

DESIGN AND EVALUATION OF TEST RIG FOR MEASURING HIP FLEXOR STRENGTH IN STANDING POSITION

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



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DECLARATION

I hereby, declared this report entitled "Design and Evaluation of Test Rig for Measuring Hip Flexor Strength" is the result of my own research except as cited in references.



APPROVAL

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



ABSTRAK

Otot fleksor pinggul memainkan peranan penting dalam melakukan aktiviti harian dan kerja, terutamanya dalam industri pembuatan dan pembinaan seperti perancah naik/turun dan tangga. Aktiviti kerja ini berpotensi menyebabkan masalah kepada pergerakan pekerja jika fleksor pinggul menjadi lemah. Akibatnya, pekerja mungkin mengalami sakit di bahagian bawah belakang, dan kecekapan kerja dan produktiviti mungkin terjejas. Untuk mengelakkan akibatnya, pengamal ergonomik dan jurutera industri mempunyai data teknikal yang terhad berkaitan kekuatan lentur pinggul. Ini disebabkan ketiadaan pelantar ujian yang kukuh untuk mengukur kekuatan lentur pinggul. Oleh itu, objektif kajian ini adalah menentukan keperluan reka bentuk untuk membangunkan prototaip pelantar ujian untuk mengukur kekuatan fleksor pinggul dan menilai kebolehgunaan dan kefungsian prototaip pelantar ujian. Hasil analisis ini menunjukkan bahawa keperluan reka bentuk untuk pelantar ujian adalah stabil, saiz padat (tidak besar), kukuh, ringan dan mesra alam. Beberapa konsep kemudiannya dibangunkan melalui kaedah Pugh, dan satu konsep terbaik dipilih berdasarkan matrik saringan. Reka bentuk konsep terbaik telah diterjemahkan ke dalam lukisan kejuruteraan pada perisian CATIA dan dianalisis menggunakan perisian simulasi kejuruteraan ANSYS untuk menilai ubah bentuk dan tegasan maksimum pada struktur prototaip. Kemudian, kajian kebolehgunaan dan ujian kefungsian telah dijalankan untuk memastikan prototaip pelantar ujian dapat mengumpul data tentang kekuatan fleksor pinggul. Kajian ini mendapati kekuatan fleksor pinggul maksimum peserta lelaki dan perempuan ialah 347.8 N, dan 211.8 N, masing-masing. Mengikut prototaip fungsi pelantar ujian menggunakan skor Skala Kebolehgunaan Sistem (SUS) ialah 74.25 ditentukan sebagai kebolehgunaan julat yang boleh diterima. Berdasarkan keputusan yang diperoleh, kajian ini merumuskan bahawa data kekuatan fleksor pinggul adalah boleh dipercayai apabila menggunakan prototaip pelantar ujian ini. Prototaip pelantar ujian yang dibangunkan oleh kajian ini akan memberi makna kepada pengamal ergonomik untuk mengumpul data tentang kekuatan lentur pinggul supaya proses kerja dalam industri boleh direka bentuk secara ergonomik.

ABSTRACT

The hip flexor muscles play a significant role in performing daily and work activities, especially in manufacturing and construction industries such as ascending/descending scaffolding and ladders. These work activities are potentially to cause problem to workers' motion if the hip flexor is weakened. Consequently, the workers may experience pain in the lower back, thus work efficiency and productivity might be affected. To prevent these consequences, however, ergonomics practitioners and industrial engineers have limited technical data on the hip flexor strength. This is due to absent of a sturdy test rig for measuring the hip flexor strength. Therefore, the objectives of this study are to determine design requirements to develop a prototype of test rig for measuring hip flexor strength and evaluate the usability and functionality of test rig prototype. The result of this analysis revealed that the design requirements for the test rig were stable, compact size (not bulky), sturdy, light weight, and environmental-friendly. Several concepts are then developed through Pugh method, and one best concept was chosen based on the screening matrix. The best concept design has been translated into engineering drawing on CATIA software and analysed using ANSYS engineering simulation software to evaluate the deformation and maximum stress on the structure of the prototype. Then, usability study and functionality test were carried out to ensure the test rig prototype is able to collect data on hip flexor strength. This study found the maximum hip flexor strength of male and female participants was 347.8 N, and 211.8 N, respectively. According to the functionality prototype of test rig using System Usability Scale (SUS) score is 74.25 determined as an acceptable range usability. Based on the results obtained, this study concluded that the data of hip flexor strength was reliable when using this prototype of test rig. The test rig prototype developed by this study would be meaningful to ergonomics practitioners to collect data on hip flexor strength so that work process in industries can be designed ergonomically.

DEDICATION

Only

my beloved father, Abdul Talib my appreciated mother, Salbiah Ismail my adored brother, Aiman, Adam and AIkal my adroble friend, Wan, Jane, Beng, Mar and Fiza

for giving me moral support, money, cooperation, encouragement and also understandings

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LIST OF ABBREVIATIONS

ACE	-	American Council on Exercise
ANP	-	Analytic Network Process
BOM	-	Bill of Materials
CAD	-	Computer Aided Design
EMG	-	Electromyography
FKP	-	Fakulti Kejuruteraan Pembuatan
HOQ	-	House of Quality
MVC	-	Maximum Voluntary Contraction
PIV	ALAYSI,	Particle Image Velocimetry
QFD	- Alter Mar	Quality Function Deployment
SOP	N. C.	Standard Operating Procedure
SVC	۳. <u>=</u>	Submaximal Voluntary Contraction
TRIZ		Theory of Inventive Problem Solving
SUS	- AINO	System Usability Scale
	بسيا ملاك	اونيومرسيتي تيكنيكل ملب

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LIST OF SYMBOLS



CHAPTER 1 INTRODUCTION

The first chapter presents the background of the study, problem statement, objectives, scope of the study, the significance of the study, and report of the organization. The background of the study elaborates how the test rig is significant to the manufacturing industry and construction sector. The problem statement describes a problem in the industry that inspired the concept for this project. Additionally, the problem statement highlights the limitations of the existing prototype and existing test rig. The objectives represent this project's main goal, while the scope of the study shows the limitation and approaches used to create this project. The significance of this study shows how this test rig prototype will collect the data on hip flexor strength in a standing position. Finally, the organisation's report explains how this report is carried out in total.

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1.1 Background of Study

Working with scaffolds is highly associated with severe injuries in the construction industry since less priority has been focused on health issues. This equipment is often used as a workstation on construction sites for temporary structures and to repair or clean structures. Professional exhaustion is becoming more of an issue in the construction sector as projects get more intricate and time and cost constraints become more extreme. However, the building sector has dedicated inadequate attention to health hazards and ergonomics issues. For example, when employees climb scaffolds using their hands and feet, they must keep their bodies as close to the frame as possible, which is ergonomically hazardous.



Figure 1.1: A worker climbing the scaffolds (Webb, 2017)

In addition, the muddy area also plays a role in the workplace of construction which sludge or mud can pose several hazards. Mud is a mixture of various soil types that typically form after raining or near the water source. It can cause problems for workers in the construction area as accidents may happen, including slipping, tripping, or falling. Workers in the construction industry will impact the ergonomic risk factor. Sometimes, when they climb the scaffolds, the lower body, the hip flexor muscle, needs to pull up their leg to climb up from scaffolding and muddy areas. As shown in Figure 1.2, the boot is stuck in a muddy area, whereas it requires high torque exertion of the hip.

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Figure 1.2: Boots stuck in a muddy area (Strommen, 2018)

Subsequently, designing a scaffolding and effective safety boot needs to study the ergonomic, which involves designing and optimizing products, workplaces, or systems for people to reduce discomfort and risk of injuries. For instance, when the workers climb the scaffolding with the heavy safety shoes, either the size of the ladder and distance of the ladder is ergonomic or not. The group of muscle hip strength, which is gluteal, adductor, iliopsoas and lateral rotator, cause movement at the hip joint. The iliopsoas is the strongest group of muscles in the hip flexor, which connect the spine to the femur and help pull the thigh towards the torso or raise your knees to chest.

The hip flexors perform an important mechanical function, which is why, if not done correctly, even basic abdominal crunches may sometimes wear them out. The hip flexors are important in human movement because it creates stability. The hip flexors, along with the other 'main' muscles of the torso and glutes, play an essential part in maintaining the pelvis and spine, ability to move and exercise without losing balance to the lower back. Next, the powerful musculature is utilized in abrupt sprinting and jumping, specifically in athletes. Also, one of the most frequent causes of musculoskeletal concerns and preventing injuries is hip flexor strain. Weaker hip flexor strength was seen in people whose function was declining compared to those who performed similarly or better. According to the researchers, focusing on maintaining hip flexor strength could offer significant benefits once you become older (Millard, 2021). Therefore, several postures can strengthen the hip flexor to maintain strength and prevent injuries, as shown in Figure 1.3.



Figure 1.3: Hip flexor Exercises

As a result, there is a lack of research on ergonomics studies, especially when designing and evaluating the equipment. Therefore, according to the topic of the study, it is important to be aware and ensure the flexor muscles work efficiently.

1.2 Problem Statement

Implementing ergonomics solutions can make employees more comfortable and increase productivity for the industry. Ergonomics is an important part of research in the product development process. Its purpose is to increase the safety, comfort and performance of a product or an environment. According to the annual report by the Society Organization Society (SOCSO), accident involving scaffolding has been reported in as many as 368 for five years. The engineer can reduce the number of these accidents by helping the engineer study and design the ergonomic structure. The accident might happen because of slipping, tripping, or falling from height when workers are on scaffolding, as shown in Figure 1.4. An engineer lacks data on hip flexor strength to determine the optimum size, shape, and form of a product to create and design an ergonomic product.



Figure 1.4: Hazard at construction area

Next, Figures 1.5 and 1.6 show that force gauges and torque gauges are available on the market and in the FKP lab. The functionality gauges are to measure force and torque. However, gauges are made for simple mechanics experiments that involve pushing and pulling force and measuring torque strength. These gauges can be used to measure hip flexor strength, but the test rig is not suitable for use. Since the existing test rig did not meet the requirements, there is no method to gather data. As illustrated in Figure 1.7, a former student attempted to conduct an experiment to determine hip flexor strength using a method that was clearly ineffective.



Figure 1.6 Torque Gauge Mark 10



Figure 1.7: A wrong way to measure hip flexor strength

Furthermore, the existing test rig is quite extensive to bring anywhere because the size and functionality are not suitable for measuring the hip flexor strength, as shown in Figure 1.8. Mostly, the test rig, which is utilized in a variety of industries, can test an unlimited number of parameters using a variety of testing methods.



Figure 1.8: Biodex System 3 Dynamometer (Ceylan, 2014)

1.3 Objectives

The objectives of this study are:

- i. To determine design requirements to develop a test rig for measuring hip flexor strength in standing position.
- ii. To design and fabricate a test rig for measuring hip flexor strength in standing position.
- iii. To evaluate the functionality and usability of the developed test rig.

1.3.1 Relationship Between Problem Statement & Objective

WALAYS/4

A problem statement is a statement of a current issue or problem that requires timely action to improve the situation. Therefore, the objective purpose of a project was to solve the problem state, as shown in Table 1.1.

Problem Statement	Objective		
Existing test rigs are largely used to	To determine design requirements to		
evaluate and test the capabilities and	fabricate a test rig for measuring hip		
performance of components on a large	flexor strength in standing position.		
scale, which is why it are so expensive.			
There is a scarcity of data on hip flexor	To design and fabricate a test rig for		
strength in Malaysians.	measuring hip flexor strength in		
	standing position.		
The technical information will be used	To evaluate the functionality and		
to assist in the design of the ergonomic	usability of the developed test rig.		
product.			

Table 1.1: Relationship between problem statement & objective

1.4 Scope

This study aims to identify the analysis data of hip flexor strength action to know the strength of hip flexor participants whether its good condition or in injuries condition. To get the data, the design specifications of the test rig allow a force gauge to collect data on hip flexor strength. This study mainly focuses on the hip flexor in a standing position. For the analysis of strength hip flexor, the participants involved are 60 participants of Malaysian young adult. This experiment is focused only on the maximum hip flexor force of dominant leg of the participant. However, the limitations of data are carried out the condition of healthy participants and injuries on hip flexor. This limitation can be investigated in the future for further improvement.

1.5 Significance/Importance of Study

This analysis collects data on hip flexor strength using a rigid test rig. Therefore, the test rig can gain some potential benefits by collecting data for this analysis. Using this experiment method will help know the strength and weakness of hip flexor strength in a standing position. Also, to know whether the product's design is suitable for the user to use it without any injuries at the hip flexor. The test rig will help measure a general situation, not limited to specific cases, or develop products. Designing the scaffolding can help an engineer exact parameter with the data of the hip flexor. Badly designed scaffolds and safety boots, using inappropriate material, make the equipment too heavy. Also, the limited space between the cogs, which restricted movement on the scaffold, and the difficulty of installing scaffolds with a limited width wall results in a dangerous and awkward position to reach the wall when installing scaffolds. Therefore, the anthropometric data can design the products with ergonomic needs to prevent hazards in the construction area.

1.6 Organization of The Report

To summarize the content of the project, the organization of the report is shown in Figure 1.9.



Figure 1.9: Organization of report

1.7 Summary

Briefly, to conclude, the chapter will discuss the background of the study for test rig and hip flexor. Problems are identified through observation by using the prototype of the test rig. The report is followed by the objectives that will be attained throughout the study and the scope of the study, which narrows down the scope of the study. In this analysis, the hip flexor muscles play a huge role in daily activities like walking, running, squatting up and moving side to side. This muscular activity related to fatigue, muscle activation and other issues relating to the neuromuscular system is discussed in detail. As a result, we began to employ electromyography (EMG) as a tool to acquire better results in this investigation. Therefore, the hip flexor's strength will measure using a force gauge.



CHAPTER 2 LITERATURE REVIEW

This chapter describes the literature review, substantive findings of academic knowledge in terms of theory, and methodology of previous studies and experimental will be discussed. This chapter is built according to the study's objectives, and all the information presented is supported by relevant journals, articles, books, and online resources.

2.1 Test Rig

Test rigs are pieces of machinery typically employed to test and evaluate the capabilities and performance of components intended for industrial application. This analysis requires a solid test rig as an essential apparatus to collect accurate data using a force gauge. The term "test rig" refers to an apparatus, or more specifically, a system including numerous pieces of equipment operating together that is specifically designed to test anything. A test bench is typically a more general-purpose platform adapted for various tests or practical applications. A setup is more general than the above and includes the circumstances and methods that form the testing or experimental process. The test rig is built with minimal cost, simple hardware, and a high degree of flexibility as primary considerations. During the experiment, when executing the test movement, it is required for participants to place their hands lightly on stable support in front of them to ensure their safety while doing the test movement. Participants began the activity by standing straight and actively flexing their knees to their utmost extent.

Using both numerical and experimental methods, it is possible to examine the deformation of the testing structure during the measurement of relatively large or heavy body weights (Previati, 2018). The body under study and the test equipment are both rigid bodies in most of the approaches that are now available. The frequency-domain data can distinguish severe and deformable body modes under investigation. Fixed frame, carrying frame, and linkage system are the three basic components of a dynamic mass property measuring test setup for various applications. The carrying frame's primary role is to support the subject's body during the inquiry. It is a structure that connects the test rig to the ground; it is made up of two frames, the carrying frame and the specified frame, which are linked together by a relative motion system. Table 2.1 shows the test rig used as a test bench.

The study	Purpose	Method	Result
The study	There has been a	Using CAD modelling, a conceptual	The
involves build	paucity of	test rig was created, and the finite	mechanical
and simulate the	research into the	element analysis was carried out using	properties and
mechanical	long-term	ANSYS's static structural analysis tool	safety features
properties of a U	mechanical	as shown in Figure 2.1. A MELAKA	of the baseline
cantilever beam	behaviour of		model have
creep testing rig	massive		been improved
for a full-scale	structures in		as a result of
size crossarm in	recent years. The		the hybrid
transmission	creep life of the		bracing
towers, which	cantilever beam		configuration.
will be used in	structure will be	Figure 2.1: Test rig cross arm (Asyraf M	
the actual	predicted with the	2019)	
testing. (Asyraf	help of the test	_~->)	
M., 2019)	equipment.		

Table 2.1: The studies of test rig

According to the	The examination	The goal of bearing simulation testing	A more
findings of the	of rolling	is to reproduce as closely as possible	dependable and
study, the design	bearings without	the real-world circumstances of	precise
for the building	the need for the	operation of the bearings when they	representation
of a rolling	bearings to be	are mounted in the device under	of the impact
bearing rig	mounted in a	consideration. Figure 2.2 shows the	of numerous
testing facility	specific machine	test rig rolling bearings has using in	operational
has been chosen.	component unit is	this study.	conditions on
(Jurecki R.,	possible.	1 4333616 31011 13 19 10 10 10 10 10	the durability
2017)			of the bearings
			under test can
			be obtained
		1 <u>7 7 1</u>	with this
	at MALAISIA MC	Figure 2.2: Test rig rolling bearings	method.
Sun .	Y YE	(Jurecki R. , 2017)	
The	Using a sapphire	At various rotating speeds, PIV	As the speed of
development of	outer ring, it has	measurements enabled the	rotation
a specialised test	been	reconstruction of the lubricant velocity	increases,
equipment for	demonstrated that	field in a cavity between the cage and	bubbles caused
performing	it is possible to	the outer ring.	by aeration
Particle Image	optically access	NIKAL MALAYSIA MELAKA	phenomena are
Velocimetry	the inside of a		more likely to
(PIV)	bearing without		form, which
measurements	altering the		can
on the lubricant	bearing's		significantly
contained within	kinematic		alter the
a tapered roller	properties.		behaviour of
bearing.			the lubricant in
(Maccioni,			a negative way.
2021)			
The assessment	To be more	In order to determine whether the	Notably, it was
of the thermal	specific, the	experimental test rig could produce	necessary to
performance of	experimental test	results that were equivalent to those	compare the



2.2 Design Requirement of Test Rig for Measuring Hip Flexor Strength

To collect reliable data with an emphasis on user comfort and excellent ergonomic design principles, the design requirement depends on the wishes and needs of the intended user and the design need. Depending on its physical architecture and the qualities of its constituent materials, the performance of each product element has an impact on the overall product performance. The shape and size of a product element are considered part of its physical construction. The parts of a product must be made to meet all of the product's needs, which include performance, reliability, and cost. The design requirements, defined during the product development process, are part of the comprehensive set of criteria that must be satisfied (Pfiefer, 2009).

In addition to individuals who will be purchasing the goods, many products include groups of "customers" interested in the product. These other clients are organizations that impose standards, and even though they will not be purchasing the goods, it is vital to meet those needs to maintain their business relationships. Overall product design needs can be broken down into the following main categories: performance requirements, size and shape; mass and style requirements; cost and production considerations; environmental impact considerations; sustainability considerations; and industry standards.

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The target client typically communicates their demands and needs in nontechnical and sometimes unclear ways to the product's manufacturer. The design team translates customer desires and needs into product engineering specifications. Some of its fundamental assumptions need to be thoroughly evaluated, and as a result, its research scope may have to expand (Jarke, 2011). This section of the study will go over the design phases and approaches that previous researchers have used.

2.2.1 Muscle Strength

Muscular strength is defined as the amount of force a person can exert or the amount of weight a person can lift. Muscular endurance is defined as the number of times you can move a certain amount of weight before becoming weary. Strength training, in conjunction with other aspects of fitness such as cardiorespiratory fitness and endurance, and flexibility and body composition can provide several health benefits to the individual (Williams, 2020). The development of muscle strength aids in body alignment, making performing daily activities more manageable, and enhancing metabolic rate and efficiency. Figure 2.4 shows the muscle size that affects the strong person and maintains healthy body weight.



Figure 2.4: Muscle size (Duquette, 2021)

According to the American Council on Exercise (ACE), physical strength can generate the greatest amount of muscle force possible while executing a specific exercise type (Jennifer, 2021). On the other hand, other elements influence how powerful and how much strength the human body needs to execute daily tasks or routines. Muscular endurance is defined as generating and maintaining muscle force over a specified amount of time. Muscular power is defined as generating enough energy to move a significant quantity of weight in the shortest amount of time, as shown in Figure 2.5.



Figure 2.5: Muscular strength (Silverman, 2017)

Strength is also dependent on the muscle's ability to provide enough support for the movement of the joint, which includes the health of the joints, bones, ligaments, and tendons, among other things. On the other hand, humans begin to lose muscle strength and bone density beyond the age of 40, and hormone synthesis begins to drop. The loss of muscle strength that occurs with ageing puts the elderly at significant risk of developing functional impairment. The risk of muscle strength deterioration is entirely due to the loss of muscle mass resulting from the ageing process. Muscle strength may be affected by chronic diseases, decreased physical activity, poor nutrition, and other pathological changes in the muscle that occur due to the ageing process.

Furthermore, a healthy lifestyle combined with weight loss is the most effective strategy to increase muscle strength. Squats, lunges, biceps curls, pushups, planks, and other workouts that increase the size of muscle fibers and the ability of your neurons to interact with muscles are examples of activities that can aid and improve these traits. It is critical to maintain a person's body's strength and muscle mass to counteract the natural loss of lean muscle mass due to ageing. It also positively impacts patients who suffer from chronic health disorders such as obesity, arthritis, or heart disease.

2.2.2 Hip Flexor Strength

The hip flexors are a group of muscles that work together to bring the legs and trunk together in a flexion movement. They allow you to lift a leg or knee towards your torso and bend the body forward at the hip. Essentially, the hip flexors are a collection of muscles that include the gluteal, adductor, iliopsoas, and lateral rotator. These muscles are responsible for movement at the hip joint. The influence of hip flexion angle on muscle activation during hip flexion revealed that the muscle recruited from 20° of hip flexion (Kato, 2019). However, bending the legs while standing is more functional than bending the legs while lying down; for example, actions such as walking up and downstairs and putting on pants or shoes while standing are more functional than lying down hip flexion. (Kuo, 2009) as shown in Figure 2.6.



Figure 2.6: Hip flexor in standing and supine position (Lindell, 2021)

2.2.2.1 Procedures for Measuring Hip Flexor Strength

The researchers have carried out a variety of methods to evaluate hip flexor strength to understand it better. Standing hip flexion was chosen as the test movement to conduct the test, as shown in Table 2.2:
Step	Procedure
1	The subject need to be in standing position.
2	Raise the hip flexed to 90° taking 2s to complete the manoeuvre.
3	The position was held for 3s.
4	The test was repeated 3 times within a 1 min rest between repetitions.
5	The surface electromyography (EMG) was detected wirelessly the data.

Table 2.2: The procedure test coronal plane hip muscle in standing hip flexion (Morrissey, 2011)

The test exercise required that participants stand with their hips flexed. It has functional significance to the sampled sporting group, has broader applicability to gait and stair-climbing, and largely imposes a coronal planeload on the stance leg, as demonstrated by the study results (Morrissey, 2011). Hence, the data on hip flexor strength can be acquired using a test rig, a customised research and testing gear built for a particular application. It is a hardware prototype that has been constructed for laboratory testing and is typically comprised of a set of reconfigurable circuits or modules that demonstrate the critical functioning of a new idea or piece of technological innovation. A hip flexor strain occurs when one or more of the hip flexor muscles are stretched or damaged, causing pain and discomfort. Those who practise martial arts, football, soccer, and hockey players, are more prone than the general population to sustain this type of damage.

2.2.3 Anatomy

Anthropometry is concerned with measuring physical characteristics such as body shape and composition, the body's ability to move and exert force, and the body's consumption of space. Anthropometric measurements were widely employed in several scientific and technical disciplines and something like that. Concerning ergonomics, the application of anthropometric measurements has historically been linked primarily to various aspects of product design for human usage (Hassan, 2015). Anthropometry is the study of the physical features of the human body, including reach, body segment length and circumferences, width, and heights, among other things, as shown in Figure 2.7. It is the company's policy by design to provide a safe and healthy environment for all users and safeguard those who may be harmed by its actions, among other things. When developing a product, this factor should be taken into account.



It can create pains and symptoms around the shoulder, neck, nape, and wrist and difficulties with the muscular and skeletal systems if it is not appropriately designed. A human factor professional's contribution to the design process is one of the most important ways to help enhance the fit between humans, machines, and environments. As a result, this information will be used to create a test rig and collect correct data when conducting experiments. Table 2.3 and Figure 2.8 shows a figure of anthropometric body measurement. According to the necessary measurement variables, anthropometric data collection can be carried out while in a sitting or standing position.

No	Body Dimensions	No	Body Dimensions
	Standing Posture		Sitting Posture
1	Vertical grip reach	13	Elbow span
2	Stature	14	Span
3	Eye Height	15	Sitting height (erect)
4	Shoulder height	16	Eye height, sitting
5	Armpit height	17	Shoulder height, sitting
6	Elbow height	18	Elbow height, sitting
7	Hip height	19	Elbow-Fingertip length
8	Knuckle height	20	Shoulder-elbow length
9	Fingertip height	21	Buttock popliteal length
10	Tibial height	22	Thigh clearance
11	Biacromial breadth	23	Knee height
12	Bideltoid breadth		

Table 2.3: List of Anthropometric Dimensions



Figure 2.8: Standing and sitting measurements (Hassan, 2015)

2.2.3.1 Application of Anthropometry in designing

The purpose of the employer is to ensure that the product is manufactured in a safe and healthy environment and safeguard individuals who the company's actions may harm. When developing the product, this should be taken into consideration. It can create aches and symptoms around the shoulder, neck, nape, and waist and difficulties with the muscular and skeletal systems if it is not appropriately built and constructed. It is important to note that product design is one of the most critical areas in which human factor professionals may improve the fit between humans, machines, and environments. Over this, considering the anthropometry of the working population could result in a more effective design of a repetitive work job. For example, while building a test rig, the height and width of the test rig are important measurements to consider to provide comfort.

C. S.					
Anthropometry Dimension (cm)	P5	P25	P50	P75	P95
		-	- 6	. 12.	2
Hip Height SIT	77.10	K 82.20	85.10	89.00 A	¥9 4.90
Bideltoid Breadth Right	19.22	22.00	23.70	25.30	27.98
Bideltoid Breadth Left	19.72	21.90	23.30	25.00	27.78

Table 2.4: Percentile Values (P) of Anthropometry Dimensions of Malaysia Male Workers

Anthropometry Dimension (cm)	Р5	P25	P50	P75	P95
Hip Height	71.92	79.50	83.70	88.00	92.64
Bideltoid Breadth Right	17.70	20.00	21.60	23.40	26.32
Bideltoid Breadth Left	16.12	19.00	20.80	22.70	25.68

Table 2.5: Percentile Values (P) of Anthropometry Dimensions of Malaysian Female Workers

The anthropometry data can describe the population of Malaysian factory employees. Design solutions that take anthropometric considerations into account will make it easier for users to complete their tasks and increase their overall performance. The use of anthropometric measurements in the design process will also help avoid incorrect data collection.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA 2.2.4 User Requirement

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User needs are phases that deal with identifying the aims and expectations of the user for the technology in a straightforward manner. It should also include information regarding constraints, usage context, goals and tasks to be supported, design rules, and any recommendations for design solutions that have emerged from the user needs (Bevan, 2018). The product's characteristics must be geared toward making the user and the manufacturer's lives easier. For example, when employing lightweight materials, the product's weight is lowered, which means it requires less energy to move the product. The requirements are dependent on the product's features. Products that can be adjusted are typically more comfortable to use because they are more efficient, enhancing workforce

efficiency—the functionality to prevent physical complaints among users when the product is used consistently without altering the product's position frequently.

On the other hand, another requirement is that product must ensure safety at every stage of the product manufacturing process because unsafe reasons can emerge at any point during the procedure. A product can produce severe and even life-threatening injuries if not designed properly. Broken bones, lacerations, amputations, choking hazards, strangulation, and other types of injuries are all possible.

2.3 Design and Fabricate a Test Rig for Measuring Hip Flexor Strength

This section contains a variety of methods that can be investigated and applied in designing and constructing a product. In addition, there are many concepts and decision-making procedures that can design a test rig.

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2.3.1 Technical Specifications KNIKAL MALAYSIA MELAKA

A technical requirement specifications document defines the product's purpose, functionalities, and behaviour. It is essential to describe how the product should function and its behaviour. Examples of design requirements include required dimensions, environmental factors, ergonomic factors, aesthetic factors, and maintenance requirements required. The product design specification of what the customer wants the product to achieve with measurable elements will allow the designer to target the design formulation precisely (Johnson, 2014).

2.3.2 House of Quality (HOQ)

The House of Quality (HOQ) matrix represents an interactive process known as Quality Function Deployment (QFD), which is frequently used in the process planning industry. It is an approach that can translate the customer requirements into the technical parameters called the engineer's voice. It comprises six major components: customer needs, technical parameters, planning matrix (which also includes an interrelationship matrix), technical correlation matrix (which also includes a technical target), and technical target. The customer requirements describe the customer needs, whereas the technical parameters convert the customer needs into measurable terms. Furthermore, a planning matrix is used to assign the design requirements. An interrelationship matrix is used to define the relationship of HOQ, while a correlation matrix between technical parameters using template Figure 2.9.



Figure 2.9: HOQ template (Basri, 2015)

2.3.3 Concept Screening Method

The designer uses the concept screening method to ensure that it generates the design based on a few concepts, combining each concept's advantages. When determining the important idea, it is necessary to use quantitative and qualitative measures, such as assigning datum to a reference concept in which the eventual design may fulfil the critical client needs. The selection criteria assess each solution in its sub-functions by taking each solution as an assessment reference (Satria, 2018).

The concept screening process is used to eliminate product concepts that are deemed weaker and select the best idea from among those considered strong. The rating is critical in preventing the introduction of softer concept goods into the concept screening matrix in the first place. The following were the selection criteria used is to evaluate each solution in each of its sub-functions, use one solution from each sub-function as an assessment reference for each solution. To rate a notion, three types of symbols are used: (+) symbols denoting a positive value, (-) symbols denoting a negative value, and (0) symbols denoting the same criteria as shown in Figure 2.10.

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2.3.4

Sketching is a vital component of creative expression and one of the most powerful visual thinking tools, and it is widely used in the design industry. Engineering design scholars and experts agree that sketching can help to improve visual thinking and, as a result, creativity. Yet, there is little evidence of sketching being used in engineering education (Martin-Erro, 2016). In contrast to simple and rough drawings, sketches are graphical representations that thoroughly define a concept, design, or idea. They are not to be confused with drawings. Sketching is a quick, simple, and practical technique for completing a design assignment, and it is a common and repeated tool for dealing with design difficulties of all kinds. It is critical to understand the importance of sketching, and the capacity to communicate an idea that is more abstract and best represented through sketches is understood. The investigative sketching stage of product design is used as the designer's initial research during the ideation stage of product design. Initially, it describes

the project before generating concepts through exploratory sketching of shapes, functions, and solutions (Vere, 2012), shown in Figure 2.11.



Figure 2.11: Example sketching of ideation (Martin, 2016)

2.3.5 Engineering Drawing

For 3D solid objects, engineering drawings have proven to communicate mechanical design and manufacturing information effectively. Engineering drawings are a graphical language used by engineers and other technical personnel associated with the engineering profession to communicate mechanical design and manufacturing information. Drawing for engineering is used to portray the ideas and information required for graphically building or analyzing machines, structures, or systems; this is known as engineering illustration. Engineering drawings frequently feature a variety of line styles, dimensions, lettered comments, sectional views, and symbols, among other elements. It is clear from the picture that each thesis contributes information to understanding the object depicted by the orthographic perspective, information not contained in the other ideas. These drawings are commonly used in production because they do not suffer from perspective distortion and make inspection easier, which can be accomplished rapidly by comparing the manufactured item to the original model (Haralick, 1982). It commonly involves CAD drawing and math's application. Software that is available and capable of

illustrating the design model with proper specifications approximate to the actual design includes AutoCAD, SolidWorks, CATIA, etc.

2.4 Evaluate the Functionality and Usability of The Test Rig

Testing is critical because it contributes to improving the quality, dependability, and performance of a system, service, or product by thoroughly inspecting all of its functions. Usability studies analyse the entire user experience by assessing the relative ease with which end users can perform tasks that a typical user would be required to complete. Usability tests are conducted on a variety of devices.

2.4.1 Usability Testing

Usability testing evaluates a product or service by putting it through its paces with real users. Normally, participants will attempt to accomplish a standard task during a test while paying attention to the surroundings and taking notes. This study aims to identify usability issues, collect qualitative and quantitative data about the participants' experiences, and determine their happiness with the product. The roots of usability may be traced back to experimental approaches in psychology and human factors engineering, and the concept of iterative design is intimately associated with them (Lewis, 2006). The primary purpose of usability testing is to assist in developing more useable products. Practitioners will continue to use their professional judgment, when necessary, when it comes to usability testing. However, usability testing doesn't have to be perfect to be valuable and effective because it does not detect all possible usability issues. However, to use it effectively, one must know its strengths, limits, and best practices.

2.5 Analysis and Synthesis of Literature Review

Previous researchers have conducted numerous studies related to hip flexor strength. These researchers may have similarities and differences with the present study. The benefit of this study analysis and synthesis is to provide a useful guide and information regarding methodologies and experimental results as references for the present study. Table 2.6 tabulates the difference between the previous studies and the present study in terms of subjects' background, study variables, and test rig design.

Studies	Subject of	Variables of study	Test Rig design
	Study		
(Matia, 2021)	Manufacturing	It is a comprehensive and	
TEK	Automation	adaptable experimental	Send Distant Second Sec
1.		apparatus that has the	
	A Data	ability to be utilized with a	
4		wide range of servomotors	Figure 2.12: test rig of high
2	Ma Lundo,	and reducers, among other	dynamic servo-mechanisms
U	NIVERSITI TE	things. KNIKAL MALAYSIA	(Matia, 2021)
			• Operational flexibility
			provided by a multifunctional
			arrangement for measuring
			purposes
			• A wide range of testing
			devices to ensure that it is as
			usable as possible.
			• High-capacity active load that
			can be configured to suit the
			needs of the experiment.
(Asyraf M.,	Cross arm	There has been no	TRIZ, morphological charts,

Table 2.6: An analysis of differences between previous studies and present study

2019)		investigation into the	and analytic network processes
		assessment of creep	were used to build the design
		qualities for the real size	test rig for the cross arm
		cross arm.	(ANP).
(Asyraf M.,	Multi-operation	The optimal design	Using the ANP technique, the
2020)	outdoor	concept for a product's	multi-criteria decision-making
	flexural creep	development in	process for selecting the
	test rig	accordance with its	optimal concept design for the
		requirements.	multi-operations creep flexural
			test rig was carried out in this
			study.
(Maccioni,	Particle Image	For this study, lubricant	
2021)	Velocimetry	levels inside a tapered	Electric Motor
	(PIV)	roller bearing must be	
CHILE	* K	measured in order to	Bellows Joint
H E A		increase the bearing's	Test Rig
14th		performance and optimize	Frame
	SAMO -	its behavior while in	Danje
5	Malala	operation.	
	in the second	ىيى ئىسىيە ر	Figure 2.13: Vertical test rig
U	VIVERSITI TE	KNIKAL MALAYSIA	MELA (Maccioni, 2021)
			The test rig has been
			constructed so that it may
			rotate along a vertical axis of
			rotation.
(Kato, 2019)	17 healthy	The isometric hip flexion	
	young male	was performed at three	Dynamometer
	volunteers	distinct hip flexion angles	COTAS
		$(0^{\circ}, 40^{\circ}, \text{ and } 80^{\circ})$ to	
		determine the maximum	
		voluntary contraction	Figure 2.14: Testing position

		(MVC) and submaximal	during hip flexion and extension
		voluntary contraction	tasks (Kato, 2019)
		(SVC) of the hip flexion.	
			According to the findings of
			the study, mechanical stress on
			the adductor longus of the AL
			muscle may be greater during
			0° of hip flexion than at other
			points during hip flexion.
(Murray,	14 student's	Individuals lying supine	
2001)	volunteers: 9	experience a change in hip	(r)
	males and 5	flexion angle as a result of	
	females.	their pelvic rotation.	000
	MALAYSIA 4		
	7 K		
EKA			DA
T			Figure 2.15: Standing hip flexion
8			(Murray, 2001)
	Alwn -		
5	Juni all	ىتى تىكنىكا	Participants were told to flex
	10 10 V		their right hip to its maximum
IU	IVERSITI TE	KNIKAL MALAYSIA	extent and then extend it back
			to its original position.
(Eun, 2012)	10 healthy male	Hip flexion in standing	The participants were required
	adults and 10	position.	to stand for 5 seconds and flex
	healthy old		their hip joint while standing
	males.		each time.
(Morrissey,	9 male football	Standing hip flexion.	The participant was given 3
2011)	code subjects		seconds to count down and
	with chronic		elevate their leg until their hip
	adductor injury		was flexed to 90 degrees,
	and 9 matched		which took 2 seconds. The
	controls.		experiment was carried out

					break between each repetition.
Present study	60 volunteer of	Measuring	hip	flexor	In order to acquire data on hip
	Malaysia young	strength	in	standing	flexor strength, the test
	adult.	position.			apparatus must be rigid and
					steady while the analysis is
					being performed.

From Table 2.6, there are combining parts or ideas to come up with a new idea or theory for designing the test rig to measure the hip flexor strength. From the researchers, the analysis has been conducted was relatedly for 3 to 5 times to reliability and validity of the data. Next, the average time when conducting the test was 3 seconds to 5 seconds in standing position and needed to flex the leg at 90°, which is the procedure to measure the hip flexor. Also, from researchers (Murray, 2001), the position of participants is in standing with maximally flexing up and holding onto a stabilization frame. Therefore, this information can be collected as a test rig design for frame structure. Lastly, integrating the theory of creative problem solving (TRIZ), the morphological chart, and the analytic network technique can be used to create a test rig for a specific application (ANP). Another method described in the article (Asyraf M., 2020) was the design was selected by conceptual designs and selected using the ANP method to select the best concept design.

2.6 Summary

In this chapter, the literature review comprises information needed to develop and guide the method flow in the next chapter. This chapter aims to achieve the objectives effectively by choosing the best combination of ideas. Besides that, the literature review can act as a guideline to prevent any deviation of projects from expected results. Hence, the optimal technique will be constructed by combining and modifying the ideas mentioned in this chapter and coming up with new ideas.

CHAPTER 3 METHODOLOGY

This chapter presents the methodology of the study. The procedures, equipment and software used to perform the study will be mentioned and elaborated on to attain the objectives in Chapter 1. First, the method to achieve objective 1, which is to determine the design requirements for fabricating a test rig in a standing position, is discussed. For designing a test rig that is stable and convenient for participants, methods used to obtain the design requirement and select the best design were explained. The design for this project was created with CATIA software, and the process of making it is discussed in detail. The methods and techniques used to meet the objectives will be described in this part of the study. It was mainly concerned with measuring the strength of the hip flexor participants in standing position by using a reliable measurement instrument, the force gauge Mark 10.

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3.1 Design Requirement to Fabricate a Test Rig

Design requirements are important for determining the performance, reliability, and cost to satisfy all of the requirements of a test rig. It is possible to identify, assess, and select the materials utilised for the test rig after all of the design requirements for the production elements have been established. However, the device is not meant for consumers but is rather used for experiments. The design concept of the test rig has been used to make the design we had before more functional. The test rig has been defined to develop, evaluate, and select new product designs from the design requirements. Several design requirements must be met to design a product, including performance, cost, size, shape, mass, style, industry standards, manufacturing and sustainability requirements. Figure 3.1 illustrates the flowchart of process design requirements to fabricate the test rig.



Figure 3.1: Flowchart of process design requirement

3.1.1 Perform Benchmarking

Benchmarking is one of the most useful tools for improving management, customer relations, product design, and manufacturing processes. This strategy attempted to make design a more hands-on experience by providing an industrial performance setting. This is an example of a method for meeting the design requirements of a test rig. This is a collection of techniques for meeting the design criteria of a test rig that does more than providing results. It's a method of comparing the best tactics and performance, both within and outside the sector. This project aims to find the best techniques that the organisation can embrace and use to achieve the project's goal. The benchmarking process is broken down into numerous parts that compare the safety, convenience, material, dimension, and physical construction. This method is required to determine the design requirements for the test rig concept. As a result, the test is created by merging the benefits of current prototypes.



Inexperience design, observation is strong but frequently underestimated tool. Learn how to use it, when and where it's beneficial, and how to enhance your observation abilities to boost research outcomes. In the context of experience research, observation is described as witnessing someone do a process, task, or activity, or interact with a product or service, as opposed to just hearing about it. This is an active form of observation in which the observer pays close attention to detail and has a specific objective or outcome in mind. However, in this method, the design test rig was observed using an existing test rig from Fakulti Kejuruteraan Pembuatan's Basic Mechanics Lab (FKP). The existing test rig at the facility is depicted in Figure 3.2. The material, aluminium extrusion, is suited for fabrication based on the existing test equipment because it is lightweight and easy to build. Furthermore, the construction is quite stable for conducting the experiment and providing convenience to the participants. The test rig material is suitable for this project since non-permanent joints can be adjustable and easy to bring.



Furthermore, the observation has been done through the equipment gym since its stable and rigid physical structure, as shown in Figure 3.3. This exercise equipment is an item or device used during physical activity to increase the strength of the user's muscles. The gym equipment can replace the traditional fitness equipment with equipment that serves the purpose. The physical structure analysis and intensity check are performed to optimise the structure of materials when there is an excess of them and reinforce the materials when there is a concentration of stress (Zhang, 2014). Thus, this physical structure can be applied to this prototype of test rig where it consumes by a human.





Figure 3.3: Gym equipment

3.1.3 Gather Information from Previous Studies

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Background and supporting materials and reputable references for the research, such as books, journals, and articles, are provided in the literature review. An excellent literature review resource will provide you with a thorough understanding of the research's concerns. The literature review is an important part of the project's beginning. At this point, you've accumulated all of the information and findings from your research. This initiative is critical since the study would not proceed smoothly without it. The requirements for building the test rig can be found in Table 3.1.

Article	Information to be used in this study	Requirement
(Hassan,	From the article we take a higher percentile	This study can be used for
2015)	value of anthropometry dimensions.	the dimension of test rig
		which is the heigh and
	Table 3.2: Dimension of hip height	width.
	Gender Dimensions (cm)	
	Male 94.90	
	Female 92.64	
	Table 3.3: Dimension of Bideltoid Breadth	
	Gender Dimensions (cm)	
	Male 27.98	
	Female 26.32	
	Straning	
(Mazur, The	Many of the industrial design considerations	This study has proved the
importance	that could obstruct and complicate the	test rig is suitable tools or
of test rigs in	collection of reliable data and cause	equipment as the test bench
research and	progress to be excessively slowed can be	for this analysis.
development,	avoided by building a test rig to prove new	
2019)	technologies on the test bench before they	
	are implemented. Essentially, a test rig is	
	comprised of the physical chassis to which	
	all other components are attached, as well as	
	the fittings that connect all of the	
	mechanical components together.	
(Camara,	According to the findings, the pelvic	This application can fulfil
2013)	position during hip flexion should be	the design requirement
	between 45° and 90° . The technique was	where the suitable angle to
	repeated three times, with the average value	put force gauge at the test

Table 3.1: Criteria test rig

	in healthy individuals.	rig.
(Murray,	Participants were told to bend their hips to	This study shows the
2001)	their maximum extent and subsequently	position participant when do
	stretch them back to their initial position	the analysis need to hold
	while holding onto a stabilisation frame, as	onto a stabilisation frame.
	shown in Figure3.4.	Therefore, the frame needs
		on the structure test rig.
	Figure 3.4: Position during standing hip flexion	
	(Murray, 2001)	
(Kuo, 2009)	When the test movement was completed, the	This study has been used to
	participants were instructed to softly place	create a height frame that
1	their hands on a stable support (at waist	will be held in place while
	height) in order to assure their own safety.	the experiment is carried
	*Alun	out using the prototype test
	بتي تيڪنيڪ مليسيا ملاك NIVERSITI TEKNIKAL MALAYSI	اونيومر. MELAKA
	Figure 3.5: Position participant while	
	performing the test (Kuo, 2019)	

3.1.4 House of Quality

The House of Quality (HOQ) technique can identify and implement user requirements. Benchmarking, observation, and previous studies were used to gather requirements for the test rig design for determining the hip flexor strength in the standing position. This project's HOQ template can be seen in Figure 3.6.



Figure 3.6: House of quality (HOQ)

Product engineering standards are specified in the template above, while user requirements can be described in a left-hand column on the left side of the form. The correlation matrix is used when assessing the relationship between a product's engineering specs and its performance. An empty column in the matrix indicates no correlation between the product's technical standards and the evaluation's values 9=strong, 3=moderate, and 1=weak. The second row of the correlation matrix shows the engineering standards that must be enhanced, lowered, or targeted. At this point, a relationship matrix is employed, which assigns a numerical rating to the user's requirements and the product's

engineering specifications based on how well they meet those criteria. As a final step, a relationship matrix is employed to assign a numerical value to each of nine possible strengths, three moderate strengths, one weak strength, and zero no strengths to the user's requirements and the product's engineering standards.

3.2 Design and Fabricate a Test Rig

Illustrates the flowchart of design and fabrication of the test rig defined as the process of producing a product from raw materials using the selected design as shown in Figure 3.7. The process to develop the prototype and the efficiency will be discussed in this section.





Figure 3.7: Flowchart of design and fabricate a test rig

3.2.1 Conceptual Design

Various test rig design designs have been offered to fulfil the end customer's needs. Design and sketching of concepts will be done following the House of Quality's prior user requirements (HOQ). The most significant component of developing the prototype of the test rig will be the user needs that receive the highest mark. Early in the design process, conceptual design articulates the general purpose and shape of anything. Interaction, experience, process, and strategy design are all included. Table 3.4 depicts the four types of conceptual design discussed in this section. We'll go over how we used a concept screening matrix and a concept scoring matrix to narrow down the field of design possibilities.





Several new concepts can be developed using the preceding need and technical requirements obtained from the House of quality (HOQ). New test rig design designs have been developed for further assessment. Hand sketches were used to present the ideas. The concept selection process is separated into two categories: concept screening and concept scoring. The concept screening process is used to narrow down some of the proposed concepts by removing or combining them. A matrix was created with selection criteria based on the customer's needs. The weightage has been assigned for each selection criteria.

In addition to the concepts themselves, the matrix contains references to other concepts. After the matrix had been constructed, the concepts were assessed by comparing them to the reference concept for each category in the matrix. They were allocated to a scale with "+" representing more than the reference notion, "0" being equal to the reference concept, and "-" representing worse than the reference concept. The frequency of each concept's rating scales has been added together, and the net score of each concept may be calculated by subtracting the frequency of "-" from the frequency of "+." Each notion was ranked according to how well it performed overall. On whether to discard the lowest-ranking concept or combine two concepts while maintaining only the "+" features, certain decisions were taken. The initial concepts were whittled down to two or three concepts for further analyses by the end of the concept screening phase. The framework of concept screening is shown in the Table 3.5.

	CL AK	Table 3.5: Cor	ncept screening	;	
Select Criteria	Concept A	Concept B	Concept C	Concept D	References
Criteria 1				7	
Criteria 2					
Criteria 3	undo)	<u>Cail</u>	-i.i.	ونتقريس	
Criteria 4	0		Q	02.2	
Sum '+'s	RSITI TEP	NIKAL M	ALAYSIA	MELAKA	
Sum'0's					
Sum '-'s					
Total					
Rank					
Continue					

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Before each concept was ranked, a cumulative number of plus, minus and the same were measured, and their net ranking decided the net score of the principles. Table 3.6 indicates the scores used for concept comparison and assessment in the screening concept.

Type of rating symbol	Relative Performance
+	Better than
0	Same as
-	Worse than

Table 3.6: Type of rating symbol used in concept screening matrix

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A weight was assigned to each of the criteria, and concepts were then assessed based on their relative performance, with the highest scoring concepts obtaining the highest marks due to this process. It was decided that the rating scale would be 1 to 5, with 1 to 2 being significantly worse than the references, 3 same as the references, and 4 to 5 being noticeably better than the references. Each selection criterion's weight and rating were multiplied by the total number of criteria to get the final score. The sum of all the idea weights was used to compute the overall scores for each concept. Lastly, the concept was ranked based on the overall scores, and the concept with the highest score was chosen to develop, as indicated in Table 3.7.

Evaluation Weight Criteria (%)	Waight	Concept A		Concept B		Concept C	
	Ranking (1-5)	Weight score	Ranking (1-5)	Weight score	Ranking (1-5)	Weight score	
Criteria 1							
Criteria 2							
Criteria 3							
Criteria 4							
Criteria 5							
Total S	core						
Ran	k MALAY	\$1A					
Contin	nue	Ser P					
		(A					
	Elec				ЗV		

Table 3.7: Concept scoring

3.2.3 Detail of Design

The design of each component of the test rig has been included in this section. This design has been selected based on the screening and ranking of concepts in the previous phase. CATIA software was used to design each component, and the description was sorted by function. A test rig for assessing hip flexor strength in the standing position is shown in Table 3.8, which lists the components, their quantities, and descriptions.

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- au g

Table 3.8: 1	Detail	design
--------------	--------	--------

No	Components	Quantity	Description

3.2.4 CAD Drawing

Concept selection was automated, and the software displayed the best design concept based on the dimensions. In this inquiry, CAD drawings were created using CATIA V5. An example of a CATIA drawing can be seen in Figures 3.8 and 3.9. CATIA designs were used to conduct an engineering analysis of the test rig's functionality before it was developed into an actual prototype, and any errors were fixed. One of the advantages of using computer software to draw before manufacturing is that time and money are saved.



Figure 3.8: Sample of computer aided design drawing



Fabrication is the process of turning raw or semi-finished materials into completed goods. The fabrication procedures required to create the test rig prototype will be detailed in this context. Milling and joining were among the procedures used. The processes that are employed are determined by machine availability and cost. The prototype was made by combining aluminium extrusions as the test rig's foundation construction and attaching them with bolts and nuts.

3.2.5.1 Drilling

To attach two parts with an allen key, holes were drilled through the aluminium bar and force gauge. The vertical milling machine in the FKP machine lab is used to drill four holes. Figure 3.10 and Figure 3.11 depicts the milling machine drilling procedure.



Figure 3.11: Drilling holes through aluminium bar

3.2.4.2 Fastening

Fastening is a method of securely securing two pieces together or securing a part to something as shown in Figure 3.12. It's used to make non-permanent junctions that can be taken apart without causing damage to the two joining parts. Screws, bolts and nuts, pins, rivets, and other fasteners can be used to link the aluminium extrusion as a structure. Bolts and nuts were utilised in this investigation because they are readily available and less expensive than other fasteners.



3.2.6 Bill of Materials (BOM)

Bill of material (BOM) illustrated the materials and cost used where all the materials have been listed to fabricate the prototype test rig. Creating an accurate BOM ensures that parts are available when needed and ensure that the assembly process is as efficient as possible. Table 3.9 shows the BOM of the prototype and the instructions on how to assemble it.

Name of Part	Price per Unit (RM)	Units Needed	Cost (RM)
Extrusion Aluminium 40x40 (300mm)	18	7	126
Extrusion Aluminium 40x40 (1050mm)	60	4	240
Extrusion Aluminium 40x40 (100mm)	6	2	12
45 degree Profile bracket 40x40	ڪنيڪ	بر سيەبتى تيە	36 اونيو
90 degree bracket 40x40	KNIKAL MA	LAYSIA MEI	AKA 48
Aluminium Plate 6061 (5x130x380mm)	22	1	22
Allen key 7/64	0.6	1	0.6
Bolt and Nut M8	1	40	40
Socket Cap Screw M6x20	0.5	6	3
	1	Total	527.6

Table 3.9: Bill of materia

3.3 Evaluate the Functionality and Usability of The Test Rig

In this section, to determine the usability of the test rig in term of practical, ease of use, stable, not complexity and safety to test. This method will help to get the reliable data of hip flexor in standing position as shown in Figure 3.13.



Figure 3.13: Flowchart of evaluate the functionality and usability of the test rig
3.3.1 Stress Analysis on Structure Body

To prepare for the medium-fidelity prototype's construction, stress analysis and an analysis of the test apparatus were used to evaluate the design's hip flexor strength in standing. The third objective of this project was met with the completion of this section which assessed the functionality of the test rig. This section was a little lengthier and more in-depth than the rest due to the importance placed on analysis and testing during the product development process.

Using stress analysis, we could determine the extent to which a given load would cause stress, displacement, strain, and stress structure or component forces. CATIA V5 was used to perform the analysis. Figure 3.14 shows the test rig used to measure hip flexor strength based on the part of the body that was most important when the body was subjected to the most significant stresses.



Figure 3.14: Sample interface of stress analysis

3.3.2 Development of Standard Operating Procedure (SOP)

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SOPs were developed before beginning the experiment. The researcher consulted the study's supervisor and a past researcher who had previously conducted the experiment in order to develop the study's SOP. To ensure that the methods were effective, five people choose to take the test before performing the actual trial. During pilot testing, it is determined whether or not the experiment can be carried out successfully. The results of the pilot test were utilised as a standard for the entire trial in order to prevent significant discrepancies in the outcomes. You can see an example of how to test your strength in this posture by looking at Table 3.10.

Table 3.10: Standard Operation Procedure (SOP) for measuring hip flexor strength in a standing

No	Step	Figure
1	Measure the thigh circumference	
	and thigh length in cm. The thigh	
	circumference will be measured	
	below, middle, and top of the thigh circumference and record the	اويوم سيتى تيك
	measurement ONIVERSITI TEKNIKAL	MALAYSI

position.

2	Place the force gauge on plate	
2	before starting the experiment and turn on the gauge.	
3	Reset the force gauge to zero.	
4	Before measure the force, make sure the angle of thigh and force gauge is 90° or adjust the height of plate.	
5	Stand in front of test rig and grip the handle. UNIVERSITI TEKNIKAL	اونو MALAYSIA
6	Flex the thigh with maximum force and touch the gauge.	
7	Put a pressure on the gauge for 5 seconds and take the data.	

8	After completing the testing candidate must answer the questionnaire and set the instrument to default for next candidate.	

3.3.3 Usability of The Test Rig

This task necessitates that participant in the test rig prototype choose a response to the usability question that is relevant to them. In most cases, the test rig designer would enquire whether the test rig is easy to use and comfortable to use after the user has used it to evaluate hip flexor strength in standing. An inquiry was used to generate a meaningful response from participants, whether orally or spontaneously. Their answers will be assessed to determine whether or if the prototype testing equipment is appropriate for the participants. Usability research participants will be asked a variety of questions, such as:

- 1. I would need the support of technical person while conduct the experiment to use the test rig. (1-5)
- 2. I found the test rig unnecessarily complex. (1-5)
- 3. I found the various function in this test rig were well integrated. (1-5)
- 4. I thought there was too much inconsistency in this test rig. (1-5)
- 5. I would imagine the most people would learn to use this test rig very quickly. (1-5)
- 6. I found the test rig very cumbersome to use. (1-5)
- 7. I felt easy to use the test rig. (1-5)
- 8. I found the test rig unnecessarily complex. (1-5)
- I would like to use the test rig as experimental tool to know my hip flexor strength.
 (1-5)
- 10. I need to learn a lot of things before I could get going with this test rig. (1-5)

3.3.4 System Usability Scale (SUS) Scoring

The Likert scale-based System Usability Scale (SUS) is a quick and effective technique to measure the usability of this test rig. A Likert scale is commonly misunderstood as a simple forced-choice questioning system in which a statement is stated on a 5-point scale, as depicted in Table 3.11. Users will be asked to complete a 10-question SUS survey after they have used the test rig to measure hip flexor strength. The results of this survey will be used to help improve the test rig's usability.

Table 3.11: Likert scale of SUS score

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

To calculate the SUS score, each response was given a numerical value. The answers are as follows: strongly disagree with 1 point, highly disagree with 2 points, neutral with 3 points, agree with 4 points, and strongly agree with 5 points of disagreement. The number score assigned to each response by respondents can be seen below. While for odd-numbered questions, the total score is added, then 5 is subtracted to get to (X), for even-numbered questions, it is added, then the sum of 25 is removed to arrive at (Y). Finally, multiply by 2.5 the new value's total score (X+Y). Table 3.12 illustrates how to calculate a SUS score using a table.

MALAYSIA	Calculation
Question 1 (Odd)	Q1
Question 2 (Even)	Q2
Question 3 (Odd)	Q3
Question 4 (Even)	Q4
Question 5 (Odd)	Li nuQ5 ning
Question 6 (Even)	- Q6
Question 7 (Odd)	AYSIA MELAKA Q7
Question 8 (Even)	Q8
Question 9 (Odd)	Q9
Question 10 (Even)	Q10
Total odd	Q1+Q3+Q5+Q7+Q9
Total even	Q2+Q4+Q6+Q8+Q10
Х	Total odd - 5
Y	25 – Total Even
(X+Y)	Total X and Y
SUS Score	(X+Y) ×2.5

Table 3.12: Calculation for SUS score



Figure 3.15: Acceptability Score

A SUS score will display a score out of 100 if the above scoring technique is followed. In this case, the total out of 100 is not a percentage but a total score. As shown in Figure 3.15, the range of possible SUS scores includes the best-case scenario, excellent, acceptable, ok, terrible, and the worst-case scenario. It is possible to find specific product improvements to be made using the SUS's reliable rating of overall usability and user satisfaction.

3.3.6 Statistical Analysis of Data UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Minitab and Microsoft Excel were used to perform descriptive statistics, normality tests, and regression analyses on the maximum force of hip flexor measurement obtained Trends. The simplest form of statistical analysis that uses numbers to describe the characteristics of a data set is called fundamental statistical analysis. Using this method, data from a sample or a whole can be summarised or represented in a research population. Minimum, mean, maximum, standard deviation and skewness are listed here. Force male and female averages, range, variation, and standard deviation may be calculated using descriptive analysis. Analysis of anthropometric characteristics such as height, weight, leg length, and leg circumference was used to link hip flexor strength with the force of the muscle. Anthropometric measurements were compared to discover which one's impact hip flexor strength most. There was either a positive or negative association between R square and coefficient values, as illustrated in Figure 3.16.

Regression :	Statistics							
Multiple R	0.629674181							
R Square	0.396489574							
Adjusted R Square	0.340608979							
Standard Error	53.40746957							
Observations	60							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	5	101192	20238.3	7.0953	3.66073E-05			
Residual	54	154027	2852.36					
Total	59	255219						
	Coefficients	andard Ern	t Stat	P-value	Lower 95%	Upper 95%	ower 95.09	pper 95.0%
Intercept	-56.62373963	284.979	-0.19869	0.84325	-627.9727813	514.725	-627.973	514.725
Gender	-54.39859504	21.6286	-2.51513	0.01491	-97.76127475	-11.0359	-97.7613	-11.0359
Body mass	0.636408227	0.71884	0.88533	0.3799	-0.804773134	2.07759	-0.80477	2.07759
Body height	0.555790722	1.76469	0.31495	0.75401	-2.982189785	4.09377	-2.98219	4.09377
Thigh length	1.201905958	1.70567	0.70465	0.48405	-2.217753001	4.62156	-2.21775	4.62156
Thigh Circumference	1.230595151	1.06461	1.15592	0.2528	-0.90381306	3.365	-0.90381	3.365

Figure 3.16: Sample of regression model

3.4 Summary of The Methodology

From the methodology, the method project has been discussed the method to conduct this project, what will do in this analysis, where this analysis will be done, and what purpose. A collection of methods, practices, processes, techniques, procedures, and rules will help achieve the analysis objective. Therefore, Table 3.13 shows the methodology of the study and objective.

Objectives	Methodology		
To investigate design requirements to	Benchmarking		
develop a test rig for measuring hip flexor	Observation		
strength in standing position where the	Previous Study		
criteria of test rig has been discussed in this	House of Quality (HOQ)		
part.			
To design and develop a test rig for	Conceptual design		
measuring hip flexor strength in standing	Concept screening		
position which is the procedure from the	Concept scoring		
idea will generate to conceptual design in	Best concepts translate to engineering		
order to fabricate the prototype from raw	drawing		
material.	Bill of Material		
ALL	Fabrication of Prototype		
To evaluate the functionality and usability	Mechanical analysis		
of developed test rig will discussed in this	Standard Operation Procedure		
part to analyse and testing the prototype.	System Usability Scale (SUS) score		
in the second se	Statistical Analysis Data		
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Table 3.13: Summary of methodology

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CHAPTER 4 RESULTS AND DISCUSSION

This chapter provides results and discussion of the design requirement which is to determine the needs and criteria for designing a test rig to measure hip flexor strength in standing position. The benchmarking, observation, earlier research, and Quality Function Deployment methods were utilised to compile the list of design criteria for the testing rig (QFD). In addition, the findings of the Pugh method analysis relating to screening and scoring of a conceptual design of the test rig are shown in this chapter. These results are presented in the context of the chapter. In this section, we also address the fabrication and analysis of a prototype of the test rig using engineering simulation tools such as CATIA and Ansys. The purpose of the prototype is to evaluate the test rig's functionality by using MINITAB software and scoring on the System Usability Scale (SUS). At the end of this chapter will discuss the data that has been collected and prove the data is reliable by comparing the force strength of male and female study participants.

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4.1 **Design Requirements**

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Since the test rig is not a consumer product, this study generates the Quality Function Deployment (QFD) by providing experimental data and discussion based on benchmarking, observation, and previous studies. Table 4.1 were summarized the design requirements to fabricate the test rig for measuring hip flexor strength which obtain from the benchmarking of similar equipment, observation to laboratory facilities and information of previous studies. This study found that the most critical design requirements in the test rig include materials, physical characteristics, performance characteristics, user needs and environmental requirements.

Some of these requirements for making the test rig to measure hip flexor strength came from earlier studies. (Mazur, 2019) A test rig is a new technology that can be used as a test bench before an actual project to get accurate data. According to (Previati, 2018), the deformation of the testing structure due to large or heavy bodies can affect the accuracy of the measurement; as a result, the structure test rig needs to be as strong as possible. The fabrication was done to validate the quality of the test rig, which included not only a device's ability to produce something that would fulfil the goals and specifications that were decided upon but also the environmental impact of the device from its production (Jurecki R., 2017). The concept of a cantilever beam creeps testing rig was developed using CAD modelling and finite element analysis by employing a static structural analysis within the ANSYS engineering simulation software from previous research (Asyraf M., 2020).

Table 4.1: Design requirements of test rig for measuring hip flexor strength

Design	Specification	Justification		
Doquiromonto	Sprimourien			
Requirements				
Materials	Aluminium Extrusion Profile	Observation at Basic Mechanic Lab.		
Kle	کنیکل ملیسیا م	Mostly aluminium extrusion has been used on test rig because it's		
UNIV	ERSITI TEKNIKAL MAL	lightweight, easy to fabricate and		
		assemble/disassemble the tools.		
Physical	Weight: below 25kg	Based on anthropometry dimensions		
characteristics	Size:	of hip height as a height test rig and		
	• Height: 95cm	bideltoid breadth as the width of the		
	• Length: 28cm	test rig.		
	• Width: 28cm			
Performance	• Safety	The test rig needs to be safe when		
characteristics	• Strength	use it doesn't harm to user and the		
		ability of material to resist		
		deformation.		
User needs	• Sturdy	To measure the strength of the hip		
	• Stable	flexors, the test rig needs to be		

	• Light weight	stable so that accurate data can be
	• Portable	collect without any errors.
	• Safe	The test rig not harmful to user.
Environmental	• Environmentally friendly	The test rig does not generate any
requirements		potentially hazardous products that
		could contribute to environmental
		harm.

4.1.1 Quality Function Deployment (QFD)

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Table 4.2 presents both the symbol and the value of the relationship that exists between the functional necessity and the user demand. The symbol " \bullet " is used to denote a strong relationship, which is then given the highest possible score of 10, while the symbol " \circ " is used to denote a moderate relationship, which is then given the lowest possible score of 5. The weak connection between the user needs and the functional requirement has been given the symbol " \bigtriangledown " and the numerical value 1 in this definition.

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Scale	Symbol	Relationship
10	•	Strong
5	0	Moderate
1	\bigtriangledown	Weak

The correlation symbol for the correlation between functional needs was shown in Table 4.3 the character "+" indicated a positive correlation between functional requirements, whereas the character "-" indicated a negative correlation. When no symbol was used, there was no association.

Table 4.3:	Correlation
------------	-------------

Scale	Symbol	Correlation
-3	+	Positive
-3	-	Negative

The House of Quality, which is one of the instruments used in the study to identify Quality Function Deployment, is shown in Figure 4.1. The functional equipment needs were stated by the test rig and hip flexor in standing position requirements. The user requirement section was described using benchmarking, observation, and previous studies. The competitive analysis included a comparison of the specifications by the user's needs and used a scale that ranged from 1 (Very Poor) to 5 (Extremely Good). The connection between the various functional needs was illustrated by the "roof" of the House of Quality.

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After the summation of all relationship ratings, it can be concluded that the five most critical specifications are portable (271), easy to carry (271), the compact size (not bulky) (263), stable (217), easy to assemble and disassemble (190) and material (184). Based on the rating section, the five specifications were carried out for identifying the best design in the next section. In this case, portable, easy to carry, compact size (not bulky), stable and material.



Figure 4.1: House of Quality for designing test rig of hip flexor strength measurement

4.2 Design and Fabricate a Test Rig

The design specifications of the hip flexor strength are derived in this section, as well as a few design concepts that are proposed for consideration. The notion that best represents the design is chosen after which it is depicted in CATIA. It is decided to make a prototype of the test rig that was created.

4.2.1 Conceptual Design

Designs for test suits have been proposed to meet the needs of the design or the user. A method will be produced using the design requirements acquired from the evaluation of design requirements. To focus the ideas, the sketches were refined. Table 4.4 depicts an illustrative depiction of a conceptual design.



Table 4.4 Conceptual design of test rig for measuring hip flexor strength



4.2.2 Concept Screening

The outcomes of the concept screening that were done to pick the final concept for this study are shown in this section. The relative performance is the same as (0), which is the same as (+), and it is worse than (-) as shown in Table 4.6. The final tally is arrived at by subtracting the sum of (+) from the total of (-). The greatest and equal rank among the concepts is 3 and 4 since they each have a total of 2 points. The concept screen has shown in Table 4.5 for selection criteria, and within that section were listed the five most important criteria that had been chosen from the preceding section.

Selection Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Reference concept
Easy to carry	0 2	-	0	0	0
Stable		+	+	+	0
Compact size (not bulky)	_		+	7 +	0
Portable	0	0	0	0	0
Easy to assemble & disassemble	ل مارسي	0	يتى ۋېرىخ	وينون س	0
Materials VE	RSIT ⁰ TEK		ALAYSIA	MECAKA	
Sum '+'s	0	1	2	2	
Sum'0's	4	3	4	4	
Sum '-'s	2	2	0	0	
Net score	-2	1	2	2	
Rank	4	3	1/2	1/2	
Continue	No	Yes	Yes	Yes	

Table 4.5: Concept screening

Type of rating symbol	Relative Performance
+	Better than
0	Same as
-	Worse than

Table 4.6: Type of rating symbol used in concept screening matrix

4.2.3 Concept Scoring

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From the concept screening to concept scoring in Table 4.7, concepts 2, 3, and 4 were carried forward to identify the best concept. According to the importance of the study criteria, the weight percentage of the criteria was defined.

		Table	4.7: Concep	ot scoring	N		
	Vanne.	Concept 2		Concept 3		Concept 4	
Criteria	(%)	Ranking (1-5)	Weight score	Ranking (1-5)	Weight score	Ranking (1-5)	Weight score
Easy to carry	NIV20RSI	TITEKN	IK0.2. M	AL/3YSI/	A 10.6 A	KA 4	0.8
Stable	20	3	0.6	3	0.6	5	1.0
Compact size (not bulky)	10	3	0.3	3	0.3	5	0.5
Portable	20	3	0.6	3	0.6	3	0.6
Easy to assemble and disassemble	2	2	0.2	2	0.2	2	0.2
Materials	10	2	0.2	2	0.2	2	0.2
Total Score		2.1		2.5		3.3	
Rank		3		2		1	
Continue		No		No		Yes	

According to the data in Table 4.6, the total value of the weighted score for concept 4 was 2.7, making it the one with the highest value overall; concept 3 came in second with a weighted score of 2.0. The unweighted score for concept 2 was only 1.8, making it the concept with the lowest score. After carrying out the process of idea screening, it was determined that concept number 4 was the most suitable option for this investigation. This was because the design of this concept satisfied both the criteria and the specifications.

4.2.4 Detail Drawing of Test Rig

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Table 4.8 shows the design details for concept 4, built mainly from an aluminium extrusion profile. The material utilises various combinations of its advantageous properties such as strength, lightness, corrosion resistance, reliability, and formability.

No	Components	Quantity	Description
1	UNIVERSITI TEKNIKAL M	AL/2YSI	AluminiumExtrusionProfile 4040 (100mm)This part will support thetop of the test rig at back.
2		7	AluminiumExtrusionProfile 4040 (300mm)This dimension will use forthe base test rig, handle andattached plate of the forcegauge.

Table 4.8: Detail design of concept 4.



7	40	Bolt and nut
		Used to connect two or
		more parts.

4.2.5 Design of Assembly View

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From a 3D design point of view, Figure 4.2 and Table 4.9 shows how the test rig for measuring hip flexor strength is formed. Part 1 is the base structure of the test rig, made from four pieces of aluminium profile, each 0.3 m long. One of these pieces is used for the test rig's handle, and the other is used to make a 45° angle on the plate base. The test rig's body is made of an aluminium profile that is 1.05m long and has four pieces for part 2. Next, the test rig is more stable because the top structure is made of two joint parts. Part 3 of the aluminium profile has been used 16 times with a bolt and nut. Part 6 is then used to place the force gauge at a 45° angle with two units, as shown in Part 5.



Figure 4.2: Assembly view of a test rig for measuring hip flexor strength

	alo	14	2:C	aï	nu.	اونيةم
e e	Table 4.	9: Descr	ription of a	assembl	y view	12.2

UNIVERSI	TEKNIKAL MPart Name
1	Base 0.3m
2	Body 1.05m
3	90° bracket
4	Top 0.1m
5	45° bracket
6	Plate

4.2.6 Computer Aided Design (CAD) Drawing

The software presented the best design concept from the concept selection process with given dimensions. CATIA V5 is the CAD drawing software used in this investigation. Figure 4.3 depicts a CATIA drawing example. An engineering study of the functionality of the test rig created was performed using CATIA drawings before the construction of the real prototype, and corrections were made for results that were not as predicted. One of the advantages of using software to draw before fabricating is that time and money are saved. Figure 4.4 shows the CATIA drawing of the test rig for measuring hip flexor strength.



Figure 4.3: Final assembly of a test rig for measuring hip flexor strength



Figure 4.4: Engineering drawing of the test rig for measuring hip flexor strength

4.2.7 Medium Fidelity Prototype

Finally, following extensive research and analysis, a medium-fidelity prototype was produced. This prototype has followed the design and the technical specifications from the preceding section. Figures 4.5 through 4.18 illustrate the medium-fidelity prototype of the test rig that was designed to measure an individual's hip flexor strength while standing. The test rig has a size of 1.05 m x 0.38 m and a weight of 19.5kg.



Figure 4.5: Assembly aluminium profile of the structure of a test rig (1)



Figure 4.6: Assembly aluminium profile of the structure of a test rig (2)



Figure 4.7: Assembly aluminium profile of the structure of a test rig (3)



Figure 4.8: Fastening the 45° bracket



Figure 4.9: Slot in the plate between aluminium extrusion



Figure 4.10: Test rig for measuring hip flexor strength





Figure 4.12: Attached force gauge on plate aluminium



Figure 4.14: Force gauge on plate aluminium



Figure 4.16: Side view of a test rig for measuring hip flexor strength



Figure 4.17: Top view of a test rig for measuring hip flexor strength



Figure 4.18: Participant measuring hip flexor force using the test rig

4.3 Evaluate the Functionality and Usability of the Test Rig

This study provides the results and discussion for evaluating the maximum point or critical point on structure based on static and stress analysis. This section serves to achieve the third objective of this study.

4.3.1 Results of Mechanical Analysis using Ansys Engineering Simulation Software

The study's goal is to locate the point of most incredible stress, also known as the critical point, which indicates a significant probability of error. This research made use of the Ansys engineering software. Each component was assigned material to assemble the test rig, and the analysis was conducted in this order. Each component's connection and the joint were then given a connection type. When this had been completed, a force was applied to our plate at the top of our test rig. In this study, 180N was delivered to the hip flexor for 5 seconds, a moderate force.



Figure 4.19: Total deformation of the test rig

Figure 4.19 shows that the test rig's top handle was subjected to the most deformation in the red area. The least amount of deformation in the findings is shown by the blue area at the bottom of the test rig, which has a value of 0mm. Table 4.10 reveals that after 5 seconds of stress, the minimum deformation is 0 and the average is 9.4066N. The test rig deforms to its maximum extent by 2.415e-4 m over five seconds, as shown by the results.

Time (s)	Minimum (m)	Maximum (m)	Average (m)
0.5	0	2.416e ⁻⁵	9.407e ⁻⁵
1.0	0	4.829e ⁻⁵	1.881e ⁻⁵
1.5	AYSIA 0	7.244e ⁻⁵	2.822e ⁻⁵
2.0	0	9.658e ⁻⁵	3.763e ⁻⁵
2.5	0>	1.207e ⁻⁵	4.703e ⁻⁵
3.0	0	1.449e ⁻⁵	5.644e ⁻⁵
3.5	0	1.690e ⁻⁵	6.585e ⁻⁵
4.0	0	1.932e ⁻⁵	7.525e ⁻⁵
4.5 <u>1</u> 00	يكل مليسيا	2.173e ⁻⁵	8.466e ⁻⁵
5.0		2.415e ⁻⁵	9.407e ⁻⁵

Table 4.10: The deformation after applying force for 5 sec



According to the stress chart, it is possible to conclude that there are no changes in stress after the force was applied for 5 seconds. The comparable focus reveals that the area with the value of 18.214 Pa at the bottom and very top of the test rig had the lowest value. This area is shown by a dark blue shade. On the other hand, as shown in Figure 4.20, the stress levels experienced by the test rig are not exceptionally high. This is demonstrated in Figure 4.8, which shows that the maximum stress value is 3.2741 Pa, which corresponds to the most significant attainable value. Following the application of force for five seconds, the maximum stress is 18.214 Pa, while the average stress is 6.3876 Pa.

Time (s)	Minimum (Pa)	Maximum (Pa)	Average (Pa)
0.5	0	3.742e ⁵	63876
1.0	0	7.484e ⁵	1.278e ⁵
1.5	0	1.123e ⁵	1.916e ⁵
2.0	0	1.497e ⁵	2.555e ⁵
2.5	0	1.871e ⁵	3.194e ⁵
3.0	0	2.245e ⁵	3.833e ⁵
3.5	0	2.619e ⁵	4.471e ⁵
4.0	0	2.994e ⁵	5.110e ⁵
4.5	0	3.368e ⁵	5.749e ⁵
5.0	0	3.742e ⁵	6.388e ⁵

Table 4.11: The stress after applying force for 5 sec

4.3.2 Results of Usability of the Test Rig



Figure 4.21: Feedback on "easy to use"

The chart above shows the rate of a survey about the easier of test rig when using. Overall, most responses agreed with the statement when using the test rig. Therefore, this test rig is easy to use by the subject.



The pie chart illustrates the result of participants where the subject needs a technical person while conducting this experiment. For the result obtain, most of the respondents agree about the question and followed by neutral. Therefore, the results show most of them need technical support because it was their first experience using this test rig. However, some of them don't need any technical support for able to use this test rig.


Figure 4.23: Feedback on "various function on test rig"

The diagram illustrates the result of the survey among respondents about the various function of the test rig is integrate. The result shows that most of the respondents agree about the functionality of the test rig which is innovated and integrated.



Figure 4.24: Feedback on "inconsistency on the test rig"

The chart above shows the rate of a survey about inconsistency on test rig when subjects use this test rig. From the result obtain, most of them disagree about the question. Therefore, it can conclude that the participants disagree with the question because the size of the test rig is fit well with the subject.



Figure 4.25: Feedback on "people would learn to use this test rig very quickly"

Figure 4.25 shows the result of question 4 about the quickness subject would learn using this test rig. The result shows most of the respondents agree because the easiness while conducting this experiment help the subject to understand and follow the instructions given very quickly.

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Figure 4.26: Feedback on "test rig very cumbersome to use"

The diagram illustrates the result of a survey among respondents about the cumbersome while using this test rig. Overall, a majority of respondents was disagreeing with the statement because the test rig has low complexity to ease for participants to conduct this experiment using this test rig.



Figure 4.27: Feedback on "confident using the test rig"

The pie chart illustrates the result of confident respondents while using the test rig. The result shows most agree that they felt very confident because the features of the test rig are ergonomic, safe, and good appearance.



Figure 4.28: Feedback on "test rig unnecessarily complex"

The chart above shows the rate of a survey about the complexity of the test rig. From the result obtain, most of the respondents agree because the test rig has low complexity.



Figure 4.29: Feedback on "use the test rig as experimental tool"

The pie chart shows the rate of surveys about test rigs as an experimental tool to measure hip flexor strength. It highlights majority agreed that they want to use this test rig to measure the strength of the hip flexor because the sturdy and stable test rig help to know the maximum of flexion.



Figure 4.30: Feedback on "need to learn a lot of things before use the test rig"



The pie chart shows the result of respondents about "I need to learn a lot of things before I could be going with this test rig'. From the result, the majority of respondents disagree, and 17 respondents rated moderate. Therefore, respondents felt very easy to use this experimental tool and no need to learn a lot of things before being able to use it. However, there are still 18 respondents who agree which is they felt hard to use this test rig.

4.3.3 System Usability Scale (SUS) scoring

The System Usability Scale (SUS) is a quick and effective way to evaluate the usability of this test rig using the Likert scale. Table 4.12 shows the result of SUS which shows the average of 60 respondents for each question till the score of SUS. The odd questions and even questions will be summing up. For odd-numbered questions will subtract 5 from the total to get the value X while for even-numbered questions will subtract that total from 25 to get the Y value. Lastly, to get SUS to score the X and Y need a total score and multiply by 2.5.

	Question 1 (Odd)	4.80	
ALAY	Question 2 (Even)	3.27	
state line	Question 3 (Odd)	4.65	
	Question 4 (Even)	2.20	
	Question 5 (Odd)	4.83	W
SA AIND	Question 6 (Even)	1.78	
·Male	Question 7 (Odd)	4.70	-
	Question 8 (Even)	3.70	כביצי
JNIVERS	Question 9 (Odd)	LAYSIA N 4.57	IELAK/
	Question 10 (Even)	2.90	
	Odd	23.55	
	Even	13.85	
	X	18.55	
	Y	11.15	
	(X+Y)	29.70	
	SUS Score	74.25	

Table 4.12: SUS scoring calculation

By following the scoring tabulation methodology, the test rig gets a SUS score is 74.25 out of 100 which determines as an acceptable range. Therefore, this proved that the design test rig is more likely to be recommended and might need minor improvement to upgrade the functionality of the test rig.

4.3.4 Data Analysis and Results of Hip Flexor Strength

In this part, the main findings of the study which is the hip flexor strength data will be analyzed and presented. For hip flexor measurement, the data circumferences, distance and force are collected. The result has been analyzed using MINITAB software that shows the graphical summary of the hip flexor strength.

4.3.4.1 Anthropometric Data of Participants

This section presents the analysis of anthropometric data of gender, height, weight, and Body Mass Index (BMI) as well as the thigh length, thigh circumference and forces of hip flexor. These data are collected from Malaysia's young adults of age 18-25 years. Figure 4.31 shows the pie chart distribution of gender involved in the study. Out of the 60 participants, 38 of them are male which covered 63% of the chart. For the female participants, the number of participants is 22 which covered 27% of the chart.



Figure 4.31: Distribution of gender

For the quantitative data of weight, height and BMI of the participants, the data is presented as shown in Table 4. Based on the descriptive data presented in Table 4.13, the minimum height of participants is 151 cm while the maximum height measured is 179 cm. For weight, the minimum weight of the participant is 38 kg and the maximum weight measured is 120 kg. The mean height, weight and BMI of the participants are 165 cm (SD = 6.38), 67 kg (SD = 16.27) and 20 (SD = 4.58) respectively. According to the Malaysian Pharmaceutical Society (MPS), the desirable BMI range for adults who is aged 18 and above is between 18.5 and 25. Since the mean BMI obtained is 20.12, the participants involved in this study averagely are healthy.

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Variable	Minimum	Mean	Maximum	Standard Deviation
Height (cm)	151	164.95	179	6.38
Weight (kg)	38	66.56	120	16.27
BMI	11.62	20.12	34.88	4.58

Table 4.13: Descriptive data of height and weight of participants

4.3.4.2 Descriptive Statistics of the Hip Flexor Force

Table 4.14 shows the descriptive data of the hip flexor force of 60 participants. The mean of the male participants involved in the experiment is 192.8N (SD = 65.7) while the mean force of female participants is 126N (SD = 39.7). The maximum male participant force is 347.8N and the minimum force is 44.8N while the maximum female recorded is 211.8N and the minimum force is 59.2N. Hence, it proves that the data is reliable which male is strongest than female. Based on previous studies overseas, this study had knee and hip flexion and extension strength scores, and findings are externally validated because female were significantly difference with muscle weakness than male (Borges, 2014).

Table 4.14: Descriptive statistics analysis of hip flexor force, in Newton (N)

Gender	Minimum	Mean	Maximum	Standard Deviation	Skewness
Male	44.8	192.8	347.8	65.7	0.24
Female	59.2	126.0	211.8	39.7	0.65

4.3.4.3 Normality Test of the Hip Flexor Force Data

Figure 4.32 is a normality test performed from the MINITAB software. It is a graphical description of the hip flexor force experienced by males and displays the test results. The graphs produced have a normal distribution within the p-value range, which is 0.213, which is more than 0.05.



Figure 4.32: Normality test for male

The normality test results for female hip flexor strength demonstrated a normal distribution, as shown in Figure 4.33, and the p-value was found to be 0.199, which was more than 0.05.



Figure 4.33: Normality test for female

4.3.4.4 Regression Analysis of Hip Flexor

According to the findings presented in Table 4.15, there is a significant positive correlation between the R-Square value of 0.396 and the hip flexor strength. In the meantime, the gender anthropometric dimension has a coefficient of 54.4, making it the factor that contributes the most to the hip flexor strength.

Multiple R	0.630
R Square	0.396
Adjusted R Square	0.341
Standard Error	53.407
Observations	60

Table 4.15:	Regression	statistics
1 4010 4.15.	Regression	statistics

Table 4.16: Anova		

	df	SS	MS	F	Significance F
Regression	5 6 4	101192	20238.3	7.095	3.66E-05
Residual	54	154027	2852.36	- 03.2	
Total	59	255219			
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Table 4.17:	Coefficient	and P-value	of Regres	sion Analysis
			0	2

	Coefficients	P-value
Intercept	-56.62	0.84
Gender	-54.40	0.01
Body Mass	0.63	0.38
Body Height	0.56	0.75
Thigh Length	1.20	0.48
Thigh Circumference	1.23	0.25

A linear regression model has been generated from a regression model employing the value coefficient of intercept, gender, body mass, body height, thigh length, and thigh circumference. This model was used to generate the linear regression model. This regression model aims to predict the size of the hip flexor force that is proportional to gender, body mass, body height, thigh length, and thigh circumference. Note that gender is a categorical variable, with 0 indicating male and 1 indicating female. According to the findings of this study, factors such as body mass, body height, thigh length, and thigh circumference all have a proportionate or positive relationship to hip flexor force. A more prominent hip flexor force will be generated if the body mass, body height, thigh length, and thigh circumference are increased. On the other hand, an inverse or negative relationship exists between gender and hip flexor force. Put another way, if there is a more excellent value placed on gender (1), then less weight will be placed on the force. This suggests that females have a hip flexor force that is of a smaller magnitude. In addition, the results of this study indicated that gender is the component that has the most significant impact on hip flexor strength, as indicated by the highest coefficient value of 54.4. In the future, researchers may use this regression model to estimate the amount of hip flexor force as long as they comply with these criteria: they must be Malaysian, and their age must be 18 to 25 years. This due to the data collection and analysis were based on these criteria.

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Force = -56.62 - 54.4 (gender) + 0.63 (body mass) + 0.56 (body height) + 1.20 (heigh length) + 1.23 (theigh curcumcerence) Equation 4.1

4.4 Discussion

The result obtained in this study are discussed in this section; the anthropometric data of Malaysian young adults are compiled into data, and participants involved in this study averagely are healthy. According to findings from earlier research, the discrepancies were significantly attributable to a reduction in muscle activation on the injured side (Morrissey, 2011). As a result, to participate in this experiment, the subject needs to be in the best possible health and achieve their maximum hip flexor strength. Because of its practical significance in assessing hip flexor strength, the standing hip flexion position was selected as the testing movement (Morrissey, 2011). Excellent reliability was found in the measurement of both hip flexion angles, 45° and 90° (Camara, 2013). The 45° angle was chosen for this study because researchers believe it to be the most significant angle to test hip flexor strength. The fact that the hip joint was employed much more during the upward motion than during the downhill motion (Kuo, 2009) demonstrates that the hip flexor strength measured in this study reached its maximal value with 347.8N and 211.8N.

The design was made with CATIA, and ANSYS was used to simulate the product's mechanical performance so that the deformation, stress, strain, and safety could be analyzed on the test rig (Asyraf M., 2019). However, the prototype of the test rig was deforming to a maximum by 2.415e-4 since the static load was continuously acting on it. At the same time, no changes in stress on structure have been shown on the ANSYS engineering simulation software. For example, usability can be applied to product feedback to improve effectiveness, efficiency, and satisfaction (Kuijk, 2015). To verify the test rig's functionality, these investigations employed a SUS score of 74.25. Likert-scale usability evaluations will also grade the selected indicators based on their significance (Ma, 2021). Using the SUS score, the Likert scale rating of the usability test rig for assessing hip flexor was confirmed.

CHAPTER 5 CONCLUSION

This chapter concludes the findings of the research in line with the objectives and gives recommendations and suggestions for further improvement on the research in the future. The achievement on design of the prototype as well as the hip flexor strength will be summarized in this chapter following by the concluding the evaluation on the effectiveness of the design.

5.1 Design Requirements to Fabricate a Test Rig for Measuring Hip Flexor Strength in Standing Position

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The strength of the hip flexors was measured using a standing-position test rig that was devised, constructed, and reviewed. When designing the test rig for this research project, benchmarking and information gleaned from earlier studies, as well as Quality Function Deployment (QFD), were all utilised. According to the findings of this research, the design requirements of the test rig for determining hip flexor strength should include being stable, being able to be customised, having a compact size (not bulky), being portable, and being easy to transport. The materials that make use of aluminium extrusion aid to cut down on weight, make it easier to produce, and make it simpler to assemble and disassemble because the joint is only temporary. The dimensions of anthropometry were used as a reference point for the sizing of the test equipment. The testing apparatus is safe for both the user and the environment.

5.2 Design and Fabricate a Test Rig for Measuring Hip Flexor Strength in Standing Position

Conceptual design, concept screening, concept scoring, engineering drawing, and fabrication have all been part of this project. Besides that, all experimental tools adhere to design requirements and technical specifications while also addressing experiment tool-related issues. Following the concept selection process for the conceptual design, Concept 4 was selected as the best design and depicted in CATIA software. To make the test rig portable and easy to install and disassemble, a prototype is built using a bolt and nut assembly method based on the design concept of an aluminium profile. Based on results in Table 4.1, to summarize the prototype is fabricate based on the design concept where an aluminium extrusion profile used as main structure for more stable and sturdier while conduct the experiment.

5.3 Evaluate the Functionality and Usability of The Developed Test Rig

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An analysis of deformation, stress, and strain is used to illustrate and analyse this study's findings. The analysis on the test rig was carried out with the aid of ANSYS. During the investigation, 180N of force was measured, and the maximum and minimum locations were discovered. A survey of participants who had used the test rig and the use of the System Usability Scale (SUS) to quantify the test rig's functionality also helped achieve the goal. MINITAB software was used to measure hip flexor strength in the data that was obtained. The maximum hip flexor strength of male participants was 347.8N, which was higher than the maximum strength of female participants, according to the results of the descriptive analysis of force. As a result, this study revealed that the test rig utilised to measure hip flexor strength is suitable for use by participants who will be doing the experiment in a standing position. This software will be able to perform and generate a more ergonomically design when use the test rig for measuring hip flexor strength.

5.4 Recommendation for Future Study

Correlation of hip flexor force and distance with torque between actual and theoretical calculations to acquire the same result and determine the functionality of the test rig. This study recommends utilizing a torque gauge to measure the hip flexor strength to verify the results of the experimental and theoretical analyses. In addition, this study proposes using a substance that may adhere to walls or floors for better stability.

5.5 Sustainable Design and Development

Reduce waste and environmental damage by adopting a more environmentally friendly method. The handle of the test rig is covered with a sponge or other soft substance to make it more user-friendly and less hazardous for participants. The plate height can be automatically adjusted in the future to save time. In one study, it was found to alleviate hip flexor soreness. Reducing waste, encouraging recycling, and utilizing renewable raw materials are just a few ways a more responsible approach to production can save costs and maximize resources for the economic pillar. Finally, it encourages the volunteer to participate in this experiment to develop tools to enhance socializing.

5.6 Lifelong Learning

The lifelong component is the development of human potential through a process that encourages and helps people get all of the knowledge, values, skills, and understanding they will need throughout their lives and uses what they have learned in all their roles. In the end, both the results of this study and the proposed intervention help improve ergonomics. CATIA V5 software helps design the test rig and draught the drawing, and ANSYS software allows the structural analysis product to analyze to save time and money. Minitab software helps analyze data and find reliable information about hip flexor strength.

5.7 Complexity

Complexity during research this study is to determine the design requirements to fabricate the test rig for measuring hip flexor strength in standing position. Due to lack of information related to this experiment, the requirements were determined based on outside researchers. In order to verify that the prototype can be used as an experimental tool, the test rig and data hip flexor strength need to be reliable.



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APPENDICES

APPENDIX A: GANTT CHART PSM 1

Task	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Title EVP briefing by Supervisor														
The TTT bhening by Supervisor			NY Or											
Update Logbook		Bre-												
	No			100										
	To determine design requirement to fabricate a test rig for measuring hip flexor strength in standing position.													
Design requirement for test rig	5				-									
Design requirement for test rig	20				1									
To design and fabricate a test rig for measuring hip flexor strength in standing position														
Design the test rig														
	-				_									
Material Purchasing	2				_		/ /							
	2.		·											
Fabricate prototype	1	200												
		n N'												
	_	1			_	Report Wr	riting							
Preparation of Chapter 1:	434				1		1					· · · ·		
Introduction		1 2	Carlot and Carlot	3.0			-			والمستعم	100	106		
Preparation of Chapter 2:						-			5		1	J		
Literature Review														
Preparation of Chapter 3:														
Methodology		/ER	SIT	TE	KNI	KΔI	_ M/		YSL	$M \mathcal{L}$		KA		
Submission Logbook														
Presentation														
Submission Report PSM 1														
													Plan	ining
													Impleme	entation

APPENDIX B: GANTT CHART PSM 1

Task	Week	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week	Week 14	
Planning of tasks to	-	_					,	0	,	10			10		
do for FYP II															
Undata La aba ala															
Update Logbook			ALA	YSIA											
	To evaluate the functionality and usability of thr developed test rig														
Evaluation of		2			100										
prototype		BH													
Standard Operation					19.										
Procedure (SOP)		×			5					-					
Collect data		ш							1						
					_										
Calculation the result		1					1								
		10					1			1					
Conduct usability		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1													
survey		1	1												
	1		an			1	Report W	riting		1	1			1	1
Preparation of			1	_											
Chapter 4: Result and		511				<u></u>	· · /		1 ¹⁰						
Discussion		- 7	1 V.	اليانينين	A, Y	_			N. 0	Marine Service	104	391			
Preparation of			-								1 - 4 - 4	1			
Chapter 5:									1.0						
Conclusion															
Submission Logbook		JNI	ÆR.	5	TEK	NK.		AL	AYS	AM	ELA	KA-			
Presentation															
Submission Report															
PSM 2															

	Planning	
	Implementation	

APPENDIX C: Questionnaire Survey Form

DESIGN AND EVALUATION OF TEST RIG FOR MEASURING HIP FLEXOR IN STANDING POSITION My name is Azreen Shafira Binti Abdul Talib. I am final year student from Faculty of Manufacturing Engineering at Universiti Teknikal Malaysia Melaka (UTeM). I am performing Final Year Project entitled "Design and Evaluation of Test Rig for Measuring Hip Flexor in standing position". The test rig is an equipment for measuring hip flexor strength in standing position and allows the user to know the maximum strength of hip flexion participants. Thank you for your participation. * Required Name * Your answer MALAYS Gendre * O Male O Female Age Your answer UNIVERSITI TEKNIKAL MALAYSIA MELAKA Weight (kg) * Your answer Height (cm) * Your answer Data of Hip Flexor Distance between hip and knee (cm) * Your answer

Your answer Hip Circumference 2 (cm) * Your answer Hip Circumference 3 (cm) * Your answer Force R1 (N) * Your answer Force R2 (N) * Force R3 (N) * STITTEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I 2 3 4 5 Strongly disagree	Hip Circumference 1 (cm) *	
Hip Circumference 2 (cm)* Your answer Force R1 (N)* Force R2 (N)* Force R2 (N)* Force R2 (N)* Force R2 (N)* Force R3 (N)*SITT TEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I 2 3 4 5 Strongly disagree Note 1 2 3 4 5	Your answer	
Hip Circumference 2 (cm) * Your answer Hip Circumference 3 (cm) * Your answer Force R1 (N) * Your answer Force R2 (N) * Corde k3 (N) * SITT TEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I 2 3 4 5 Strongly disagree I 2 3 4 5		
Your answer Hip Circumference 3 (cm)* Your answer Force R1 (N)* Your answer Force R2 (N)* Ebree R3 (N)* SITT TEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I 2 3 4 5 Strongly disagree I 2 3 4 5 Strongly disagree	Hip Circumference 2 (cm) *	
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Hip Circumference 3 (cm)* Your answer Force R1 (N)* Your answer Your answer Force R2 (N)* Force R3 (N)* SITI TEKNIKAL MALAYSIA MELAKA Your answer Your answer Your answer Force R3 (N)* SITI TEKNIKAL MALAYSIA MELAKA Your answer Intervention of the test rig was easy to use.* 1 2 3 4 5 Strongly disagree Intervention of the test rig was easy to use.*		
Your answer Force R1 (N)* Your answer Force R2 (N)* Force R3 (N)* Strongly disagree 1 2 3 1 2 3 4 5 1 2 3 4 5 1 2 3 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	Hip Circumference 3 (cm) *	
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Your answer Force R2 (N)* Force R3 (N)* SITE TEKNIKAL MALAYSIA MELAKA Your answer Your answer System Usability Scale I 2 3 4 5 Strongly disagree O O O Strongly agree	Force R1 (N) *	
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Force R2 (N)* Your answer Eorce R3 (N)* SITI TEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I 2 3 4 5 1 2 3 4 5 Strongly disagree		
Your answer Force R3 (N) * SITT TEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I g g g g g g g g g g g g g g g g g g g	Force R2 (N) *	
Force R3 (N)* SITI TEKNIKAL MALAYSIA MELAKA Your answer I found the test rig was easy to use.* 1 2 3 4 5 Strongly disagree 0 0 0 0 Strongly agree	Your answer	
Force R3 (N)* SITI TEKNIKAL MALAYSIA MELAKA Your answer System Usability Scale I found the test rig was easy to use.* 1 2 3 4 5 Strongly disagree O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O	اوىيۇم سىتى ئىكتىكل ملىسىيا ملاك	
Your answer System Usability Scale I found the test rig was easy to use.* 1 2 3 4 5 Strongly disagree O O O O Strongly agree	Force RS (N) SITI TEKNIKAL MALAYSIA MELAKA	
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System Usability Scale I found the test rig was easy to use. * 1 2 3 4 5 Strongly disagree O O O O Strongly agree		
I found the test rig was easy to use. * 1 2 3 4 5 Strongly disagree O O O O Strongly agree	System Usability Scale	
1 2 3 4 5 Strongly disagree O O O O Strongly agree	I found the test rig was easy to use. *	
Strongly disagree O O O O O Strongly agree	1 2 3 4 5	
	Strongly disagree O O O O Strongly agree	

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	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
I found the various fu	unctions o	on the te	est rig w	ere well	integrate	ed. *
	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
I felt there was too r	nuch incc	onsisten	cy on th	e test riç	J. *	
AV ST	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
	E.					
AL TE						
I would imagine the m	iost peop	le would	d learn t	o use th	is test riç	g very quickly. *
ليسيا ملاك	کل م	2	3	4	5	اونيوبرسا
Strongly disagree	O			ALA	O YSIA	Strongly agree
I found the test rig ver	ry cumbe	ersome	to use. *			
	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
l felt very confident us	sing the t	est rig.	*			
	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I found the test rig un	necessa	rily com	plex. *			
	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
l would like to use this strength.	test rig	as expe	rimental	tool to	know my	hip flexor *
	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
	1	2	3	4	5	
	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree
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