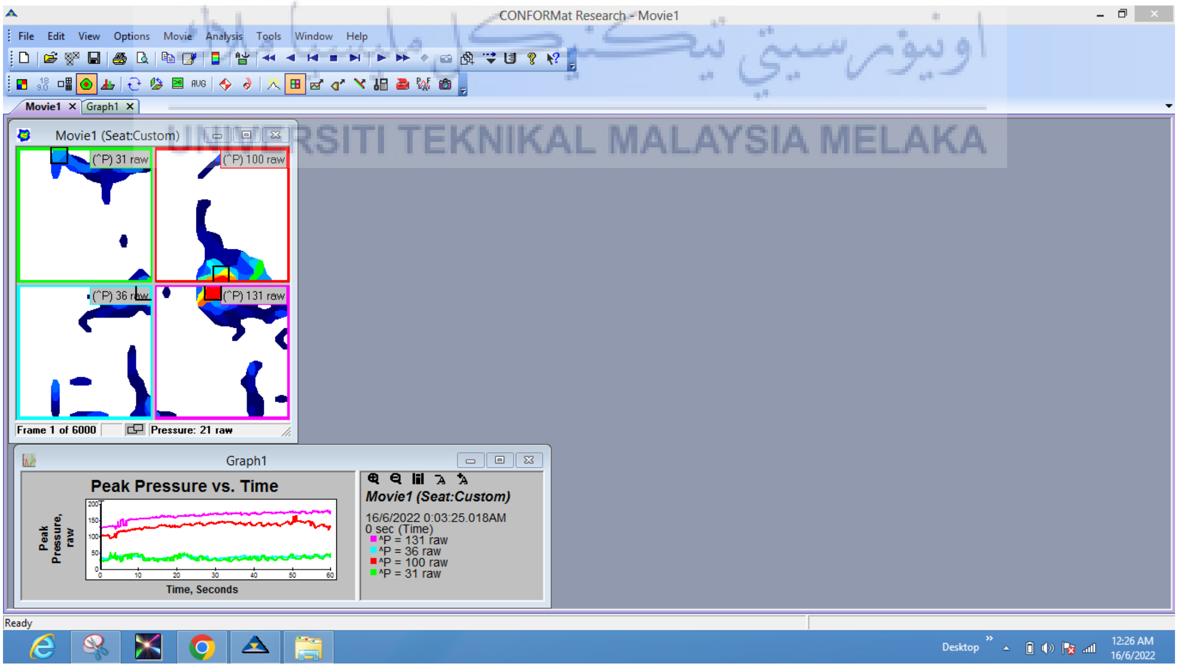


Figure 4.47: Pressure test of subject 7

Figure 4.48 shows that subject 8 experienced the highest pressure at 91 raw followed by 85 raw, 62 raw, 28 raw. This shows that the highest pressure occur at the red area which is 62 raw.

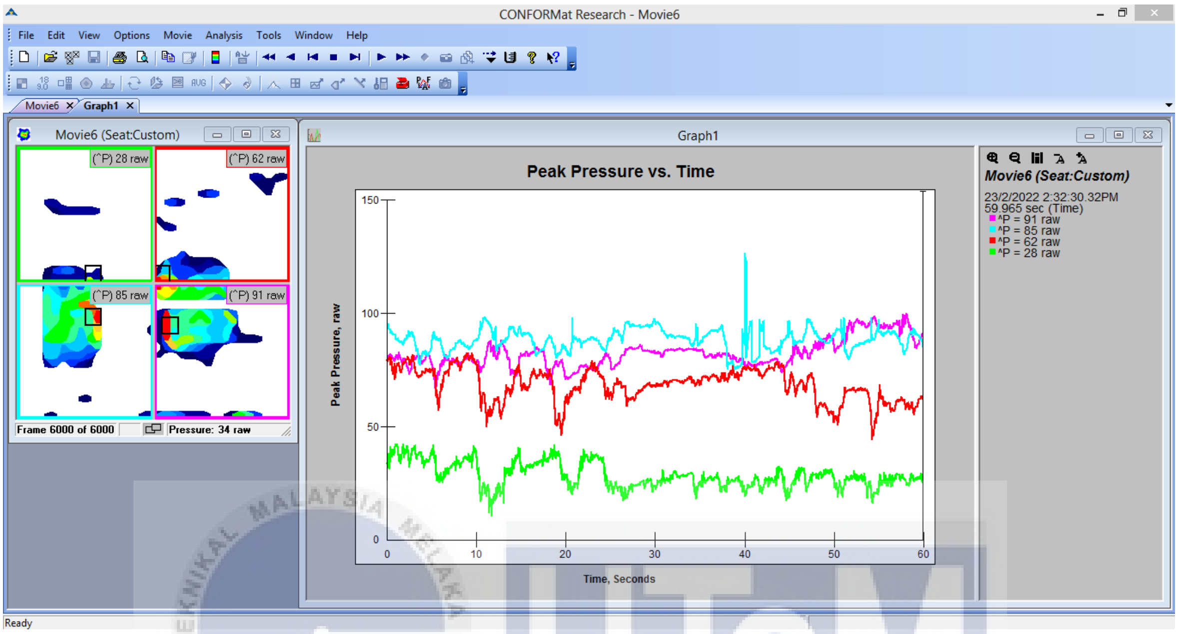


Figure 4.48: Pressure test of subject 8

Figure 4.49 shows that subject 9 experienced the highest pressure at 94 raw followed by 86 raw, 33 raw, 26 raw. This shows that the highest pressure occur at the light blue area which is 94 raw.

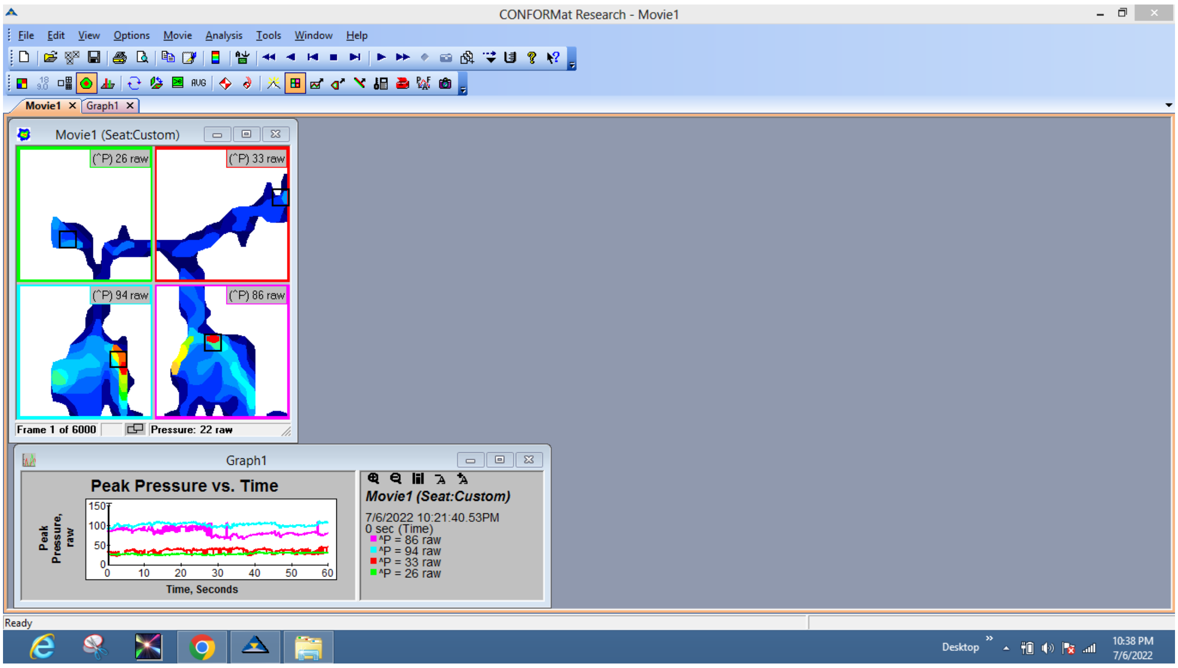


Figure 4.49: Pressure test of subject 9

Figure 4.50 shows that subject 10 experienced the highest pressure at 88 raw followed by 85 raw, 31 raw, 21 raw. This shows that the highest pressure occur at the red area which is 88 raw.

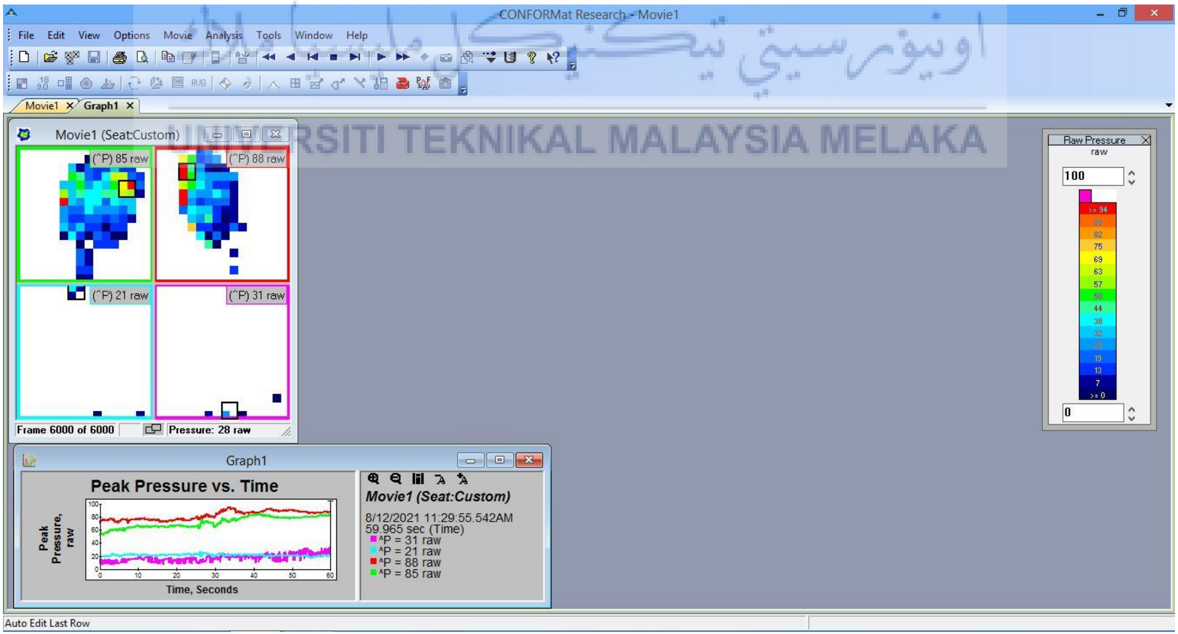


Figure 4.50: Pressure test of subject 10

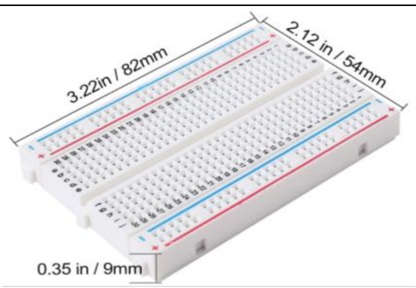
4.3 Integrate The Sit-Stand Exoskeleton with Pressure and Postural Angle Sensors for a Conceptual Smart System of Alternating Standing and Sitting Postures.

This study provides the test results and discussion for design passive sit-stand exoskeleton, which include the Internet of Things (IoT). This section serves to achieve the final objective.

4.3.1 Pressure Sensor IoT

The main goal here is to create a pressure sensor that can applied on the design exoskeleton so that it would assist the user to monitor their pressure while using the device therefore the user can alternately sit and stand during working without worrying any effect due to prolonged standing. To build a pressure sensor there are certain hardware component that are needed, table 4.14 shows the hardware component that are needed to build the pressure sensor.

Table 4.14: Hardware component for pressure sensor

Name	Component
Arduino ESP32	
Bread Board	

Jumper Wire	
10 kΩ Resistor	
Pressure Sensor	

A pressure sensor is a resistor with inversely proportional resistance to applied force. The stronger the force applied to the sensor, the lower its resistance. Pressure sensors are suitable for detecting physical compression and pressure. Figure 4.25 and Figure 4.26 shows the wiring diagram of building the pressure sensor.

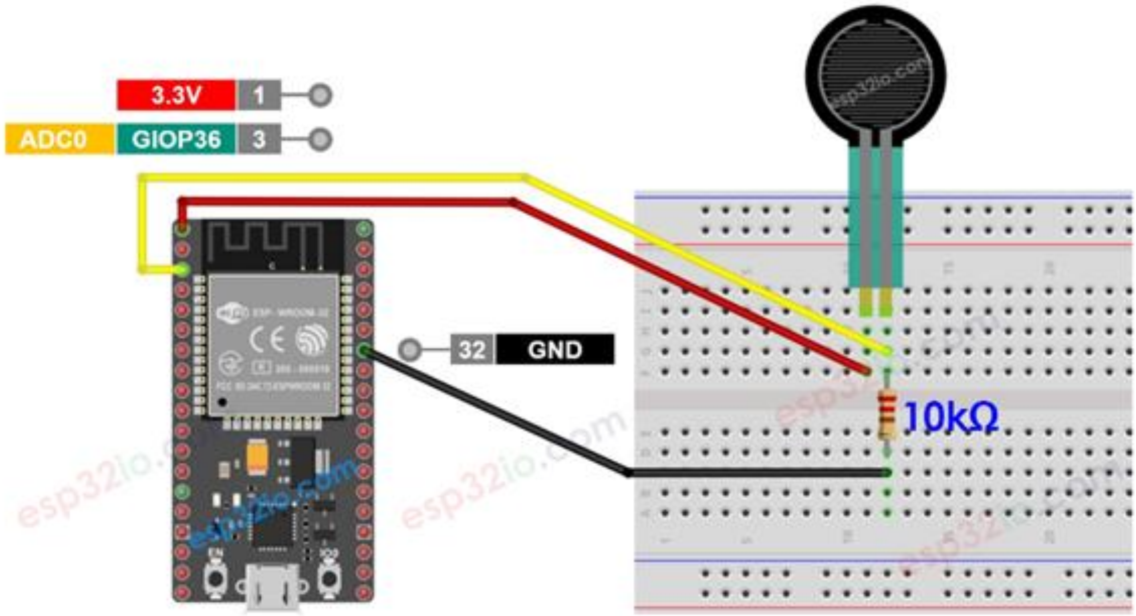


Figure 4.25: Wiring diagram for pressure sensor

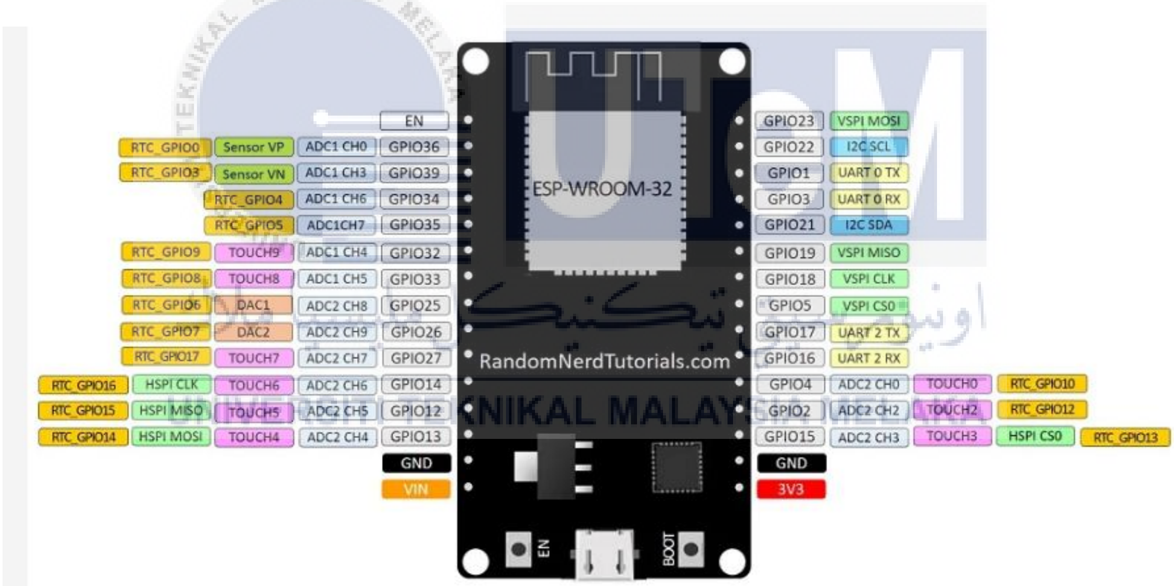


Figure 4.26: ESP32 DEVKIT V1

After finish setting up the pressure sensor, a code needed to be uploaded to the Arduino so that it could read the incoming information from the pressure sensor and display it to the application. Figure 4.27 shows user testing for pressure sensor

Figure 4.27: User testing on pressure sensor

Lastly is to transfer the information display in the desktop to the smart phone. The application use to display information in the smart phone called Blynk. After creating blynk database account there a code given by blynk that needed to be uploaded to the Arduino so everything that being displayed in the desktop also can be shown in the smart phone. Figure 4.28 and figure 4.29 shows the information display in desktop view and in smart phone view.

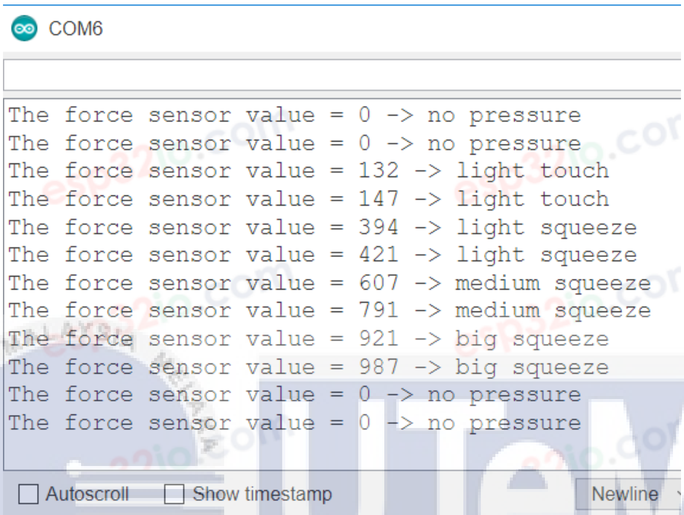


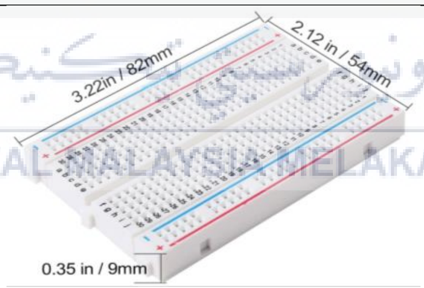
Figure 4.28: Desktop view

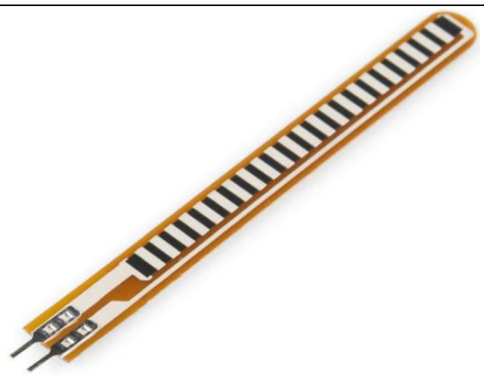
Figure 4.29: Smart phone view

4.3.2 Postural Sensor IoT

The main goal here is to create a postural sensor that can applied on the design exoskeleton so that it would assist the user to monitor their posture while using the device therefore the user can alternately sit and stand during working without worrying any effect due to prolonged standing. To build a postural sensor there are certain hardware component that are needed, table 4.15 shows the hardware component that are needed to build the postural sensor.

Table 4.15: hardware component for postural sensor

Name	Component
Arduino ESP32	
Bread Board	
Jumper Wire	

10 kΩ Resistor	
Flex Bend Sensor	

When the postural sensor is bent, the resistance output is proportional to the bend radius. The smaller the radius, the greater the resistance value. Postural sensors are suitable for detecting the body angle. Figure 4.30 shoes the wiring diagram for postural sensor.

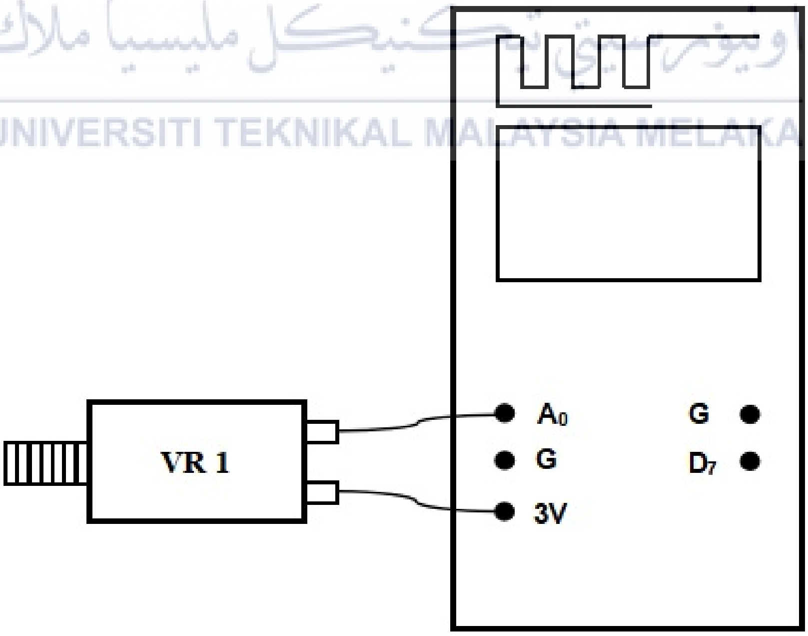


Figure 4.30: Wiring diagram for postural sensor

After finish setting up the postural sensor, a code needed to be uploaded to the Arduino so that it could read the incoming information from the postural sensor and display it to the application. Figure 4.31 shows the code for the Arduino.

Figure 4.32: User testing the IoT ergonomics feedback of postural control

Lastly is to transfer the information display in the desktop to the smart phone. The application use to display information in the smart phone called Cayenne. After creating Cayenne account there’s a code given by Cayenne that needed to be uploaded to the Arduino so everything that being displayed in the desktop also can be shown in the smart phone. Figure 4.32 and Figure 4.29 shows the information display in desktop view and in smart phone view.

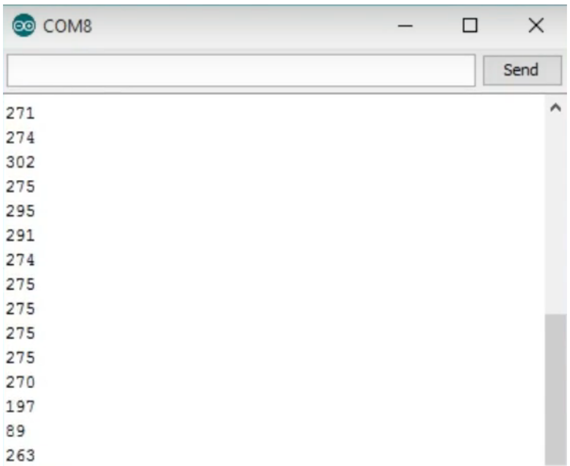


Figure 4.32: Desktop view

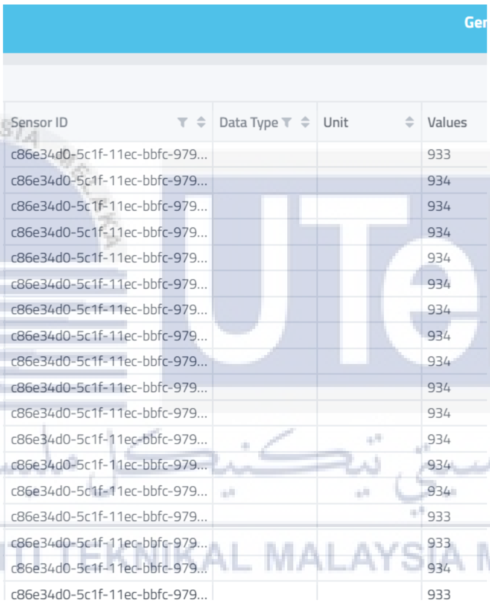


Figure 4.33 Smart phone view

4.4 Summary

The result obtained in this study are discussed in this section; the survey to determine user need are very important, early user engagement was found to be positive impact on user and customer satisfaction and demand quality (Sari Kujala, 2002). As a result, the fabricated design exoskeleton needed to follow the customer need so that it would help them reduce the exposure to the musculoskeletal disorders. The anthropometric data of Malaysian young adults are compiled into data, the participants involved in this study mostly are healthy. According to previous study anthropometric is an important research tool. As research tools, they have contributed to the analysis of human variation

(MYİşcan, 2000). As a result, the subjects that are participating in the experiment needed to be in a best health condition so that they could achieve the maximum muscle contraction. Previous study stated that the exoskeleton can be connected to a server platform to store and process sensor data, sharing useful information on the internet to increase productivity, prevent future worker injuries and reduce errors during assembly (ThomasBauernhanslab et al., 2020). This shows that the pressure sensor and postural sensor are a great help for the industrial workers, it would help them to be more alert of their exposure to the musculoskeletal disorders and can alternately sit and stand to avoid the effect of prolonged standing.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

This chapter summarised the study outcome relation to the objectives. Aside from that, this chapter covered methodology research ideas for the future. This section will summarise the achievement on the design passive sit and stand exoskeleton based on the user requirement data gathered, followed by the fabrication prototype and analysis on the passive sit and stand exoskeleton.

5.1 Design Requirements of Sit-Stand Exoskeleton

This study has determined users' needs and design requirements of sit-stand exoskeleton from Malaysian industrial workers which was obtained through several studies. The study conducted consist of questionnaire survey, Quality Function Deployment, conceptual design, Pugh concept selection, concept scoring, and detail design. This study concluded that the design passive sit-stand exoskeleton needed the improvement such as easy to carry, stable, adjustable, portable, low restriction of movement, lightweight and low cost. As a result, based on the data collected, one conceptual has been chosen as the best design and fits all the requirement thus the first problem statement have been solved with the first objective.

5.2 Evaluate the Effects of the Fabricated Sit-Stand Exoskeleton on Muscle Activity and Contact Pressure.

This study has evaluated the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure based on the result for 10 test subjects. The study conducted has provide result of muscle activity percentage between muscle contraction without exoskeleton and muscle contraction with exoskeleton, also the result of muscle activity percentage between muscle contraction with design exoskeleton and muscle contraction with commercial exoskeleton. The results of this study showed that the design exoskeleton has met the requirement and also have been tested. This shows when wearing the design exoskeleton, a reduction in muscle fatigue can be seen by lowering muscle contraction up to 75 percent thus it is very suitable for the industrial workers that have suffer due to the effect of prolonged standing thus second problem statement has solved by second objectives.

5.3 Integrate The Sit-Stand Exoskeleton with Pressure and Postural Angle Sensors for a Conceptual Smart System of Alternating Standing and Sitting Postures.

The study is to integrate the sit-stand exoskeleton with pressure and postural angle sensors for a conceptual smart system of alternating standing and sitting postures. The study provides the component and wiring diagram to create the pressure and postural sensor that is suitable to applied on the design exoskeleton. The result shows that the created pressure and postural sensor are fully functional. This shows that with the help of information shown to the user, the user can be alert of their health issues due to prolonged standing thus final problem statement has solved by the final objectives.

5.4 Recommendation for Future Study

This study recommended to evaluate the effects of the fabricated sit-stand exoskeleton on muscle activity and contact pressure. Furthermore, this study suggests to use a better material in the future, so that the exoskeleton would be more lightweight so that user can move comfortably with out any strict of movement thus the user can continue with their work easily.

5.5 Sustainable Design and Development

The passive sit-stand exoskeleton with a wide range base so that user could feel safe and balance while using it and not worrying of falling backward. The saddle is made of high comfort sponge, this will reduce the pressure below the bottom part also it the user will feel more comfort while sitting on it. Lastly the exoskeleton has the most important feature and that is the ergonomic feedback, this feature will be very helpful to the user because it can alert the user about their pressure and posture information in their smart phone.

5.6 Complexity

The complexity in the study is to determined users' needs and design requirements of sit-stand exoskeleton from Malaysian industrial workers. The passive sit-stand exoskeleton must be designed according to the user's requirements for providing Quality Functions Deployment to satisfy the user's satisfaction. Then based on the data collected, one conceptual has been chosen as the best design and fits all the requirement. After choosing the best design the fabrication process is proceed. The device is then testes with 10 male test subjects, this is to see whether the improvement added to the passive sit-stand exoskeleton can reduce the user muscle activity when wearing the device. In addition, the prototype must be further developed to ensure that the prototype is suitable for use and meets the user's requirements.

5.6 Life-long Learning

During the experiment, the most recent equipment and software are used to analyse muscle contraction using EMG software. Furthermore, it is suggested that the fabricated exoskeleton contain IoT (Internet of Things), which allows data from the exoskeleton to be delivered to cloud-based management systems. The IoT for exoskeleton allows organisations that operate smart factories to detect and analyse user working habits in order to monitor their health and performance.

APPENDIX A

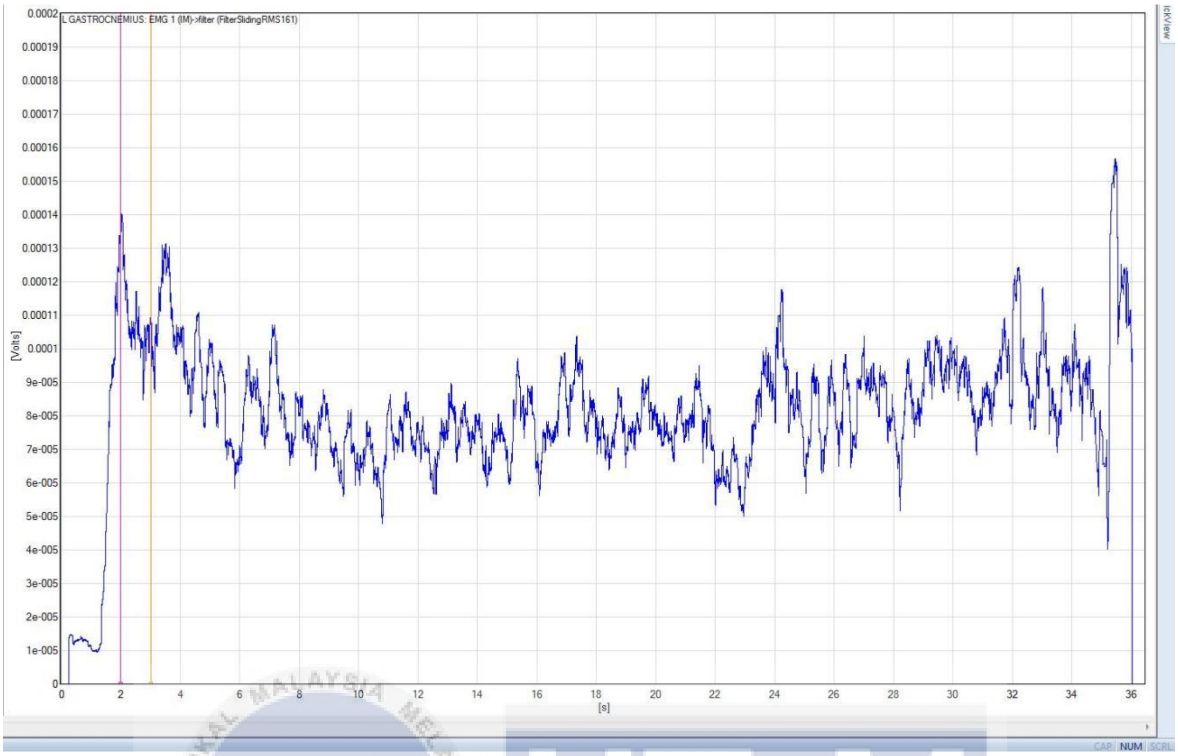


Figure A.1: MVC (L) Gastro

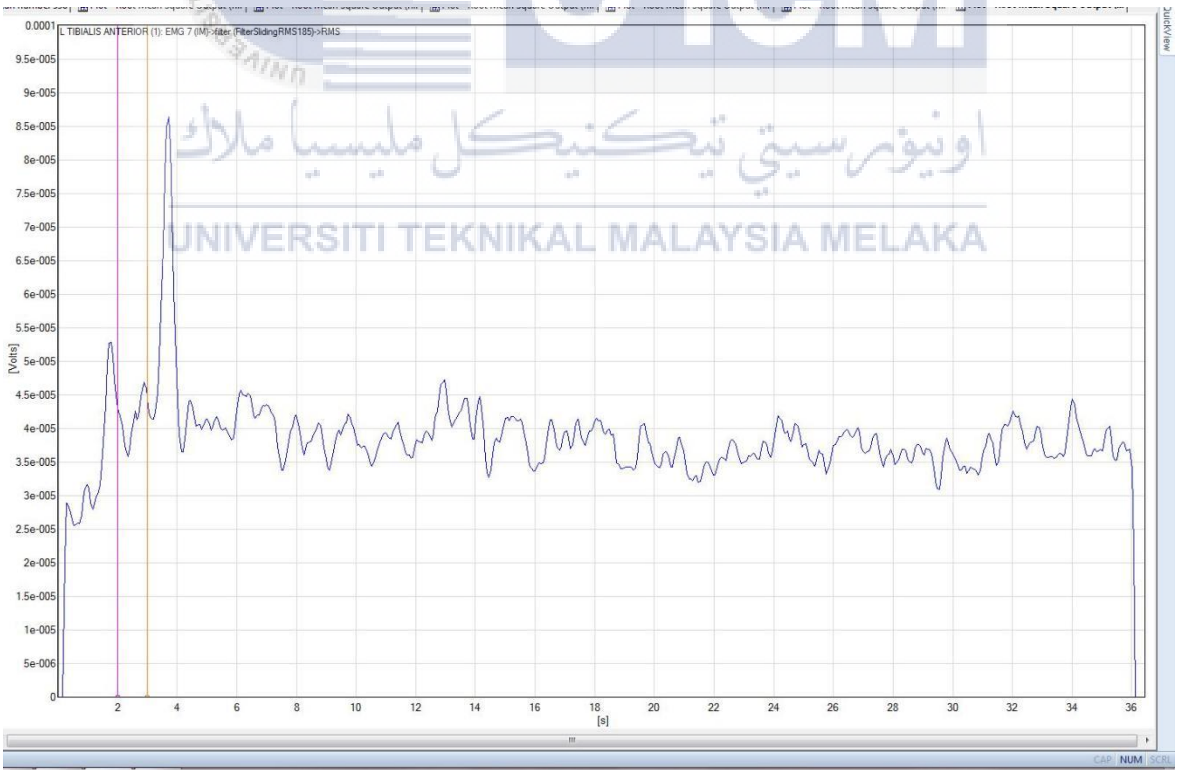


Figure A.2: MVC (L) Tibialis

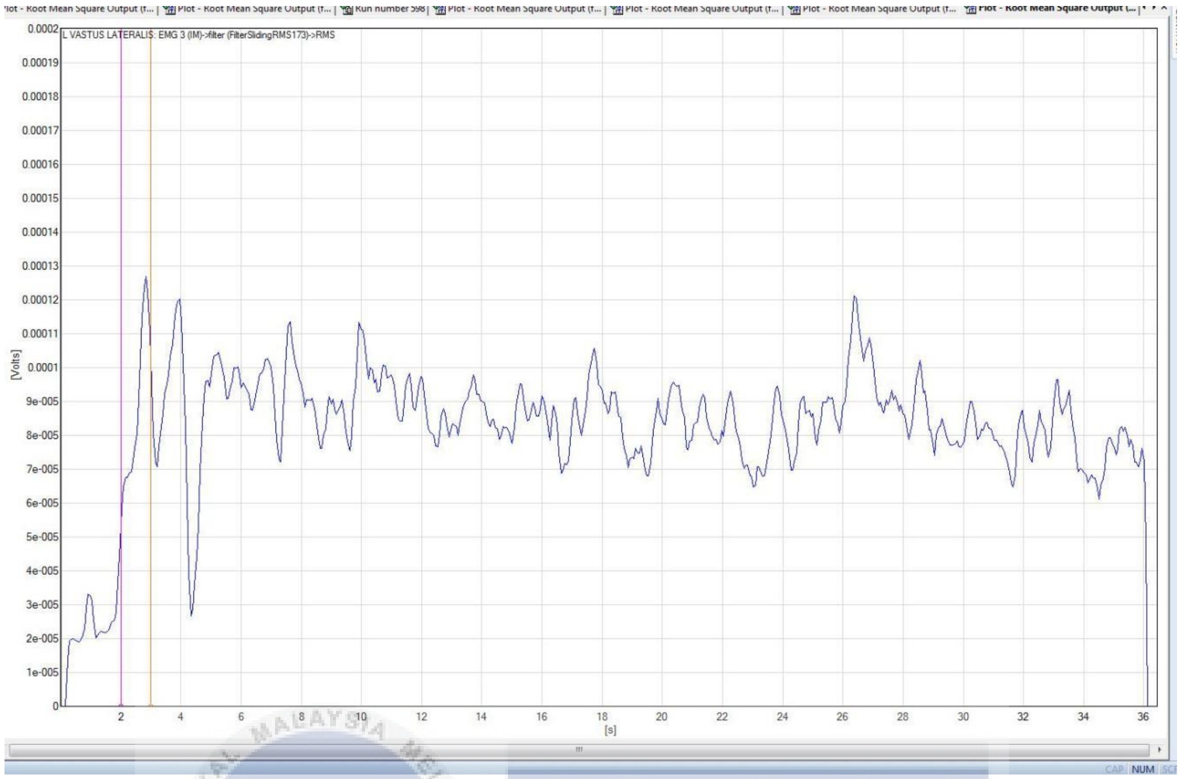


Figure A.3: MVC (L) Vastus

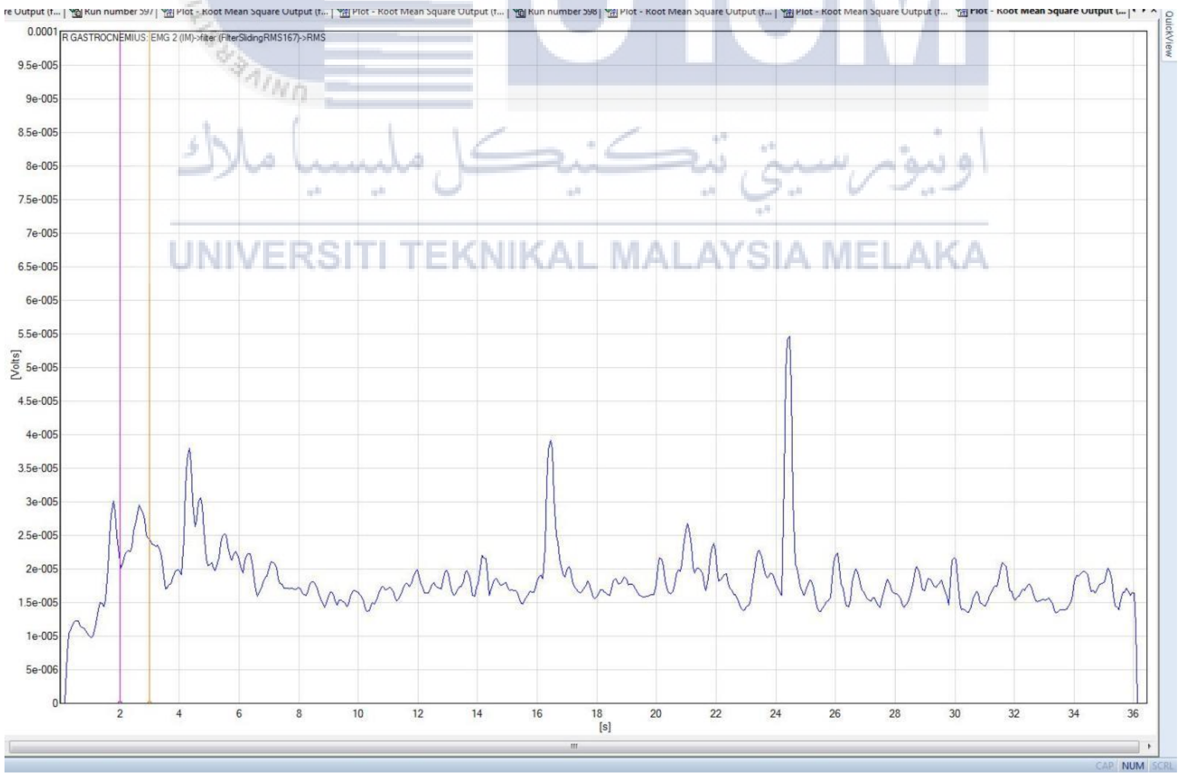


Figure A.4: MVC (R) Gastro

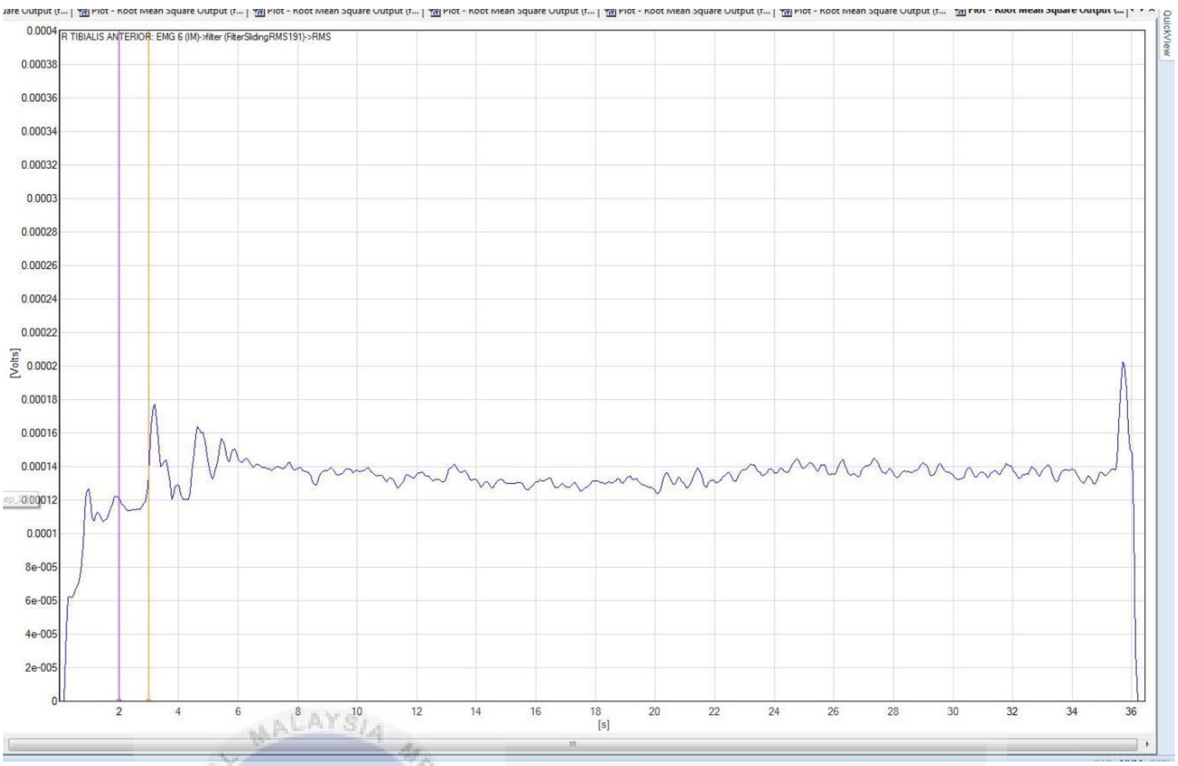


Figure A.5: MVC (R) Tibialis

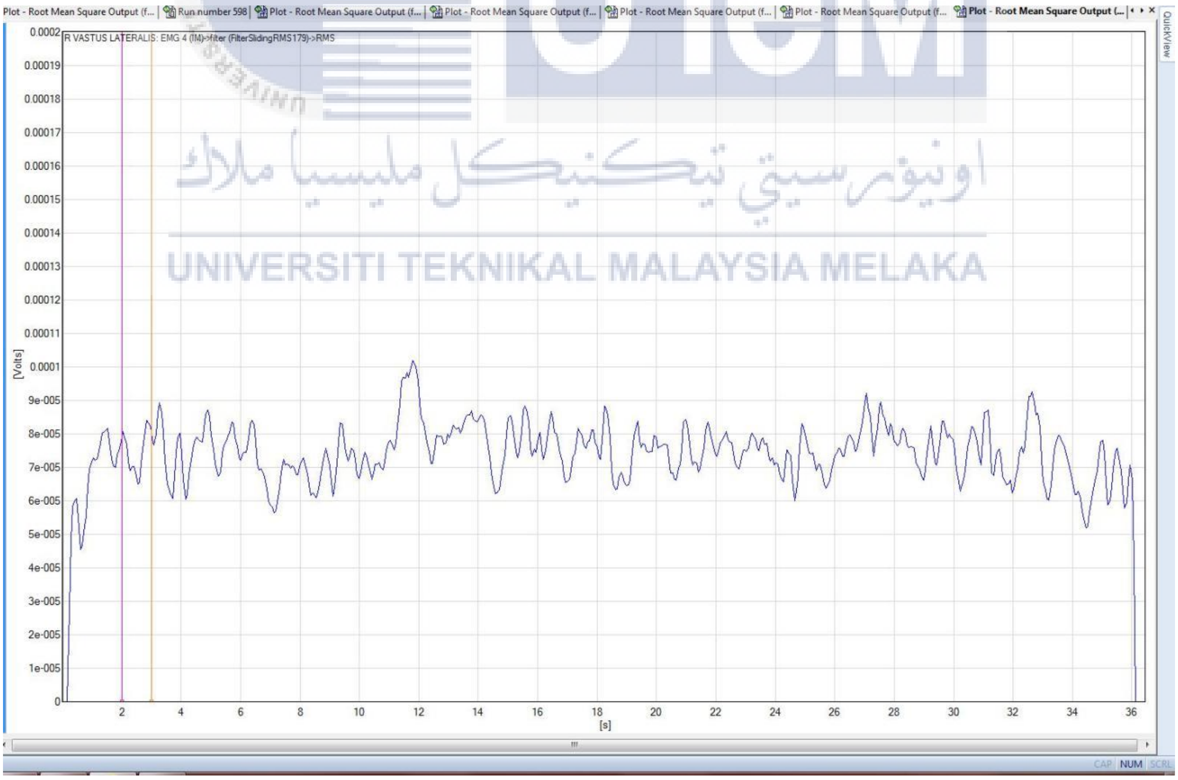


Figure A.6: MVC (R) Vastus

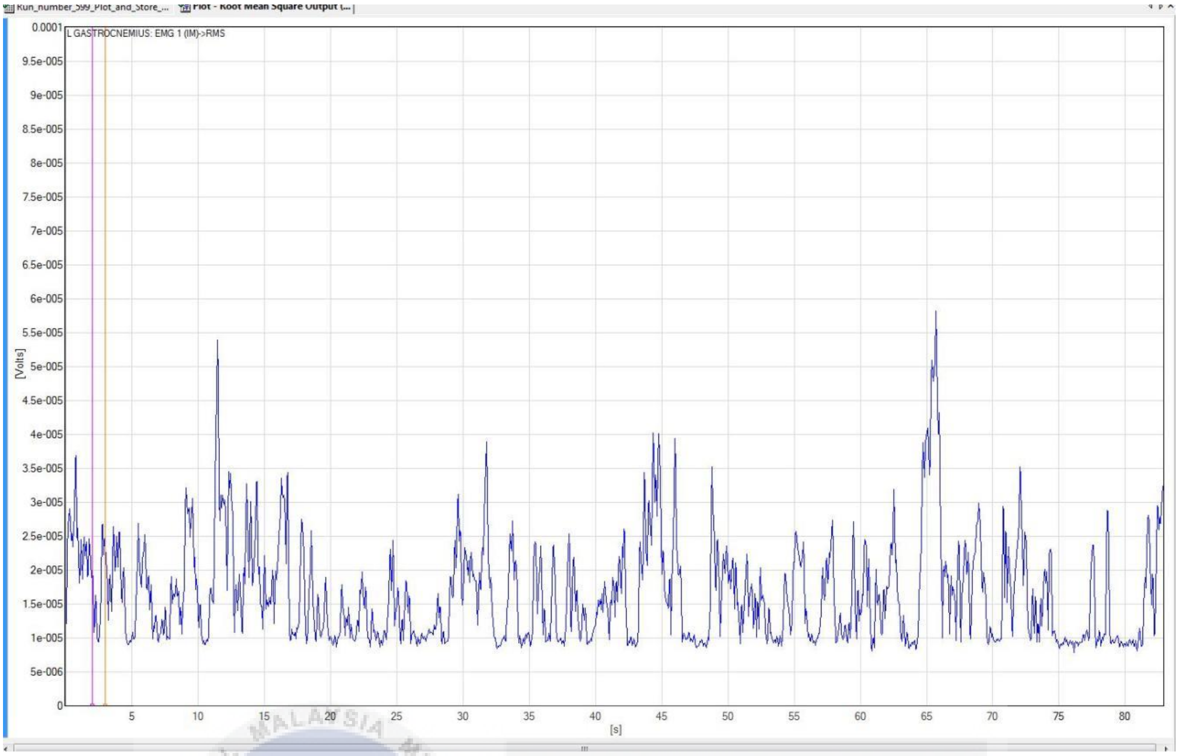


Figure A.7: (L) Gastro – standing still

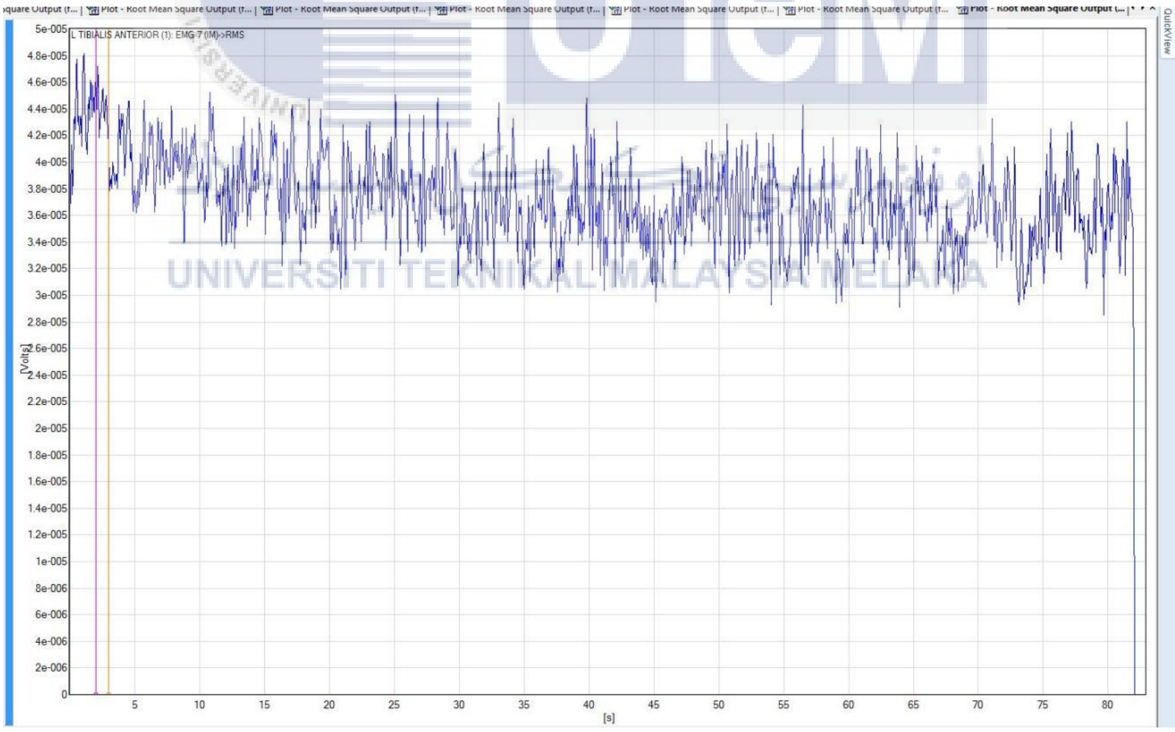


Figure A.8: (L) Tibialis – standing still

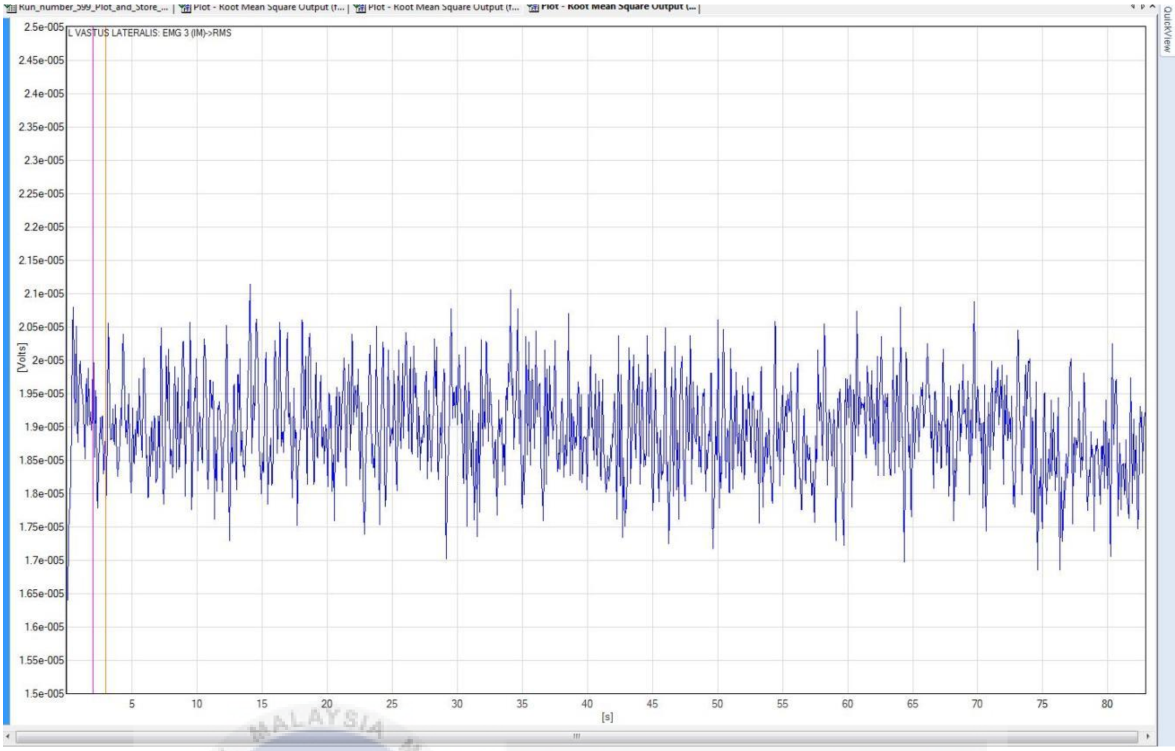


Figure A.9: (L) Vastus – standing still

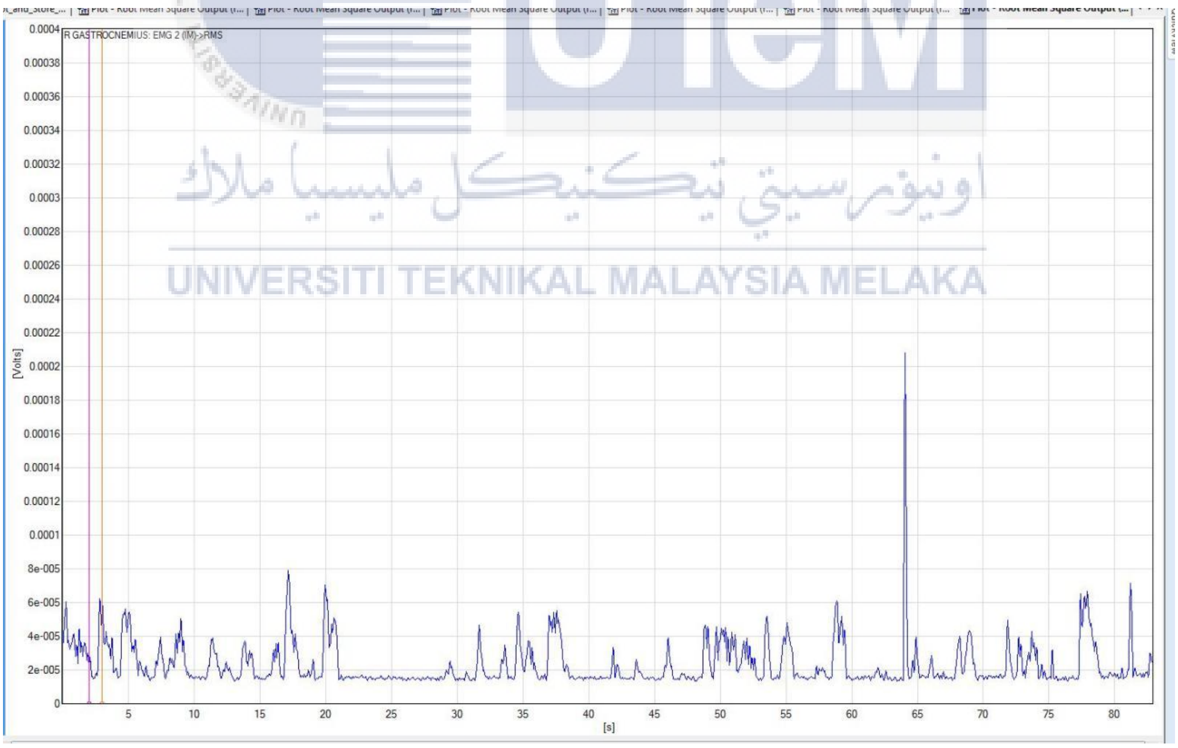


Figure A.10: (R) Gastro – standing still

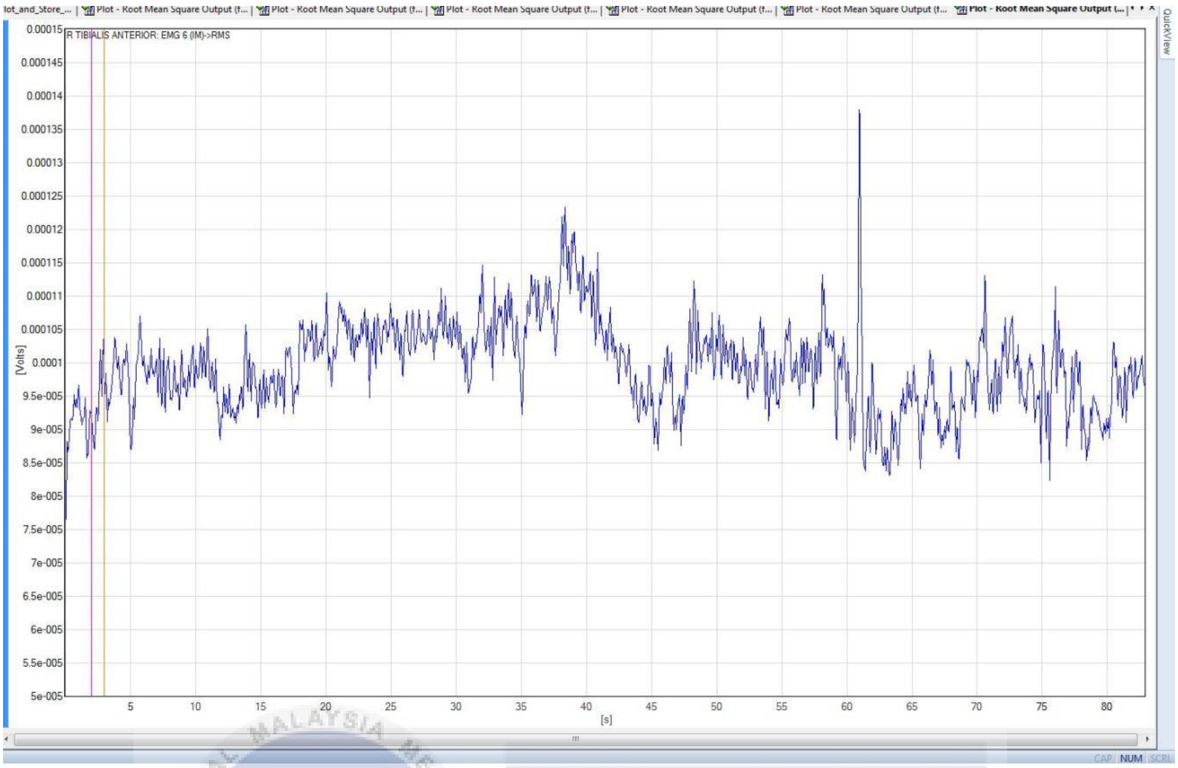


Figure A.11: (R) Tibialis – standing still

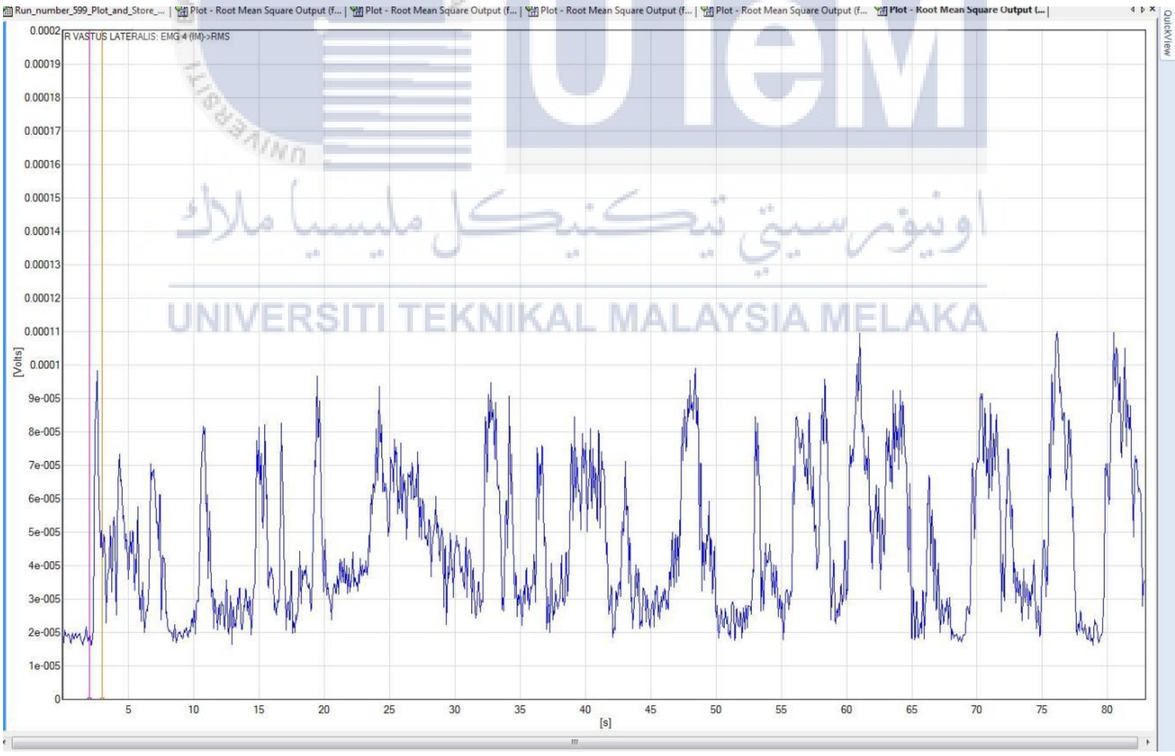


Figure A.12: (R) Vastus – standing still

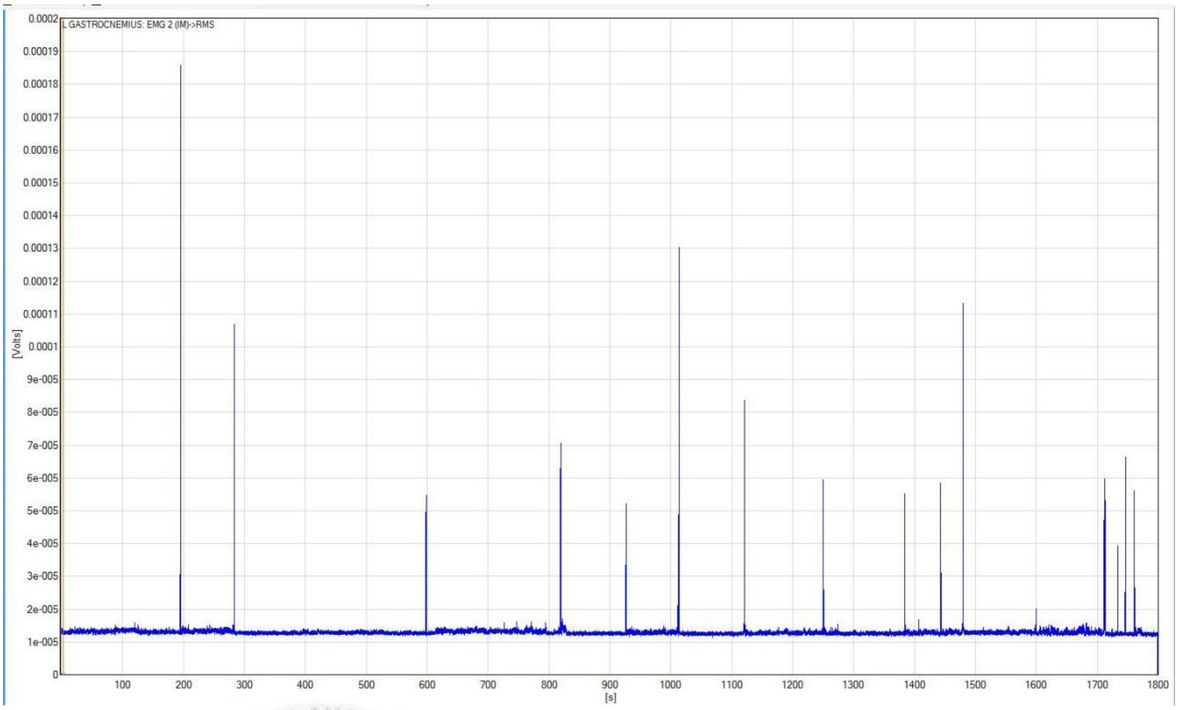


Figure A.13: Design exoskeleton (L) Gastro – sitting

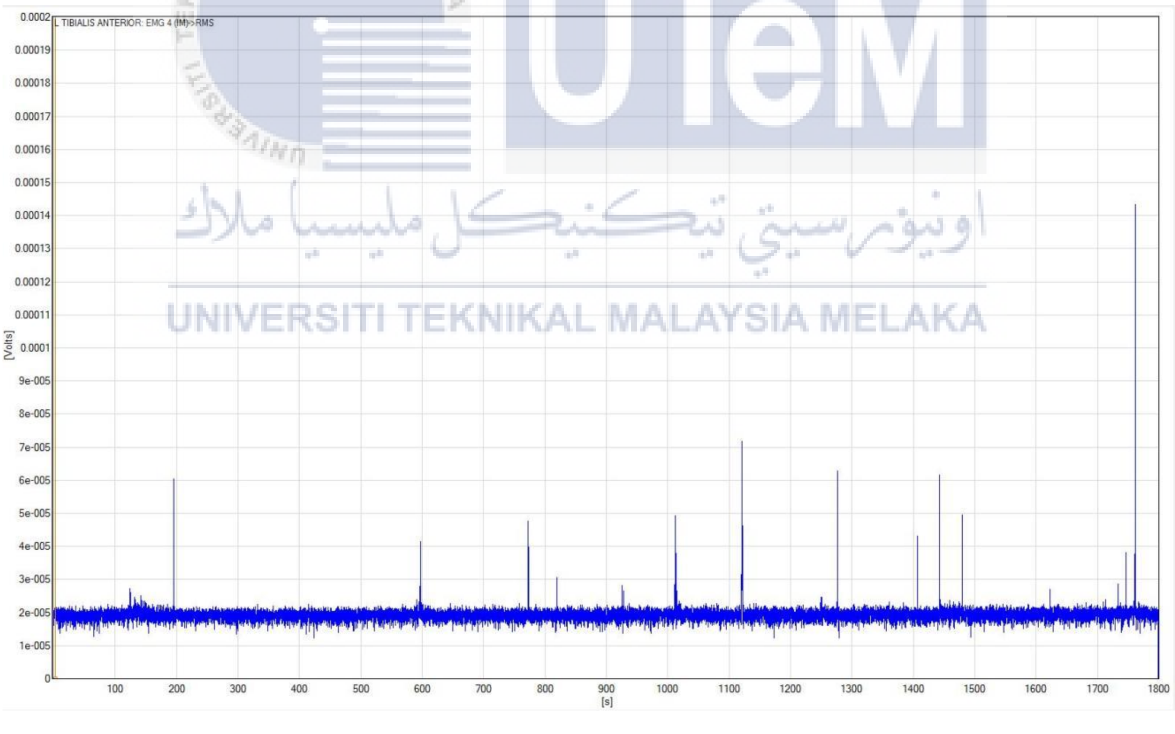


Figure A.14: Design exoskeleton (L) Tibialis - sitting

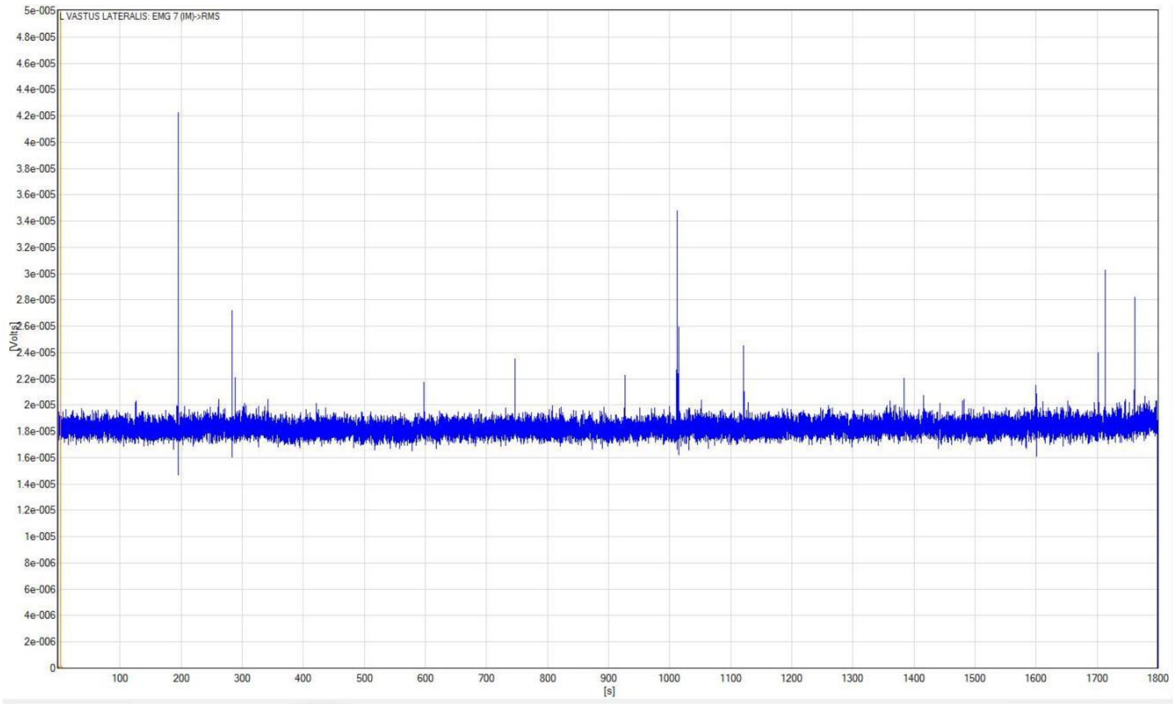


Figure A.16: Design exoskeleton (L) Vastus - sitting

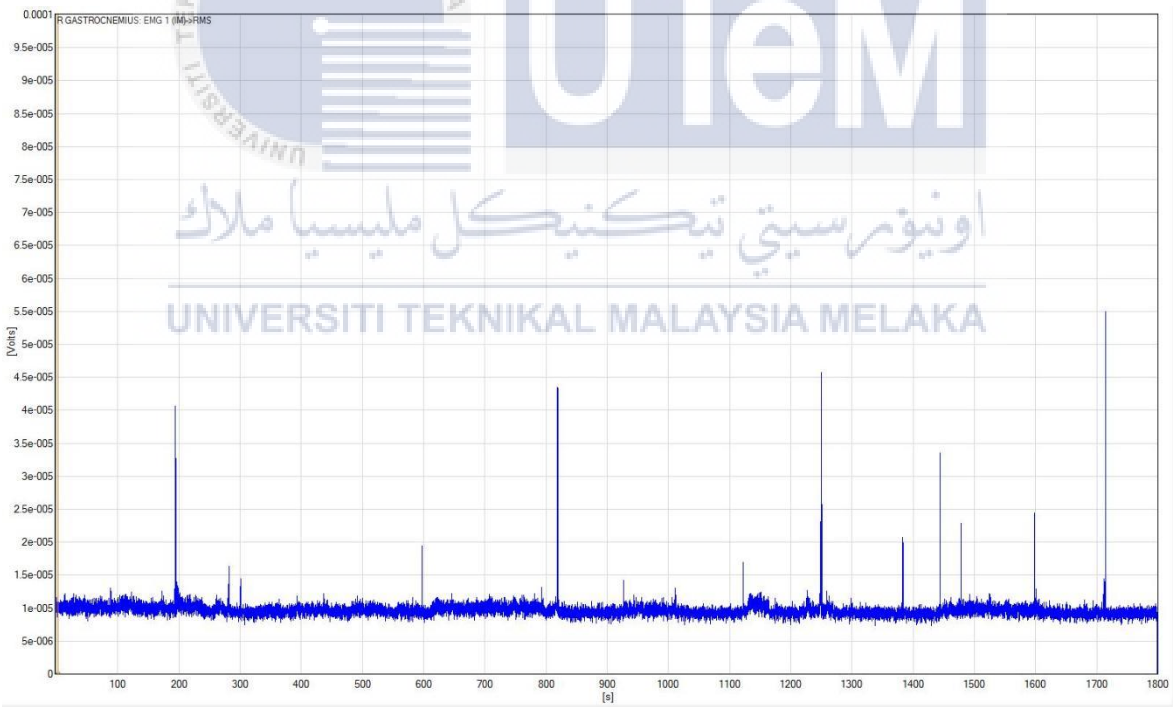


Figure A.17: Design exoskeleton (R) Gastro - sitting

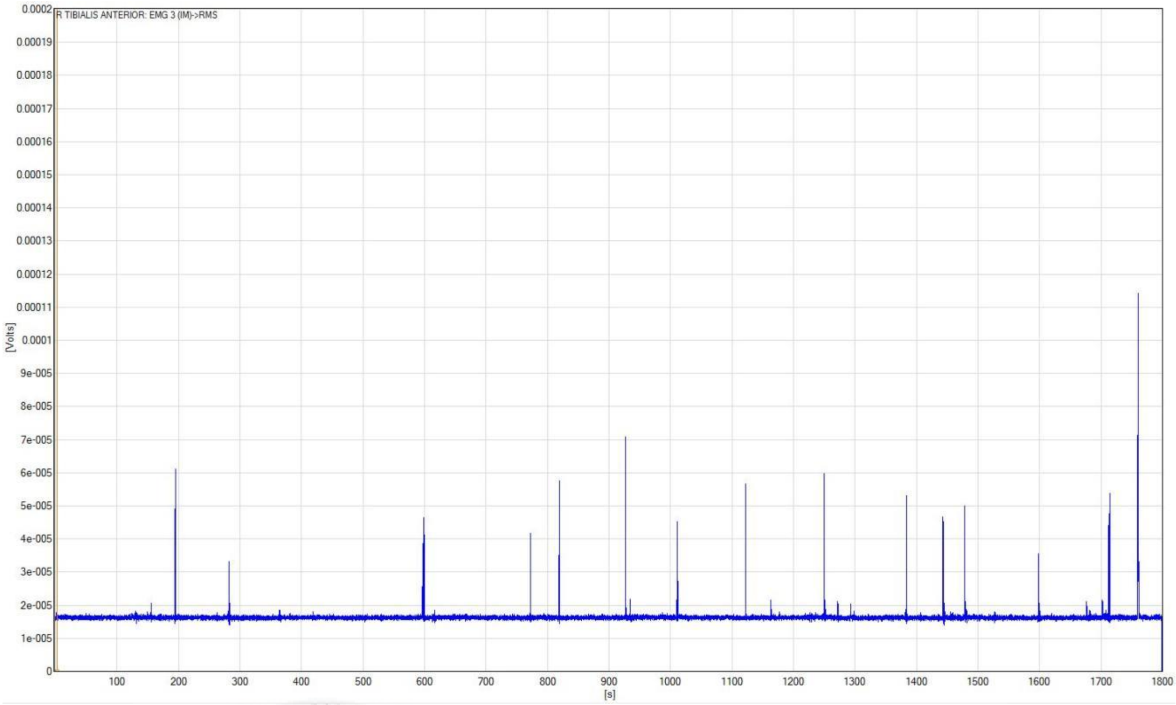


Figure A.18: Design exoskeleton (R) Tibialis – sitting

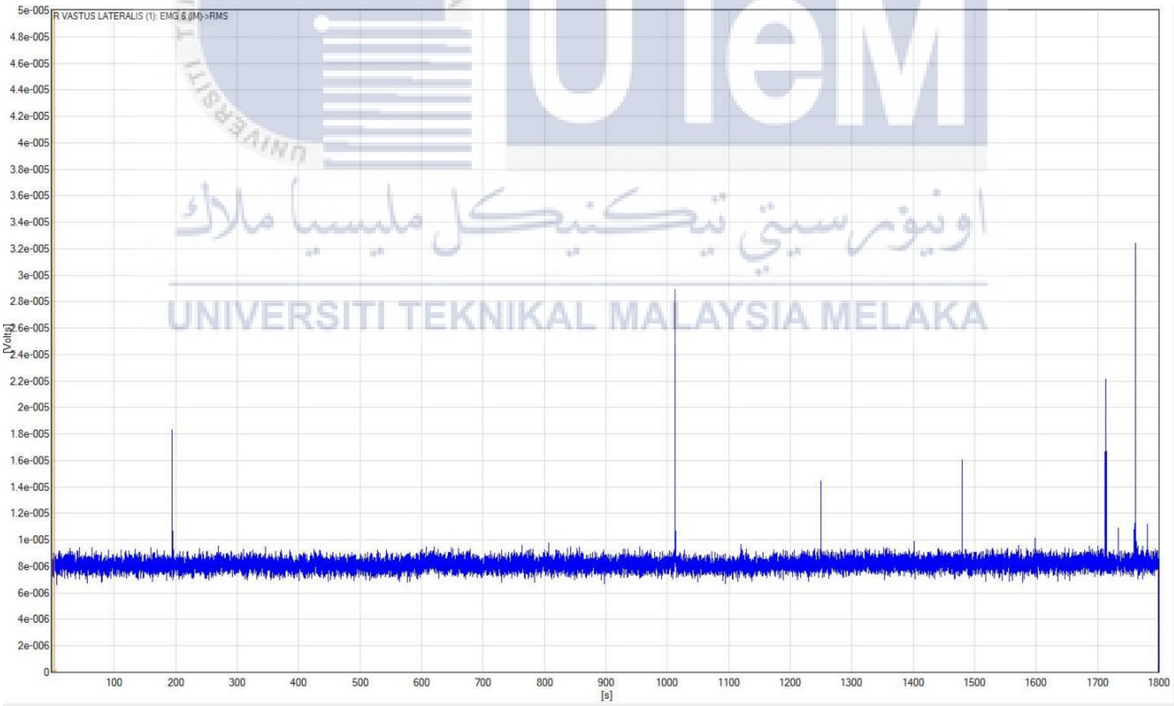


Figure A.19: Design exoskeleton (R) Vastus – sitting

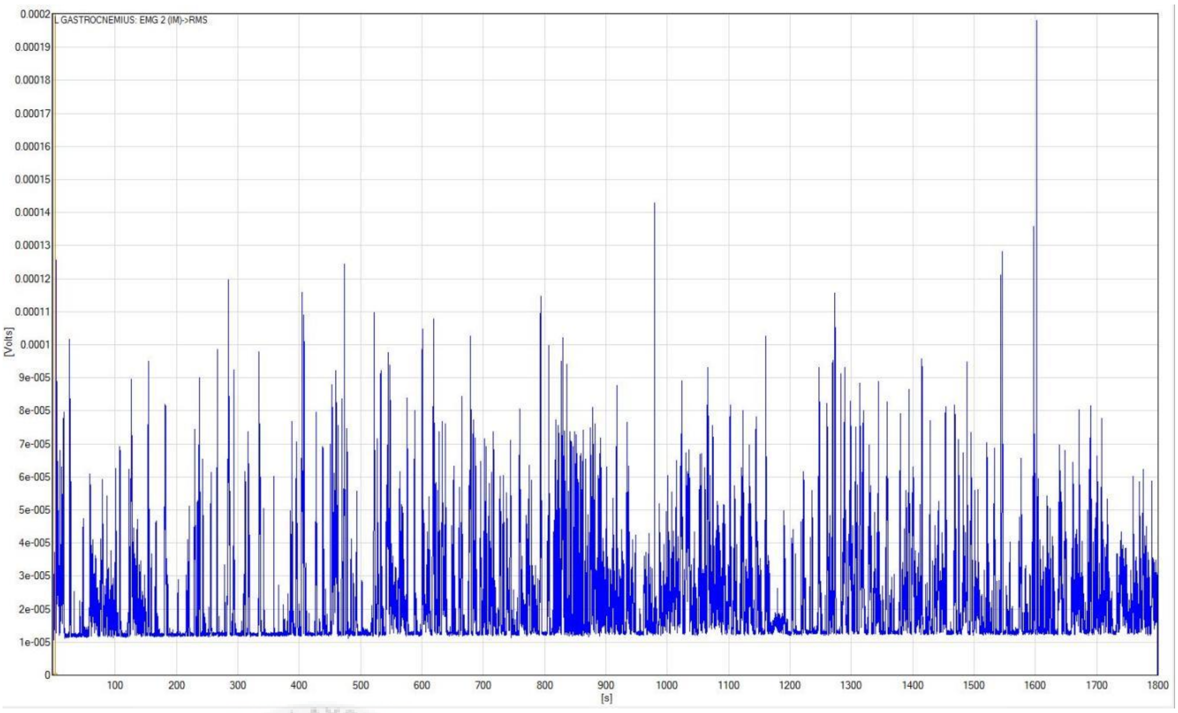


Figure A.20: Design exoskeleton (L) Gastro – standing

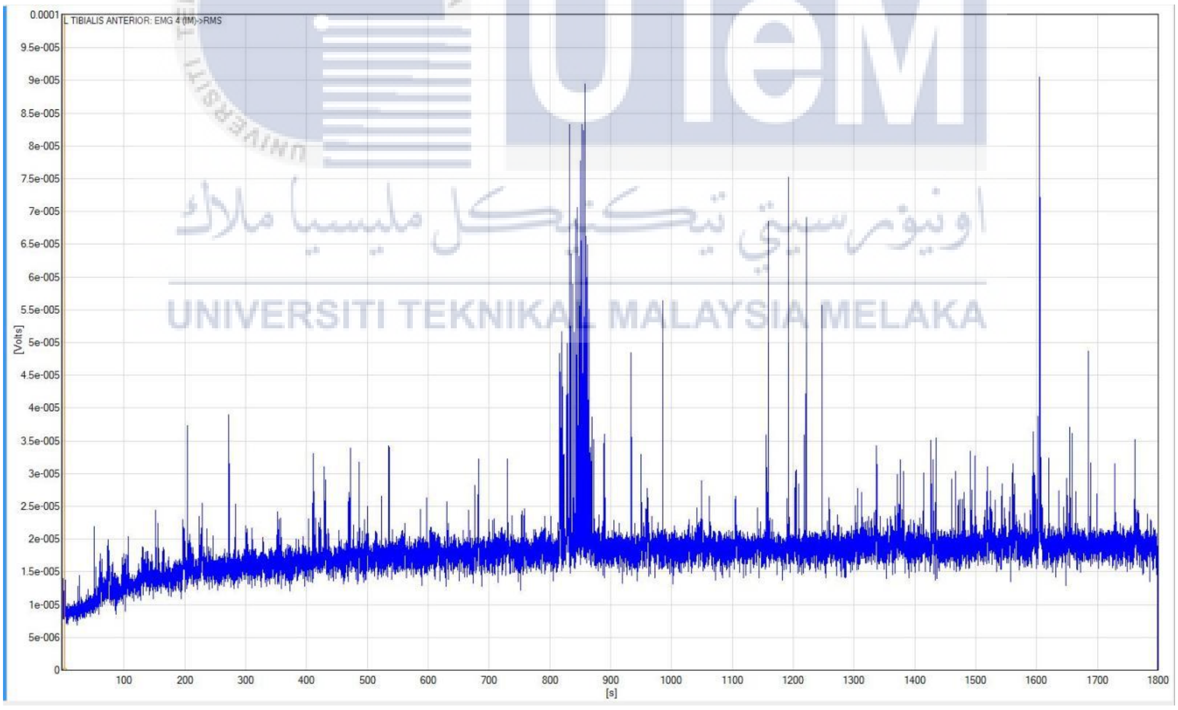


Figure A.21: Design exoskeleton (L) Tibialis – standing

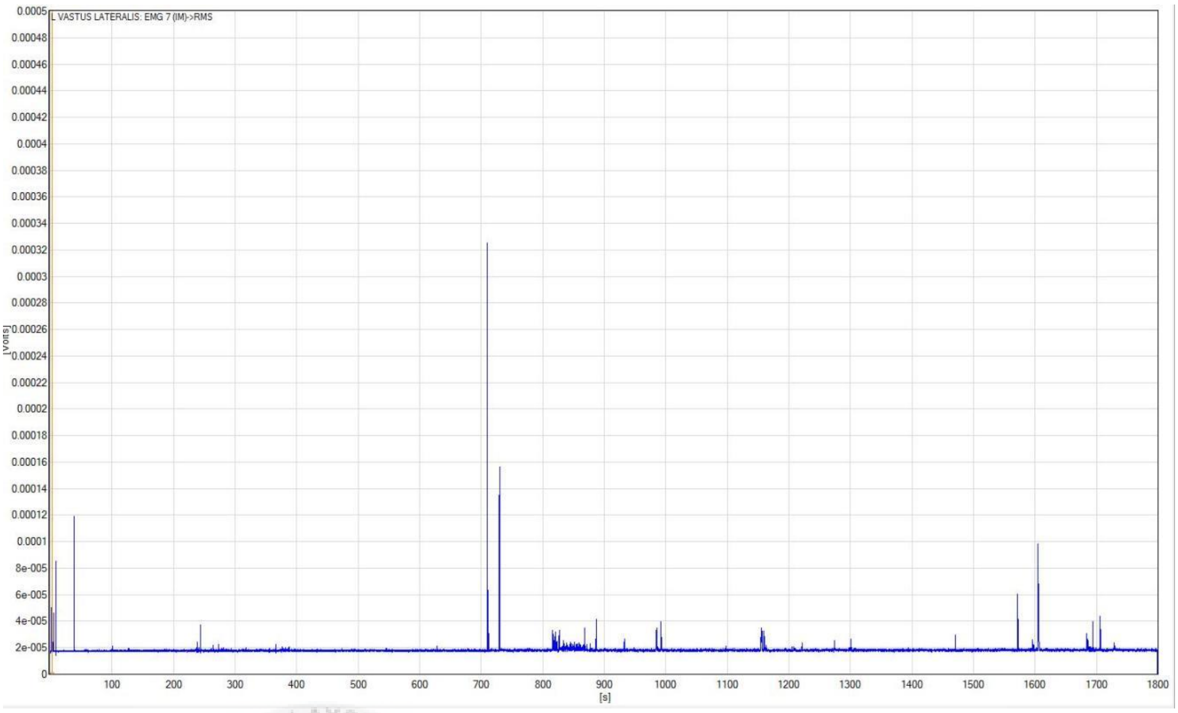


Figure A.22: Design exoskeleton (L) Vastus – standing

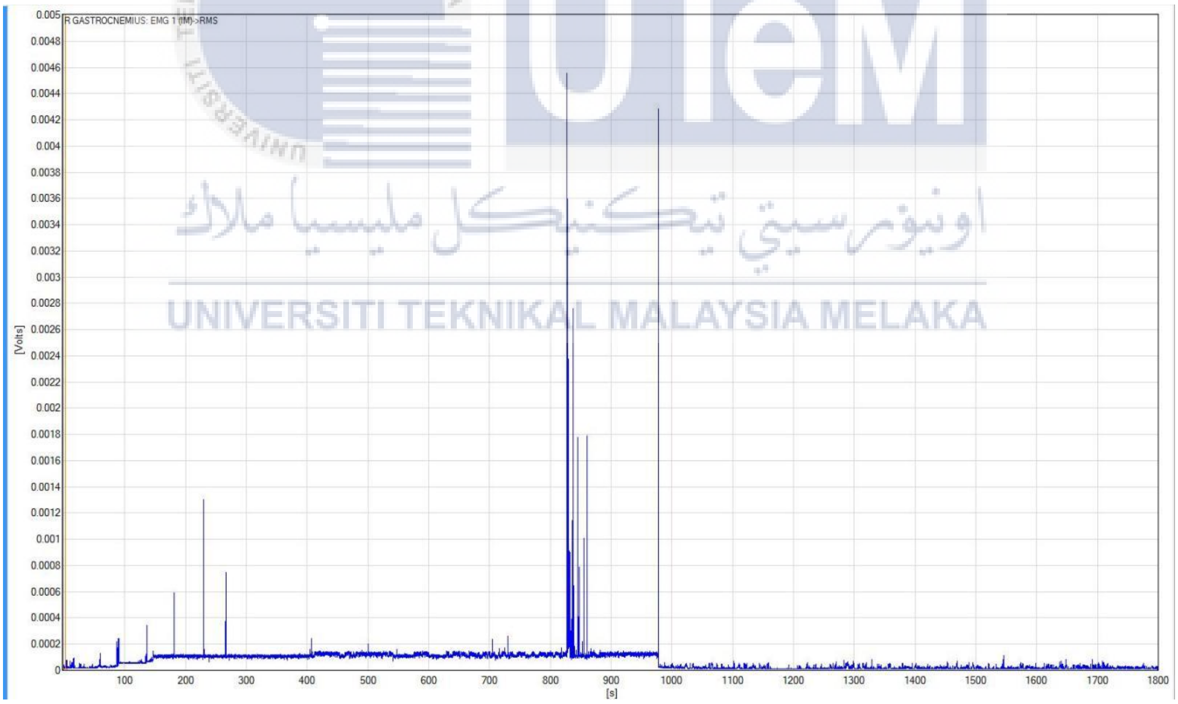


Figure A.23: Design exoskeleton (R) Gastro – standing

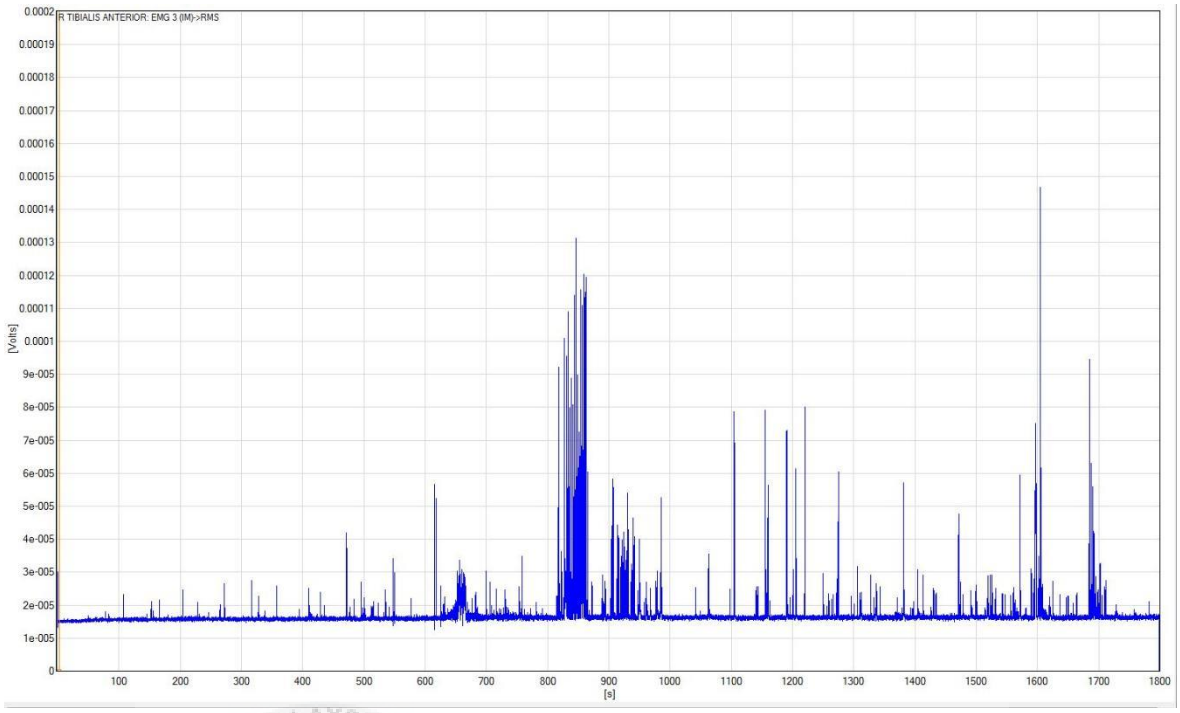


Figure A.24: Design exoskeleton (R) Tibialis – standing

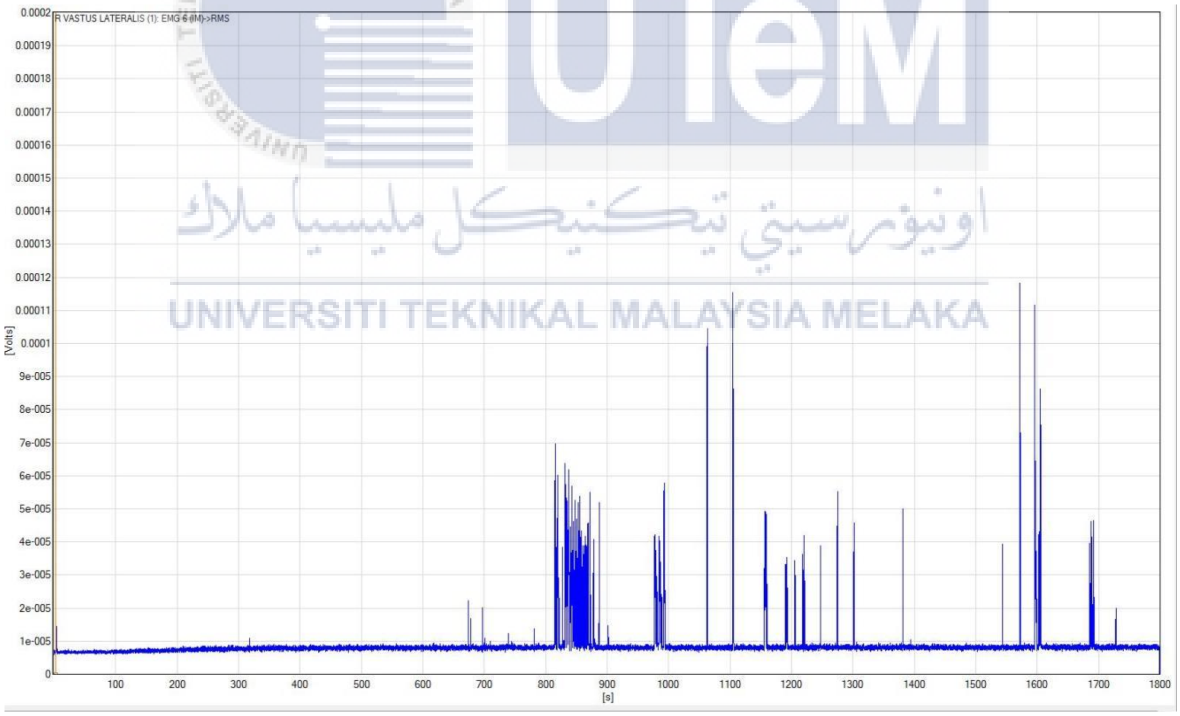


Figure A.25: Design exoskeleton (R) Vastus – standing

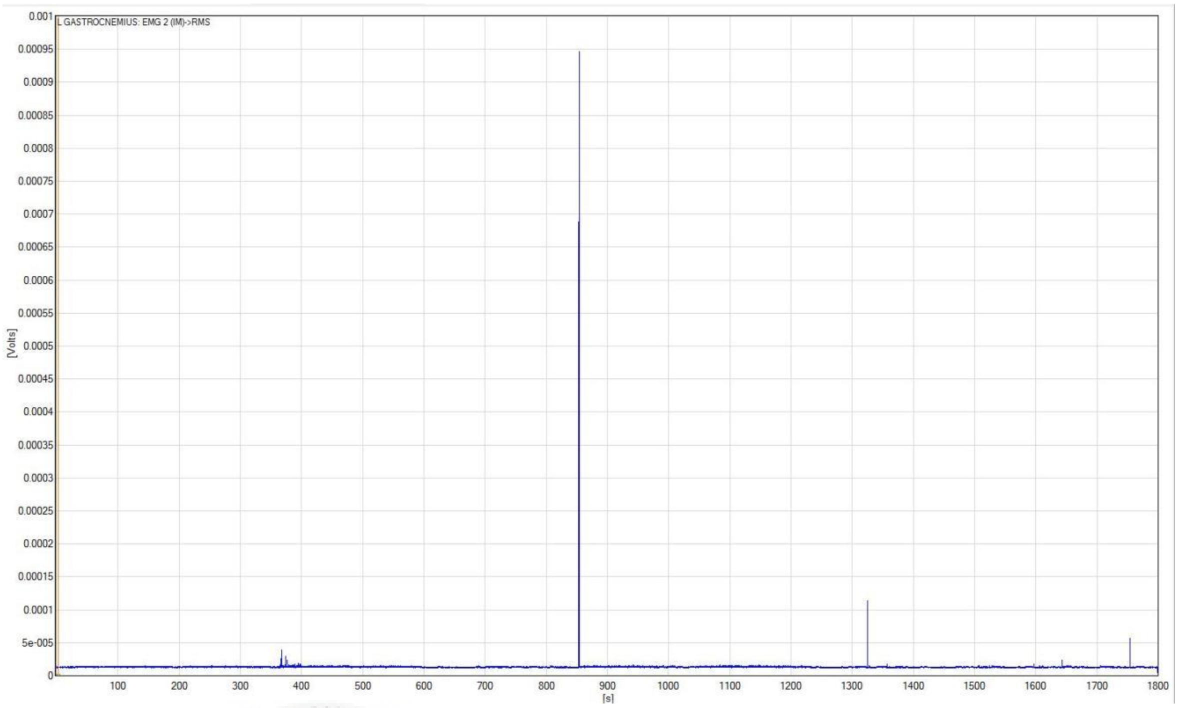


Figure A.26: Commercial exoskeleton (L) Gastro – sitting

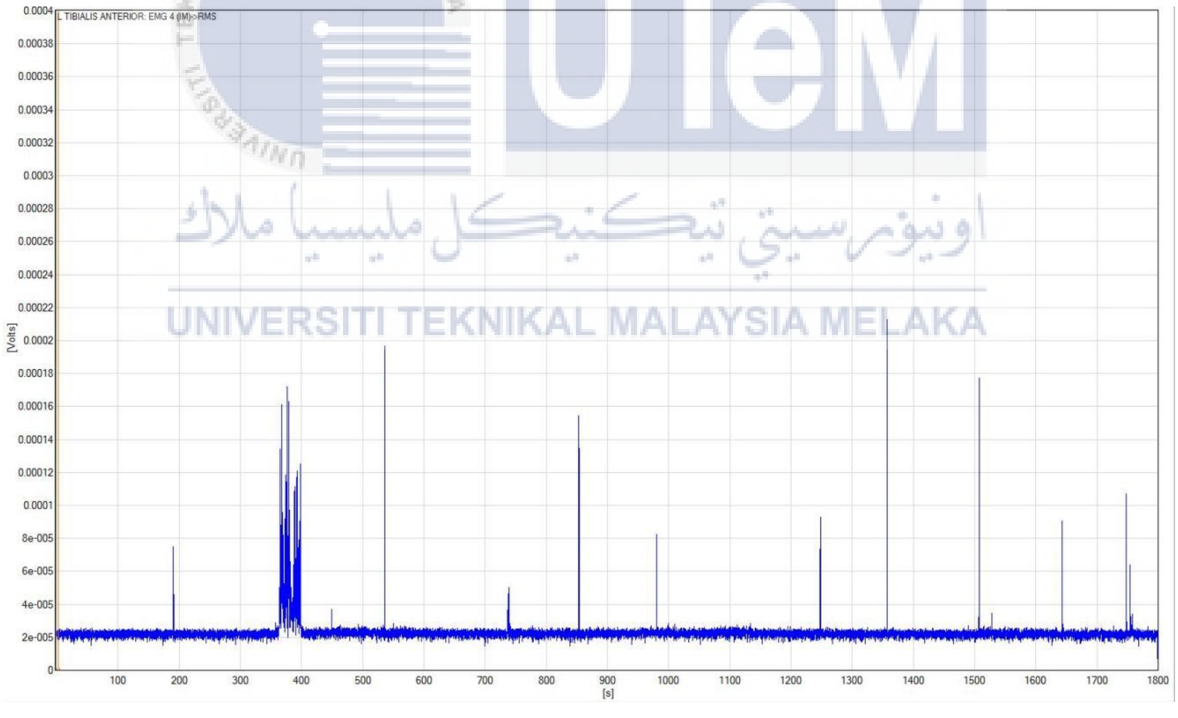


Figure A.27: Commercial exoskeleton (L) Tibialis – sitting

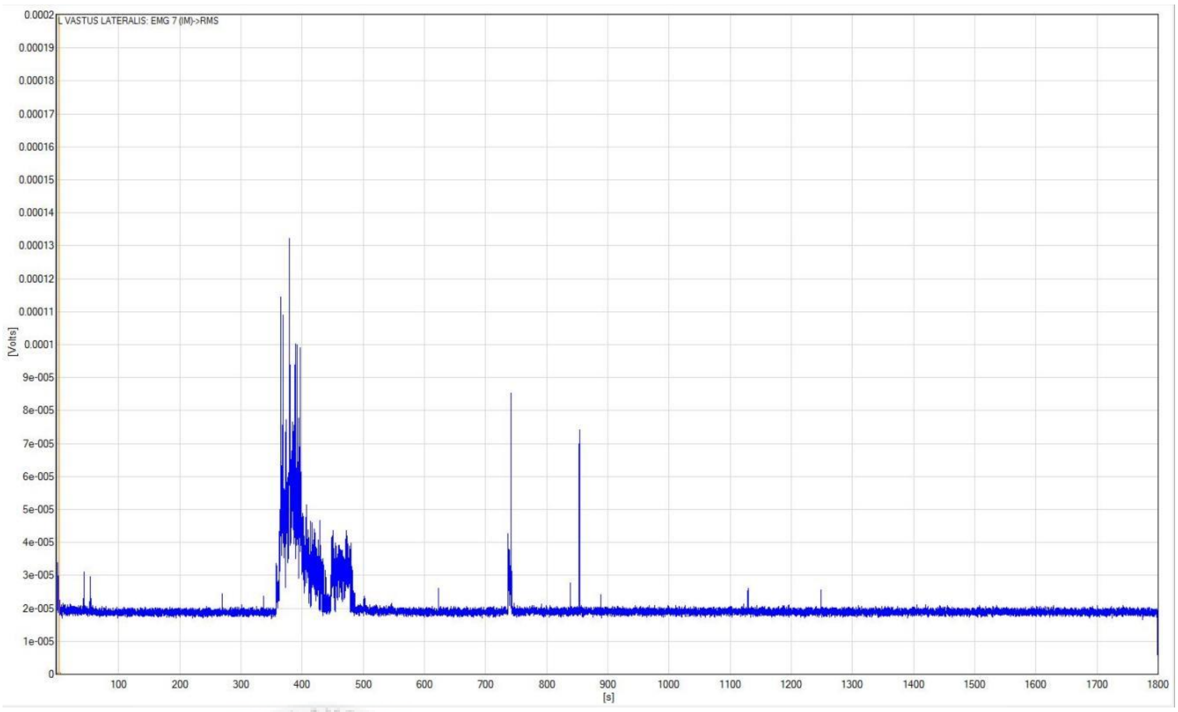


Figure A.28: Commercial exoskeleton (L) Vastus – sitting

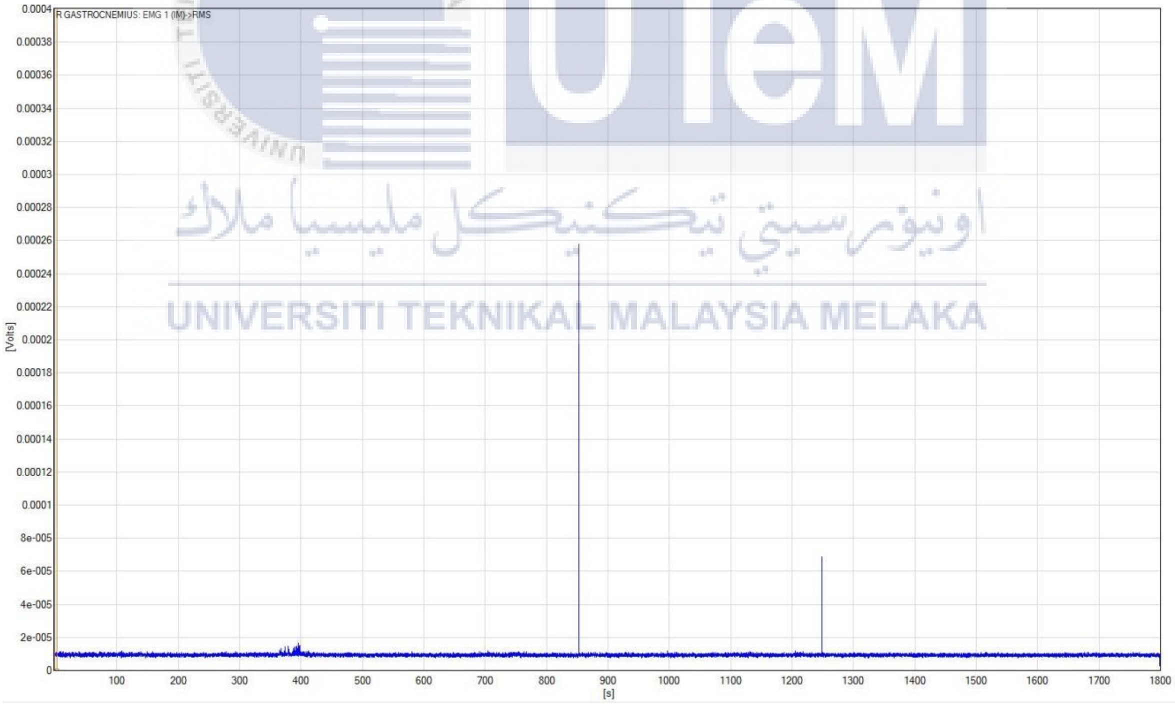


Figure A.29: Commercial exoskeleton (R) Gastro – sitting

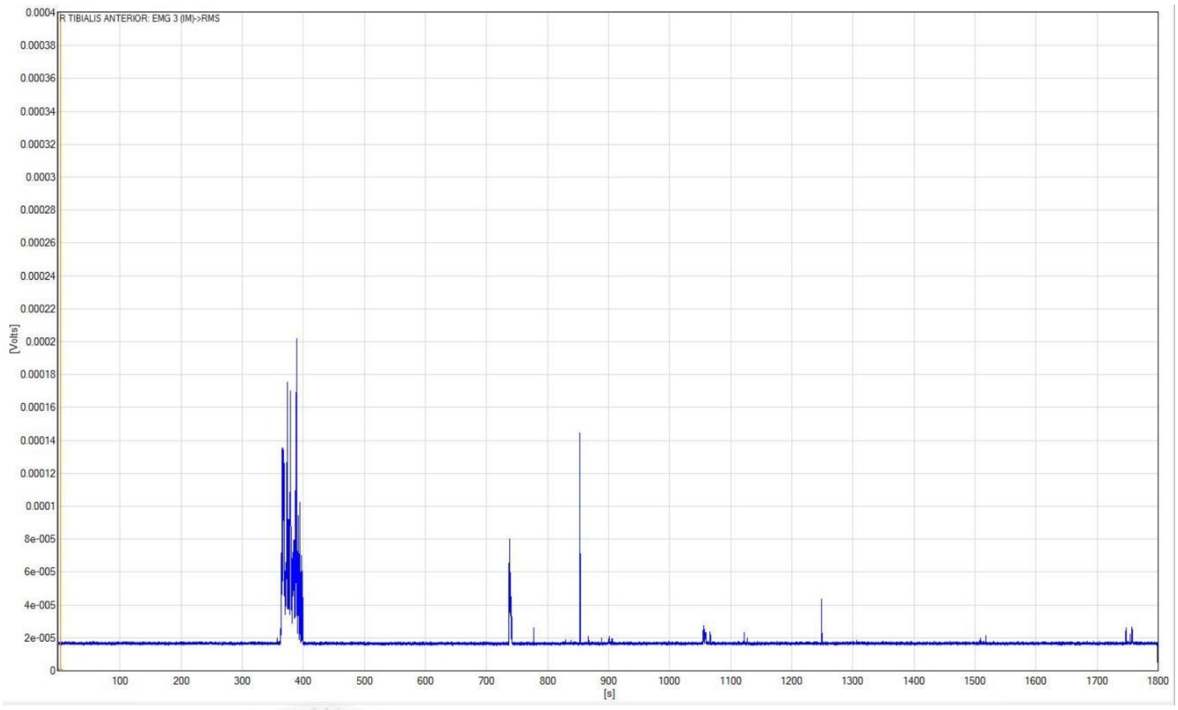


Figure A.30: Commercial exoskeleton (R) Tibialis – sitting

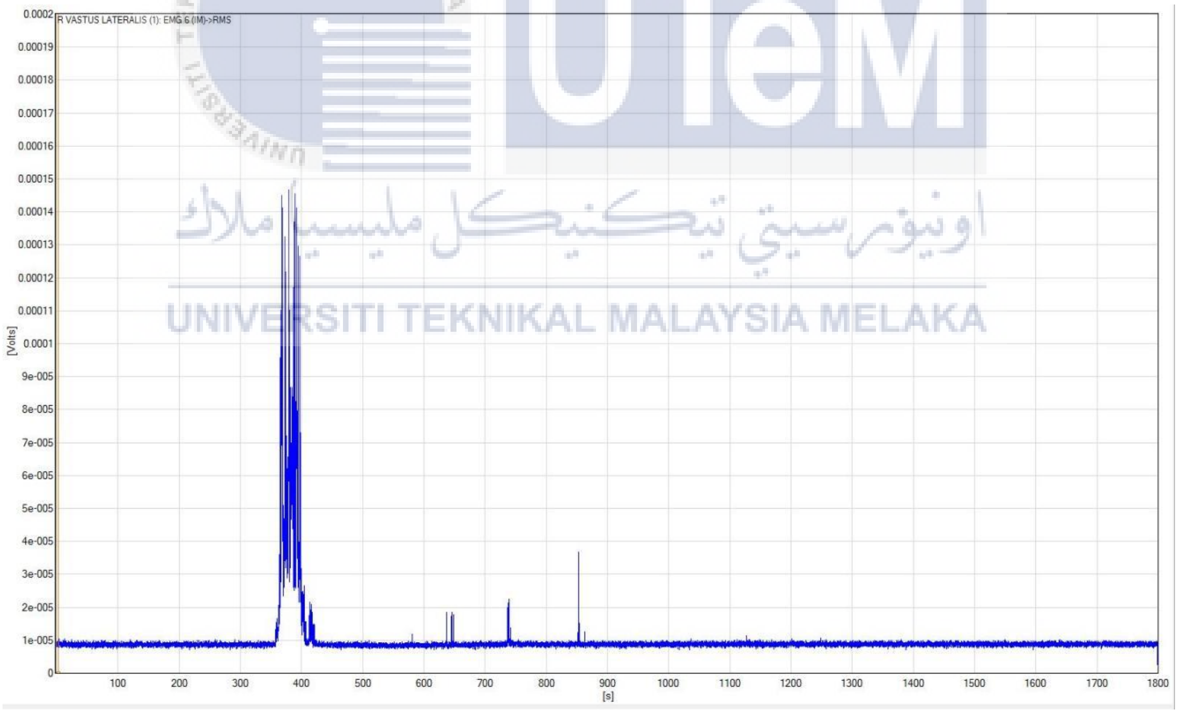


Figure A.31: Commercial exoskeleton (R) Vastus – sitting

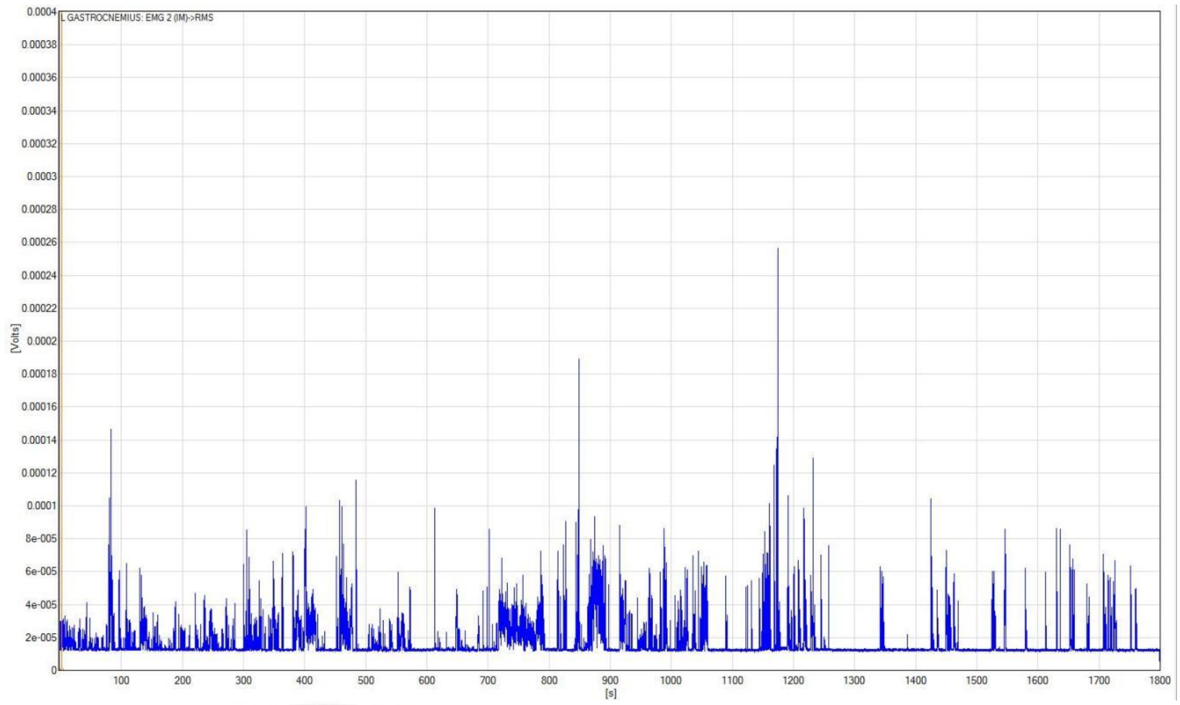


Figure A.32: Commercial exoskeleton (L) Gastro – standing

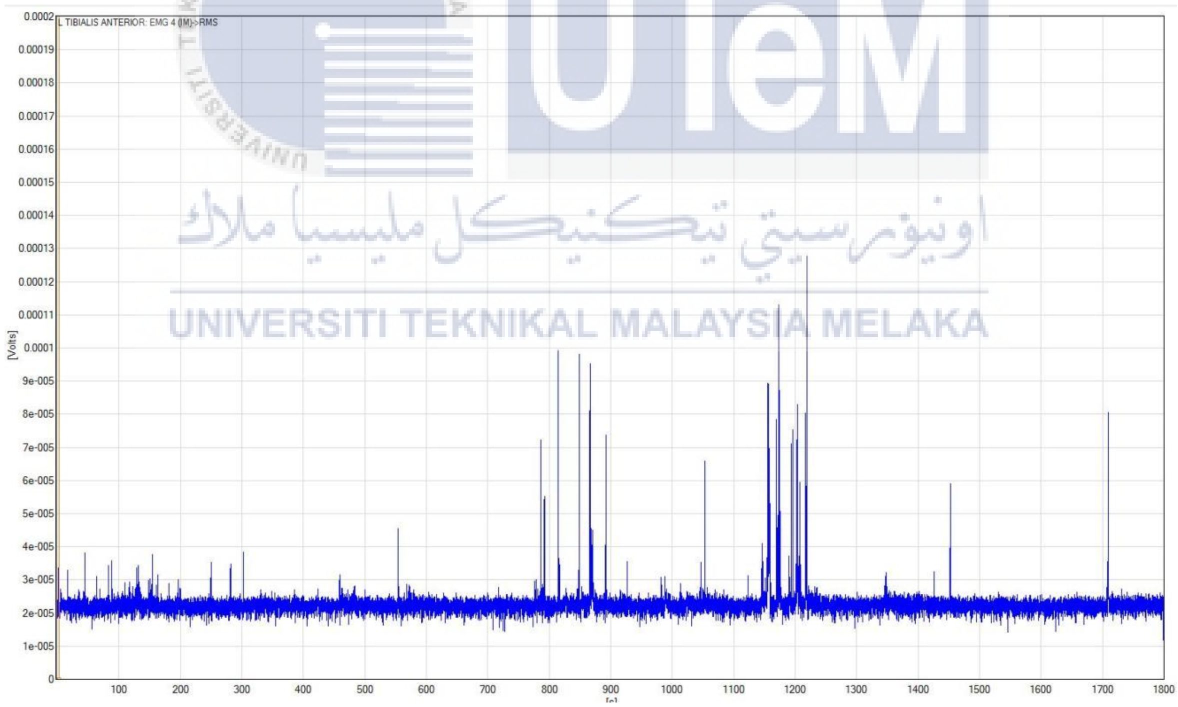


Figure A.33: Commercial exoskeleton (L) Tibialis – standing

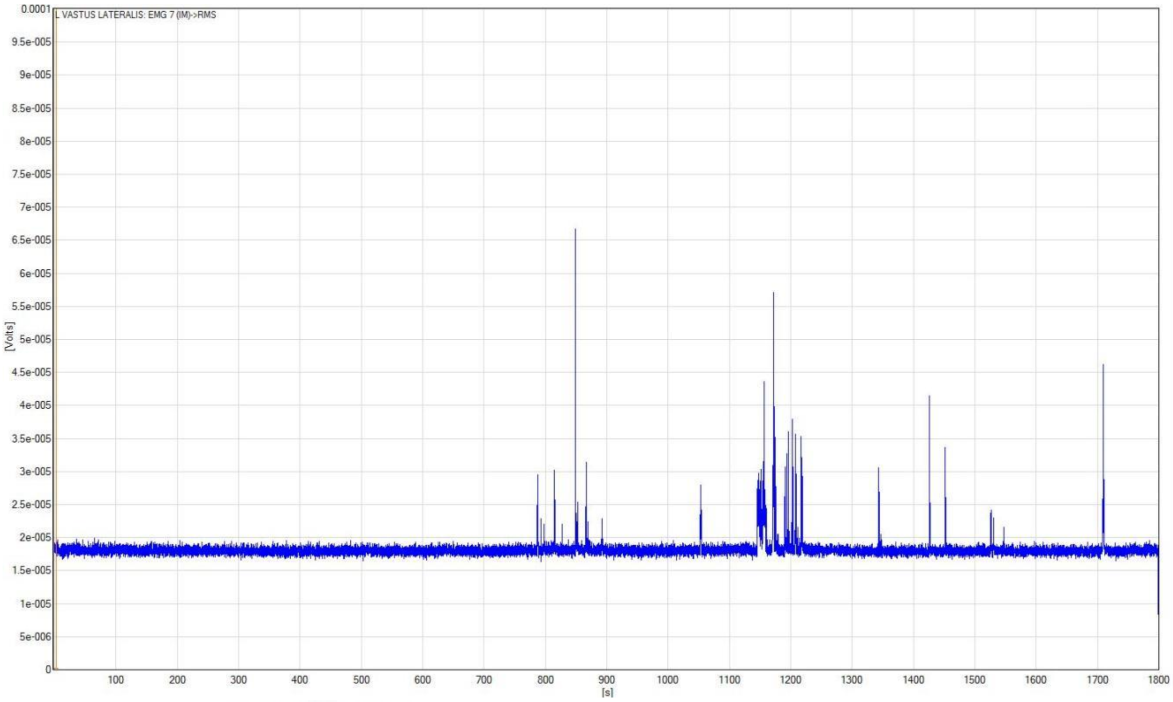


Figure A.34: Commercial exoskeleton (L) Vastus – standing

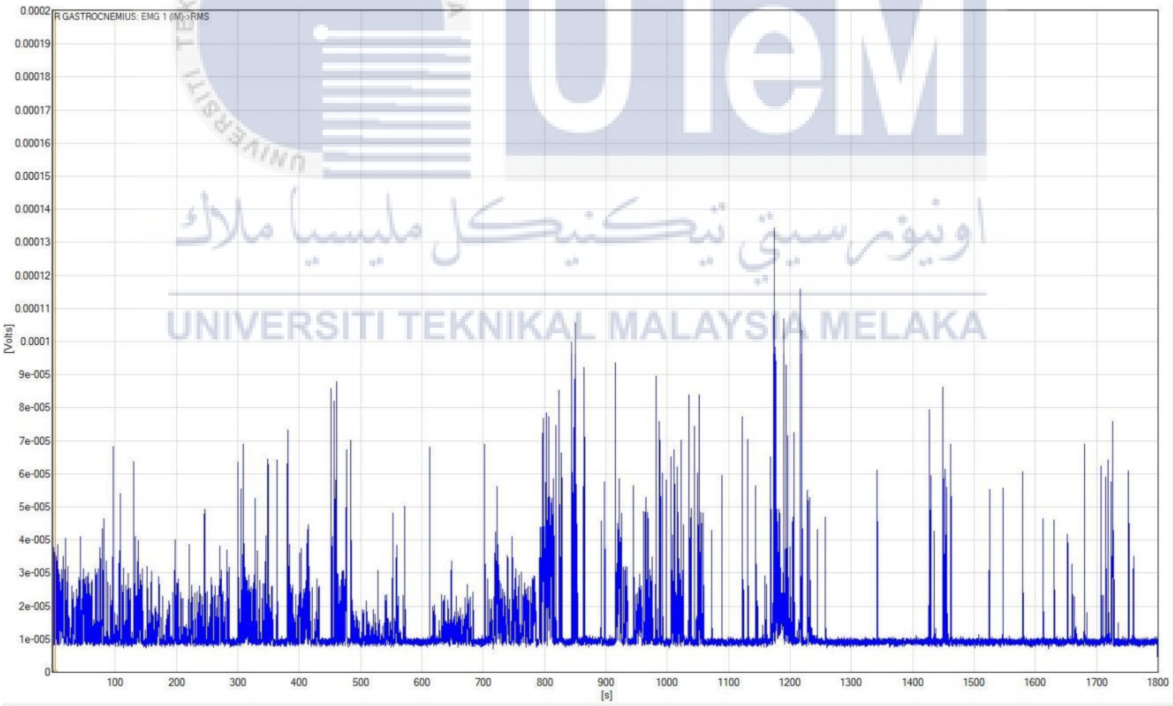


Figure A.35: Commercial exoskeleton (R) Gastro – standing

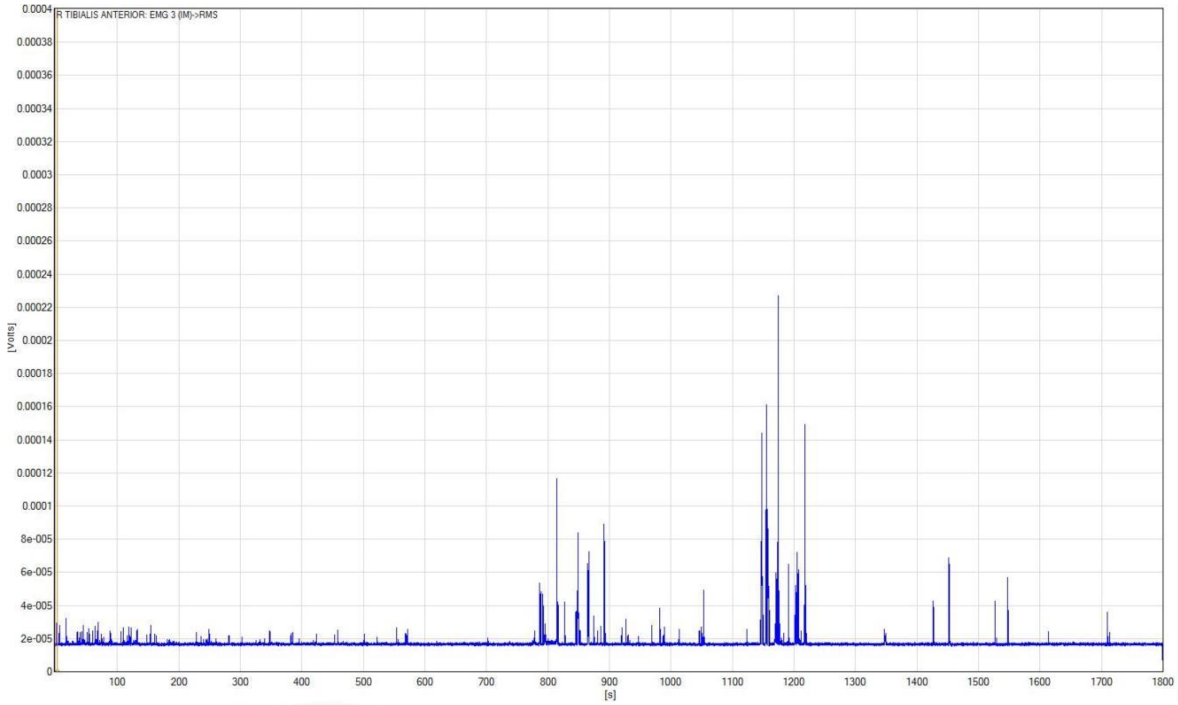


Figure A.36: Commercial exoskeleton (R) Tibialis – standing

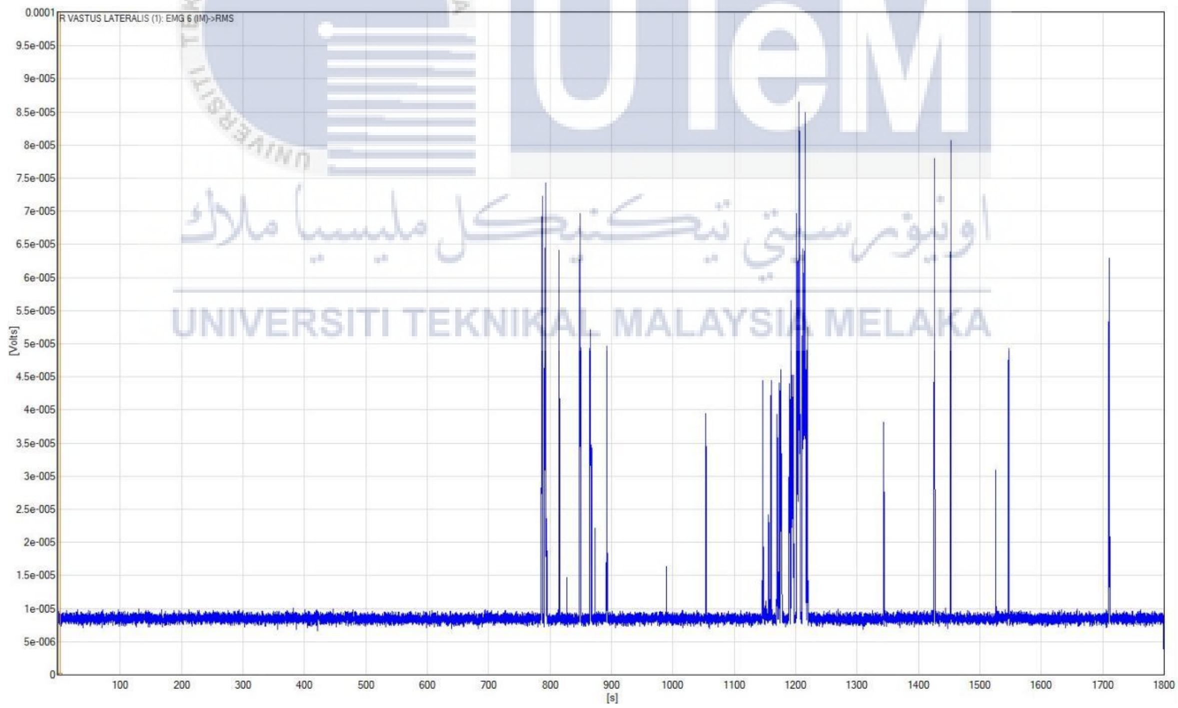


Figure A.37: Commercial exoskeleton (R) Vastus – standing

Table A.1: Muscle contraction of subject (without exoskeleton)

Subject No	name of muscle	Maximum Voluntary Contraction (MVC/ V)	Muscle contraction with EXOSKELETON (DESIGN)				
			Minimum (V)	Mean (V)	Maximum (V)	Standard Deviation (V)	Percentage of Muscle Activity (%)
1	LEFT GASTROCNEMIUS	0.000812689	7.87091E-06	1.33309E-05	4.1551E-05	3.99834E-06	5.11
	RIGHT GASTROCNEMIUS	5.49173E-05	0	9.99979E-06	1.467E-05	3.40438E-07	26.71
	LEFT VASTUS LATERALIS	0.000131521	1.35573E-05	1.93698E-05	9.07066E-05	1.95043E-06	68.97
	RIGHT VASTUS LATERALIS	0.000107692	1.28355E-05	1.87039E-05	9.67329E-05	2.85419E-06	89.82
	LEFT TIBIALIS ANTERIOR	8.88513E-05	1.78424E-05	6.27538E-05	7.87945E-05	1.18918E-05	88.68
	RIGHT TIBIALIS ANTERIOR	0.000207293	2.55666E-05	0.000158346	0.000179993	3.0113E-05	86.83
2	LEFT GASTROCNEMIUS	0.000153127	7.81E-06	1.65362E-05	5.81679E-05	2.07508E-07	37.99
	RIGHT GASTROCNEMIUS	5.46416E-05	1.3086E-05	1.97186E-05	3.49645E-05	6.15698E-06	63.99
	LEFT VASTUS LATERALIS	0.000126758	1.63933E-05	1.89679E-05	2.11399E-05	7.11778E-07	16.68
	RIGHT VASTUS LATERALIS	0.000101696	1.59876E-05	4.28619E-05	7.46525E-05	1.69797E-05	73.41
	LEFT TIBIALIS ANTERIOR	8.63704E-05	0	3.68281E-05	4.81197E-05	4.96677E-06	55.71
	RIGHT TIBIALIS ANTERIOR	0.000202052	7.64323E-05	9.93326E-05	0.000137896	6.65767E-06	68.25
3	LEFT GASTROCNEMIUS	0.001709239	0	0.00078182	0.001650775	0.000286041	96.58
	RIGHT GASTROCNEMIUS	0.004241894	0	0.001517488	0.003213273	0.000606498	75.75
	LEFT VASTUS LATERALIS	0.001949217	0	0.003661599	0.001034672	0.000432667	53.08
	RIGHT VASTUS LATERALIS	0.001140644	0	0.001096444	0.000791463	0.00034347	69.39
	LEFT TIBIALIS ANTERIOR	0.003434575	0	0.001159239	0.001009875	0.000341271	29.40
	RIGHT TIBIALIS ANTERIOR	0.001958865	0	0.000533366	0.00163539	0.000164716	83.49

4	LEFT GASTROCNEMIUS	3.96848E-05	1.3624E-05	1.50365E-05	2.21862E-05	7.47073E-07	55.91
	RIGHT GASTROCNEMIUS	3.92469E-05	8.71984E-06	1.41866E-05	2.24381E-05	2.15898E-06	57.17
	LEFT VASTUS LATERALIS	0.000175366	0	1.34514E-05	1.38072E-05	1.27472E-06	7.87
	RIGHT VASTUS LATERALIS	0.000222482	4.03954E-06	4.25595E-06	4.87507E-06	7.31654E-08	2.19
	LEFT TIBIALIS ANTERIOR	0.000106673	4.44296E-06	6.50134E-06	7.56903E-05	4.0901E-06	70.96
	RIGHT TIBIALIS ANTERIOR	0.000103772	1.3835E-05	1.47717E-05	2.27529E-05	4.65673E-07	21.93
5	LEFT GASTROCNEMIUS	7.07816E-05	7.54375E-06	1.68964E-05	3.26344E-05	5.50386E-06	46.11
	RIGHT GASTROCNEMIUS	9.88799E-05	1.12566E-05	1.50779E-05	3.13075E-05	3.57619E-06	31.66
	LEFT VASTUS LATERALIS	0.000124857	5.99454E-06	7.69235E-06	8.55566E-06	3.18165E-07	6.85
	RIGHT VASTUS LATERALIS	9.16587E-05	1.32924E-05	1.63069E-05	1.69656E-05	2.55062E-07	18.51
	LEFT TIBIALIS ANTERIOR	5.69618E-05	1.31898E-05	1.62183E-05	2.71748E-05	1.15273E-06	47.71
	RIGHT TIBIALIS ANTERIOR	7.3401E-05	1.55578E-05	2.17699E-05	2.53086E-05	1.41072E-06	34.48
6	LEFT GASTROCNEMIUS	4.07277E-05	1.57241E-05	1.86985E-05	2.3063E-05	1.27079E-06	56.63
	RIGHT GASTROCNEMIUS	3.85536E-05	1.03125E-05	1.33662E-05	1.77076E-05	1.23012E-06	45.93
	LEFT VASTUS LATERALIS	0.000155736	1.35761E-05	1.52005E-05	1.7672E-05	7.60642E-07	11.35
	RIGHT VASTUS LATERALIS	0.000163154	7.52246E-06	8.88654E-06	1.03018E-05	5.18118E-07	6.31
	LEFT TIBIALIS ANTERIOR	0.000152427	0	1.42143E-05	1.78449E-05	1.58487E-06	11.71
	RIGHT TIBIALIS ANTERIOR	0.00014417	1.33661E-05	1.55415E-05	1.64242E-05	2.69695E-07	11.39
7	LEFT GASTROCNEMIUS	9.62262E-05	7.60401E-06	9.57449E-06	1.33836E-05	7.26613E-07	13.91
	RIGHT GASTROCNEMIUS	0.00014878	1.10491E-05	1.80829E-05	3.95914E-05	6.7556E-06	26.61
	LEFT VASTUS LATERALIS	0.00019726	5.20201E-06	5.53775E-06	9.86715E-06	2.70709E-07	5.00

	RIGHT VASTUS LATERALIS	0.000105907	1.4324E-05	1.63E-05	1.97816E-05	2.62351E-07	18.68
	LEFT TIBIALIS ANTERIOR	0.000224833	1.32307E-05	1.51832E-05	1.96937E-05	3.46192E-07	8.76
	RIGHT TIBIALIS ANTERIOR	0.000153591	5.42763E-06	6.64198E-06	9.1673E-06	4.49689E-07	5.97
8	LEFT GASTROCNEMIUS	0.000355719	5.6064E-06	8.5128E-06	3.61105E-05	4.32525E-06	10.15
	RIGHT GASTROCNEMIUS	0.000251516	1.12417E-05	1.45659E-05	2.66488E-05	2.7578E-06	10.60
	LEFT VASTUS LATERALIS	5.38571E-05	9.32661E-06	1.16279E-05	1.64234E-05	9.70932E-07	30.49
	RIGHT VASTUS LATERALIS	5.67973E-05	1.64643E-05	1.77538E-05	2.34179E-05	5.77757E-07	41.23
	LEFT TIBIALIS ANTERIOR	0.000224567	1.4546E-05	1.57482E-05	1.71732E-05	3.54574E-07	7.65
	RIGHT TIBIALIS ANTERIOR	0.000216414	5.90466E-06	7.80855E-06	2.30708E-05	1.07844E-06	10.66
9	LEFT GASTROCNEMIUS	3.03876E-05	0	1.52708E-05	2.01731E-05	7.26929E-06	66.39
	RIGHT GASTROCNEMIUS	5.20869E-05	0	1.34583E-05	2.90702E-05	3.37954E-05	55.81
	LEFT VASTUS LATERALIS	3.20901E-05	0	1.31709E-05	1.99724E-05	1.02188E-06	62.24
	RIGHT VASTUS LATERALIS	0.000100299	0	4.31956E-06	4.0061E-05	5.90923E-07	39.94
	LEFT TIBIALIS ANTERIOR	0.000758295	0	4.75498E-05	0.00030736	7.61674E-05	40.53
	RIGHT TIBIALIS ANTERIOR	0.000116053	0	4.01753E-05	5.42623E-05	0.000119391	46.76
10	LEFT GASTROCNEMIUS	8.31727E-05	0	2.16768E-05	6.34284E-05	6.22968E-06	76.26
	RIGHT GASTROCNEMIUS	5.45075E-05	0	1.11296E-05	4.00971E-05	3.07686E-06	73.56
	LEFT VASTUS LATERALIS	0.000414482	0	1.61073E-05	0.000284486	8.95213E-06	68.64
	RIGHT VASTUS LATERALIS	0.000119195	0	7.12736E-06	4.79794E-05	2.73302E-06	40.25
	LEFT TIBIALIS ANTERIOR	0.000148897	0	1.02299E-05	8.69045E-05	7.84128E-06	58.37
	RIGHT TIBIALIS	0.000210485	0	1.56612E-05	0.000169126	3.07308E-06	80.35

	ANTERIOR						

Table A.2: Muscle contraction of subject (with exoskeleton)

Subject No	name of muscle	Maximum Voluntary Contraction (MVC/ V)	Muscle contraction with EXOSKELETON (DESIGN)				
			Minimum (V)	Mean (V)	Maximum (V)	Standard Deviation (V)	Percentage of Muscle Activity (%)
1	LEFT GASTROCNEMIUS	0.000812689	0	1.2064E-05	1.37625E-05	5.59095E-07	1.69
	RIGHT GASTROCNEMIUS	5.49173E-05	0	9.08877E-06	1.09995E-05	1.72923E-06	20.03
	LEFT VASTUS LATERALIS	0.000131521	0	1.70679E-05	2.3095E-05	8.1188E-07	17.56
	RIGHT VASTUS LATERALIS	0.000107692	0	7.58608E-06	1.56512E-05	8.84877E-07	14.53
	LEFT TIBIALIS ANTERIOR	8.88513E-05	0	2.17681E-05	3.87168E-05	6.08508E-06	43.57
	RIGHT TIBIALIS ANTERIOR	0.000207293	0	1.59538E-05	1.92397E-05	6.08691E-07	9.28
2	LEFT GASTROCNEMIUS	0.000153127	0	1.27338E-05	1.94827E-05	5.11152E-07	12.72
	RIGHT GASTROCNEMIUS	5.46416E-05	0	1.16787E-05	1.49953E-05	2.5915E-06	27.44
	LEFT VASTUS LATERALIS	0.000126758	0	1.8002E-05	1.99318E-05	6.81262E-07	15.72
	RIGHT VASTUS LATERALIS	0.000101696	0	7.94789E-06	9.96504E-06	5.216E-07	9.80
	LEFT TIBIALIS ANTERIOR	8.63704E-05	0	1.83684E-05	2.49982E-05	2.24756E-06	28.94
	RIGHT TIBIALIS ANTERIOR	0.000202052	0	1.60104E-05	1.77273E-05	5.43098E-07	8.77
3	LEFT GASTROCNEMIUS	0.001709239	0	1.93515E-05	2.43856E-05	2.95364E-06	1.43
	RIGHT GASTROCNEMIUS	0.004241894	0	1.57106E-05	2.57504E-05	4.23446E-06	0.61
	LEFT VASTUS LATERALIS	0.001949217	0	1.9051E-05	2.46292E-05	1.19438E-06	1.26
	RIGHT VASTUS LATERALIS	0.001140644	0	1.40845E-05	1.74204E-05	2.0153E-06	1.53
	LEFT TIBIALIS ANTERIOR	0.003434575	0	6.88743E-05	0.000166109	3.57676E-05	4.84

	RIGHT TIBIALIS ANTERIOR	0.001958865	0	6.37943E-05	0.000104338	2.14542E-05	5.33
4	LEFT GASTROCNEMIUS	3.96848E-05	0	1.46578E-05	2.07503E-05	2.56888E-06	52.29
	RIGHT GASTROCNEMIUS	3.92469E-05	0	2.11544E-05	2.18595E-05	4.7811E-06	55.70
	LEFT VASTUS LATERALIS	0.000175366	0	1.44628E-05	5.44338E-05	3.23708E-05	31.04
	RIGHT VASTUS LATERALIS	0.000222482	3.1363E-06	1.01253E-05	0.000149681	2.02207E-05	67.28
	LEFT TIBIALIS ANTERIOR	0.000106673	0	3.43618E-06	6.6864E-05	1.40153E-06	62.68
	RIGHT TIBIALIS ANTERIOR	0.000103772	1.34984E-05	1.53425E-05	2.00858E-05	6.87814E-07	19.36
5	LEFT GASTROCNEMIUS	7.07816E-05	0	1.511E-05	2.12991E-05	5.68662E-06	30.09
	RIGHT GASTROCNEMIUS	9.88799E-05	0	9.74091E-06	2.94951E-05	4.47154E-06	29.83
	LEFT VASTUS LATERALIS	0.000124857	0	1.45925E-05	2.73742E-05	4.02288E-06	21.92
	RIGHT VASTUS LATERALIS	9.16587E-05	0	1.47714E-05	2.28414E-05	7.1237E-05	24.92
	LEFT TIBIALIS ANTERIOR	5.69618E-05	0	7.81114E-06	2.58356E-05	4.28447E-06	45.36
	RIGHT TIBIALIS ANTERIOR	7.3401E-05	0	1.57699E-05	2.20557E-05	2.27274E-06	30.05
6	LEFT GASTROCNEMIUS	4.07277E-05	0	2.35249E-05	2.22226E-05	2.90466E-06	54.56
	RIGHT GASTROCNEMIUS	3.85536E-05	0	1.19539E-05	1.63515E-05	2.2042E-06	42.41
	LEFT VASTUS LATERALIS	0.000155736	0	1.39823E-05	1.92676E-05	4.71879E-07	12.37
	RIGHT VASTUS LATERALIS	0.000163154	0	7.67838E-06	3.62176E-05	6.47894E-06	22.20
	LEFT TIBIALIS ANTERIOR	0.000152427	0	7.19294E-06	1.77653E-05	1.52388E-06	11.65
	RIGHT TIBIALIS ANTERIOR	0.00014417	0	1.58001E-05	1.53654E-05	6.06E-07	10.66
7	LEFT GASTROCNEMIUS	9.62262E-05	6.81602E-06	9.68136E-06	1.3185E-05	4.62571E-06	13.70
	RIGHT GASTROCNE	0.00014878	1.10491E-05	6.37155E-05	3.68908E-05	3.39074E-05	24.80

	MIUS						
	LEFT VASTUS LATERALIS	0.00019726	4.84058E-06	6.49516 E-06	5.60347E-05	2.32694E-06	28.41
	RIGHT VASTUS LATERALIS	0.000105907	1.23327E-05	1.66608 E-05	2.24185E-05	1.74257E-06	21.17
	LEFT TIBIALIS ANTERIOR	0.000224833	1.16595E-05	1.75395 E-05	5.80789E-05	1.04246E-05	25.83
	RIGHT TIBIALIS ANTERIOR	0.000153591	5.17368E-06	1.05849 E-05	5.49334E-05	5.45367E-06	35.77
8	LEFT GASTROCNEMIUS	0.000355719	0	8.81199 E-06	4.03083E-05	5.36436E-06	11.33
	RIGHT GASTROCNEMIUS	0.000251516	0	1.21968 E-05	2.98255E-05	1.41299E-06	11.86
	LEFT VASTUS LATERALIS	5.38571E-05	0	7.60847 E-05	2.09985E-05	0.000102749	38.99
	RIGHT VASTUS LATERALIS	5.67973E-05	0	1.77146 E-05	3.11674E-05	7.93727E-07	54.87
	LEFT TIBIALIS ANTERIOR	0.000224567	0	1.5606 E-05	5.11291E-05	1.83658E-06	22.77
	RIGHT TIBIALIS ANTERIOR	0.000216414	0	4.96537 E-06	4.23675E-05	2.24508E-06	19.58
9	LEFT GASTROCNEMIUS	3.03876E-05	5.3565E-06	1.59046 E-05	9.69408E-06	5.47103E-06	31.90
	RIGHT GASTROCNEMIUS	5.20869E-05	0	9.51326 E-06	2.67688E-05	5.19425E-06	51.39
	LEFT VASTUS LATERALIS	3.20901E-05	0	1.34754 E-05	1.93656E-05	2.80136E-06	60.35
	RIGHT VASTUS LATERALIS	0.000100299	2.43488E-06	5.92858 E-06	2.88763E-05	1.89243E-06	28.79
	LEFT TIBIALIS ANTERIOR	0.000758295	0	1.30071 E-05	5.97657E-05	3.40093E-06	7.88
	RIGHT TIBIALIS ANTERIOR	0.000116053	0	1.79591 E-05	5.86776E-05	2.60859E-06	50.56
10	LEFT GASTROCNEMIUS	8.31727E-05	0	1.84341 E-05	4.92188E-05	3.48698E-06	59.18
	RIGHT GASTROCNEMIUS	5.45075E-05	0	9.78068 E-06	3.06567E-05	3.51656E-06	56.24
	LEFT VASTUS LATERALIS	0.000414482	0	1.48903 E-05	5.48758E-05	6.49108E-07	13.24
	RIGHT VASTUS LATERALIS	0.000119195	0	6.6247 E-06	8.11612E-06	3.35467E-07	6.81
	LEFT TIBIALIS	0.000148897	0	1.39215 E-05	3.46465E-05	1.18471E-06	23.27

	ANTERIOR						
	RIGHT TIBIALIS ANTERIOR	0.000210485	0	1.53616E-05	2.1602E-05	4.92445E-07	10.26

Table A.3: Muscle contraction with commercial exoskeleton

Subject No	name of muscle	Maximum Voluntary Contraction (MVC/ V)	Muscle contraction with EXOSKELETON (DESIGN)				
			Minumum (V)	Mean (V)	Maximum (V)	Standard Deviation (V)	Percentage of Muscle Activity (%)
1	LEFT GASTROCNEMIUS	0.000812689	0	1.27784E-05	0.000746303	7.99178E-06	91.83
	RIGHT GASTROCNEMIUS	5.49173E-05	0	9.17123E-06	4.96519E-05	2.29147E-06	90.41
	LEFT VASTUS LATERALIS	0.000131521	0	2.01844E-05	0.000131195	6.14889E-06	99.75
	RIGHT VASTUS LATERALIS	0.000107692	0	9.72258E-06	0.000106622	8.16969E-06	99.01
	LEFT TIBIALIS ANTERIOR	8.88513E-05	0	2.27542E-05	8.25921E-05	6.67141E-06	92.96
	RIGHT TIBIALIS ANTERIOR	0.000207293	0	1.75078E-05	0.000201485	8.40956E-06	97.20
2	LEFT GASTROCNEMIUS	0.000153127	0	6.01601E-05	0.000151215	4.71219E-05	98.75
	RIGHT GASTROCNEMIUS	5.46416E-05	0	1.59784E-05	5.37704E-05	3.7215E-06	98.41
	LEFT VASTUS LATERALIS	0.000126758	0	0.000479715	0.000115679	0.000765101	91.26
	RIGHT VASTUS LATERALIS	0.000101696	0	2.8187E-05	9.26229E-05	0.000139683	91.08
	LEFT TIBIALIS ANTERIOR	8.63704E-05	0	1.44275E-05	6.01546E-05	3.11617E-06	69.65
	RIGHT TIBIALIS ANTERIOR	0.000202052	0	2.38132E-05	0.000194973	1.04995E-05	96.50
3	LEFT GASTROCNEMIUS	0.001709239	0	1.81137E-05	3.5693E-05	6.99975E-07	2.09
	RIGHT GASTROCNEMIUS	0.004241894	0	1.77571E-05	0.000109986	1.06003E-06	2.59
	LEFT VASTUS LATERALIS	0.001949217	0	3.81987E-05	0.001928025	4.41372E-05	98.91
	RIGHT VASTUS LATERALIS	0.001140644	0	5.00351E-05	0.001035862	3.6267E-05	90.81

	LEFT TIBIALIS ANTERIOR	0.003434575	0	1.5662E-05	0.002621597	2.97342E-05	76.33
	RIGHT TIBIALIS ANTERIOR	0.001958865	0	0.000260533	0.001914572	4.83219E-05	97.74
4	LEFT GASTROCNEMIUS	3.96848E-05	0	1.36125E-05	3.58576E-05	9.67416E-06	90.36
	RIGHT GASTROCNEMIUS	3.92469E-05	0	6.57165E-06	3.84451E-05	2.36581E-06	97.96
	LEFT VASTUS LATERALIS	0.000175366	0	3.93173E-05	0.000172956	7.54381E-05	98.63
	RIGHT VASTUS LATERALIS	0.000222482	0	2.97578E-05	0.000216579	1.40653E-05	97.35
	LEFT TIBIALIS ANTERIOR	0.000106673	0	2.60122E-06	1.20195E-05	4.75046E-07	11.27
	RIGHT TIBIALIS ANTERIOR	0.000103772	0	1.48157E-05	2.49245E-05	4.8559E-07	24.02
5	LEFT GASTROCNEMIUS	7.07816E-05	0	1.34663E-05	3.05603E-05	4.69241E-07	43.18
	RIGHT GASTROCNEMIUS	9.88799E-05	0	4.6241E-05	7.27622E-05	0.000187895	73.59
	LEFT VASTUS LATERALIS	0.000124857	0	1.38092E-05	0.000106152	3.12476E-06	85.02
	RIGHT VASTUS LATERALIS	9.16587E-05	0	9.50393E-06	6.87645E-05	3.65503E-05	75.02
	LEFT TIBIALIS ANTERIOR	5.69618E-05	0	2.85648E-06	1.71744E-05	7.11217E-07	30.15
	RIGHT TIBIALIS ANTERIOR	7.3401E-05	0	1.47994E-05	5.4839E-05	7.06768E-07	74.71
6	LEFT GASTROCNEMIUS	4.07277E-05	0	1.40444E-05	3.99549E-05	8.0163E-07	98.10
	RIGHT GASTROCNEMIUS	3.85536E-05	0	7.55815E-06	1.37345E-05	9.30108E-07	35.62
	LEFT VASTUS LATERALIS	0.000155736	0	1.9812E-05	0.000110211	4.17596E-06	70.77
	RIGHT VASTUS LATERALIS	0.000163154	0	1.96635E-05	0.000136072	2.02349E-05	83.40
	LEFT TIBIALIS ANTERIOR	0.000152427	0	1.53672E-05	5.67633E-05	7.92467E-07	37.24
	RIGHT TIBIALIS ANTERIOR	0.00014417	0	9.10951E-06	0.0001039 7	2.13644E-06	72.12
7	LEFT GASTROCNE	9.62262E-05	1.58779E-05	2.13537E-05	7.30279E-05	1.36916E-05	75.89

	MIUS						
	RIGHT GASTROCNE MIUS	0.00014878	1.74578E-05	2.24551 E-05	0.0001103 38	1.37341E-05	74.16
	LEFT VASTUS LATERALIS	0.00019726	0	1.02165 E-05	0.0001727 27	6.57903E-06	87.56
	RIGHT VASTUS LATERALIS	0.00010590 7	8.17788E-06	1.08039 E-05	9.61604E-05	4.59368E-06	90.80
	LEFT TIBIALIS ANTERIOR	0.00022483 3	1.36574E-05	1.72307 E-05	0.0002066 62	3.56453E-06	91.92
	RIGHT TIBIALIS ANTERIOR	0.00015359 1	8.91795E-06	1.5575 E-05	0.0001080 98	1.01092E-05	70.38
8	LEFT GASTROCNE MIUS	0.00035571 9	4.58382E-06	5.46703 E-06	8.20493E-05	1.4906E-06	23.07
	RIGHT GASTROCNE MIUS	0.00025151 6	1.05155E-05	1.1179 E-05	6.44601E-05	8.76528E-07	25.63
	LEFT VASTUS LATERALIS	5.38571E-05	7.61281E-06	1.17225 E-05	3.68757E-05	1.23507E-06	68.47
	RIGHT VASTUS LATERALIS	5.67973E-05	1.31256E-05	1.67114 E-05	2.74093E-05	3.08024E-07	48.26
	LEFT TIBIALIS ANTERIOR	0.00022456 7	1.35545E-05	1.60692 E-05	5.4843E-05	1.74191E-06	24.42
	RIGHT TIBIALIS ANTERIOR	0.00021641 4	3.06383E-06	6.45389 E-06	9.80682E-05	4.3574E-06	45.32
9	LEFT GASTROCNE MIUS	3.03876E-05	0	1.1929 E-05	1.9855E-05	6.14232E-06	65.34
	RIGHT GASTROCNE MIUS	5.20869E-05	0	8.1784 E-06	3.29548E-05	1.25823E-06	63.27
	LEFT VASTUS LATERALIS	3.20901E-05	0	2.26011 E-05	2.48639E-05	0.0001598 46	77.48
	RIGHT VASTUS LATERALIS	0.00010029 9	0	9.89659 E-05	7.30252E-05	3.73198E-05	72.81
	LEFT TIBIALIS ANTERIOR	0.00075829 5	0	1.38046 E-05	2.79314E-05	3.84344E-06	3.68
	RIGHT TIBIALIS ANTERIOR	0.00011605 3	0	1.87921 E-05	5.81457E-05	3.76103E-06	50.10
10	LEFT GASTROCNE MIUS	8.31727E-05	0	1.29839 E-05	1.62992E-05	4.18393E-07	19.60
	RIGHT GASTROCNE MIUS	5.45075E-05	0	1.76774 E-05	2.39409E-05	6.61498E-07	43.92
	LEFT VASTUS LATERALIS	0.00041448 2	0	1.76383 E-05	5.60556E-05	5.93656E-06	13.52
	RIGHT VASTUS	0.00011919 5	0	3.05022 E-05	0.0001135 67	6.71293E-06	95.28

	LATERALIS						
	LEFT TIBIALIS ANTERIOR	0.000148897	0	1.75505E-05	2.62865E-05	1.64718E-06	17.65
	RIGHT TIBIALIS ANTERIOR	0.000210485	0	1.56882E-05	4.59356E-05	1.5129E-06	21.82

Table A.4: Muscle contraction with design exoskeleton

Subject No	name of muscle	Maximum Voluntary Contraction (MVC/ V)	Muscle contraction with EXOSKELETON (DESIGN)				
			Minimum (V)	Mean (V)	Maximum (V)	Standard Deviation (V)	Percentage of Muscle Activity (%)
1	LEFT GASTROCNEMIUS	0.000812689	0	1.29438E-05	0.000185593	3.04649E-06	22.84
	RIGHT GASTROCNEMIUS	5.49173E-05	0	9.60152E-06	2.48897E-05	1.06599E-06	45.32
	LEFT VASTUS LATERALIS	0.000131521	0	1.82612E-05	4.22017E-05	7.29966E-07	32.09
	RIGHT VASTUS LATERALIS	0.000107692	0	8.14052E-06	3.23874E-05	6.01048E-07	30.07
	LEFT TIBIALIS ANTERIOR	8.88513E-05	0	1.91857E-05	5.32339E-05	2.31859E-06	59.91
	RIGHT TIBIALIS ANTERIOR	0.000207293	0	1.62625E-05	0.00011404	2.19019E-06	55.01
2	LEFT GASTROCNEMIUS	0.000153127	0	1.18297E-05	5.09709E-05	7.27878E-07	33.29
	RIGHT GASTROCNEMIUS	5.46416E-05	0	1.03319E-05	3.82054E-05	4.32113E-06	69.92
	LEFT VASTUS LATERALIS	0.000126758	0	1.6986E-05	5.29793E-05	9.90252E-07	41.80
	RIGHT VASTUS LATERALIS	0.000101696	0	8.31308E-06	6.57871E-05	2.05E-06	64.69
	LEFT TIBIALIS ANTERIOR	8.63704E-05	0	2.674E-05	5.46705E-05	2.69276E-06	63.30
	RIGHT TIBIALIS ANTERIOR	0.000202052	0	1.68984E-05	0.0001908	6.11474E-06	94.43
3	LEFT GASTROCNEMIUS	0.001709239	0	2.17532E-05	3.40984E-05	1.07458E-06	1.99
	RIGHT GASTROCNEMIUS	0.004241894	0	1.95751E-05	9.23568E-05	3.26285E-06	2.18
	LEFT VASTUS LATERALIS	0.001949217	0	1.97061E-05	6.10107E-05	3.63062E-06	3.13

	RIGHT VASTUS LATERALIS	0.001140644	0	1.52095E-05	8.77323E-05	1.04455E-06	7.69
	LEFT TIBIALIS ANTERIOR	0.003434575	0	0.000103739	0.00170157	1.76529E-05	49.54
	RIGHT TIBIALIS ANTERIOR	0.001958865	0	8.33022E-05	0.001002488	2.76419E-05	51.18
4	LEFT GASTROCNEMIUS	3.96848E-05	0	1.30666E-05	1.99529E-05	1.74617E-06	50.28
	RIGHT GASTROCNEMIUS	3.92469E-05	0	5.33118E-06	3.09589E-05	9.26193E-07	78.88
	LEFT VASTUS LATERALIS	0.000175366	0	1.45186E-05	0.000101139	2.43397E-06	57.67
	RIGHT VASTUS LATERALIS	0.000222482	0	6.86122E-06	0.000140387	2.92341E-06	63.10
	LEFT TIBIALIS ANTERIOR	0.000106673	0	1.48341E-05	1.00712E-05	3.69912E-07	9.44
	RIGHT TIBIALIS ANTERIOR	0.000103772	0	3.22158E-06	2.30755E-05	1.26086E-06	22.24
5	LEFT GASTROCNEMIUS	7.07816E-05	0	1.4775E-05	1.90587E-05	8.96401E-06	26.93
	RIGHT GASTROCNEMIUS	9.88799E-05	0	7.61549E-06	5.84059E-05	6.54664E-06	59.07
	LEFT VASTUS LATERALIS	0.000124857	0	1.44654E-05	0.000101431	2.09934E-06	81.24
	RIGHT VASTUS LATERALIS	9.16587E-05	0	8.21067E-06	5.46944E-05	1.25727E-05	59.67
	LEFT TIBIALIS ANTERIOR	5.69618E-05	0	1.13638E-05	1.59451E-05	6.92947E-06	27.99
	RIGHT TIBIALIS ANTERIOR	7.3401E-05	0	1.67427E-05	1.23716E-05	3.12721E-06	16.85
6	LEFT GASTROCNEMIUS	4.07277E-05	0	1.39023E-05	2.90843E-05	2.2921E-06	71.41
	RIGHT GASTROCNEMIUS	3.85536E-05	0	8.13441E-06	2.35715E-06	1.85471E-06	6.11
	LEFT VASTUS LATERALIS	0.000155736	0	1.36346E-05	1.74513E-05	6.53779E-07	11.21
	RIGHT VASTUS LATERALIS	0.000163154	0	7.08457E-06	4.06621E-05	5.89914E-07	24.92
	LEFT TIBIALIS ANTERIOR	0.000152427	0	6.56375E-06	2.13226E-05	1.08867E-06	13.99
	RIGHT TIBIALIS	0.00014417	0	1.55596E-05	1.94522E-05	4.69405E-07	13.49

	ANTERIOR						
7	LEFT GASTROCNE MIUS	9.62262E-05	0	8.49987E-06	6.48391E-05	1.05518E-06	67.38
	RIGHT GASTROCNE MIUS	0.00014878	0	1.49338E-05	6.46398E-05	1.55138E-06	43.45
	LEFT VASTUS LATERALIS	0.00019726	0	6.50487E-06	7.53277E-05	1.46789E-06	38.19
	RIGHT VASTUS LATERALIS	0.000105907	0	1.69553E-05	2.13215E-05	5.22777E-07	20.13
	LEFT TIBIALIS ANTERIOR	0.000224833	0	1.68741E-05	5.1379E-05	1.42055E-06	22.85
	RIGHT TIBIALIS ANTERIOR	0.000153591	0	1.44091E-05	0.000106052	4.36588E-06	69.05
8	LEFT GASTROCNE MIUS	0.000355719	0	5.70623E-06	5.95463E-05	2.19457E-06	16.74
	RIGHT GASTROCNE MIUS	0.000251516	0	1.1364E-05	2.25309E-05	1.43209E-06	8.96
	LEFT VASTUS LATERALIS	5.38571E-05	0	7.57039E-06	1.36048E-05	6.29833E-07	25.26
	RIGHT VASTUS LATERALIS	5.67973E-05	0	1.76777E-05	2.64674E-05	5.49639E-07	46.60
	LEFT TIBIALIS ANTERIOR	0.000224567	0	1.59124E-05	4.67764E-05	1.459E-06	20.83
	RIGHT TIBIALIS ANTERIOR	0.000216414	0	1.11782E-05	1.22109E-05	6.68564E-06	5.64
9	LEFT GASTROCNE MIUS	3.03876E-05	2.46919E-06	1.6346E-05	1.85329E-05	1.7255E-05	60.99
	RIGHT GASTROCNE MIUS	5.20869E-05	0	1.39126E-05	3.049E-05	8.29335E-05	58.54
	LEFT VASTUS LATERALIS	3.20901E-05	0	1.37757E-05	2.0894E-05	1.19029E-05	65.11
	RIGHT VASTUS LATERALIS	0.000100299	1.03361E-06	6.36543E-06	4.94471E-05	1.20875E-05	49.30
	LEFT TIBIALIS ANTERIOR	0.000758295	0	4.89712E-05	1.93172E-05	6.32407E-05	2.55
	RIGHT TIBIALIS ANTERIOR	0.000116053	5.13393E-06	2.05995E-05	5.14035E-05	2.04262E-05	44.29
10	LEFT GASTROCNE MIUS	8.31727E-05	0	1.32005E-05	9.02418E-06	2.52218E-06	10.85
	RIGHT GASTROCNE MIUS	5.45075E-05	0	4.83899E-06	8.02243E-06	2.54315E-06	14.72
	LEFT VASTUS	0.00041448	0	1.62314	0.0001104	3.11307E-	26.64

	LATERALIS	2		E-05	32	06	
	RIGHT VASTUS LATERALIS	0.000119195	0	8.8819E-06	2.93721E-05	3.37884E-06	24.64
	LEFT TIBIALIS ANTERIOR	0.000148897	0	1.56813E-05	1.76847E-05	1.30892E-06	11.88
	RIGHT TIBIALIS ANTERIOR	0.000210485	0	1.95413E-05	2.79069E-05	8.7658E-06	13.26

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