ERGONOMIC RISK ASSESSMENT OF WORKERS AND PROTOTYPE DEVELOPMENT OF A HOT WORK CHAIR

By

SIVABALAN A/L SANMUGUM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair : Karmegam a/l Karuppiah, PhD
Faculty : Medicine and Health Sciences

Introduction: Workers employed at a selected company, engaged in hot work activities while seated without proper seating arrangements, experience prolonged static and awkward body postures, resulting in muscle discomfort and pain, particularly in the buttocks, lower back, thighs, and other regions. A substantial number of workers in the hot work section of the company have reported muscle pain complaints, with many currently performing hot work using improper seating tools. **Objective:** This research aims to address the issue of muscle discomfort caused by improper seating practices during hot work activities to prevent potential long-term effects on musculoskeletal disorders (MSD) among the workers. **Methodology**: The study is conducted in three phases. In the initial phase, ergonomic problems are assessed using body discomfort chart and ergonomic risk assessment tools, including muscle fatigue assessment, rapid entire body assessment (REBA), and quick exposure checklist (QEC). The data collected during this phase are analysed and serve as input for the second phase, which involves developing product design specifications (PDS), design and development of a hot work chair prototype and Initial testing. Subsequently, an experimental study is conducted in the third phase involving 24 hot work workers (12 participants in each control and experimental group). They use their current seating tools and a prototype of the hot work chair during routine tasks for six full working days. Body muscle discomfort is assessed using a 100-millimeter Visual Analogue Scale (VAS) after each session. **Results and discussion:** There was a high muscle discomfort rating associated with hot works among workers of the selected company. Buttocks, knee, and thigh are the most effected body part with highest discomfort rating level among the hot-work. Initial ERA has shown that hot-work workers are exposed to the identified risk factors including awkward postures, repetitive motions, static and sustained work postures with their current seating tools. Muscle fatigue assessment, REBA and QEC results show the selected workers from hot work section are extremely exposed to high risk and immediate intervention required. A prototype has been successfully designed and developed in this study based on the inputs from end-users, extensive literature, and the PDS. The operations and functions of the prototype have been successfully tested at the selected company and have shown potential to improve the body postures, and work station of the workers in the hot works section. During the evaluation of the prototype, experimental group reports a 49% reduction in discomfort rating after using the hot work chair, with no significant differences observed in the control group during the same duration. **Conclusion**: The intervention of the hot work chair has effectively reduced muscle discomfort during prolonged hot work activities and has improved body postures. As a result, the hot work chair has the potential to reduce muscle discomfort leading to MSD and other muscle injuries associated with this work task.

Keywords – Muscle discomfort, hot works, ergonomic risk assessment, product design specification, prototype design and development

Abstrak tesis telah dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENILAIAN RISIKO ERGONOMIK PEKERJA DAN PEMBANGUNAN PROTOTAIP KERUSI UNTUK KERJA-KERJA PANAS

Oleh

SIVABALAN A/L SANMUGUM

Julai 2023

Pengerusi : Karmegam a/l Karuppiah, PhD
Fakulti : Perubatan dan Sains Kesihatan

Pengenalan: Pekerja yang bekerja di sebuah syarikat terpilih, terlibat dalam aktiviti kerja panas sambil duduk tanpa mengunakan alat duduk yang betul, mengalami kedudukan badan statik yang lama, menyebabkan ketidakselesaan otot, terutamanya di bahagian punggung, bahagian bawah belakang, peha, dan bahagian badan yang lain. Sejumlah besar pekerja di bahagian kerja panas syarikat tersebut telah melaporkan sakit otot, di mana banyak daripadanya menggunakan alat duduk yang tidak sesuai semasa bekerja. **Objektif:** Kajian ini bertujuan untuk mengatasi masalah ketidakselesaan otot yang disebabkan oleh amalan tempat duduk yang tidak betul semasa aktiviti kerja panas untuk mencegah kesan jangka panjang ke atas gangguan otot dan tulang (MSD) di kalangan pekerja. **Metodologi:** Kajian ini dijalankan dalam tiga fasa. Dalam fasa awal, masalah ergonomik dinilai menggunakan carta ketidakselesaan badan dan alat penilaian risiko ergonomik, termasuk penilaian keletihan otot (MFA), penilaian keseluruhan badan dengan cepat (REBA), dan senarai semakan pendedahan cepat (QEC). Data yang dikumpulkan dalam fasa ini dianalisis dan digunakan sebagai input untuk fasa kedua, yang melibatkan pembangunan spesifikasi reka bentuk produk (PDS), reka bentuk dan pembangunan prototaip kerusi kerja panas serta ujian awal. Kemudiannya, satu kajian eksperimen dijalankan dalam fasa ketiga yang melibatkan 24 pekerja kerja panas (12 peserta dalam setiap kumpulan kawalan dan eksperimen masing-masing). Kumpulan kawalan telah menggunakan alat duduk semasa bekerja seperti biasa dan kumpulan eksperimen prototaip kerusi kerja panas dalam tugas rutin selama enam hari bekerja penuh. Ketidakselesaan otot badan dinilai menggunakan Skala Analog Visual (VAS) 100 milimeter selepas setiap sesi. **Hasil dan perbincangan**: kadar ketidakselesaan otot didapati tinggi di kalangan pekerja kerja panas. Bahagian punggung, lutut, dan peha adalah bahagian badan yang paling terjejas dengan tahap ketidakselesaan tertinggi semasa kerja panas. Penilaian factor risiko ergonomik menunjukkan pekerja kerja panas terdedah kepada faktor-faktor termasuk kedudukan badan yang tidak selesa, gerakan berulang, kedudukan statik dan kekal untuk jangka masa lama. Penilaian keletihan otot (MFA), REBA dan QEC menunjukkan pekerja yang dipilih dari bahagian kerja panas terdedah kepada risiko ergonomik yang tinggi dan intervensi segera diperlukan. Prototaip telah berjaya direka dan dibangunkan dalam kajian ini berdasarkan hasil dari penilaian di fasa satu, kajian literatur yang terperinci, dan maklumbalasa dari para responden. Operasi dan fungsi prototaip telah berjaya diuji di syarikat terpilih dan menunjukkan potensi untuk memperbaiki posisi badan semasa melakukan kerja panas. Semasa penilaian prototaip, pengurangan kadar ketidakselesaan sebanyak 49% didapati di kalangan kumpulan ekperimen yang telah menggunakan kerusi kerja panas, manakala perbezaan tang signifikan tidak dapat diperhatikan dalam kumpulan kawalan dalam tempoh yang sama. **Kesimpulan**: Intervensi prototaip kerusi kerja panas berjaya mengurangkan ketidakselesaan otot semasa aktiviti kerja panas dan memperbaiki posisi badan. Maka, kerusi kerja panas berpotensi mengurangkan ketidakselesaan otot yang boleh menyebabkan kecederaan otot-otot dan tulang (MSD) pada pekerja kerja panas di industri logam.

Kata kunci - Ketidakselesaan otot, kerja panas, penilaian risiko ergonomik, spesifikasi reka bentuk produk, reka bentuk dan pembangunan prototaip

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The thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisor committee were as follows:

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Date: 11 January 2024

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LIST OF ABBREVIATIONS

N	Number of sample size
σ	Estimated standard deviation (assumed to be equal to each group)
μ_1	Estimated mean (larger)
μ_2	Estimated mean (smaller)
MSD	Musculoskeletal disorders
MFA	Muscle Fatigue Assessment
REBA	Rapid Entire Body Assessment
QEC	Quick Exposure Check
VAS	Visual Analog Scale
PDS	Product design specifications
OSHA	Occupational Safety and Health Act
DOSH	Department of Occupational Safety and Health
SOCSO	Social Security Organization

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The name of ergonomics comes from the Greek word's 'ergon' meaning work or effort of human while 'nomos' means natural law and the ergonomics objective is to fit machine and man together to improve the performance of the worker, reduce risk, stresses and fatigue at workplace (Kushwaha et al., 2016). Ergonomics giving more attention to change things like working tools, equipment that being used, facilities at workplace and not changing the people (Bridger, 2018). Ergonomic at workplace concerns the interaction's understanding between human and system of work. Hot work is any work process that involves work activities like welding, soldering, brazing, grinding, cutting, drilling, melting of substances or burning that is capable of generating flame or a spark with sufficient temperature to ignite flammable vapours and/or combustible material. Hot work includes flame-producing activities, spark-producing activities, and heat producing activities either through conduction or radiation or convection (Samuel et al., 2017). The hot work activities playing the most important role in the offshore container's fabrication and framework structuring processes. This research study focused in an offshore container manufacturing company that involved hot works as major task in their operational activities. This company manufactures the offshore containers, skids, offshore baskets and other offshore related metal products for oil and gas companies in the past 20 years ago. Offshore containers are defined as a portable unit that is specially designed for repeated use in transporting goods or equipment to, from or between fixed and/or floating offshore installations and ships (Staff, 1999). Offshore containers or portable tanks built for the storage and transport of goods, which can include general cargo containers, cargo baskets, special containers, boxes, an extensive range of equipment, tools, liquids and gas cylinder racks. Offshore service containers are generally custom built for a specific task that is usually temporary for labs, workshops and control stations. Offshore containers are also commonly called "skids" in the offshore oil and gas industry. These can be as simple as frames that hold the contents. Some examples of offshore containers are explosive storage boxes, shelved mini containers, dry goods /storage containers, open top containers, toolbox containers, waste skips/ rubbish skips and tote tank containers.

Offshore container's production is more complex involving a lot of compliances of International Standards. This is because unlike ISO containers, offshore containers are exposed to harsh environments, loading, and unloading forces and non-standard designs. The methods of loading and unloading put different types of pressure on the structures of offshore containers. Offshore containers are supplied with a permanently installed sling set. Most do not have corner castings, and if they do, they are not allowed to be lifted from them. Most offshore containers are built to fit a specific piece of equipment, and as a result, do not fit into the categories of ISO containers. These criteria make the production of offshore containers to be done more preciously and effectively to prevent any unwanted incidents at the oil rigs or during transportation of dangerous waste. Hot work activities commonly highlighted with hazards like fire, explosion, radiation, and fume exposure and always will get attention by safety practitioners to take control measures for these hazards. However, ergonomics shall also be given serious consideration as equally to other hazards. Hot work including welding, grinding and cutting introduces many ergonomic challenges. Hot works often require awkward body positions, seating for long time or without proper chair, long duration of works, vibration and others. Body position and time are key factors in causing injuries among hot work workers (Society, 2021).

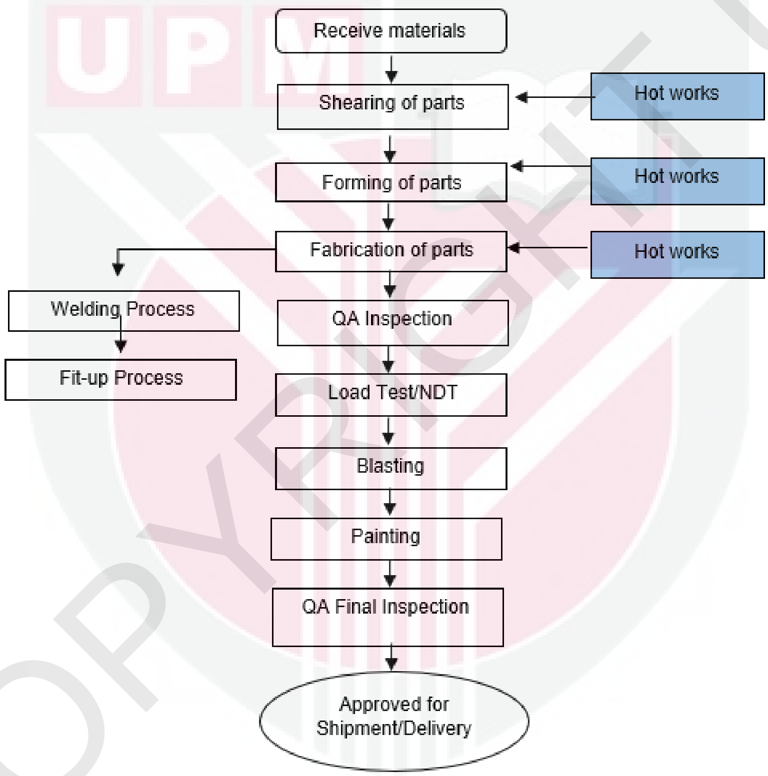


Figure 1.1: Flow chart of production of general offshore containers

Musculoskeletal disorders (MSDs) represent one of the leading causes of occupational injury and disability in the welding fabrication industries (Genaidy, 2017). The flowchart in figure 1.1 shows the production of general offshore containers at this selected company. Production will begin once the approved design is received from the planning team. The materials required will be ordered according to the specification(s) stated in the design. This will be followed by the shearing of parts, forming of parts and fabrication of parts. All these processes will involve hot works including welding, cutting, and grinding. Once the container has been fabricated, it will be sent for QA inspection and load test. If there are no damages and witnessed by the client, the fabricated container will be sent for blasting and painting process. Then QA final inspection will be conducted to approve these containers for shipment to the respective clients.

1.2 Problem Statement

Hot works require physical demands on the welder’s wrists, elbows, arms, shoulders, and neck due to awkward postures and forceful exertions needed. Musculoskeletal injuries (MSI) are very common among hot work workers especially welders (Dahlstrom et al., 2014). Hot work workers have high chances of musculoskeletal disorders, including back injuries, shoulder pain, tendonitis, reduced muscle strength, carpal tunnel syndrome, white finger, knee joint diseases and others. Improper body position or awkward posture is a major risk factor that may cause muscle pain or discomfort among workers who perform hot work as a routine job. The nature of hot working with awkward body postures has exposed welders to a significant danger of injuries and disorders affecting the human body's mobility and musculoskeletal system, which includes the muscles, tendons, ligaments, nerves, discs, and blood vessels (Isiohia, 2020). Hot work is required in nearly every phase of structuring, fabrication, finishing, repairing, maintenance and for product modification at the select company where most of the time, working desk or chairs are not available for related workers. According to the statistics, about 44 million workers in Europe were suffered from the occupational musculoskeletal disorder (Otto et al., 2017). Table 1.1 shows that the majority of the workers out of a total of 200 employees were classified as hot work workers since they only carry out welding, grinding, metal cutting and other hot works in this selected company.

Table 1.1: Number of workers at the selected company

Num	Role /Department	Number of workers
1	Hot work workers	120
2	Final assembly	35
3	Painting/Blasting	10
4	Supervisors	5
5	Engineers/Tech team	10
6	Office employees	15
7	Management	5
	TOTAL	**200**

The initial survey shows that many of the workers have reported to management on the current seating practices which caused them to undergo whole body pain and muscle pain at several regions in their body while performing hot works in seating position. Human resource team of this company also reported that many workers had taken medical leaves and undergone treatment due to MSD, back pain and other ergonomics related illness as in table 1.2. Based on the initial survey it is found many workers had reported with muscle pain or discomfort and about 15 workers had to undergo medical removal due to permanent MSD issues. Hot work workers who are not normally provided with specific chairs in many industries, suffer from muscle discomfort due to bending over prolonged duration, sitting on floors or any non-suitable materials, frequent awkward body postures and others (Oanh Nguyen, 2016).

Table 1.2: Number of workers taken medical leaves due to MSD and other illness related to ergonomics

Years	Hot work workers (welding, grinding, cutting)	Other category of workers
2011	60	8
2012	65	15
2013	75	12
2014	68	10
2015	65	8
2016	74	18
2017	69	14
2018	70	10
2019	72	5
2020	75	11
2021	82	14

Figure 1.2 below show the tools used by workers for hot works and example of how they perform hot works in seating position. Most hot work activities are performed while sitting (on metal or plastic sheets), with the worker's head and trunk flexed forward and shoulders flexed abducted. Because it involves awkward positions, static, repetitive movement, and carry out the hot works for prolonged hours in seating position, a high rate of Workplace MSDs occurrence is expected.

Grinding work	Welding work	Cutting work

Figure 1.2: Type of hot-works in the selected company

Based on feedback from the workers, the current seating practices are suspected as main factors that contribute to ergonomic issues among the workers like muscle cramps, muscle pain at multiple body regions, and other MSDs problems since many years ago. Therefore, this research needs to be conducted at any hot work section in this selected company with the aim to conduct an ergonomic risk assessment and to develop a hot work chair which can improve the sitting and working position of workers during the hot works.

1.3 Study Justification

There are several justifications for this study in conducting ergonomic risk assessment and designing and developing a hot work chair prototype among hot work workers. The primary justification is to prioritize the health and safety of hot work workers. Hot work activities often involve prolonged periods of static and awkward body postures, which can lead to muscle discomfort, pain, and potentially long-term musculoskeletal disorders (MSDs). By conducting an ergonomic risk assessment and developing a hot work chair prototype, the aim is to reduce ergonomic risk factors and mitigate the potential for work-related injuries and health issues. Unaddressed ergonomic issues can lead to increased absenteeism and turnover among workers. When workers experience ongoing discomfort and pain, they may take more sick days or even consider leaving their jobs. By implementing ergonomic interventions, such as a hot work chair, the aim is to create a more comfortable work environment that promotes employee satisfaction, reduces absenteeism, and enhances retention rates. Providing ergonomic solutions, such as a hot work chair also can improve workers' comfort and well-being, leading to increased productivity and efficiency. By reducing muscle discomfort and improving body postures, workers are less likely to experience fatigue and can perform their tasks more effectively, resulting in higher productivity levels.

Many jurisdictions have regulations and standards in place to ensure workplace safety and health. In the context of Malaysia, one of the objectives of Occupational Safety and Health Act 1994 that is to promote occupational environment for person at work which adapted to their physiological and psychological needs. Section 15(1) of the OSHA1994 is requires each employer to safeguard the safety, health and welfare of all workers. Conducting an ergonomic risk assessment and implementing appropriate solutions, such as the hot work chair, demonstrates compliance with these regulations and reinforces the commitment to worker welfare. Investing in ergonomic interventions, such as the development of a hot work chair, can lead to cost savings in the long run. By addressing ergonomic risk factors, the likelihood of work-related injuries and associated costs, such as medical expenses and workers' compensation claims, can be reduced. Additionally, improved productivity and reduced absenteeism contribute to overall cost savings for the organization. Researching and developing a hot work chair prototype demonstrates a commitment to innovation and advancement in the field of occupational health and safety. By exploring new solutions and designing ergonomic equipment tailored to the specific needs of hot work workers, the research contributes to the overall progress in creating safer and healthier work environments. Therefore, it is essential that this research be carried out to design and develop a hot work chair and to offer a comfortable and ergonomic workstation for hot work workers.

1.4 Research Objectives

1.4.1 General Objective

To conduct Ergonomic Risk Assessment and develop a prototype of hot work chair to reduce muscle discomfort among hot work workers.

1.4.2 Specific Objectives

The specific objectives of this study are as follows:

1. To identify the muscle discomfort among hot work workers
2. To conduct the initial risk assessment among the hot work workers
3. To conduct advanced ergonomic risk assessment among hot work workers during seating position through REBA - Rapid Entire Body Assessment, Muscle Fatigue Assessment and QEC- Quick Exposure Check.
4. To develop a hot work chair for the workers
5. To compare the muscle discomfort level between the pre-test and post-test session (experimental and control groups) among hot work workers.

1.5 Research Questions

These objectives of research study were addressed via a series of research questions as noted below:

1. What is the muscle discomfort level among hot work workers?
2. What is the outcome of initial risk assessment among the hot work workers?
3. What is the outcome of the advanced ergonomic risk assessment conducted among hot work workers during seating position through advanced risk assessment methods (Muscle Fatigue Assessment, Rapid Entire Body Assessment, and Quick Exposure Check?
4. Is the hot work chair designed and developed for workers?
5. Is/Are there any significant difference(s) of muscle discomfort level between the pre-test and post-test session (experimental and control groups) among hot work workers?

1.6 Hypothesis

1. significant differences of Muscle discomfort rating between samples before and after using the prototype of designed and developed hot work chair.

1.7 Scope of the study

The study's scope is centred on conducting ergonomic risk assessments among hot work workers and then designing, developing and verifying the hot work chair which is aimed to reduce the muscle discomfort level faced by workers in the hot work section at the selected company which is located at Pulau Indah, Selangor.

1.8 Conceptual Framework

Figure 1.3 summarizes the conceptual framework of the product designed as stated in the problem statement which is the main objective of this research which is to design and develop a hot work ergonomic chair for the offshore containers manufacturing industry. This research had been divided into three phases. Phase 1 consists of two stages. The first stage to assess the musculoskeletal pain and muscle discomfort level among the hot work workers. The second stage is to identify the ergonomic risk factors in the hot work section of the company where three work units have been determined and one respondent from each work unit has taken part in this risk assessment. Stage 3 which is from phase 2 of this study is to develop the designs of hot work chair product specifications and stage 4 is to select the best design for hot work chair. This will be continued with step 5 in phase 2 to build the prototype of the hot work chair finalized design with specifications. Phase 3 with stage 6 which is the last stage of the study is to evaluate the effectiveness of the developed hot work chair in reducing muscle discomfort level among the selected workers at the selected company. All data collected have been analysed using SPSS.

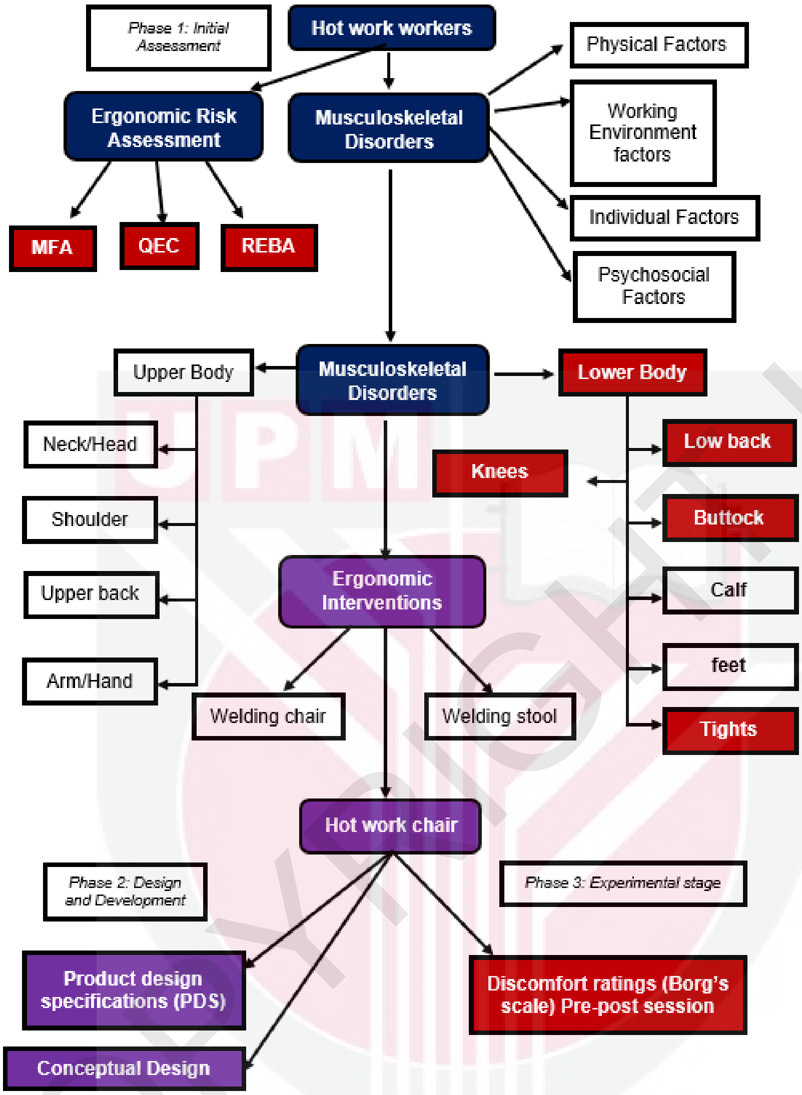


Figure 1.3: Conceptual Framework of design and development of prototype hot work chair

1.9 Thesis contribution

This hot work chair is a new invention for hot-work workers with affordable price that targeting metal working or manufacturing industries that involved with hot-works. The research focused on designing a hot-work chair specifically tailored to the ergonomic needs of hot work workers especially at the selected company. This could involve considering factors such as posture support, adjustable features, cushioning, and overall comfort during long seating position. By reducing muscle discomfort and improving body postures, workers are less likely to experience fatigue and can perform their tasks more effectively, resulting in higher productivity levels. The research focused on conducting an ergonomic risk assessment specifically faced by hot work workers, such as prolonged sitting, awkward postures, and repetitive motions. By considering these factors, the research can provide targeted recommendations and interventions for mitigating ergonomic risks in hot work settings. A novel research direction could involve adopting a user-centered design approach, actively involving hot work workers in the design and development process. By incorporating their feedback and insights, the research can ensure that the hot work chair prototype meets the actual needs and preferences of the end-users, improving its usability and effectiveness. The research focused on evaluating the effectiveness of the hot work chair in reducing ergonomic risks and improving the well-being and productivity of workers. A new designed and developed hot-work chair that been tested and evaluated in the real work condition. The developed hot-work chair able to be used for variable body position during hot-works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains work-related musculoskeletal disorders, discomfort survey, ergonomic risk assessment tools used, Hot works and problems associated with ergonomics, design and development of the Hot work chair prototype, design process and conceptual framework. The understanding of what ergonomics is at the workplace, types of ergonomic risk assessment tools, benefits of improving ergonomics at the workplace, and Ergonomic problems associated with hot works, will help readers to understand the need to design and develop hot work chairs at the selected company. The resources obtained for this chapters are basically from previous research studies, journals, online articles, official websites, guidelines from local authority and other relevant information which have been retrieved from online sources.

2.2 Work-Related Musculoskeletal disorders (MSDs)

Work-related MSDs harm the lumber spine's bones, muscles, ligaments, and tendons as a result of lifting, twisting, bending, static postures, and extended sitting. Work-related low back MSDs include spinal disc issues, muscle and soft tissue injuries. The most common types of ergonomics injuries and illness are musculoskeletal disorders (MSDs) (Ismail et al., 2015). Musculoskeletal disorders are conditions that affect the human musculoskeletal system (muscles, ligaments or other sift tissues of the body joins). The concerned soft tissues are listed below:

a) Muscle - contractile tissue of the body that generates force and causes motion (skeletal, cardiac/smooth muscle).
b) Ligaments - connective tissue that connects one bone to another.
c) Tendons - tough fibrous connective tissue that connects muscle to bone.
d) Nerves - Nerves transport sensory information. Spinal nerves link to the spinal cord via the spinal column. Cranial nerves are nerving that link to the brain stem.
e) Spinal disc - also known as an intervertebral disc since it is positioned between the vertebrae of the spine.
f) Bursa sacs are tiny sacs comprised of white fibrous tissue that are filled with synovial fluid. They act as a cushion between the bones and the tendons and/or muscles that surround a joint.

Occupational Overuse Syndrome, Repetitive Strain Injury, Repetitive Motion Injury, Cumulative Trauma Disorders, Upper Limb Disorders, and Upper Extremity Musculoskeletal Disorders are other MSD names (Guidelines on

Ergonomic Risk Assessment at Workplace 2017). Work-Related Musculoskeletal Disorders (MSDs) are prevalent in many countries, including Malaysia. These disorders can arise from various physical activities, repetitive motions, awkward postures, and ergonomic factors that strain the musculoskeletal system. Some of the factors contributing to Work-Related MSDs in Malaysia may include:

a) Occupational hazards: Workers in certain industries or job roles may be more susceptible to MSDs due to the nature of their work. Industries like manufacturing, construction, agriculture, and healthcare often involve repetitive movements, heavy lifting, and prolonged static positions.
b) Lack of ergonomic awareness: Poor ergonomic practices and improper workstation design can lead to increased stress on the body, contributing to the development of MSDs.
c) Work organization: Work demands, including long hours, inadequate breaks, and high production targets, can contribute to fatigue and increased risk of MSDs.
d) Workforce aging: As the workforce ages, the risk of developing MSDs may increase due to natural age-related changes in the musculoskeletal system.

According to a report from DOSH Malaysia, in figure 2.1, out of 4,289 confirmed occupational diseases, 201 cases are Occupational musculoskeletal disorders which are third highest in the list. The most recent SOCSO report, in table 2.1, on the number of invalidity and survivors' cases recorded in 2021. In total, 2,607 cases of musculoskeletal and connective tissue illnesses were reported, with 1,847 cases of male workers and 760 cases of female workers. Table 2.2, which was also derived from the same report, indicates that there were 8,059 Musculoskeletal illness cases reported that were caused by specific work activities/work environments with specified risk variables.

Figure 2.1 Disease by Category - National Occupational Accident and Disease Statistics 2021
(Source: DOSH Malaysia)

Table 2.1: Number of Invalidity and Survivors' Cases Reported, 2021

Disease	Invalidity			Survivors		
	Male	Female	Total	Female	Male	Total
Musculoskeletal system and connective tissue diseases (eg arthritis)	1771	741	2,512	76	19	95

Table 2.2: Occupational Musculo-Skeletal Disorders, 2021

Agent Causes	Accident reported			TD paid		
	Male	Female	Total	Male	Female	Total
Musculoskeletal illnesses caused by certain work activities/ work environments with distinct risk factors	6293	1,766	**8,059**	6,193	1,615	**7,808**

Preventing Work-Related Musculoskeletal Disorders (MSDs) among workers is crucial for several reasons, as these disorders can have significant negative impacts on both individuals and organizations. Here are some compelling reasons why it is essential to prioritize prevention:

a) Worker well-being and quality of life: MSDs can cause pain, discomfort, and reduced mobility, significantly affecting the overall well-being and quality of life of affected workers. Preventing MSDs helps maintain a healthier and more productive workforce.
b) Reduced absenteeism and increased productivity: When workers suffer from MSDs, they may need to take sick leave or time off work for medical treatment and recovery. Preventing these disorders can help reduce absenteeism and enhance overall productivity in the workplace.
c) Lower healthcare costs: Treating and managing MSDs can be expensive, both for the affected workers and their employers. By preventing MSDs, the need for medical treatments and interventions is reduced, leading to cost savings for individuals and organizations.
d) Improved work performance: Workers experiencing MSDs often have reduced physical capabilities and may struggle to perform their tasks effectively. Preventing MSDs ensures that workers can maintain optimal performance and meet their job demands.
e) Enhanced workplace morale and satisfaction: A workplace that prioritizes employee health and safety fosters a positive work environment, leading to higher job satisfaction and increased employee morale.
f) Long-term health implications: Untreated or mismanaged MSDs can lead to chronic health conditions, affecting workers' lives even after they leave the workforce. Prevention helps avoid long-term health complications.

g) Legal and regulatory compliance: Many countries have regulations and standards related to workplace health and safety. Employers are obligated to provide a safe working environment for their employees, including measures to prevent MSDs.
h) Sustainable workforce: A workforce that is healthy and free from work-related injuries or illnesses can sustain higher productivity levels and contribute more effectively to the growth and success of the organization.
i) Reputation and brand image: Employers that prioritize employee health and safety build a positive reputation and image, which can attract and retain skilled workers and customers.
j) Social responsibility: Ensuring the well-being of workers is not only an ethical responsibility but also a demonstration of social responsibility on the part of employers and organizations.

In summary, preventing Work-Related Musculoskeletal Disorders (MSDs) benefits both workers and employers by promoting a healthier and more productive workforce, reducing healthcare costs, and fostering a positive work environment. It is a proactive approach that aligns with legal requirements, business interests, and ethical principles.

2.3 Muscle discomfort survey

In general, discomfort refers to the feeling of being uncomfortable or in pain, either physically, mentally, caused by the environment or situation (*Discomfort*, 2023). However, there is still no exact definition of discomfort or sitting discomfort has been accepted in the field of research (Looze et al., 2003). Meanwhile, in the field of ergonomics, the term "discomfort" is a unique form of measurement because it involves the human perception (feedback) of the machine and work system environment (Karmegam et al., 2011). In this study, muscle discomfort while performing hot works is the focus together with the development of hot work chairs to reduce muscle discomfort levels among the affected workers. Assessing muscle discomfort among hot work workers is essential for several reasons, as it helps identify potential issues and enables employers to implement preventive measures and support the overall well-being of their workforce. Here are some key reasons why assessing muscle discomfort is important:

a) Early detection of potential musculoskeletal issues: Regular assessments can help identify early signs of muscle discomfort, which could be indicative of developing musculoskeletal disorders. Detecting these issues early allows for prompt intervention and prevents the conditions from worsening.
b) Preventive measures: Assessing muscle discomfort allows employers to identify and address potential risk factors that contribute to discomfort. By implementing preventive measures, such as ergonomic adjustments, proper training, and workstation improvements, employers can reduce the likelihood of more serious musculoskeletal problems.

c) Employee well-being: Monitoring and addressing muscle discomfort demonstrate employers' commitment to the health and well-being of their workforce. When employees feel that their concerns are taken seriously, it can improve job satisfaction and morale.
d) Reduced absenteeism and increased productivity: Addressing discomfort promptly can help prevent employees from taking sick leave or time off work due to musculoskeletal issues. As a result, productivity levels can be maintained, and the impact of absenteeism on business operations is minimized.
e) Workplace safety and compliance: Regular assessments of muscle discomfort align with workplace safety regulations and demonstrate an organization's commitment to complying with health and safety standards.
f) Ergonomic improvements: Assessing muscle discomfort can highlight areas where ergonomic adjustments are needed. Properly designed workstations and tasks can reduce physical strain, leading to improved work performance and reduced risk of injury.
g) Personalized interventions: Understanding the specific areas of discomfort reported by workers allows employers to implement targeted interventions and accommodations tailored to individual needs, optimizing the effectiveness of support measures.
h) Long-term health and cost savings: Addressing muscle discomfort and preventing more serious musculoskeletal conditions can lead to long-term health benefits for employees. Additionally, it can result in cost savings for both employees (reduced healthcare expenses) and employers (lower medical claims and compensation costs).
i) Improved employee engagement: Employees are more likely to feel valued and engaged when their employers take proactive steps to ensure their health and safety. This positive work environment can contribute to higher employee retention rates and attract potential talent.
j) Risk management: Assessing muscle discomfort helps identify potential risks in the workplace that may lead to work-related injuries and legal liabilities. By proactively managing these risks, employers can avoid potential legal and financial consequences.

A standardised questionnaire of the examination of the musculoskeletal discomforts in an ergonomic health context was used to assess the discomfort of various regions of the body. Prolonged sitting discomfort is big concern at the workplace and when it’s combined with other risk factors like awkward postures, vibration, working for long hours and others leading to Musculoskeletal Disorders (Kyung et al., 2008). The musculoskeletal assessment or discomfort survey must be carried out for all sorts of risk factors in order to identify and validate the affected body areas of workers participating in this research project. We can use any existing form for the musculoskeletal assessment, such as the Nordic Musculoskeletal Questionnaire, the Dutch Musculoskeletal Questionnaire, the Cornell Musculoskeletal Questionnaire, and others. The muscle discomfort assessment has been used in this research and has been attached in the appendix section. It is very important and necessary to obtain human feedback and direct concern from a subjective evaluation through a set of questionnaires (Deros et all.,2009). The discomfort surveys used for respondents to rate scale the discomfort level undergone at specific body parts or body regions using the Likert scale, Visual Analogue Scale (VAS) or Borg's scale CR-10 (Yusof et al., 2019). Visual Analogue Scale (VAS) was used in this study because it is more sensitive to small changes than Likert scale and the results are more distinct when looking at change within individuals. This assessment also usually takes less than one minute to complete and no training or details explanation is required compared to the Likert scale. The questionnaire that consists of muscle discomfort ratings using the Visual Analogue Scale (VAS) had been attached in the appendix.

2.4 Ergonomic Risk Assessment

Ergonomics Risk Assessment is a systematic plan and objective approach to finding, assessing, and managing ergonomics risk factors linked with occupational tasks and activities. The goals of ergonomics risk assessment are to find ergonomics risk factors that may cause injury to employees, to quantify the likelihood of harm resulting from exposure to the ergonomics risk factors, and to prescribe appropriate risk-reduction actions. An ergonomics risk factor is a situation that exists or is created intentionally or unintentionally that may contribute to results that contravene or are against ergonomics principles and may be harmful to workers' health and well-being at work or after work. Repetition, force, awkward posture, vibration stress, static loading, and extreme temperature are examples of ergonomic risk factors (Mat, 2003). In a study on ergonomic risk assessment among 66 welders in construction, the researched used the ergonomic risk assessment tools and successfully found that the primary ergonomic risk factors identified are awkward posture, repetition, force, static loading, contact stress and extreme temperature (Abd Mutalib et al., 2016). An ergonomic risk factor is also defined as any attribute, characteristic, exposure, or source of potential that may cause or contribute to a musculoskeletal injury or any other ergonomic-related injuries or illness (Guidelines on Ergonomic Risk Assessment at Workplace 2017). In general, two or more ergonomic risk factors may be present at one time which may increase the risk of MSD injuries among workers. The ergonomic risk assessment is determined by the risk factors evaluated. The exposure and duration of each work position may vary depending on the trained person's professional judgement. The researcher is a trained person who is registered as a trained person for ergonomic risk assessment under the Department of Occupational Safety and Health, Malaysia.

An ergonomic assessment tool is a form or checklist used to detect, assess, and evaluate ergonomic risk factors in the workplace. In this research study, initial ergonomic risk assessment and advanced ergonomic risk assessment have been conducted among the selected workers as per procedures and assessment tools from Guidelines on Ergonomic Risk Assessment at Workplace 2017. The initial level ergonomic risk assessment is a preliminary evaluation of ergonomic hazards and risks associated with a task, job, or work environment. It involves identifying potential ergonomic issues and determining if further investigation or action is required. The purpose of the initial assessment is to quickly identify areas that may have a higher likelihood of ergonomic problems and prioritize them for further analysis. During the initial level assessment, common ergonomic risk factors are typically considered, such as awkward postures, repetitive motions, forceful exertions, vibration exposure, and inadequate workstations or tools. The assessment may involve visual inspections, checklists, basic measurements, and discussions with workers to gather information and identify potential areas of concern. The output of the initial level ergonomic risk assessment may include a list of tasks or areas that require more detailed evaluation, recommended actions for improvement, or the need for an advanced level assessment to gather more specific data. The advanced level ergonomic risk assessment involves a more detailed and comprehensive evaluation of ergonomic hazards and risks in a specific task, job, or work environment. It focuses on gathering quantitative and qualitative data to better understand the nature and extent of ergonomic issues. An advanced level assessment may involve various methods and tools such as direct observations, measurements of physical demands (e.g., force, posture), surveys, interviews, and analysis of work practices.

The assessment aims to identify specific ergonomic risk factors, assess their severity and duration, and determine their potential impact on workers' health and well-being. The output of an advanced level ergonomic risk assessment typically includes a detailed report that outlines the identified ergonomic hazards, associated risks, recommendations for mitigating or controlling those risks, and a prioritized action plan for implementation. It may also include ergonomic design guidelines, training needs, and ongoing monitoring strategies. The advanced level assessment provides a more thorough understanding of ergonomic issues and helps guide the development and implementation of appropriate ergonomic interventions to improve workplace conditions and prevent work-related musculoskeletal disorders (MSDs). The advanced ergonomic risk assessment tools used in this study are Rapid Entire Body Assessment (REBA), Muscle Fatigue Assessment (MFA) and the Quick Exposure Check (QEC). These assessment tools were used to identify and evaluate risk factors connected with hot work in the process of designing and developing a hot work chair to improve the level of discomfort experienced by hot work workers at the selected organisation.

2.4.1 Muscle Fatigue Assessment (MFA)

Muscle fatigue assessment method (MFA) was established in the year 1987 by Rodgers and Williams, also known as the functional job evaluation approach, which was used in this research study to characterise the discomfort experienced by workers in hot works at the selected organisation. During the initial observation by the researcher at the initial stage, it was found that the workers encounter fatigue in some muscle groups throughout the workday especially those workers performing hot works in the seating position. According to Rodgers (2004), most workers' muscular discomfort could not be explained by biomechanical studies of the task, but it appeared to be tied to their working pattern and body postures. There is a possibility for workers to take shortcuts when the task duration was being prolonged to complete the task quickly than the standard duration time required. Based on initial discussion, hot work workers at the selected company admitted that they used to speed up their work and sometimes take shortcut(s) to add recovery time for their fatigued muscles for each effort cycle. The frequency of muscle attempts will impact how much healing time is available for the personnel involved. The degree of accumulated fatigue in a muscle throughout any hot work activity can be characterised and analysed by estimating the length of time required from the recovery time curves and comparing this to the original time between efforts with the same intensity (Rohmert, 1973). Bernardo et al., (2018) enhanced the format of this muscle fatigue assessment by including a table of "effort intensity" definitions in the layout of this assessment instrument, as well as a separate table for "priority for change" score based on the three number ratings, when he placed the MFA method, also known as the Rodgers fatigue tool, on his website (Bernardo et al., 2018). From 1987 to 2002, this MFA approach was utilised to assess, evaluate, and analyse over 1000 work activities and tasks in over 100 ergonomic team training courses, and many changes were made as a result of this assessment. Each factor has been added with fourth levels that facilitate the fatigue or injury risk more accurately which was underestimated earlier. If the ratings are 4 for any of the factors, the task will be highlighted with highest priority for improvement. The MFA approach was utilised in this research study to detect, assess, evaluate, and analyse muscle fatigue problems affecting selected workers.

2.4.2 Rapid Entire Body Assessment (REBA)

REBA (rapid entire body assessment) was created to evaluate the sorts of irregular working postures common in health care and other service industries (Hignett et al., 2000). Data on body position, forces employed, movement or action types, repetition, and coupling were recorded, and a final REBA score was calculated to indicate the risk level and urgency, with prompt attention required. REBA fits between between comprehensive event-driven systems and time-driven tools on the postural analysis tool range. REBA was initially developed based on limb position ranges using concepts from rapid upper limb assessment (RULA), OWAS, and NIOSH (Hignett, 1998). The functional anatomically neutral posture is the basic body posture (Karwowski et al., 2021). Yet, when the body posture deviates from the neutral position, the risk score rises. The REBA checklist includes tables that can be used to convert the 144 body posture possibilities into a single score that can reflect the level(s) of musculoskeletal risk. These ratings are then tagged with five action levels, which help us understand the immediate steps that should be implemented to lower the risk of the evaluated body postures. According to Neville in 2005, the Rapid Entire Body Assessment (REBA) can be used as an ergonomic risk factor assessment tool when further postural analysis is required and for conditions as below:

- The entire body is used;
- Posture is static, dynamic, rapidly changing, or unstable;

- Animate or inanimate loads are handled on a frequent or infrequent basis; and
- Changes to the workplace, equipment, training, or risk-taking attitude of workers are supervised on a pre or post change basis.

Two stages were involved in establishing REBA's reliability. The 144 posture combinations were coded individually by three ergonomists/physiotherapists in the first step. Incorporating the additional risk scores for load, coupling, and activity, they reviewed and settled any discrepancies in the values before generating the final REBA score, which ranges from 1 to 15. The second stage included two seminars with 14 health professionals who used REBA to code over 600 work postures from the health-care, manufacturing, and power industries. Since then, REBA has been widely employed, especially in the healthcare sector, having demonstrated strong face validity (Mcatamney et al., 2005). Rapid Entire Body Assessment (REBA) is a beneficial tool and was used in this research study because of reasons as below:

a) Efficiency: REBA is a rapid assessment tool, meaning it can be performed quickly, which is particularly valuable in workplaces with multiple tasks and limited time for in-depth assessments. Its efficiency allows for more tasks to be assessed in a shorter period.
b) Identifying Risk Factors: The assessment evaluates posture, force exertion, and other ergonomic risk factors that can contribute to the development of MSDs. By identifying these risk factors, employers can take proactive measures to minimize or eliminate potential hazards.
c) Preventing MSDs: By identifying and addressing ergonomic risk factors early, REBA helps prevent the development of work-related musculoskeletal disorders. Preventive measures can lead to healthier and more productive workers.
d) Injury Reduction: Implementing ergonomic improvements based on REBA assessments can reduce the risk of workplace injuries, leading to decreased absenteeism and workers' compensation claims.
e) Worker Well-being: REBA supports the overall well-being of workers by providing a means to evaluate and improve their work environment. Employees who feel that their health and safety are prioritized are likely to be more satisfied and engaged.
f) Compliance with Regulations: Many countries have regulations and guidelines related to ergonomics and worker safety. Using REBA helps employers comply with these regulations and demonstrate their commitment to providing a safe working environment.
g) Easy Implementation: REBA does not require specialized equipment or extensive training, making it accessible to a wider range of workplaces. Ergonomics professionals, supervisors, and even workers themselves can use REBA to assess tasks and propose improvements.
h) Cost-Effectiveness: Conducting ergonomic assessments using REBA can be cost-effective compared to more complex and time-consuming methods. It allows employers to allocate resources efficiently while still addressing ergonomic concerns.

i) Task Prioritization: REBA allows employers to prioritize tasks based on their ergonomic risk levels. This can help organizations focus their efforts on addressing the most critical issues first.

Workers at the selected company use their whole body to perform hot works especially during welding, grinding and metal cutting works, and with other ergonomic risk factors such as static, rapidly changing, and unstable body postures. The information of the body posture, forces used, types of movement(s) or actions, repetition, and coupling were collected in this study, and a final REBA score was generated to assist the designing and developing hot work chair expected to minimise the ergonomic risk factors and the muscle discomfort level that affects workers at the company's hot work section. Overall, Rapid Entire Body Assessment (REBA) is an important tool for assessing and improving ergonomic conditions in the workplace. By identifying and addressing ergonomic risk factors, employers can create a safer and healthier work environment, reduce the risk of musculoskeletal disorders, and enhance worker well-being and productivity.

2.4.3 Quick Exposure Check (QEC)

The Quick Exposure Check (QEC) was developed to assist health and safety practitioners to understand evaluation of the exposure of workers to workplace musculoskeletal risk factors (WMSDs) that occur at specific workplace or for specific task (Li et al., 1999). It was initially developed with the participation of approximately 200 ergonomic practitioners who were involved throughout the entire development, testing, modification, and validation process using simulation and real work tasks that cover tasks such as manual handling, routine work, static or dynamic tasks, seated or standing tasks (Quick Exposure Check Reference Guide, 2005). Quick Exposure Check (QEC) is essentially focused on exposure assessment and change, allowing the benefits of workplace interventions to be assessed quickly. The four characteristics of using this instrument explored by QEC are attitude, learnability, adaptability, and efficacy (Shackel, 1991). QEC enables hot work activities to be evaluated in cooperation with all hot work personnel. This tool is intended to be a rapid assessment that is simple to use and does not require considerable training for assessors prior to usage. To measure exposure to the risks of WMSDs, a one-page assessment sheet includes questions for both the ergonomic practitioner (observer) and the worker. The exposure scores for the back, shoulder/arm, wrist/hand, and neck have been classified as 'Low,' 'Moderate,' 'High,' or 'Very High'. The steps or procedure to conduct a Quick Exposure Check (QEC) at the selected company will be explained in further in Chapter 3. The benefits of the Quick Exposure Check (QEC) in ergonomic risk assessment at workplace as below:

a) Time Efficiency: Quick exposure assessment tools allow for rapid evaluation of workplace hazards without the need for time-consuming and resource-intensive assessments. This efficiency enables more tasks to be evaluated in a shorter period.

b) Early Hazard Identification: QEC might help in identifying potential hazards at an early stage, allowing employers to take preventive measures promptly and avoid the development of more significant risks.
c) Informed Decision Making: The tool could assist in making informed decisions regarding workplace safety and the allocation of resources for risk reduction measures.
d) Accessible to All Levels: A user-friendly and straightforward exposure assessment tool like QEC could be used by workers, supervisors, and safety personnel alike, making it accessible throughout the organization.
e) Worker Engagement: Involving workers in the assessment process can enhance their awareness of potential hazards and engage them in safety discussions and initiatives.
f) Compliance with Regulations: Utilizing a standardized exposure assessment tool can help organizations comply with occupational health and safety regulations and industry best practices.
g) Cost-Effectiveness: A quick check exposure assessment tool might be more cost-effective than more complex assessments, making it practical for smaller organizations or workplaces with limited resources.
h) Risk Prioritization: The tool could assist in prioritizing tasks or activities based on their exposure levels, helping employers focus on high-risk areas first.
i) Data Collection for Trend Analysis: Regular use of the tool can provide a data source for trend analysis, enabling employers to monitor changes in exposures over time and assess the effectiveness of implemented controls.
j) Continuous Improvement: By incorporating QEC into routine safety practices, organizations can promote a culture of continuous improvement in occupational health and safety.

In this research study, Quick Exposure Check (QEC) has been used to assess the exposure of main risk factors for MSDs among the workers at hot work section of the company. By assessing the correct exposure level of workers, the risk factor could be identified and the results will support the researcher in designing and developing the hot work chair that can reduce the exposure of affected workers toward the identified ergonomic risk factors.

2.5 Hot works and problems associated with Ergonomics

The ergonomics objective is to fit machine and man together to improve the performance of the worker, reduce risk, stresses and fatigue at workplace (Kushwaha et al., 2016). Cutting, grinding, or welding operations for operation tasks involving the use of portable gas or arc welding equipment, soldering, grinding, or any other comparable activities creating a spark, flame, or heat, are referred to as hot work. Because to awkward postures and severe exertions, hot works impose physical demands on the welder's wrists, elbows, arms, shoulders, and neck. Back injuries, shoulder pain, tendonitis, decreased muscle strength, carpal tunnel syndrome, white finger, knee joint illnesses, and other musculoskeletal disorders are common among hot workers. These disorders have been contributed by many ergonomic risk factors such as performing hot works in awkward position(s), working for long hours, seating for long time, static postures, and vibration (Letuyen, 2022). Improper body position or awkward posture is a major risk factor that may cause muscle pain or discomfort among workers performing hot working as a routine job. Hot work is required in nearly every phase of structuring, fabrication, finishing, repairing, maintenance and for product modification in metal fabrication industries where most of the timetables or chairs are not available for related workers. According to the findings of a study, awkward postures were revealed to be the leading cause of occupational muscular injuries among the various work postures (Mahendra K.C et.al., 2016). Working while bending over is frequent among metal fabrication hot work workers. Bending over position, as seen in figure 2.2, compresses the spinal column and places strain on the lower back, which can lead to chronic back pain or other major back problems if performed for an extended period of time.

Figure 2.2: The bending posture of the welder in the shipyard
(Source: Letuyen, 2022)

In a separate study, it was found that welding workers who working in static conditions cause the blood flow to become slow thus reducing the supply of nutrients to the muscles and then slowing the acid removal, excretory, healing and recovery process in the affected muscle's region (Khairul, 2020). Structuring and fabrication process of metal sheets at the selected company are performed on open floor and at different working height(s) due to the different size of containers. This working environment causes the related workers to perform their hot works in improper and awkward body positions for extended periods of time. Furthermore, most hot work in metal container manufacturing requires workers to bend, squat, sit on any available material, and extend their legs repeatedly. Sitting on the knees, often results in contact stress, is another frequent cause of musculoskeletal ailments. If the kneeling posture is maintained for an extended amount of time, the problem may worsen. Basically, there are three main risk factors that would increase the probability of developing musculoskeletal injuries in hot works (Muzammil et al., 2021):

(i) A high-repetitive task performed by the operator that keeps them in a static position for an extended period of time or repeating the same movements.
(ii) Any activity that requires an operator to exert significant pressure and force, such as pushing, pulling, or lifting up or down.
(iii) Improper or poor postures, such as awkward postures such as bent wrist(s) or a backward tilted neck

Another study has stated that an Improper body position or awkward posture are major risk factor that may cause muscle pain or discomfort among workers performing hot working as routine job (Schnieders et al., 2017). During hot works performed in a seating position, such as welding or other tasks involving heat or open flames, the body mechanisms involved can vary depending on the specific task, equipment used, and the worker's technique. However, here are some general body mechanisms that may be involved:

a) Seated Posture: Hot work tasks often require workers to sit for extended periods. Maintaining an upright and stable seated posture is important for proper body alignment, stability, and minimizing strain on the body. This involves maintaining a straight back, aligning the head with the spine, and ensuring the feet are flat on the ground or appropriately supported.
b) Arm and Hand Movements: In a seating position, the worker's arms and hands are usually actively engaged in manipulating tools or equipment. This can involve precise movements for tasks like welding, cutting, or soldering. The worker's hands and arms may move in a coordinated manner to hold the tool, guide the workpiece, and apply the necessary force or pressure.
c) Upper Body Stability: Seated hot work tasks often require upper body stability to maintain control and precision. The core muscles, including the abdominal and back muscles, play a crucial role in providing stability and balance. These muscles help to keep the torso steady, reducing excessive strain on other body parts.
d) Head and Neck Position: The worker's head and neck position can vary depending on the task and the need for visual focus. They may need to keep their head steady or turn it to different angles to ensure proper vision and access to the work area. Maintaining a neutral position of the head and avoiding excessive twisting or prolonged tilting can help prevent strain or discomfort.
e) Weight Shift and Adjustments: During hot works in a seating position, workers may need to shift their weight and make adjustments to maintain stability, reach different areas, or access tools or equipment. This can involve minor changes in body position, weight distribution, or body angles to optimize comfort and control.

Implementation of good body postures and usage of ergonomically designed keyboard could help office employees to decrease the discomfort that they experience because of sitting at a desk all day. However, for hot work workers who are not normally provided with specific chairs in many industries, suffer from muscle discomfort due to bending over prolonged duration, sitting on floors or any non-suitable materials, frequent awkward body postures and others (Oanh Nguyen, 2016). Another aspect of ageing that should be considered is the increased frequency and severity of back and other musculoskeletal problems that result from improper body posture. Workers as they age are prone to a cumulative degeneration process and loss of flexibility, which may increase the potential and level of exposure to certain sorts of musculoskeletal disorders. According to the Welding guide published by Manitoba Family Services and Labour in March 2013, the welding activity puts physical demands on the welder's wrist, elbows, arms, shoulders and neck, due to the awkward postures and forceful exertions required. Work procedures and structures should be developed to allow for a comfortable posture, reducing excessive body movements. In this study, the hot work chair which has been proposed will play an important role in the work process and system in hot works. There are quite a number of studies in ergonomics that proves that improvements done in a workstation directly or indirectly improve the quality of products, productivity, efficiency, reduce hazard levels, reduce occupational health problems and their cost of expenses (Yew et al., 2006).

Hot work workers around the world are affected with musculoskeletal pains and disorders due to many ergonomic risk factors. The most common symptoms occur among welding operators or other hot work workers which are shoulder pain, range of motion loss and reduced muscle strength and the most affected areas by injuries include the back, the shoulders, the wrists (such as with tendinitis), and the knees. Extended static body postures associated with neck flexion, lengthy working duration on knees or in positions that promote abnormal body postures, contact stress, and hand gripping are the primary causes of muscle injuries in metal fabrication workers. Additional ergonomic risk factors affecting workers include frequent bending, kneeling, squatting, and working in extreme heat also can cause muscle discomfort among workers. Working on the knees while performing welding or grinding causes contact stress which may cause musculoskeletal injuries for the affected workers. This problem will worsen if the kneeling posture is maintained for a prolonged amount of time. Leaning forward at the waist and remaining in the bending over position puts a tremendous pressure on the lower back, compresses the spine, and, if done repeatedly, can damage the shock- absorbing pads and discs placed between the vertebrae (Bernardo et al., 2018). According to NIOSH USA, the herniated or ruptured disk developed in the body might create a constant pressure on the spinal cord and the nerves to the legs of workers. If workers sustain irreversible damage to the absorbing pads and discs in their vertebrae, it will result in expensive healthcare expenditure and compensation from their respected companies. Doctors will then permanently restrict the workers to continue welding or any other hot work in the workplace, resulting in a drop in productivity. In the context of the selected company, there are some ergonomic risk factors contributing to muscle pain or discomfort level among hot work workers which have been identified through the initial survey. The hot workers at the selected company mostly perform hot works in seating position with the worker's head and trunk flexed forward and shoulders flexed and abducted. Figure 2.3 shows how some of the welders at the selected company perform welding activities at the container framework fabrication area. Awkward body postures, repetitive movements, working surfaces that are too low, retaining the same work positions or posture for an extended length of time, and working in high heat are some of the ergonomic risk factors observed. Initial observation shows workers doing hot works activities in squat positions while some others sitting on metal sheets and plastic containers while carrying out their welding, grinding or metal cutting works with no proper workstation the provided by the employer.

Figure 2.3: Ergonomic position of a welder performing welding activities at the container framework fabrication area

Our body's musculoskeletal system will function better when there is muscle mobility, which leads to adequate blood flow; on the other hand, prolonged absence of muscle movement due to static work postures will have negative consequences on our body's musculoskeletal system. Repetitive movements for lengthy periods of time, forceful exertions, and poor posture of the joints and appendages are all risk factors for developing musculoskeletal injuries. In terms of tiredness, strain, and more serious damage to the muscles or ligaments, performing too many repetitive movements when welding or performing other hot activity for an extended period of time is also harmful for the musculoskeletal system. In their "neutral" postures, the spines, joints, and appendages will generate less internal force. Yet, any movement away from these 'neutral' positions generates the potential for increased force, especially when reaching their anatomic limits. Studies have shown that the majority of work-related musculoskeletal disorders (WMSDs) arise from the body's enduring repeated microtraumas (Nurathirah, 2021). The hot work workers at this selected company have reported multiple muscle pain and muscle discomfort during initial survey by the researcher. Some of them are under medical treatment for back pain, muscle injuries and slip disc condition. Some of them have started to have symptoms for musculoskeletal disorders like continual pain in some body region and could not sit for long time along with regular muscle cramps and so on. A person's physical attributes, such as their height, weight, age, level of fitness, and health issues, naturally place constraints on them. The risk of work-related musculoskeletal problems, including injuries to the muscles, tendons, ligaments, joints, nerves, or spinal discs, increases when the work design exceeds the typical limitations and employees are working with poor body postures, sitting on inappropriate materials, and doing repetitive tasks for extended periods of time. Workplace musculoskeletal disorders (WMSD) will not only affect the workers but the company's business to face the consequences.

The hot work workers at this selected company have reported multiple muscle pain and muscle discomfort during initial survey by the researcher. Some of them are under medical treatment for back pain, muscle injuries and slip disc condition. Some of them have started to have symptoms for musculoskeletal disorders like continual pain in some body region and could not sit for long time along with regular muscle cramps and so on. A person's physical attributes, such as their height, weight, age, level of fitness, and health issues, naturally place constraints on them. The risk of work-related musculoskeletal problems, including injuries to the muscles, tendons, ligaments, joints, nerves, or spinal discs, increases when the work design exceeds the typical limitations and employees are working with poor body postures, sitting on inappropriate materials, and doing repetitive tasks for extended periods of time. Workplace musculoskeletal disorders (WMSD) will not only affect the workers but the company's business to face the consequences. The intervention suggested in this research study is a prototype of hot work chair and Introducing intervention at the selected company is crucial to reduce muscle discomfort among hot work workers for several reasons. Hot work activities can lead to prolonged static and awkward postures, causing significant muscle discomfort and pain. By implementing interventions, employers prioritize the health and well-being of their workers, ensuring a safer and more comfortable work environment. Continuous exposure to muscle discomfort and strain during hot work activities can contribute to the development of musculoskeletal disorders. Interventions that address ergonomic issues can help prevent the onset of these debilitating conditions. Workers experiencing muscle discomfort are likely to be less productive due to reduced focus, discomfort, and potential distractions caused by pain. By reducing discomfort, interventions can improve productivity and work efficiency. The summary of the previous studies on muscle discomforted among hot work

Table 2.3: Summary of the studies related to Muscle discomfort and Ergonomic Risk assessment among industrial workers

Nu	Setting	Method	ERA Factors / Muscle discomfort	Results	Author
1	Field setting	Muscle discomfort survey, ERA	• Awkward position(s), • seating for long time, • static postures. • Muscle discomfort	Back injuries, shoulder pain, tendonitis, and other MSDs are common among hot workers and contributed by many ergonomic risk factors such as performing hot works in awkward position(s), working for long hours, seating for long time, and static postures	Letuyen, 2022
2	Field setting	Muscle discomfort survey	• Awkward postures	Awkward postures were revealed to be the leading cause of occupational muscular injuries among the various work postures	Mahendra K.C et.al., 2016
3	Laborato ry	Muscle discomfort survey, ART, ERA	• static position, • extended period, • repeating movements, • awkward postures	A high-repetitive task performed by the operator that keeps them in a static position for an extended period of time or repeating the same movements. Improper or poor postures, such as awkward postures such as bent wrist(s) or a backward neck	Muzammil et al., 2021
4	Field setting	Muscle discomfort survey, ERA	Prolonged sitting, Muscle discomfort	Musculoskeletal dysfunction has been linked to extended sitting. Inconvenient and painful musculoskeletal conditions may be avoided with the use of chairs that reduce aberrant neuromuscular system strain	Van Niekerk et al., 2012

Table 2.3: Continued

Nu	Setting	Method	ERA Factors / Muscle discomfort	Results	Author
5	Laboratory	100-mm VAS, electromyographic (EMG)	• Awkward position, • Prolonged seating, • Improper tools • Muscle discomfort	Hot work workers suffer from muscle discomfort due to bending over prolonged duration, sitting on floors or any non-suitable materials, frequent awkward body postures and others	Oanh Nguyen, 2016
6	Field setting	Body discomfort chart (0-10)	• Awkward position(s), • Prolonged working • Muscle discomfort	According to the, the odder the operating posture during hot work, the greater the risk of fatigue and long-term harm to the workers engaged.	Manitoba Family Services and
7	Field setting	5-point Likert scale	• Awkward position(s), • Muscle discomfort	Improvements done in a workstation directly or indirectly improve the quality of products, productivity, efficiency, reduce hazard levels, and reduce occupational health problems.	Yew et al., 2006
8	Laboratory and field settings	CR10 Borg Scale, Likert Scale	• Awkward position(s), • Prolonged seating • Contact stress	Working on the knees while performing welding or grinding causes contact stress which may cause musculoskeletal injuries for the affected workers	Bernardo et al., 2018
9	Laboratory	CR10 Borg Scale	• Awkward position(s), • Repetitive task • Muscle discomfort	Studies have shown that the majority of work-related musculoskeletal disorders (WMSDs) arise from the body's enduring repeated microtraumas.	Nurathirah, 2021

Table 2.3: Continued

Nu	Setting	Method	ERA Factors / Muscle discomfort	Results	Author
10	Field setting	Muscle discomfort survey	• ERA • Awkward position(s), • Prolonged seating • Muscle discomfort	Another study has stated that an Improper body position or awkward posture are major risk factor that may cause muscle pain or discomfort among workers performing hot working as routine job.	Schnieders et al., 2017
11	Field setting	100-mm (VAS), electromyographic (EMG)	Awkward position(s),	Prolonged seating Blood flow to become slow thus reducing the supply of nutrients to the muscles and then slowing the acid removal, excretory, healing and recovery process in the affected muscle' s region of welding workers who working in static conditions cause the.	Khairul, 2020
12	Field setting	chairs with backrests	Muscle discomfort • Prolonged sitting	Prolonged sitting commonly exacerbates low back pain (LBP). Several modifications to seated posture and chair design have been recommended.	Curran M. et al., 2015
13	Field setting	•Borg Scale: •Muscle Discomfort	• Awkward position(s), • Prolonged working	Muscle discomfort - Unsafe and unhealthy body positions in the welding workshop had caused muscle comfort among the students during welding activities and if continued repeatedly, can cause muscle pain and cause musculoskeletal disorder.	Ruliati et al., 2015
14	Laboratory	•Muscle Discomfort, ERA	• Awkward posture • Muscle discomfort	Another study has stated that an Improper body position or awkward posture are major risk factor that may cause muscle pain or discomfort among workers performing hot working as routine job.	Mittal et al., 2013

Muscle discomfort may lead to increased absenteeism as workers may need to take time off to recover from discomfort-related issues. Implementing interventions can help reduce absenteeism and ensure a more consistent and engaged workforce. Preventing or reducing muscle discomfort through interventions can lead to cost savings for employers. Fewer workplace injuries and reduced workers' compensation claims result in financial benefits. Implementing interventions to reduce discomfort demonstrates that employers care about their workers' comfort and safety. This can lead to improved work morale, increased job satisfaction, and better employee retention rates. Many countries have regulations and guidelines related to workplace health and safety, including ergonomic requirements. Introducing interventions to reduce muscle discomfort ensures compliance with these regulations. In the context of Malaysia, Objective of OSHA 1994 that is to promote occupational environment for person at work which adapted to their physiological and psychological needs. Section 15(1) of the OSHA1994 which requires each employer to safeguard the safety, health and welfare of all workers.

Organizations that prioritize employee well-being and safety foster a positive image among employees, clients, and the general public. It can also attract top talent to the organization. Implementing interventions to address muscle discomfort fosters a culture of continuous improvement. Organizations that regularly assess and improve working conditions are more likely to create a safer and healthier work environment. Addressing muscle discomfort proactively reduces the risk of work-related injuries and disorders. Identifying and mitigating ergonomic risks before they escalate helps maintain a safer workplace. The employee's health and safety over the long term, as well as the organization's reputation for occupational health and safety performance, might be significantly improved by a hot work chair that has been proposed and developed in this study. Designing an ergonomic workplace is always a challenging task because it involves many issues especially the body postures that a worker might need to adopt with it. The designing and developing process of hot work chair will be explained further in next chapter and also in chapter 3.

2.6 Hot work chair as an Ergonomic intervention

A workplace that is properly designed could give significant effects to a great extent of the body postures if the workers are able to adopt with it. The most common working postures involving hot working at the selected company are performing hot work task in sitting posture using improper tool for longer duration in a day. Based on study conducted, there is significant evidence that sitting adopted for prolonged duration of time will result in discomfortability among the workers (Ashkenazy et al., 2019). To achieve an optimal balance between worker skills and worker requirements, an ergonomic approach to the design of the workstation or equipment for the industrial industry is a difficult assignment (Das, 1991). In the welding operation, for example, physical dimensions of the workplace design have a significant impact on production performance and worker physical and mental well-being. Poor posture produced by an inadequately designed equipment may result in static muscle efforts, causing in acute localised muscle fatigue, lowering productivity and increasing welder-related health risks (Corlett, 2005). When analysing and designing chairs for welding or any other hot work, some variables must be taken into account, such as the worker's physical ability, the weight of the welding gun or grinder, design tools, body mechanics during welding, the type of protective equipment used, the physical environment of the work, and the body positions that take place during the hot work (Commission, 1996). There are some recommendations from the American National Standard for Human Factor Engineering (Karwowski et al., 2021) to be considered for the proposed hot work chair in this research study which are as mentioned in table 2.4.

Table 2.4: List of some recommendation from ANSI/HFES 100 – 2007 for standard seating chair

Chair	- Shall have a lumbar support - Shall have a backrest that reclines - Shall have a seat pan that adjusts for height and tilt - Shall support at least one other of the seated reference postures in addition to the upright sitting posture - Shall provide support to the user's back and thighs in the chosen reference posture
Seat Pan and Backrest Adjustments	- Shall be height adjustable - Shall have a user adjustment for tilt - of the user's knee and the front edge of the seat pan - Should have a tilt lock or stop position that the user can select while seated, if a tilt lock is provided
Backrest	- Shall not constrain the user's torso to a position forward of vertical - Should allow the user to control the resistance necessary to recline the backrest - Should provide support to the lumbar and thoracic regions of the back
Seat Height	- Shall be adjustable by the user over a minimum range of 11.4 cm (4.5 in.) within the recommended range of 38 to 56 cm (15 to 22 in.)
Seat Pan	- Shall, if nonadjustable, be no greater than 43 cm (16.9 in.) - Shall be at least 45 cm wide (17.7 in.)
Casters	- Should be appropriate for the type of flooring at the workstation
Armrest	- Should be adjustable in height - Should allow adjustment of the clearance width between the armrests - Should be detachable - Should not create excessive pressure points - Should be able to be detached from the chair if necessary to fit the workplace

However not all recommendations from ANSI/HFES 100 – 2007 will be used for developing hot work chair because of the working environment and needs of different body postures while performing hot works. Developing seats that are appropriate for certain tasks is a tough task. Due to the dramatic increase in the number of workers, the growth of numerous types of industries and factories, and the rise in the number of musculoskeletal problems experienced by many workers worldwide, the sitting posture and the design of seats have long drawn the interest of many researchers from various nationalities, designers, and manufacturers. This has caused a legitimate research domain to emerge, which has led to a deluge of publications and design solutions (Corlett, 2005). Fitted, comfy chairs are essential when designing ergonomic workspaces. For the best comfort alternatives for hot job workers, the right chair can offer the right cushions and support for the right lumbar through backrest adjustments, adjustable arm rests, a five-legged star base, and depth settings. According to the user's size, it is suggested that the hot work chair include an adjustable component that raises up and down and can be adjusted to any fixed-height limits of the work surface. The chair is also proposed to have wheels which ease the workers to move around at short distance (Sovella Human Workspace, 2016). There are some ergonomic requirements concerning the design of seat for specific work at workplace to be included in this research study of designing and developing hot work chair by including the following:

a) The seat can be adjusted to accommodate both the varying working heights and the various anthropometric postures needed for a particular task.
b) The seat must give users with stability and freedom of movement.
c) The seat's lining material must be water-absorbing and able to endure hot sparks from hot workings.

In the context of Malaysia, even we do not have a specific standards or guidelines for the designing of seats for the workplace. There are many studies and researches which have been carried out to support the efforts in improving workplace design. Malaysia's Department of Occupational Safety and Health (DOSH) already given their attention in improving ergonomics at the workplace by releasing a few guidelines on ergonomics as guidance for local industries including Guidelines for Manual Handling at the Workplace 2018 and Guidelines on Ergonomic Risk Assessment at the Workplace 2017. Ergonomics have a wide scope in living environment especially at the workplace involving engineering processes and techniques, physical and biomechanics, sociology, physiology, design & manufacturing, and others (Sulaiman et., 2011). The ergonomical design is the application of the knowledge body on the design of equipment, machines, systems, required tasks, required jobs, and environmental factors that is safe and effective for humans (Mittal et al., 2013). Using a product with an ergonomic design helps to reduce worker pain and injury risk, boost employee output, and enhance the workplace environment as a whole. This is in line with the demands of Section 15 (1) of the Occupational Safety and Health Act of 1994, which states that it is the responsibility of each employer and employee to safeguard the safety, health, and welfare of all workers. One of the key areas where experts in human factors may contribute to bettering the fit between people, machines, and the environment is workplace designs. Other considerable factors in workplace design also include cost of expenditure, aesthetics, durability, and architectural characteristics.

An ergonomic workstation design encourages good postures on the workers, and it covers three classes of variables including task requirements, personal factors, and workplace design. Decisions about the effectiveness and advantages of specific designed workstation or equipment can only be made after considering the characteristic of users and the requirements of their jobs. In order to identify these ergonomic risk factors and to develop requirements and principles that should be taken into account while designing the suggested hot work chair, this research has been undertaken. The endeavour to discover better postures and formulate better requirements and criteria for hot works that are included in designing, developing, and evaluating a hot work chair would encourage healthy work postures and cease the prolonged adoption of harmful postures that are currently prevalent within the hot work area of this organisation. To ensure they are working as close to a neutral posture line as possible when performing hot work, workers should position their task as often as possible between their waist and shoulders. In order to attain this position, utilising the right height-adjustable chair can make a significant difference in reducing awkward postures and enabling the individual employee to work in more neutral positions. As compared to other types of control measures, such as administrative controls, this specifically designed and developed hot work chair, which is part of an engineering control, will be the most effective control measure in lowering or eliminating risk factors in the selected organisation. The summary of the previous studies on design and development of prototype and interventions introduced in reducing muscle discomforted among hot work workers is illustrated in Table 2.5.

Table 2.5: Summary of the studies on design and ergonomic interventions related to muscle discomfort among industrial

Nu	Setting	Design	Intervention	Results	Author
1	Field setting	Modified chair based on identified elements	Randomised Controlled Trials, modified chair	In order to relieve pain and discomfort in workers who have to sit for extended periods of time, the review's findings show an ongoing pattern to support of the chair solution.	Van Niekerk et al., 2012
2	Field setting	welding armrest using ergonomics approach	Welding armrest	It can also be concluded that the proposed design (welding armrest) using ergonomics approach reduces fatigue and musculoskeletal disorders and the students can perform welding activities with comfort and safety and thus produce better welding results.	Yusof, 2018
3	Laboratory	Chair based on Anthropometric data & work environment	Anthropometric measurement	Chair's dimensions and control features should be such that they meet the anthropometric characteristics of at least 90% of the potential users and appropriately designed for the intended type of job and working environment	Occhipinti E, 1993
4	Laboratory	Different type of cushions	Chair development	The cushion contour had a greater effect on seat pan interface pressure parameters than the sitting posture	Li W. et al., 2020

Table 2.5: Continued

Nu	Setting	Design	Intervention	Results	Author
5	Laboratory	Different type of chair	100-mm visual analogue scale Questionnaire electromyographic (EMG)	the sitting posture and the design of seats have long drawn the interest of many researchers from various nationalities, designers, and manufacturers which caused a legitimate research domain to emerge, which has led to a deluge of publications and design solutions.	Corlett, 2005
6	Field setting	New chair designed with wheels	New chair Pre – post test	The chair is also proposed to have wheels which ease the workers to move around at short distance.	Sovella Human Workspace, 2016
7	Field setting	New stool	5-point Likert scale	Ergonomics have a wide scope in living environment especially at the workplace involving engineering processes and techniques, physical and biomechanics, sociology, physiology, design & manufacturing, and others.	Sulaiman et al., 2011
8	Laboratory	Not specified	CR10 Borg Scale (7-point Likert Scale): Leg discomfort	The ergonomically design is the application of the knowledge body on the design of equipment, machines, systems, required tasks, required jobs, and environmental factors that is safe and effective for humans.	Nurathirah, 2021
9	Laboratory	Not specified	CR10 Borg Scale: Discomfort	Another study has stated that an Improper body position or awkward posture are major risk factor that may cause muscle pain or discomfort among workers performing hot working as routine job.	Mittal et al., 2013

Table 2.5: Continued

Nu	Setting	Design	Intervention	Results	Author
10	Laborator y	ergonomic chair for near-ground welding operations	electromyography (EMG) activity	Using a suitable chair or support for different work postures can prevent detrimental muscle activities during work and the development of musculoskeletal disorders caused by intense muscle activity due to awkward postures.	Tahmasebi R, 2020
11	Laborator y	Comfort chair design	pressure measurements, measurements of posture, EMG	The peak pressure on the seat pan, the pressure distribution on the backrest and the pressure pattern changes (seat pan and backrest) all appear to be reliable measures for quantifying comfort or discomfort.	Zemp R et al., 2015
12	Field setting	chairs with backrests and chairs	Prototype development pre/post assessment	There was considerable evidence that chair backrests minimize paraspinal muscle activation and low back disorders in seven studies that reviewed the effect of sitting with and without a backrest.	Curran M. et al., 2015
13	Laborator y	Newly dynamic office chair with a moveable seat	surface electromyography	Active sitting on the new chair significantly affected the lumbar trunk muscles, with characteristic cyclic unloading/loading in response to the seat movement. The new chair may have a potential positive impact on back health during prolonged sitting.	Kuster et al., 2020
14	Field setting	Unspecified	Pre -post on developed chair	Programs for ergonomic intervention may be successful in lowering workers' ergonomic risk factors and, as a result, in the secondary prevention of MSDs	Esmaeilzade h S. et al., 2012

2.7 Design and development process of the Hot work chair

The Pugh Method, also known as the Pugh Total Design Approach or the Pugh Concept Selection Matrix, is a systematic technique used in engineering and product design to evaluate and compare multiple alternatives or concepts. It helps designers and engineers make informed decisions by providing a structured framework for comparing different design options based on predefined criteria. The method was developed by Stuart Pugh, a British engineer, and it is commonly used in various industries to select the most suitable design concept for a given problem. The Pugh Method is particularly effective when there are multiple possible solutions, and the goal is to find the one that best meets the design requirements. This study used Pugh's total design idea as a reference to build a suitable chair design. This method reviews the systematic steps that must be taken to fulfil a requirement, ranging from identifying market/user needs and takes into account people, processes, products, and organizations. Figure 2.4 illustrates the various steps of the process. The creation of numerous different conceptual designs and the selection of the best conceptual design using the controlled convergence method are the key components of this methodology (Pugh, 1991). A conceptual design reflects how all the system's subsystems and its parts fit together as a whole. The objective of the design and development stages was to design, develop, fabricate, and test a prototype. This study included a muscle discomfort assessment, prototype design and development, pilot testing of the prototype, and product execution for the intended target group. The prototype concept in this study (a hot work chair) was based on Pugh's total design process model, which includes six components, as shown in Figure 2.5 (Pugh, 1991). The best design was selected to be developed and tested after a few alternatives conceptual designs were considered.

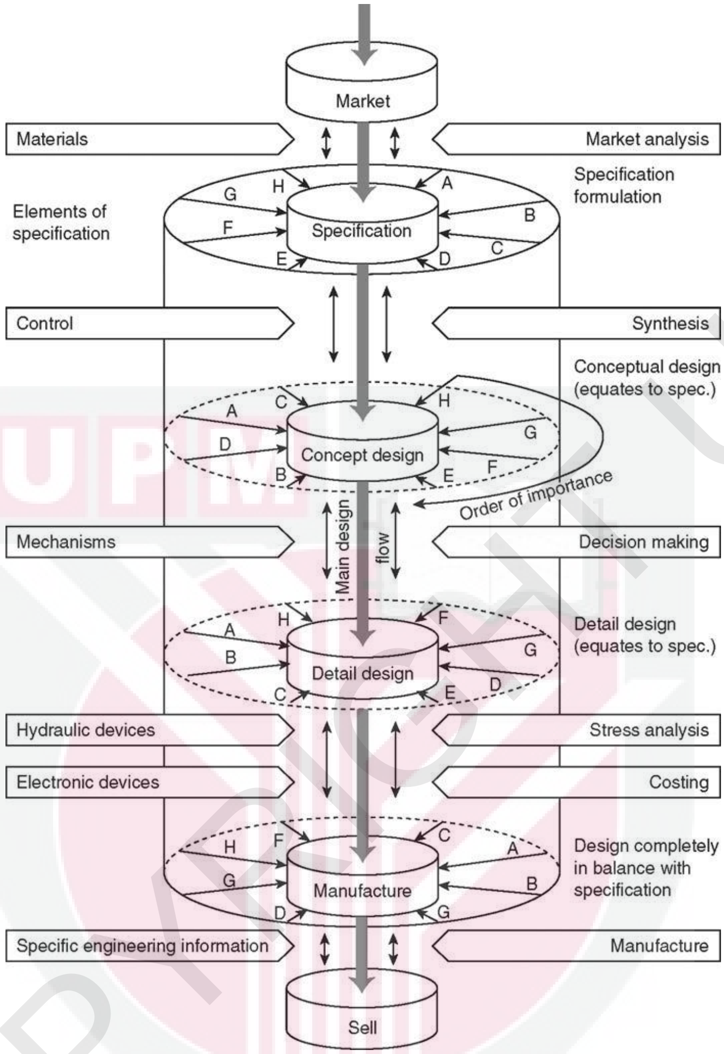


Figure 2.4: Total design approach
(Source: Pugh, 1991)

The primary objective of hot work chair was to provide workers with safety and comfort by minimizing or preventing discomfort for muscles during prolonged working and improper seating positions. The Pugh Method is a valuable tool for decision-making in design projects because it provides a structured and quantitative approach to evaluating multiple concepts. It encourages systematic thinking, helps avoid subjective biases, and promotes collaboration among team members involved in the decision-making process.

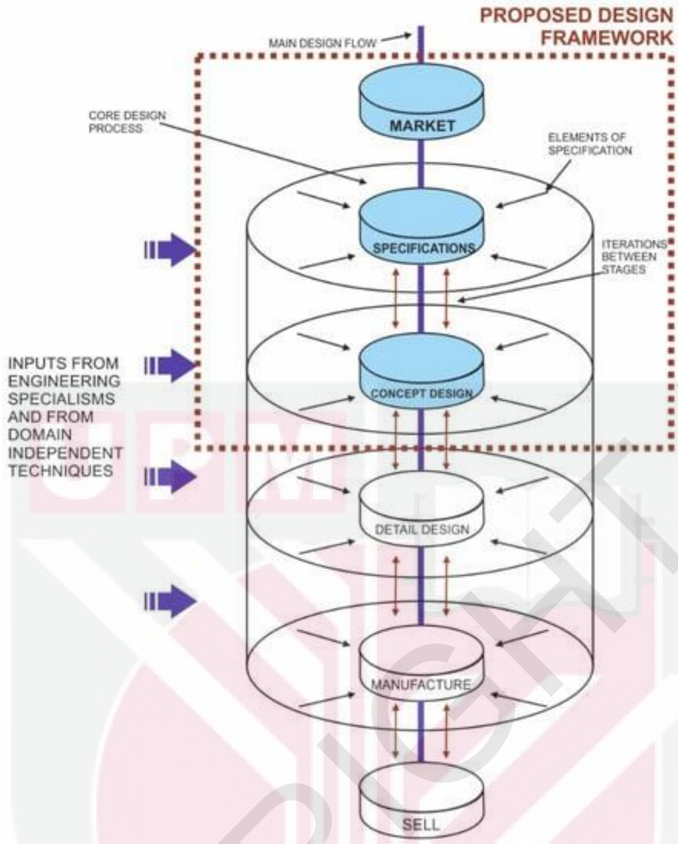


Figure 2.5: Pugh's Total design process model
(Source: Pugh, 1991)

The prototype development procedure is a systematic approach used to create an initial version of a product, system, or software application to test and validate its design, functionality, and usability before moving on to full-scale production or development. The general prototype development procedure typically involves the following steps (Pugh, 1991):

a) Identify Requirements and Objectives: Clearly define the purpose and goals of the prototype. Identify the key features, functionalities, and performance criteria that the prototype should exhibit.
b) Conceptualization and Design: Create a preliminary design and layout of the prototype based on the identified requirements. This can involve sketches, wireframes, or mock-ups to visualize the basic structure and user interface.
c) Prototype Development: Begin building the prototype based on the chosen type. Depending on the complexity, this could involve coding and programming, physical construction, or a combination of both.
d) Testing and Validation: Evaluate the prototype's performance and functionality against the established requirements. Gather feedback

from stakeholders, potential users, and experts. Identify areas for improvement.

e) Iterative Refinement: Use the feedback obtained during testing to make necessary adjustments and improvements to the prototype. Iteratively refine the prototype until it meets the desired objectives.

f) User Feedback and Usability Testing: Conduct usability testing with real users to gather insights into the user experience. This helps identify any usability issues and further enhances the prototype's design and functionality.

g) Finalize Prototype: Once the prototype meets the desired objectives and has undergone sufficient testing and refinement, finalize the prototype for presentation or demonstration.

h) Presentation and Review: Showcase the prototype to stakeholders, clients, or decision-makers for review and feedback. Discuss the results of testing and validation.

i) Decision-making: Based on the feedback and assessment of the prototype, make decisions about whether to proceed to full-scale production, development, or further iterations of the prototype.

j) Documentation: Document all aspects of the prototype, including design specifications, testing results, feedback, and refinements made during the development process.

2.8 Summary

There are significant previous studies that have proven that hot work workers had gone through multiple ergonomic issues and muscle discomforts due to improper seating and awkward position(s) during hot works. The initial and ergonomic risk assessments are also crucial to be conducted to identify and assess the muscle discomfort level and other MSD issues that could be affected due the current seating practices when carrying out the hot works. This research is conducted to design and develop a hot work chair which can improve the sitting and working position during the hot works, giving a comfortable environment for work, and reducing the number of muscle discomforts that affect the hot work workers. There are some inputs and theories that have been considered from previous research studies to design and develop a better chair specially made for hot works in seating positions. The findings of this study are also likely to improve individual and corporate productivity by enhancing overall hot works workers' health and work quality in other industries that use hot works as a primary component of their everyday operations. In the beginning it could be challenging for a hot work worker to get used with the new chair since the job had been carried out previously in different ways for many years. Therefore, it is very important for all involved hot work workers to use the designed chair by the researcher properly and frequently to provide valid feedback, comments, complaints, and how well the new chair gives comfortability to them. The advantages of ergonomics can only be obtained through teamwork, which eventually creates a comfortable work environment and safe working position, which leads to a more productive and lucrative hot work operation and also maintains the long-term health of hot work personnel.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, the samples for this study are selected from all workers who are directly involved in hot work activities in the production area. There are three phases of study in this research. Different numbers of samples have been selected from the hot work workers based on different aspects of the studies. Ergonomic problems of hot work workers have been identified through assessment of muscle discomfort among the hot work works. Then, Initial Ergonomic Risk Assessment, REBA (Rapid Entire Body Assessment), Muscle Fatigue Assessment, and QEC (Quick Exposure Checklist) have been conducted for each sample from the determined three work units to identify the Ergonomic Risk Factors. Next, a product design specification was established, and the hot work chair had been designed and developed based on the established PDS. The developed prototype and then it has been used by an experimental group at the hot work section of the company. A questionnaire which contains muscle discomfort rating was used to evaluate the effectiveness of this hot work chair among selected hot work workers. The muscle discomfort level was compared before and after using the hot work chair.

3.2 Research Design

This research has been conducted to evaluate the effectiveness of the designed and developed hot work chair in order to reduce the discomfort level among the hot work workers at the selected company. To achieve this general objective, this research is divided into three phases of study. Phase 1 of this study is to assess muscle discomfort level among the hot work workers and to identify Ergonomic Risk Factors in the hot work section of the company. Four ergonomic risk assessment tools have been used as stated in this phase where three work units were determined and one respondent from each work unit had been selected for the assessment. Phase 2 of this study consist of 3 steps to complete proceed with final evaluation process of the prototype. Step 1 is problem identification which all the findings from the assessments in phase 1, feedbacks from workers and findings from the observation were recorded and taken into the consideration to determine the criteria and specification to develop the prototype of the hot-work chair. Step 2 is the design and development process which including establishment of product design specification, conceptual design and prototype development. In Phase 3, there are two groups consisting of experimental and control groups determined with specific number of respondents. The experimental group was given the hot work chair and the control group kept following the current seating practices. Pre-test and post-test had been conducted to evaluate the effects of this developed hot work chair in reducing the discomfort level among the selected hot work workers. All data collected was analysed using SPSS. A quantitative experimental method was used for this study and the overall research design has been described in figure 3.1 as below.

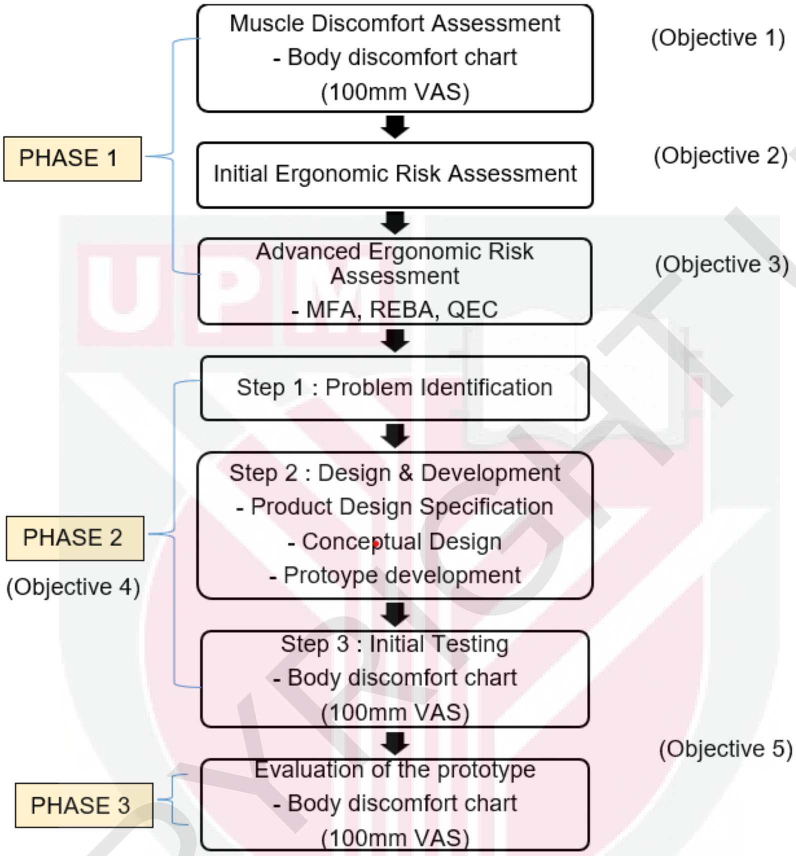


Figure 3.1: Framework of the research design

3.3 Research population and Sampling Procedure

3.3.1 Study Location

This study was conducted at the selected company in Pulau Indah, Selangor. This company is heavily involved in metal fabrication and metal related manufacturing process. Due to the pandemic situation and movement control order issued by the government, this study was conducted at this location which was convenient to conduct the study.

3.3.2 Study Duration

This study has been conducted at the selected metal container fabrication company for a duration of 6 months in the year 2020.

3.3.3 Sampling Frame

The recruitment strategy used is by taking the name list provided by human resources department from the selected company. Workers who are only involved in hot works section from the name list as the samples were selected for this study to ensure the consistency of data which the different departments have different tasks or jobs and duration of hot works. The hot works workers who were selected as samples are mainly working in hot working like grinding, cutting and welding at minimum 8 hours per day.

3.3.4 Sample Size

There are three types of sampling size involved in this full study. Phase 1 of this study consists of two assessments. The first assessment is to conduct an assessment on muscle discomfort among hot work workers. The equation 1 below was used to determine the sample size for the hot work workers for this assessment (Lemeshow et al.,1990). The value for mean of MSD was taken from a previous study conducted by Das Suman et al. (2018).

$$n = \frac{z^{2}_{1-\alpha/2}\, P\,(1- P)}{d^2} \qquad (1)$$

where

$z^{2}_{1-\alpha/2}$ = Z- score (1.96 for 95% confidence interval)

P = 85% of the workers reported MSD in multiple body parts due to in appropriate position of body posture and unergonomic man machine interface

d = Absolute precision required on either side of proportion (Margin of error is ± 5% or 0.05)

The calculation of estimated sample size:

$$\begin{aligned} n &= (1.96)^2 \times (0.85\,(1-0.85)) / (0.05)^2 \\ &= 3.8416 \times (0.85 \times 0.15) / (0.0025) \\ &= 0.489804 / 0.0025 \\ &= 196 \text{ respondents} \end{aligned}$$

An additional of 10% from the total respondents is added to counter responsive case and reject assessment samples.

$$n = 196 + (10\% \times 196)$$

$= 196 + 20$
$= 216$ respondents

The total sample size for this study after added with adjusted samples is 216 respondents. This sample size is higher than the real population from the selected three companies. Thus, all target population, 125 hot work workers from the selected company are included as samples in this assessment on muscle discomfort among hot work workers. The following assessments aims to evaluate the ergonomic risk factors among hot work workers utilising REBA, QEC, and Muscle Fatigue Assessment, which are adapted from the Guidelines on Ergonomics Risk Assessment at Workplace, 2017. Hot work workers have been categorized into 3 work units which consist of welding, grinding and cutting of metals. Only one worker was selected randomly from each work units because the ergonomic risk factors which they might get exposed would be same for the rest of workers since they were carrying out the same tasks and using the same equipment. During the phase 2 of this study, no samples were required because the focus was to design and develop the prototype of the hot work chair based on the assessment findings in phase 1. The efficacy of the developed prototype in lowering body discomfort ratings was tested in phase 3 of this study by comparing pre-test and post-test sessions in two groups. According to Donnelly et al. (2015), the estimated standard deviation, estimated larger mean, and estimated lower mean for the influence of an active lumbar support on the seated comfort of police officers using a VAS scale were 30.2, 57.2, and 19.0, respectively. The equation 2 was used to calculate the sample size for this phase 2 (Lemeshow et al.,1990).

$$N = \frac{2\sigma^2 (z_{1-\alpha/2} + z_{1-\beta})^2}{(\mu_1 - \mu_2)^2} \tag{2}$$

where

1-α/2 = The desired level of significance. In this study, $z_{1-\alpha/2} = 1.96$, since the significance level is 95%

1-β = The desired power. In this study, the $z_{1-\beta} = 0.842$ since the desired power is 80%.

The calculation of estimated sample size:

$n = 2\,(30.2)^2 \times (1.96 + 0.842)^2 / (57.2 - 19.0)^2$
$= 9.81 \approx 10$ respondents

Based on the calculation, each control group and experimental group is supposed to have 10 respondents. However, an additional 20% dropout rate was added to the calculated samples. The new sample size will be as below.

$N = 10 + (20\% \times 10)$
$= 10 + 2 \quad = 12$ respondents

There is a total of 24 respondents selected for this phase 2 of this study where each control group and experimental group have 12 respondents.

3.3.5 Study Population

There will be 3 types of study population for this research. In Phase 1 of this study, there are one hundred twenty-five workers included for the assessment on muscle discomfort among the hot work workers. Only three workers from each work unit of welding, cutting, and grinding are assessed for ergonomic risk factors among hot work workers. The effectiveness of a hot work chair in reducing bodily discomfort among hot work workers is being evaluated in phase 3 of this study, which included 24 participants—12 responders in each of the control and experimental groups, respectively. There are few inclusion and exclusion criteria had been set for this research study. The first inclusion criteria is the age of the workers shall be from the range of 20 to 50 years. Based on a study, workers over the age of 50 may have low back discomfort as a result of the age factor (Hoy et al.,2021). The second inclusion criterion is all respondents shall have a minimum of 1 year working experience in hot works at this selected company for the accuracy of the data obtained. The exclusion criteria are the worker's who are more than 50 years old, working experience lesser than 1 year and those workers who are already under medical treatment due to musculoskeletal disorders.

3.4 Study Instruments

There are several types of study instruments used, based on different stages in this research study.

3.4.1 Assessment on body discomfort level among hot work workers.

To get the initial information on the worker's musculoskeletal pain, a set of adapted questionnaires was used in this study. This questionnaire has four sections which consist of Section A for Socio-Demographic background, Part B for Medical History and finally Part C which consists of Body Discomfort Chat (BDC). Parts A and B of this questionnaire have been adapted from Appendix 1 and Appendix 4 from the Ergonomic Risk Assessment guidelines 2017. The entire questions have been used exactly without any additional information to maintain the reliability and accuracy of this questionnaire. Part C of the questionnaire which is the Body Discomfort Chart (BDC) has been adapted from Corlett (2005). This chart has been used to record the specific body location of discomfort due to hot works in seating position. This chart has proved to be a valid and reliable tool to assess the discomfort location on the body (Boussenna et al.,1982). The intensity of the body discomfort was measured using 100mm VAS and the selected respondents were asked to identify the area of discomfort on the chart and mark on the line which started with 0mm representing no discomfort and ending with 100mm representing extreme discomfort (Nur Athirah, 2021). The full questionnaire used for this study is attached in Appendix 6.

3.4.2 Assessment on Ergonomic Risk Factors among hot work workers.

The next assessment in this research study will be to conduct an initial and advanced level of ergonomic risk assessment in order to identify risk factors associated in hot work activities by workers at the chosen organisation. There are basically four assessment tools which are related to muscle pain and based on majority muscle discomfort reported by workers in previous assessment have been selected for this study. The four-assessment tools which have been selected are Initial Ergonomic Risk Assessment, Musculoskeletal Fatigue Assessment, Rapid Entire Body Assessment and Quick Exposure Check.

3.4.2.1 Initial Ergonomic Risk Assessment Checklist

The Initial Ergonomic Risk Assessment is important in identifying ergonomic risk factors affecting the hot work workers who are performing the hot works while seating on improper tools. The Initial Ergonomic Risk Assessment checklist has been adapted from Appendix 6 of Guidelines on Ergonomics Risk Assessment at Workplace, 2017. The completed Initial Ergonomic Risk Assessment checklist used in this study is attached in Appendix 7. The initial ERA was calculated using each component observed and assessed. Each 'yes' check receives a score of one. Table 3.9, the results of the initial ergonomic assessment are described.

Table 3.1: Results of Initial ERA conducted on selected 3 workers (Worker A, B and C)

Risk factors	Total Score	Minimum requirement for advanced ERA	Result of Initial ERA			Need Advanced ERA? (Yes/No)		
			A	B	C	A	B	C
Awkward Postures	13	≥ 6						
Static and Sustained Work Posture	3	≥ 1						
Forceful exertion	1	1						
Repetition	5	≥ 1						
Vibration	4	≥ 1						
Lighting	1	1						
Temperature	1	1						
Ventilation	0	1						
Noise	2	≥ 1						
TOTAL SCORE	30							
AVERAGE SCORE	30							

This table includes a list of the ergonomic risk factors that were found during the assessment as well as the assessment's parameters. The subsequent chapter provided a summary, a comparison, and a discussion of the final results.

3.4.2.2 Muscle Fatigue Assessment (MFA)

Rodgers (2004) established the muscular fatigue assessment method (MFA), also known as the functional job evaluation approach, in order to classify the discomfort of workers performing fabrication jobs. This evaluation was carried out utilising various combinations of the three parameters Effort, Duration, and Frequency. How much recuperation time is available between muscle attempts for the engaged workers will depend on how often muscle efforts are made. By calculating the amount of time required from the recovery time curves and comparing it to the actual time between efforts of the same intensity, it is possible to characterise and evaluate the degree of accumulated fatigue in a muscle during a hot work task (Rohmert, 1973). This assessment was performed out by combining numerous combinations of the three elements Effort, Duration, and Frequency. Table 3.2 depicts the muscle fatigue assessment method worksheet adopted from Bernardo et al. (2018). From the assessment, four fatigue outcomes were selected, and all of them were estimated based on five minutes of continuous work on the job. The ranges were as follows: 30 sec (low), 30 to 90 sec (moderate), >90 sec to 3 min (high), and >3 min (very high). Tables 3.3 and 3.4 provide the category scores in ascending order of fatigue for three-number ratings (Effort, Continuous Effort Duration, and Frequency) (Bernardo et al., 2018).

Table 3.2: Worksheet for Muscle Fatigue Assessment (MFA)

	Effort Level <75% of All Workers Can Exert Effort - 4			**Scores**			**Priority**
Region	**Light - 1**	**Moderate - 2**	**Heavy - 3**	**Effort**	**Dur**	**Freq**	
Neck	Head turned partly to side, back or slightly forward	Head turned to side; head fully back; head forward about 20°	Same as moderate but with force or weight; head stretched forward				
Shoulders	Arms slightly away from sides; arms extended with some support	Arms away from body, no support; Working overhead	Exerting forces or holding weight with arms away from body or overhead	R	R	R	R
				L	L	L	L

Table 3.2: Continued

	Effort Level <75% of All Workers Can Exert Effort - 4			Scores			Priority
Region	**Light - 1**	**Moderate - 2**	**Heavy - 3**	**Effort**	**Dur**	**Freq**	
Back	Leaning to side or bending arching back	Bending forward; no load; lifting moderately heavy loads near body; working overhead	Lifting or exerting force while twisting. high force or load while bending				
Arms/ Elbow	Arms away from body, no load; light forces lifting near body	Rotating arms while exerting moderate force	High forces exerted with rotation; lifting with arms extended	R L	R L	R L	R L
Wrists / Hands / Fingers	Light forces or weights handled close to body; straight wrists; comfortable power grips	Grips with wide or narrow span; moderate wrist angles, especially flexion; use of gloves with moderate forces	Pinch grips; strong wrist angles; slippery surfaces	R L	R L	R L	R L
Legs / Knees	Standing, walking without bending or leaning; weight on both feet	Bending forward, leaning on table; weight on one side; pivoting while exerting force	Exerting high force while pulling or lifting; crouching while exerting force	R L	R L	R L	R L
Ankles / Feet / Toes	Standing, walking without bending 0r leaning; weight on both feet	Bending forward, leaning on table; weight on one side; pivoting while exerting force	Pulling or lifting with great force; crouching while exerting force; standing on tiptoes	R L	R L	R L	R L
Continuous Effort Duration		< 6 s **1**	6 – 20 s **2**	20 – 30 s **3**	> 30 s **4** (Enter VH for Priority)		
Effort Frequency		< 1 / min **1**	1 – 5 / min **2**	> 5 – 15 / min **3**	> 15 / min **4** (Enter VH for Priority)		

Table 3.3: "Priority for Change" Score from Three-Number Rating

Effort Level = 1			Effort Level = 2			Effort Level = 3		
Duration	Frequency	Priority	Duration	Frequency	Priority	Duration	Frequency	Priority
1	1	L	1	1	L	1	1	L
1	2	L	1	2	L	1	2	M
1	3	L	1	3	M	1	3	H
2	1	L	2	1	L	2	1	H
2	2	L	2	2	M	2	2	H
2	3	M	2	3	H	2	3	VH
3	1	L	3	1	M	3	1	VH
3	2	M	3	2	M	3	2	VH
3	3	*	3	3	*	3	3	*

Note: Input the effort level scores (top row), along with the duration and frequency scores (columns within the section for effort level). The table indicates if there is a low (L), moderate (M), high (H), or extremely high "priority for change" (VH). '' This duration/frequency combination is not possible.

Table 3.4: Category Scores in the Order of Increasing Fatigue for Three-Number Rating (Effort, Continuous Effort Duration, and Frequency)

Low (L)	Moderate (M)	High (H)	Very High (VH)
111	123	223	323
112	132	313	331
113	213	321	332
211	222	322	
121	231		4xx
212	232		x4x
311	312		xx4
122			
131			
221			

*Note: Level of fatigue increases as you move down each column or to the right

3.4.2.3 Rapid Entire Body Assessment (REBA) Checklist

Rapid Entire Body Assessment was the second advanced ergonomic risk assessment tool employed in phase 1 of this research investigation. The REBA was created to evaluate the kind of unpredictable working postures common in health care and other service industries (Hignett et., 2000). Because hot work employees at the chosen organisation use nearly their entire body while performing hot work tasks, as well as because some of their body postures are static, fast changing, and unstable, rapid entire body assessment (REBA) will play a significant role in risk assessment. REBA basically consists of six steps: watch the task, choose the postures for assessment, grade the postures, analyses the scores, determine the REBA score, and confirm the action level in relation to the urgency for control measures (Neville, 2005). The REBA form in Figure 3.2, developed from couple of previous studies (Hignett et al., 2000). In order to determine the level of risk and the urgency of the situation, data on the body posture, forces applied, type of movement or action, repetition, and coupling were gathered. These data were then combined to produce a final REBA score. In order to determine the final REBA score, information on the body posture, forces applied, type of movement or action, and frequency of repetition of the selected workers was obtained during the assessment. The REBA score that was obtained will be compared to the action level in table 3.5 below. These scores fall into bands that show how urgently adjustments must be made.

Table 3.5: REBA Action Levels

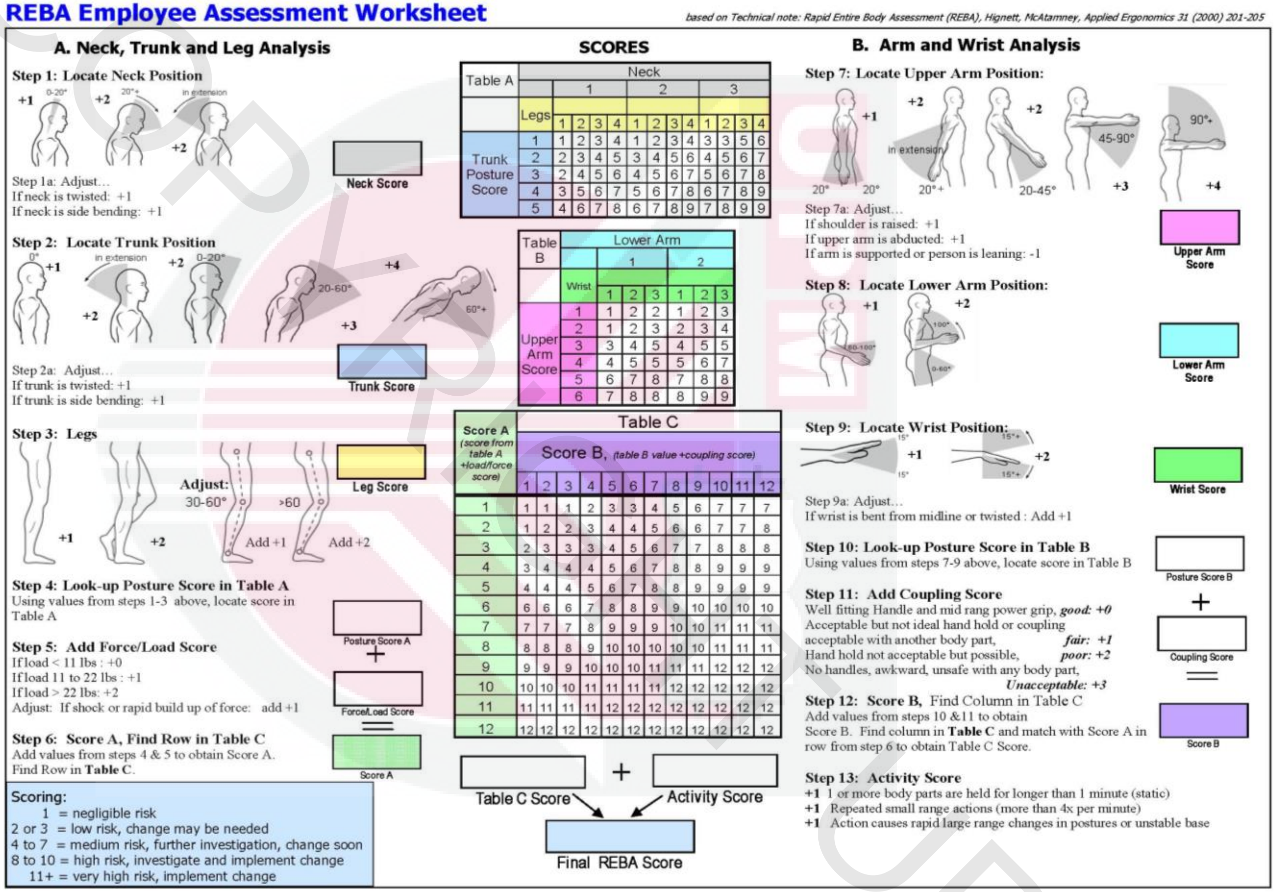
REBA score	Risk Level	Action Level	Action (including further assessment)
1	Negligible	0	None necessary
2 – 3	Low	1	May be necessary
4 - 7	Medium	2	Necessary
8 - 10	High	3	Necessary soon
11 - 15	Very high	4	Necessary now

(Source: Hignett et al., 2000)

Three workers who were subjected to muscle discomforts from hot work were chosen for this study and underwent the REBA process. Table 3.11 displays the overall REBA score for the three employees. The finished scores were compiled, compared between the work units, and described in more detail in the following chapter.

Table 3.6: Scores to be obtained by workers using REBA

Workers	Score A	Score B	Score C	Activity Score	Total score	Risk Level
A						
B						
C						



REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 0-20° +2 20°+ +2 in extension

Step 1a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 2: Locate Trunk Position

0° +1 in extension +2 +2 0-20° 20-60° +3 60°+ +4

Step 2a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

+1 +2 Adjust: 30-60° Add +1 >60 Add +2

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A

Posture Score A
+

Step 5: Add Force/Load Score
If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score
=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A		Neck 1				Neck 2				Neck 3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm 1			Lower Arm 2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C

Score A (score from table A +load/force score)	Score B, (table B value +coupling score) 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score

Final REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

20° 20° +1 in extension 20°+ +2 20-45° +2 45-90° +3 90°+ +4

Step 7a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

60-100° +1 100°+ 0-60° +2

Lower Arm Score

Step 9: Locate Wrist Position:

15° 15° +1 15°+ 15°+ +2

Step 9a: Adjust…
If wrist is bent from midline or twisted : Add +1

Wrist Score

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B
+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good:* +0**
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair:* +1**
Hand hold not acceptable but possible, ***poor:* +2**
No handles, awkward, unsafe with any body part, ***Unacceptable:* +3**

Coupling Score
=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Figure 3.2: Rapid Entire Body Assessment (REBA)
(Source from Hignett et al., 2000)

3.4.2.4 Quick Exposure Check (QEC) Assessment Checklist

Figure 3.3 depicts the two elements of a QEC checklist that must be completed. Based on their observations of the worker, the observer is to fill out the first section; the workers themselves are to fill out the second part. Answers from both the observer and the employees are entered into the scoring table in figure 3.4, and a total score is then determined. The interactions between the exposure levels for the pertinent risk variables, as given in Table 3.7, and their subsequent addition, determine the overall score for each body location in the QEC Checklist. It is essential to determine which interactions each bodily area's overall score is influenced by the most. As indicated in Table 3.8, the exposure scores for the back, shoulder/arm, wrist/hand, and neck have been divided into 4 exposure categories: Low, Moderate, High, or Very High.

Table 3.7: List of interactions between the exposure's levels for the relevant risk factors

Important risk factors	
Back	**Wrist/hand**
• Load weight • Duration • Frequency of movement • Posture	• Force • Duration • Frequency of movement • Posture
Shoulder/arm	**Neck**
• Load weight • Duration • Frequency of movement • Task height	• Duration • Visual demand • Posture


Worker's name ______________________ Date ____________

Observer's Assessment

Back

A When performing the task, is the back
(select worse case situation)
A1 Almost neutral?
A2 Moderately flexed or twisted or side bent?
A3 Excessively flexed or twisted or side bent?

B Select ONLY ONE of the two following task options:

EITHER

For seated or standing stationary tasks. Does the back remain in a static position most of the time?
B1 No
B2 Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). Is the movement of the back
B3 Infrequent (around 3 times per minute or less)?
B4 Frequent (around 8 times per minute)?
B5 Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C When the task is performed, are the hands
(select worse case situation)
C1 At or below waist height?
C2 At about chest height?
C3 At or above shoulder height?

D Is the shoulder/arm movement
D1 Infrequent (some intermittent movement)?
D2 Frequent (regular movement with some pauses)?
D3 Very frequent (almost continuous movement)?

Wrist/Hand

E Is the task performed with
(select worse case situation)
E1 An almost straight wrist?
E2 A deviated or bent wrist?

F Are similar motion patterns repeated
F1 10 times per minute or less?
F2 11 to 20 times per minute?
F3 More than 20 times per minute?

Neck

G When performing the task, is the head/neck bent or twisted?
G1 No
G2 Yes, occasionally
G3 Yes, continuously

Worker's Assessment

Workers

H Is the maximum weight handled MANUALLY BY YOU in this task?
H1 Light (5 kg or less)
H2 Moderate (6 to 10 kg)
H3 Heavy (11 to 20kg)
H4 Very heavy (more than 20 kg)

J On average, how much time do you spend per day on this task?
J1 Less than 2 hours
J2 2 to 4 hours
J3 More than 4 hours

K When performing this task, is the maximum force level exerted by one hand?
K1 Low (e.g. less than 1 kg)
K2 Medium (e.g. 1 to 4 kg)
K3 High (e.g. more than 4 kg)

L Is the visual demand of this task
L1 Low (almost no need to view fine details)?
*L2 High (need to view some fine details)?
* *If High, please give details in the box below*

M At work do you drive a vehicle for
M1 Less than one hour per day or Never?
M2 Between 1 and 4 hours per day?
M3 More than 4 hours per day?

N At work do you use vibrating tools for
N1 Less than one hour per day or Never?
N2 Between 1 and 4 hours per day?
N3 More than 4 hours per day?

P Do you have difficulty keeping up with this work?
P1 Never
P2 Sometimes
*P3 Often
* *If Often, please give details in the box below*

Q In general, how do you find this job
Q1 Not at all stressful?
Q2 Mildly stressful?
*Q3 Moderately stressful?
*Q4 Very stressful?
* *If Moderately or Very, please give details in the box below*

* *Additional details for L, P and Q if appropriate*
*** L**
*** P**

Figure 3.3: QEC checklist (Observer's Assessment & Worker's Assessment)
(Source: Li et al., 1999)

Exposure Scores Worker's name ____________________ Date ____________

Back

Back Posture (A) **& Weight** (H)

	A1	A2	A3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1

Back Posture (A) **& Duration** (J)

	A1	A2	A3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3

Now do **ONLY** 4 if static
OR 5 and 6 if manual handling

Static Posture (B) **& Duration** (J)

	B1	B2
J1	2	4
J2	4	6
J3	6	8

Score 4

Frequency (B) **& Weight** (H)

	B3	B4	B5
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 5

Frequency (B) **& Duration** (J)

	B3	B4	B5
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 6

Total score for Back
Sum of scores 1 to 4 **OR**
Scores 1 to 3 plus 5 and 6 ________

Shoulder/Arm

Height (C) **& Weight** (H)

	C1	C2	C3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1

Height (C) **& Duration** (J)

	C1	C2	C3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3

Frequency (D) **& Weight** (H)

	D1	D2	D3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 4

Frequency (D) **& Duration** (J)

	D1	D2	D3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 5

Total score for Shoulder/Arm
Sum of Scores 1 to 5 ________

Wrist/Hand

Repeated Motion (F) **& Force** (K)

	F1	F2	F3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 1

Repeated Motion (F) **& Duration** (J)

	F1	F2	F3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2

Duration (J) **& Force** (K)

	J1	J2	J3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 3

Wrist Posture (E) **& Force** (K)

	E1	E2
K1	2	4
K2	4	6
K3	6	8

Score 4

Wrist Posture (E) **& Duration** (J)

	E1	E2
J1	2	4
J2	4	6
J3	6	8

Score 5

Total score for Wrist/Hand
Sum of Scores 1 to 5 ________

Neck

Neck Posture (G) **& Duration** (J)

	G1	G2	G3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 1

Visual Demand (L) **& Duration** (J)

	L1	L2
J1	2	4
J2	4	6
J3	6	8

Score 2

Total score for Neck
Sum of Scores 1 to 2 ________

Driving

M1	M2	M3
1	4	9

Total for Driving ________

Vibration

N1	N2	N3
1	4	9

Total for Vibration ________

Work pace

P1	P2	P3
1	4	9

Total for Work pace ________

Stress

Q1	Q2	Q3	Q4
1	4	9	16

Total for Stress ________

Figure 3.4: QEC checklist (Exposure Scores)
(Source: Li et al., 1999)

Table 3.8. Exposure categories in QEC

Important risk factors				
Score	**Low**	**Moderate**	**High**	**Very High**
Back (static)	8 – 15	16 - 22	23 – 29	29 – 40
Back (moving)	10 – 20	21 – 30	31 - 40	41 – 56
Shoulder/Arm	10 – 20	21 – 30	31 – 40	41 – 56
Wrist/hand	10 – 20	21 – 30	31 – 40	41 – 46
Neck	4 - 6	8 – 10	12 - 14	16 – 18

(Source: Li et al., 1999)

3.4.3 Effect of a Hot work chair to reduce muscle discomfort among Hot work Workers

3.4.3.1 Questionnaire

An assessment will be conducted on selected respondents after the prototype of Hot work chair has been designed and developed. When used by hot workers at the chosen company, the prototype has been tested to see if it can reduce back pain and muscular discomfort. Before and after utilising the hot work chair for the time frame specified, questionnaires will be distributed to the control group and experimental group as part of this assessment. The questionnaire consists of two sections for evaluation and distributed to all control and experimental group respondents as pre-test and post-test. The initial/pilot testing and evaluation of the prototype were conducted using the same muscle discomfort questionnaire. However, the number of sample and duration of using prototype are significantly difference. Both control and experimental group answered the first questionnaire on the Monday morning (pre-test) and after 6 days they will answer the second questionnaire (post-test) on the Saturday evening after the shift end. So, the time duration between pre-test and post-test is 6 working days or one week of company operation. The first section of the questionnaire as attached in appendix 8 is the Body Discomfort Chart consisting an outline of the human body and adapted from Corlett (2005). This chart has been used to record the specific body location of discomfort due to hot work works in the seating position. This chart has proved to be a valid and reliable tool to assess the discomfort location on the body (Boussenna et al.,1982). The respondents were asked to identify the area of discomfort on the chart and mark on the line which started with 0mm representing no discomfort and ending with 100mm representing extreme discomfort. The intensity of the body discomfort was measured using 100mm VAS. Section 2 of the questionnaire is a valid seat discomfort survey to obtain information on the perceived discomfort of the hot work chair features.

3.4.3.2 Hot work Chair

The efficiency of the prototype hot work chair and the existing seat were evaluated to determine the effects on the reduction of discomfort ratings for the hot work workers. The prototype hot work chair, which was developed by the researcher, is given to each respondent in the experimental group. The respondents in the control group will not receive the hot work chair and they will keep following the current seating practices throughout the research duration. The newly designed and developed hot work chair will have an arm rest, back support, knee support and other features which may reduce the discomfort level while doing the hot works among the workers. The prototype development procedure is a systematic approach used to create an initial version of a product, system, or software application to test and validate its design, functionality, and usability before moving on to full-scale production or development. The detailed process for the design and development of the prototype used in this research study had been discussed in section 3.6.

3.5 Study Procedure for Phase 1

The first phase of this study consists of two assessments. Figure 3.5 depicts the three key processes involved in the overall process of assessing risk factors in hot works at the selected company. The first step establishes the problem's necessity after it has been investigated using employee feedback, observations, and medical data. Step two is to analyse worker muscular discomfort, and step three is to assess worker ergonomic risk factors.

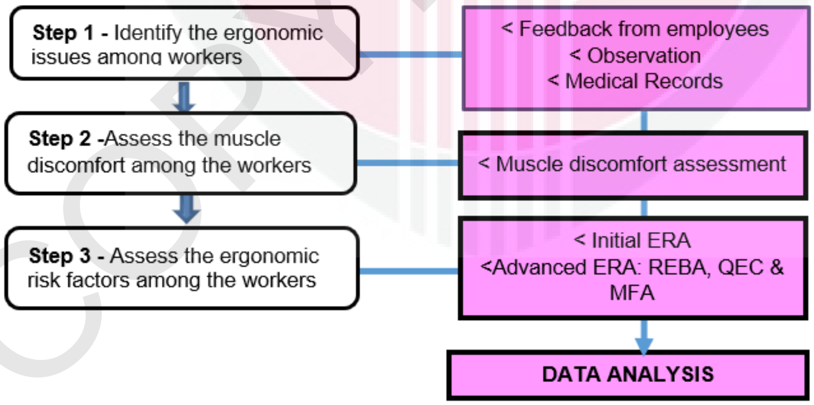


Figure 3.5: Flow chat for phase 1

3.5.1 Assessment on muscle discomfort among hot work workers.

The first assessment is to conduct an assessment on muscle discomfort among hot work workers. The questionnaire was distributed to the respondents during a special break time allowed by the selected company for this study. The study was conducted in the meeting room and all the respondents had been briefed about the objectives of this study, the assessment process and also about the questionnaire. The questionnaire was translated into Bahasa Malaysia for easy the understanding of the workers. SECA body meter and SECA body weighting scale were used to measure the height and weight of all the respondents. Due to Covid-19 SOP restriction, physical distance and personnel hygiene practices were maintained during the weight and height measuring processes. A written consent form was distributed to all the respondents and they all agreed with the assessment and signed the consent forms to participate in this study.

3.5.2 Ergonomic risk assessment among selected hot work workers

The following stage of phase 1 of this study is to evaluate the ergonomic risk factor, which will be discovered through initial ergonomic risk assessment as well from advanced ergonomic risk assessment, which includes REBA, MFA, & QEC methodologies. The researcher who is also a trained person under the Department of Occupational Safety and Health Malaysia conducted this whole ergonomics risk assessment. All data gathered during the exam will be analysed further. Three male workers who were chosen at random from hot work sections in the chosen organisation were subjected to an ergonomic risk assessment as part of this study. Based on the daily work schedule of the workers, a risk assessment was conducted for 8 hours. The maximum work schedule in a day is 4 hours straight, 1 hour of rest, and then 4 hours straight again. Hot work workers at the selected company were categorized into 3 work units as shown in table 3.9 which consisted of welding, grinding and cutting of metals.

Table 3.9: List of samples based on determined work units

Work Units	Worker
Welding	A
Grinding	B
Cutting	C

Only one worker was selected randomly from each work unit because the ergonomic risk factors from which they might get exposed would be same for the rest of workers since they were carrying out the same tasks and using the same equipment. Only hot work employees were employed in the study samples, and the assessment's focus was solely on that section of the company.

3.5.2.1 Initial Ergonomic Risk Assessment

The initial Ergonomic Risk Assessment was performed on selected hot work workers from the three work units (welding, grinding and cutting). This Initial Ergonomic Risk Assessment checklist is based on Appendix 6 of the 2017 Guidelines for Ergonomics Risk Assessment in the Workplace. An initial ergonomic assessment was conducted at a hot work section including workers A, B, and C, each from a distinct work unit, as shown in Table 3.8. The methodology for Initial Ergonomic Risk Assessment has been adapted from Guidelines on Ergonomics Risk Assessment at Workplace, 2017 as below:

a) Getting Ready for an Assessment - Getting ready for an assessment involves a number of issues, including team composition, equipment, supplies, and facilities, as well as communication and coordination.
b) Instruments, Materials, and Facilities - Before conducting an assessment, it's crucial to prepare the necessary instruments, materials, and facilities, including measuring tapes, audio-visual recording devices (such as cellphones and video cameras), assessment forms and checklists, personal protective equipment (PPE), stationery, writing boards, and computing equipment (laptop, printer, etc.)
c) Communication and coordination - Prior to the ERA, it is crucial to educate management, supervisors, the affected employees, and any other relevant parties about the assessment's goals, the work unit that will be evaluated, the ERA tools that will be utilised, and the duration of the evaluation. While interacting with management, the confidentiality of the assessment should be emphasized. By doing this, it will be certain that everyone concerned will fully cooperate with the assessment.
d) Implementation of ERA - The ERA implementation should be based on factors such as aligning with the ERA's objective(s), which include determining the risk level, assessing claim compensation, improving work units, communicating and coordinating with the person in charge, and conducting walkthrough inspections by a trained person to gather information about work posture and activities, the work environment, and any current ergonomics control measures.

The researcher conducted direct observation of the workers and recorded the findings based on the checklist. The workers continue to perform their everyday tasks as usual. As supporting documentation, video and photographic images were also taken.

3.5.2.2 Muscle Fatigue Assessment

To identify the discomfort experienced by workers performing fabrication jobs, the muscle fatigue assessment method (MFA), also known as the functional job evaluation approach, was created (Rodgers, 2004). The effort levels, effort durations (or holding times), and effort frequencies were each reduced to three categories using research on physiological muscle fatigue for various effort levels and holding the basis for this approach. By extrapolating the amount of time necessary from the recovery time curves and contrasting this with the actual time between efforts of the same intensity, it is possible to characterized and evaluate the degree of accumulated fatigue in a muscle during a hot work activity (Neville A, 2005). In this study there are six steps used in conducting Muscle Fatigue assessment which have been adapted from Rodgers (2004) as below:

a) Based on the preliminary study conducted through medical records, workers' comments, and observations, the selected company's hot work section was determined as the unit with the most musculoskeletal disorders problems when compared to other portions of the operation units.
b) Based on initial investigation at the hot works section at the selected company, workers performing hot work activities in seating position have complained of the highest number of MSDs issues compared with those performing hot works while standing. The nature of the business operation at his company requires workers to perform hot works more in seating position. So, the problem task to be assessed for MFA is performing hot works in seating position which was divided into three work units (welding, grinding and cutting)
c) The assessor is required to define the effort level from the definition in Table 3.2 and evaluate the effort intensity based on observation on the work performed by the respondent. The efforts need to be rated for right and left sides, if appropriate. If more than one level of effort is present, include both.
d) Count the number of seconds of continuous effort at the specified effort intensity in table 3.2 before switching to a different effort intensity or relaxing. Record the time of seconds of continuous effort at the specified effort intensity in table 3.2.
e) Calculate the frequency of attempts per minute at the same efforts per minute at the same effort intensity for each body component. Count the number of efforts at a given effort intensity over the course of a minute. When a task is completed in a variable manner over a period of five minutes, the frequency should be counted and the resulting number divided by five to determine the effort per minute.
f) Determine the "priority for change" score using the three-number rating generated in states 3–5. For each body part, place it in the final column. Tables 3.3 and 3.4 were used to calculate the "priority for change" rating from the three-number rating based on the effort intensity, effort duration, and effort frequency for each body part.

The Table 3.10 below will be filled up with the findings from the muscle fatigue assessment performed on each of the three workers. The completed results were summarized, compared and discussed in the next chapter.

Table 3.10: Overall results of muscle fatigue assessment for selected workers

Region		Effort – Duration –Frequency scores					
		Worker A		Worker B		Worker C	
Neck							
Shoulders	R						
	L						
Back							
Arms / Elbow	R						
	L						
Wrists / Hands / Fingers	R						
	L						
Legs / Knees	R						
	L						
Ankles / Feet / Toes	R						
	L						

3.5.2.3 Rapid Entire Body Assessment (REBA)

Rapid Entire Body Assessment (REBA) is a technique that was created expressly to be sensitive to the sort of unpredictable working postures found in the service and healthcare sectors (Hignett, et al., 2000). Each body part's score will increase in proportion to how much the neutral posture is deviated from. A final REBA score is calculated, which will indicate the degree of risk and urgency with regard to the need for immediate action, based on the information collected about the body posture, forces applied, types of movement or actions, repetition, and coupling. There were six steps used in conducting the REBA assessment which has been adapted from Mcatamney (2005) as below:

a) Step 1: Observe the task - The selected task to be observed to formulate a general ergonomic risk assessment, including the impact of workstation and environmental factors, use of equipment and worker's behaviour in risk taking while performing the hot works at the selected company. The data has been recorded using photographs and video camera as additional views to control parallax errors.
b) Step 2: Select Postures for Assessment - The task chosen in step 1 is for workers conducting hot works in seated positions. This hot work region of the organisation identified three work units, and each respondent represented one of them. The criteria followed for the selection of the posture are posture that is most commonly repeated, the longest sustained position, known discomfort-causing posture, posture that is extremely unstable or uncomfortable, especially when force is applied and Interventions, control measures, or other adjustments are most likely to improve posture.
c) Step 3: Score the Postures - The scoring sheet and body-part scores in figure 3.2 which is the REBA Employee Assessment worksheet has been used to score the posture. The initial scoring is by group A for trunk,

neck, legs and Group B for upper arms, lower arms, wrists. The scoring sheet shown in Figure 3.2 for Group B postures shows that the left and right sides were assessed individually. Depending on the situation, additional points could be added or deducted. At this point, the load/force score, coupling score, and activity score were assigned. The process can now be repeated for the other postures and for each side of the body.

d) Step 4: Process the Scores - The trunk, neck, and legs scores were combined into a single score using Table A in the REBA Assessment worksheet. This score was then entered in the box on the scoring sheet (Figure 3.2) and added to the load/force score to get score A. Using a table, a single score is generated in the same manner for the wrist, upper arms, and lower arms. The score was later combined with the coupling score to produce score B. The scores A and B were then inserted into Table C to generate a single score, C.
e) Step 5: Count the REBA score - The type of muscle activity is then represented by an activity score, which is then summed to determine the final REBA score.
f) Step 6: Confirm the Action Level - The REBA score that was obtained after that has been compared to the action level in table 3.5.

3.5.2.4 Quick Exposure Check (QEC)

The Quick Exposure Check (QEC) was developed to meet the demands of ergonomic practitioners for an efficient way to evaluate occupational exposure to WMSD risk factors. It was created using the Quick Exposure Check (QEC) reference guide and was tested, modified, and validated using simulations of real job duties. These tasks included manual handling, repetitive chores, static or dynamic tasks, seated or standing tasks, and many others. There are three steps in conducting QEC assessment which have been adapted from Quangyan Li (2005) as below:

a) Step 1: Observer’s Assessment Checklist - During the assessment, the observer performed the Observer's Assessment section of the QEC Checklist, as shown in Figure 3.4. The assessor had consulted the QEC User Guide before the assessment. Three workers were selected for this assessment representing the three-work unit consisting of grinding, welding and cutting. The assessment was carried out by direct observation.
b) Step 2: Worker’s Assessment Checklist - The respondent from each work unit then completed the Worker’s Assessment section in the QEC Checklist as in Figure 3.4. The assessor had briefed all the respondents about the questions before they started to answer the questions.
c) Step 3: Calculation of Exposure Scores - The assessor had calculated the exposure score for each respondent from each work unit using the table of scores section in QEC Checklist as in Figure 3.4. The "Observer's Assessment" and the "Worker's Assessment" answers have

all been circled along with the letters that correlate to them. Every pair of highlighted letters has had their crossing point numbers noted.

A Quick Exposure Check (QEC) evaluation was performed on three workers from various work units. The total scores acquired by Workers A, B, and C through the Quick Exposure Check (QEC) evaluation will be added to Tables 3.11 and 3.12, respectively. The completed scores were summarized, compared within the work units and discussed further in next chapter

Table 3.11: Exposure scores for Important risk factors

Important risk factors			
Factors	**Worker A**	**Worker B**	**Worker C**
Back (static)			
Back (moving)			
Shoulder/Arm			
Wrist/hand			
Neck			

Table 3.12: Exposure scores for other risk factors

Exposure level			
Factors	**Worker A**	**Worker B**	**Worker C**
Driving			
Vibration			
Work pace			
Stress			

3.6 Study Procedure for Phase 2 (Design and develop a hot work chair)

Figure 3.6 below illustrates the three key steps of the phase 2 of this research project, which built a prototype of a hot work chair and was inspired by Pugh's total design process model (Pugh, 1991). Stage 1 of the design process to identify musculoskeletal pain and ergonomic risk factors related to discomfort that affects the hot work workers during the hot work activities at the selected company. In Phase 1 of this study, two assessments were conducted to identify musculoskeletal pain and identify ergonomic risk factors among the selected respondents. The findings from this initial study were used for the next stage of the design process which is stage 2 to design and develop the prototype of hot work chair. The ergonomic risk factors and discomfort location identified has been taken as the main consideration for designing the hot work chair. First testing was done in stage 3 after the hot work chair design had been developed into a prototype to evaluate the effectiveness and level of discomfort of the designed prototype to the present seating practise.

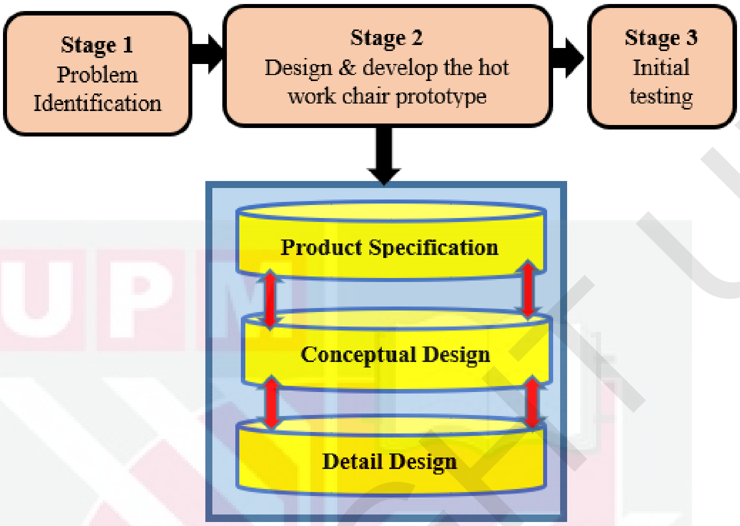


Figure 3.6: A design process of the hot work chair

3.6.1 Stage 1: Problem Identification

Stage 1 of this design process had been conducted through reviewing extensive literature, reviewing medical records of workers, feedback from workers and from the initial assessments which was conducted in the phase 1 of this study. To determine the ergonomic risk factors and the prevalence of musculoskeletal discomfort among the chosen hot workers, assessments were carried out in phase 1 of the study. Onsite inspection was also conducted at the site to get a better view of the current practice of seating during the hot works at the selected company. All the findings from the assessments in phase 1, feedbacks from workers and findings from the observation were recorded and taken into the consideration to determine the criteria and specification to develop the prototype of the hot work chair. The input from past research works and medical records especially related to musculoskeletal disorders was also reviewed to support the criteria and specification for the prototype.

3.6.2 Stage 2: Determining the Criteria List

I. **Product Design Specification -** The Product Design Specification or PDS will specify the product to be designed and also will place boundaries on the subsequent designs. The PDS formulated will lead to develop the conceptual design based on prescribed specification of the product and in this case the hot work chair. The PDS for the hot work chair was established based on the findings and results from stage 1 of the design process. The final concepts, specifications and criteria in the PDS were generated based on the consultation from engineering experts through a few detailed discussions and also through prior research in this area of studies. There were 32 important criteria (Figure 3.7) of product design specification (PDS) and several criteria were to be taken into consideration for the prototype of hot work chair.

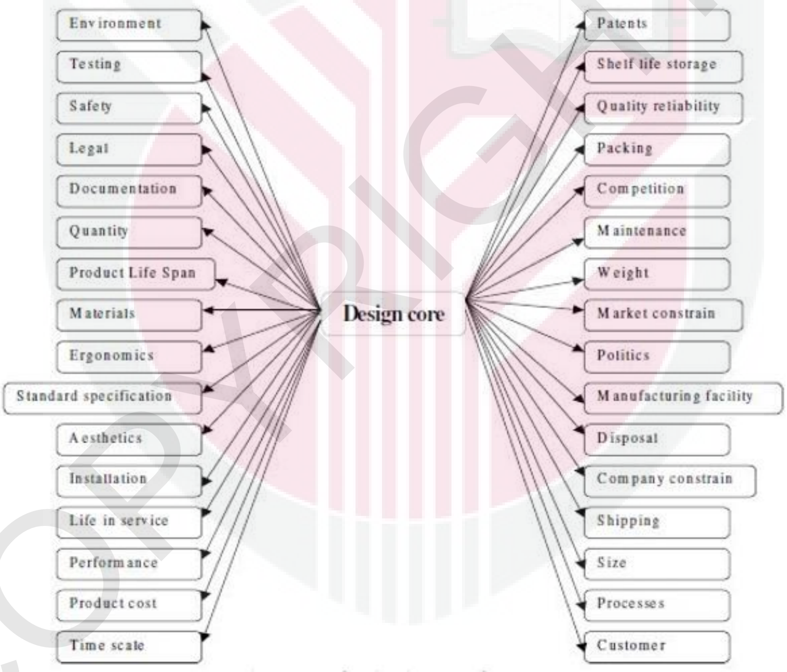


Figure 3.7: Elements of product design specification (PDS)
(Source: Karmegam et al. 2011)

II. **Conceptual Design -** The conceptual design for this study has been determined using the Pugh Chart and previous research review. For comparison with the conceptual concepts, Datum design was also utilised. Based on a standard seating chair available in the market, a datum design was chosen. The Pugh chart, a quantitative tool, was used to rank the multidimensional choices. In stage 1 of the design process, the design criteria were established, and the Pugh chart could be used to analyse several design concepts against those requirements. The best design was picked to become the prototype for the hot work chair after several ideas were created, analysed, and refined. The Pugh Chart was utilized at this step to determine the ideal seat design for this research. In the early stages of design, it is used to assess design concepts against the design criteria. The step-by-step overview of how the Pugh Method are:

- Establish criteria: Identify the critical design attributes or criteria that are essential for the project's success. These criteria represent the goals and requirements that the final design must meet.
- Select a baseline design: Choose one of the design concepts to serve as the baseline or reference point. This concept will be used as a comparison for all other alternatives.
- Compare alternatives: Compare each of the other design concepts against the baseline using the established criteria. Determine whether each alternative performs better (+), worse (-), or equally (=) compared to the baseline for each criterion.
- Create a matrix: Create a matrix or table where the rows represent each design concept, and the columns represent the criteria. Fill in the matrix with the comparison results (+, -, or =).
- Weight the criteria: Assign relative weights to each criterion based on their importance in meeting the project's objectives. This step ensures that more critical criteria have a greater influence on the final decision.
- Calculate scores: Multiply the comparison results by the weights for each criterion and sum up the scores for each design concept. This will yield a total score for each alternative.
- Select the best concept: The design concept with the highest total score is considered the most favorable option and is chosen as the recommended design.

As shown in figure 3.8, a Pugh chart is a quantitative method for ranking a group of multi-dimensional possibilities. The best design was selected to be constructed and tested after a few proposals were considered. Figure 3.9 showed the simplified version steps involved in the Pugh Chart procedure. First the design criteria had been listed in the left column such as comfort, cost and maintenance.

Figure 3.8: Pugh chart
(Source: Athirah, 2021)

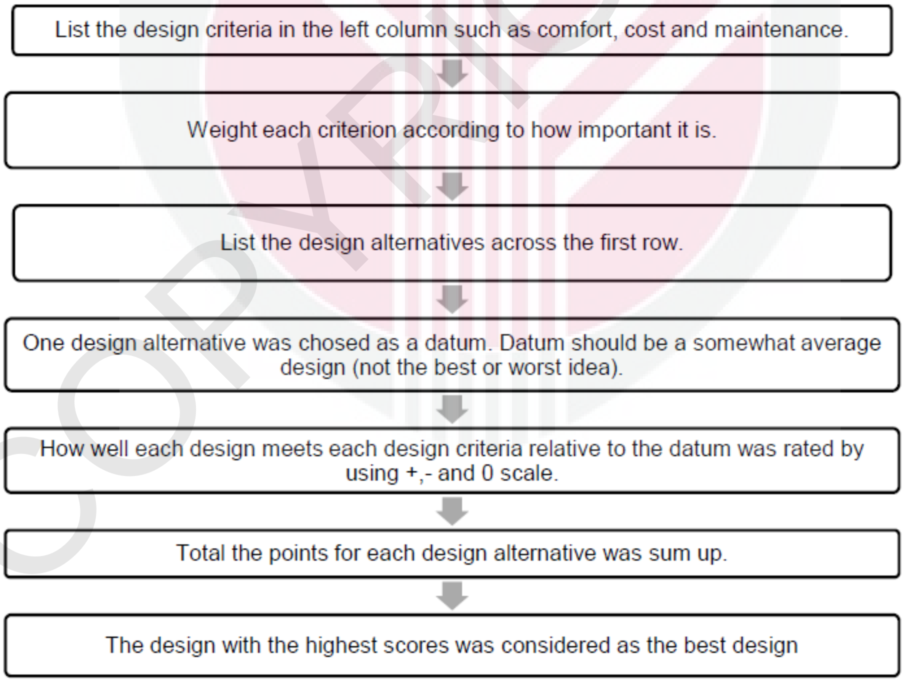


Figure 3.9: Flowchart of Pugh chart procedure

III. **Prototype development -** In accordance with the PDS and set of criteria, the conceptual design that has been chosen and finalised has been used to fabricate a hot work chair prototype. With the assistance of the engineering and fabrication professionals, the researcher was actively involved and kept in communication throughout the development process of the prototype. The general process of developing the prototype has been shown in future 3.6.

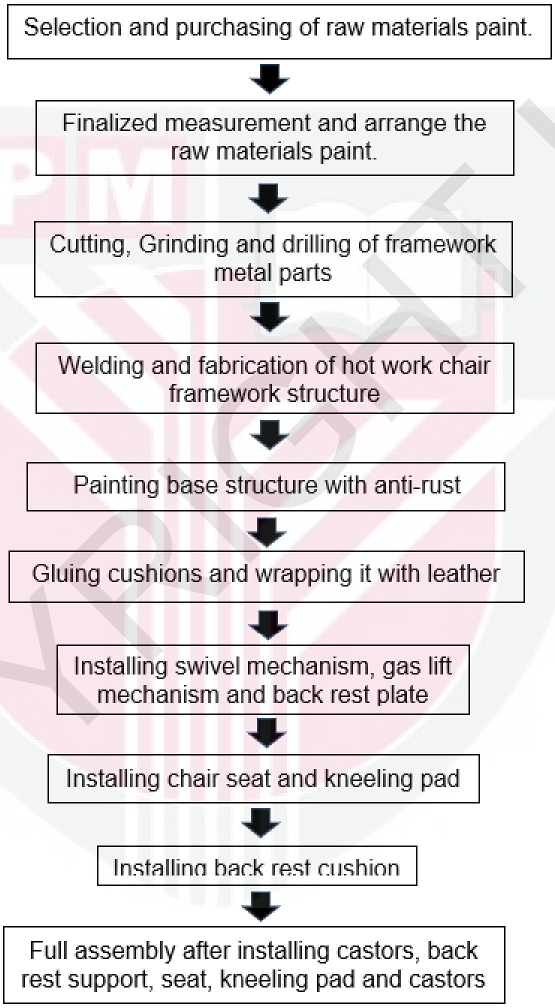


Figure 3.10: Flowchart of prototype development procedure

3.6.3 Stage 3: Initial Testing

Five hot work employees have been provided with the developed prototype to utilise while they are executing the hot work jobs in seated positions at the chosen company for an initial testing stage. During this stage of testing, the prototype was used for 2 hours per worker, and respondents were asked to complete a seat discomfort survey using a 100-mm VAS after using the designed hot work chair. To assess the efficacy of the hot work chair prototype, respondents were also directed to complete the same survey for their present seat.

3.7 Study Procedure for Phase 3 (Evaluation of the developed hot work chair)

To assess the effectiveness of the produced prototype in reducing body discomfort, 24 participants were chosen for this third phase of the research study. This evaluation will be based on a comparison of the pre- and post-test sessions in two groups. There will be 2 groups which will be divided with 12 respondents in each group. The first group is the control group and another one is the experimental group. A pre-survey form will be distributed to all these 24 respondents to assess the eligibility and determine whether they were participating voluntarily in the research. Only respondents who fulfilled the inclusive and exclusive criteria were selected in this study. Next, all the respondents had been briefed on the objective of this study, the entire process of evaluation about the questionnaires was given. To participate in this study, all of the respondents were asked to sign a written consent form. The pre-survey form, which included content and eligibility requirements, was required to be filled out by each responder. The researcher measured the BMI using the same procedure as in phase one of the investigation. All eligible respondents were chosen, based on the pre-survey form, and then divided into the control group and experimental group using a method of simple random sampling. All respondents from the experimental group (n=12) will be provided with the developed prototype of the hot work chair to use it for 6 working days each. Each respondent from the experimental group is required to use this hot work chair in their full day of shift for 6 days and in total, there will be 12 weeks including Sunday as the rest day to complete one cycle of the total respondents. The pre-test and post-test using the questionnaire which consists of the muscle discomfort rating were conducted with one-week interval. -Both control and experimental group answered the first questionnaire on the Monday morning (pre-test) and after 6 days they will answer the second questionnaire (post-test) on the Saturday evening after the shift end. So, the time duration between pre-test and post-test is 6 working days or one week of company operation.

The flow diagram in figure 3.11 shows how the study population was recruited and handled during the course of this study. The CONSORT statement, also known as just CONSORT, is a document that includes a diagram for documenting the flow of participants through a trial in order to comply with the CONSORT 2010 standard. It also includes a checklist of crucial components that should be included in reports of randomised control trials (Moher D et al, 2010). Respondents (n=12) who were assigned to the control group had undergone pre-test and post-test on the same time to experimental group but they will follow their usual practice of seating during the hot work activities. The questionnaire session had taken approximately 20 minutes for both control and experimental group. In this study, there were no cases of being unable to follow or couldn't complete the experimental testing as planned. All samples (n=24) had completed the follow up stage without zero loss to follow up cases. There are no respondents (n=0) who had discontinued intervention and no one was excluded from the analysis (n=0). All respondents (n=24) had been analysed and the data had collected successfully.

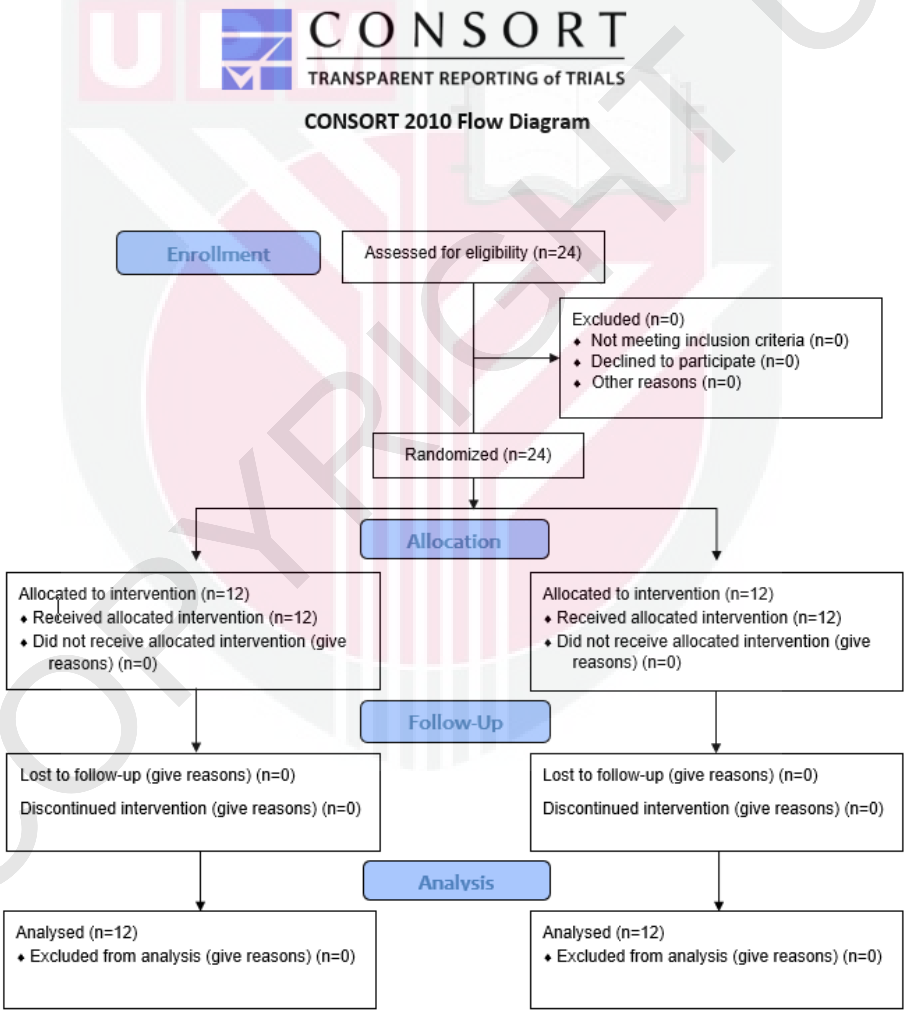


Figure 3.11: CONSORT diagram

3.8 Statistical Analysis

3.8.1 Assessment on muscle discomfort among hot work workers.

Data from the survey as well as weight and height measurements were entered into a Microsoft Excel spreadsheet and then analysed using IBM SPSS Version 26. Univariate and bivariate analysis were used to analyse the data that were acquired. With a 95% confidence level, 80% power, and a significant level of $p<0.05$, the researcher carried out this study and analysis. The data in this study had a normal distribution, hence the Pearson Correlation test was utilized to see whether there was a significant correlation between the variables.

3.8.2 Effectiveness evaluation of the developed hot work chair

IBM SPSS Version 26 will be used to analyse the information gathered from the questionnaires given to the chosen respondents during the pre and post-test. The information will be converted into a Microsoft Excel spreadsheet. Using univariate and bivariate analysis, the data was examined. A 95% confidence level, 80% power, and a significant level of $p<0.05$ were used in the data analysis. The normality of the data distribution for the study's variables has been determined using the Kolmogorov-Smirnov test. The prototype evaluation's data variables don't follow a normal distribution. Hence, in this analysis, a non-parametric test was applied. To compare the data from the control and experimental groups against one another, the Wilcoxon Signed-rank test was chosen for the independent numerical variables. A rating above 30 mm indicated the presence of discomfort in this study (Donnelly et al., 2009).

3.9 Ethical Concern

Before beginning the data collection for this study, permission from the Ethics Committee of Research involving Human Subjects at Universiti Putra Malaysia had been obtained (Reference No: JKEUPM-2022-214). Each of the respondents will be given consent form to read and sign before at the beginning of research study. The participation of the respondents will be ensured on a voluntary basis and no force will be implemented by other parties. All respondents will be briefed on the overall research study, objectives, research methods, steps that they need to undergo, the benefits and possible risks of the study. Participants also will be given chance to ask further questions on the research study and can be withdrawn from the participation in this research study if they want.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Generally, the sample for this study is from all workers who are directly involved in hot work activities a thet production area of the company. There are three phases in this research study. Different numbers of samples had been selected from the hot work workers based on different aspects of the assessment and research objectives. Muscle discomfort level and ergonomic risk factors among the hot work workers had been identified through the musculoskeletal pain assessment and followed by the initial Ergonomic Risk Assessment, Rapid Entire Body Assessment, Muscle Fatigue Assessment, and Quick Exposure Checklist. Next, a product design specification was established based on the criteria and elements from the initial investigations and findings from the assessment. The hot work chair was designed and developed based on the established PDS and the finalized design of hot work chair was developed into a prototype of hot work chair. A questionnaire which contained muscle discomfort rating was used to evaluate the effectiveness of the developed hot work chair among the selected hot work workers. The results of this research study are explained based on the research objectives as below.

4.2 Objective 1 - Assessment on musculoskeletal pain among hot work workers.

This questionnaire which was distributed to the respondents has three sections which consist of part A for socio-demographic background, part B for Medical History, and finally Part C which consists of Body discomfort chat (BDC). The data collected from the questionnaire in stage 1 of the study has been transferred onto Microsoft excel spreadsheet and analysed by using IBM SPSS Version 26 and the data obtained ha been analysed using univariate and bivariate analysis. The researcher has analysed the data collected using 95% confidence level, 80% of power and significant level $p \leq 0.05$. Data in this research has been normally distributed and therefore, the Pearson Correlation test has been used to analyse the significant correlation between the variables. There were one hundred and ten respondents from the selected company who had participated in this study and answered the questionnaire provided to them. In total ten workers had been excluded from this study because they did not fulfil the criteria set earlier for the sampling. Six workers were excluded due to age factor (more than 40 years) and four workers do not have work experience of more than 1 year. The overall mean age of the 110 respondents was 37.22 ± 5.09 years. The mean of working experience related to Hot works is 10.20 ± 3.28 years. Table 4.1 shows the main information gathered from the respondents. Out of 110 respondents, only 7 workers are locals and the balance 103 workers are foreigners. Most foreign workers are from Bangladesh which is about 54% of overall respondents and followed by Nepalese (30%), Indian citizens (17%) and Sri Lankans being 2% from the respondents. The workers were selected only from three hot works section (welding, grinding and from metal cutting section). Out of 110 workers, 50% of the respondents are from the welding section and this is followed by 35% from the grinding section and the balance 25% are from the metal cutting section.

Table 4.1: Information of respondents (N=110)

Variables	Total n (%)	Mean ± SD
Age (year)		37.22 ± 5.09
Hot works Experience (years)		10.20 ± 3.28
National		
Malaysian	7 (6.4)	
Bangladesh	54 (49.1)	
Indian	17 (15.5)	
Nepal	30 (27.3)	
Sri Lankan	2 (1.8)	
Designated hot works		
Welding	50 (45.5)	
Grinding	35 (31.8)	
Metal Cutting	25 (22.7)	

Most of the workers have not undergone any formal education and are from poor family backgrounds. So, disputing the muscle discomforts that affect them, they just continue working as usual to secure their jobs in this company. Without a proper and immediate solution, they might need to face more sever musculoskeletal injuries that can cause permanent disabilities. The figure 4.1 below shows the mean of body discomfort rating based on 20 specific body regions which were experienced by selected hot work workers. The highest mean of discomfort experienced by workers is at the buttocks (left and right) which were 71.28 ± 9.91mm and 72.07 ± 8.87mm respectively. The next highest rating of body discomfort level is at the right knee with 72.41 ± 8.60mm and right thigh with 72.07 ± 8.87mm. This is followed by the right shoulder (70.20 ± 9.54), left knee (69.65 ± 8.31), left thigh (69.43 ± 8.34), right neck (67.32 ± 9.40), left neck (65.49 ± 9.92) and left shoulder (66.35 ± 9.54). The lowest rating of body discomfort level is at the feet (right and left) which were 52.60 ± 8.37 and 52.42 ± 9.29mm respectively. The other body parts that have a rating higher than 60mm are the upper back right (63.90 ± 8.19), left upper back (61.41 ± 9.34), right lower back (64.74 ± 8.30), left lower back (63.40 ± 8.69), right calf (65.16 ± 10.24) and left calf (62.25 ± 10.74). The right and left hand also have a relatively lower rating of discomfort level compared with the other body regions which are 52.63 ± 8.88mm and 53.46 ± 9.25mm respectively. The overall body discomfort rating level experienced by the respondents is 67.98 ± 6.90mm. The discomfort rating from 5mm to 44mm is considered mild, 45mm to 60mm is moderate and

70mm to 100mm has been considered extremely discomfort (Hawker et.al., 2011).

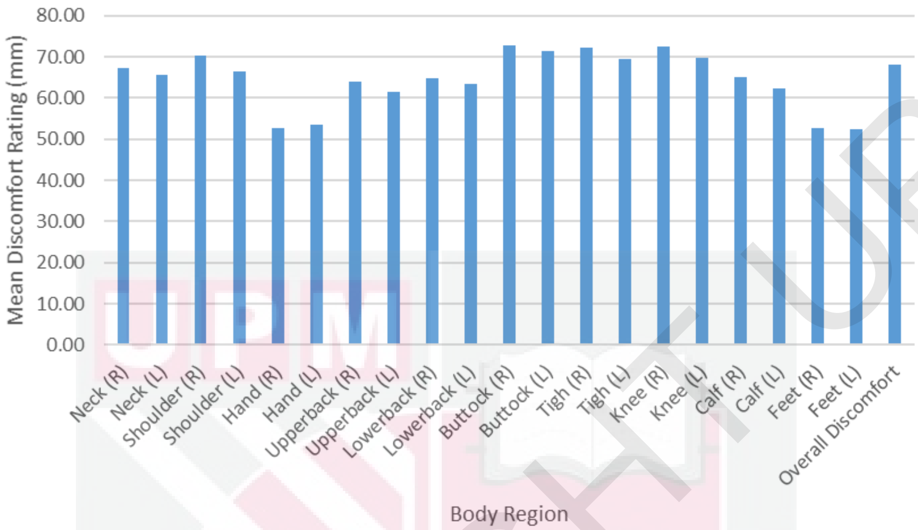


Figure 4.1: Mean discomfort ratings of 20 specific body regions (N=110)

Based on the assessment conducted, the right and left buttocks, right knee, right thigh, and right shoulder muscles have been identified as extremely discomfort regions among the selected workers. This is continued by the left knee, left thigh, right neck, left neck, left shoulder, right and left feet, right and left upper back, right and left lower back, right and left calf and finally the right and left hands were considered as moderate discomfort regions. There were no body parts that have been identified as mild /low discomfort regions from this assessment. So, this muscle discomfort assessment shows that the muscle discomfort rating is significantly associated with body posture during hot works, working hours, and current seating practices by the workers. The initial observation, medical record and medical leave statistics reviewed by the researcher also supports the fact that the current seating practice is the main factor that contributes to musculoskeletal problems among the workers including muscle cramps, muscle pain at multiple body regions, and other MSDs problems for many years in this company. Based on the discomfort level study by Mohd Nasrull among 35 hot work workers in 2015 using the Cornell Musculoskeletal Discomfort questionnaire, he found that 97.22% of respondents had reported discomfort in many parts of the body including the wrists, neck, upper back, lower back, shoulder, upper back, knee, leg and foot when performing the hot works. Another 12-month research study on musculoskeletal pain prevalence among 145 welders in Germany conducted by C Weyh (2020) discovered that the lower back (71%), neck (61%), shoulder (55%), knee (46%), upper back (36%), elbow (23%), lower leg (16%), and other hot works demanding physical demands on the welder's wrist, elbow, arms, shoulders, and neck due to awkward postures and forceful exertions were the most impacted.

Hot workers, particularly welders, frequently suffer from musculoskeletal injuries (MSI), and female welders are particularly at risk because of inadequate equipment design (Dahlstrom et al., 2014). Improper body position or awkward posture is a major risk factor that may cause muscle pain or discomfort among workers performing hot working as routine job. For a longer period of time, the hot work worker's body will be in an awkward position, which will first cause the muscle to feel uncomfortable, then it will produce an abnormality in the muscle's original function, and lastly it will result in a temporary or permanent loss of function (Schnieders et al., 2017). Isiohia (2020) reported that practically all of the study's welders stated that their awkward posture during welding operations was the primary source of their suffering. His research revealed that the employees frequently experienced poor welds as a result of their high rates of discomfort, pain, and exhaustion. Isiohia further claimed that the nature of hot working with awkward body postures has exposed welders to a significant danger of injuries and disorders affecting the human body's mobility and musculoskeletal system, which includes the muscles, tendons, ligaments, nerves, discs, and blood vessels.

In this study, it was discovered that hot workers at the chosen organisation typically carry out hot tasks while seated, with their heads, trunks, and shoulders bent and abducted. Workers carried out hot works activities in squat position while some were observed seating on metal sheets and plastic containers due to no proper workstation being provided by the employer. Together with the issues associated with lumbar kyphosis, working while seated will put an excessive amount of strain on the shoulders and back muscles. The individual doing the hot work may need to stoop too low if the surface is too low, and they may need to elevate their shoulders if the task is at a high level. This will cause discomfort at multiple parts in their body including the lower body, shoulder, back etc. Welding workers were also found working in static conditions which can cause the blood flow to become slow thus reducing the supply of nutrients to the muscles and then slowing the acid removal, excretory, healing and recovery process in the affected muscle’s region (Khairul, 2020). Prolonged static posture is the tensile state for human’s body and could cause excessive burden on the body muscles indirectly causing the collection of body fluid at the foot (Gregory et.al., 2008). The major factors that contributed to muscle discomfort level among the selected workers noticed to be associated with MSD and other ergonomic problems with the ultimate goal in this research study to develop a proper hot work chair to improve the working posture, reduce the disconformable affecting the workers and improving the efficiency of hot work activities carried out at the company. The other factors like age, gender, working experience are also associated with musculoskeletal problems for specified body regions (Li,G et al., 1999). The correlation results between age of respondents, years of work experiences in hot works and overall body discomfort ratings are shown in table 4.2.

Table 4.2: Correlation between overall discomfort ratings with age and year of hot work experience (N=110)

Variables	Age (years)	Hot works Experience	Overall discomfort ratings
Age (year)		0.763*	0.300*
Hot works Experience	0.763*		0.374*
Overall discomfort ratings	0.300*	0.374*	

* P-value is significant at p<0.01

The results show, there is a strong positive significant correlation between the years of hot work experiences and age of workers ($p < 0.01$, $r = 0.763$) and moderate positive correlation between years of hot work experiences and overall discomfort ratings ($p < 0.01$, $r = 0.374$). There is also a significant correlation between the age of workers and overall discomfort ratings ($p < 0.01$, $r = 0.300$). The strong correlation between the years of hot work experiences and age of workers shows older workers have more working experience in hot work compared with younger workers. The significant correlation between both the number of working experience and workers' ages with overall discomfort ratings showed that older workers with more working experience in hot works have higher muscle discomfort ratings compared with young workers with lower hot works experience. Age and the duration of exposure to hot works could be considered as contributing factors for the frequency and severity of back and other musculoskeletal injuries associated with improper body positioning. Workers who are getting older are subject to cumulative degeneration process and loss of flexibility that might increase the possibility and exposure level to these types of musculoskeletal injuries. For a company the working experience or experienced people is a crucial element for the sustainability of the business operation. Therefore, a hot work chair that has been designed and developed based on the needs of the workers could reduce the muscle discomfort issues, improve the working postures of the workers, and increase the production of the company.

4.3 Objective 2 - Initial Ergonomic Risk Assessment

Initial Ergonomic Risk Assessment was conducted among the selected hot work workers from the three work units (welding, grinding and cutting). This Initial Ergonomic Risk Assessment checklist has been adapted from appendix 6 of Guidelines on Ergonomics Risk Assessment at Workplace, 2017. The Initial Ergonomic Assessment has been carried out at hot work section involving workers A, B and C each from different work units and scores given based on factors observed and analyzed. Workers were instructed to carry out their routine task for observation by the researcher and the findings were recorded on the checklist. Table 4.3 shows a summarized result of the Initial ergonomic assessment conducted. Overall, the selected worker A, B and C from three different hot work sections had achieved total score of 18, 18 and 17 respectively. Awkward postures, repetitive motions, static and continuous work postures, vibration, limited ventilation, exposure to noise, and working in high temperatures are the ergonomic risk factors that were discovered during the initial ergonomic risk assessment in this organisation. The workers from this hot work section are generally affected by similar risk factors due to the same working position and using the same type of seats when carrying out hot works for the same work duration. Awkward postures recorded with the highest score in this assessment due to bending, stooping, or squatting had become the workers' primary task activity for prolonged hours. Static and sustained work posture and repletion are also commonly similar ergonomic risk factors which lead to muscle discomforts and other musculoskeletal issues among these workers.

Table 4.3: Results of Initial ERA conducted on selected 3 workers (Worker A, B and C)

Risk factors	Total Score	Minimum requirement for advanced ERA	Result of Initial ERA			Need Advanced ERA? (Yes/No)		
			A	B	C	A	B	C
Awkward Postures	13	≥ 6	10	11	10	Y	Y	Y
Static and Sustained Work Posture	3	≥ 1	2	2	2	Y	Y	Y
Forceful exertion	1	1	0	0	0	N	N	N
Repetition	5	≥ 1	3	2	2	Y	Y	Y
Vibration	4	≥ 1	1	1	1	Y	Y	Y
Lighting	1	1	0	0	0	N	N	N
Temperature	1	1	1	1	1	Y	Y	Y
Ventilation	0	1	0	0	0	N	N	N
Noise	2	≥ 1	1	1	1	Y	Y	Y
TOTAL SCORE	30		18	18	17			
AVERAGE SCORE	30		**17.7**					

In another study on ergonomic risk assessment among 66 welders in construction, the primary ergonomic risk factors identified are awkward posture, repetition, force, static loading, contact stress and extreme temperature (Abd Mutalib et., 2016). Those risk factors identified through initial ergonomic risk assessment with a score of more than the minimum requirement will proceed for advanced ergonomic risk assessment to be evaluated further on the identified ergonomic risk factor.

4.4 Objective 3 – Advanced Ergonomic Risk Assessment

To achieve the third objective for this research study, three advanced ergonomic risk assessment tools were used to assess the ergonomic risk level exposed by selected hot work workers from the company.

4.4.1 Muscle Fatigue Assessment

A, B, and C, three workers from various work units, participated in the muscle fatigue assessment method (MFA) at the hot work area. Results from the muscle fatigue assessment performed on all three workers are displayed in Table 4.4. The Effort- Duration-Frequency scores used to measure muscle fatigue show very high levels of fatigue for the right shoulders, right wrist/hands/fingers, and right legs/knees, as well as significant levels of fatigue for the left neck, left shoulder, and left back. Other areas of the body, such as the right and left arms/elbow, left wrists/hands/fingers, and right and left ankles/feet/toes, indicate moderate levels of fatigue from the hot work. How much recovery time the involved workers have between exertion will depend on how frequently their muscles are used. By predicting the amount of time needed from the recovery time curves and comparing this to the actual time between efforts of the same intensity, the degree of accumulated fatigue in a muscle during a hot work task may be described and analysed (Neville A, 2005). This overall assessment results shows that there are significant muscle fatigues detected among the hot work workers at this company. These results even though derived from only three workers, could represent similar effects among the rest of the workers because the workers from this hot

Table 4.4: Result of muscle fatigue assessment for selected workers

Region		Effort – Duration –Frequency scores					
		Worker A		Worker B		Worker C	
Neck		223	High	223	High	223	High
Shoulders	R	323	Very High	323	Very High	323	Very High
	L	223	High	223	High	223	High
Back		223	High	223	High	223	High
Arms / Elbow	R	232	Moderate	232	Moderate	232	Moderate
	L	222	Moderate	222	Moderate	222	Moderate
Wrists / Hands / Fingers	R	332	Very High	332	Very High	332	Very High
	L	232	Moderate	232	Moderate	232	Moderate
Legs / Knees	R	331	Very High	331	Very High	331	Very High
	L	322	High	322	High	322	High
Ankles / Feet / Toes	R	223	Moderate	223	Moderate	223	Moderate
	L	222	Moderate	222	Moderate	222	Moderate

work section is generally affected by similar ergonomic risk factors due the same working position and using the same type of seats when they carry out hot works for the same work duration. Even the company's medical leave records and doctor reports reveal that many of the workers in the hot work zone have suffered for years from MSDs such leg, ankle, and back discomfort, as well as muscle cramps, and some of them are currently taking medicine.

4.4.2 Rapid Entire Body Assessment (REBA)

Welding, grinding, and cutting workers A, B, and C participated in the REBA in the hot work section, and scores were assigned based on the body parts seen. The overall ratings for all three employees for REBA are shown in Table 4.5. Workers A (cutting), who received a total score of "10," is identified as "High Risk" based on the findings. Both workers B (grinding) and C (welding) obtained total scores of ‘12’ and therefore they are categorized as ‘Very High Risk’.

Table 4.5: Scores obtained by workers using REBA

	REBA ASSESSMENT																
	Part A: Neck, body, and foot						Part B: Wrist and forearm										
Job / Task	Neck Score	Trunk Score	Leg Score	POSTURE Score A (Refer Table A)	Force / Load Score	SCORE A	Upper Arm Score	Lower Arm Score	Wrist Score	Writs Twist Score	POSTURE Score B (Refer Table B)	Coupling Score	SCORE B	SCORE C (refer table c)	Activity Score	REBA FINAL SCORE (A+B+C)	RISK LEVEL
Worker A	2	2	2	4	0	4	3	2	1	0	4	0	9	8	2	**10**	**High**
Worker B	3	2	2	5	1	6	3	2	1	0	4	0	9	10	2	**12**	**Very High**
Worker C	3	2	2	5	1	6	3	2	1	0	4	0	9	10	2	**12**	**Very High**

The results show in general all selected workers from hot work section are exposed to high risk for ergonomic risk factors such as awkward posture, prolonged seating and repitative tasks. These data can be generalised for the rest of the workers in the hot work section due to the same body posture during welding and other hot works, type of the seats that currenly being used, working environment and duration of work.

In another study which had the REBA assessment conducted among politechnic students during welding activities, score 10 was recorded which meant improvements to the body's posture position and ergonomic risk control are required as soon as posible (Khairul, 2020). The study showed welding students were exposed to working posture risk while carrying out welding activities and it was recommended to control the position and duration of the body's posture. Elevated grand REBA scores were significantly associated with self-reports in various body regions. Multinomial regression analyses showed that smoking, prolonged working hours and not engaging in physical activities were significant predictors for pain (Elvis, 2022). In a separate study, REBA average assessment score of 24 hot work workers is 9.25. The large kitchen assembly, chair finishing, and door assembly workers had scored of 8- 10 (High Risk) and in this level implementing a change and redesigning is necessary. Workers in small and large kitchen ware assembly, finishing and door assembly, respectively, scored 11 and above or “very high risk” which means that changes should be implemented immediately. It shows that the total score exceeds the neutral position, implying that there is a significant msucle discomfort experienced by hot work wokrers (Samantha et al., 2021). Therefore the score results from REBA could demonstrate the actual condition of workers in the hot work section that needed immediate attention to control the ergonomic risk factors that they are exposed to.

4.4.3 Quick Exposure Check (QEC)

Quick Exposure Check (QEC) assessments were performed on three individuals from various work units (grinding, welding, and cutting) in addition to the earlier advanced ergonomic risk assessment methods. The summative Quick Exposure Check (QEC) results for Workers A, B, and C are displayed in Table 4.6. With an average score of 47 for the shoulder and arm and 16 for the neck, the respondents were found to be at "extremely high risk," according to the results. This is followed by back in static position with an average score of 23 and wrist or hand with an average score of 38 and classified as ‘high risk’. The back in moving position is identified as moderate risk with an average score of 30. Overall, all the body parts evaluated scored within the range from moderate risk to very high risk which shows that workers in this hot work section are really exposed to ergonomic risk factors that need immediate attention to prevent any muscle discomforts or MSDs. In another study on QEC assessment among welders, analyses show a high prevalence of pain in the lower back (78%), right shoulder (66%), left hand wrist (62%) and right-hand wrist (61%) (Elvis, 2022). In a separate QEC assessment conducted among 54 hot work workers in a manufacturing company, 17 workers (31.48%) are at ‘high risk’, 15 workers (27.77%) workers at ‘moderate risk’ level and 13 workers (24.07%) were found to be at ‘very high risk’ (Singh et al., 2018).

Table 4.6: Exposure scores for Important risk factors

Important risk factors					
	Worker A	**Worker B**	**Worker C**	**Average**	**Status**
Back (static)	18	26	23	23	High
Back (moving)	30	29	30	30	moderate
Shoulder/Arm	46	48	48	47	Very High
Wrist/hand	38	40	36	38	High
Neck	16	16	16	16	Very high

Eka in her research in the year 2018 using the Quick Exposure Check (QEC) research method by distributing observer questionnaires and operators, the total exposure score was 106 with an exposure level of 59.55% for the selected first welder and while welder 2, there is a total exposure score of 124 and an exposure level of 69.66%. Repairs were done on their workstation to reduce the exposure level value in their welding work and after implementation, the exposure level of the operators had been reduced to 48.31% and 49.43% accordingly (EKA, 2018). In a separate study, QEC assessment score of 24 hot work workers shows overall high exposure on WMSDs in their backs, wrist/hand and neck. 50% of the workers are very high at risk in their backs and neck when they perform grinding works and 83% of the workers are at very high risk in the welding section of chairs and doors. This means that an investigation and immediate change in the current workstation should be implemented (Samantha, 2021). If ergonomic problems were not fixed in hot works, they might be repeated throughout the year by personnel at all levels, which could have a big influence on the company's overall profit. The organisation can decrease overtime expenditures for substitute workers who might not be effective or qualified to perform hot work, absenteeism of employees owing to injuries, and medical expenses by lowering the risk of musculoskeletal injuries. As a result, investing in obtaining hot work chairs that the researcher has developed would reduce the overall ergonomic problems hot work employees at the selected organization or even other companies that operate similarly encounter.

4.5 Objectives 4 - Design and develop a hot work chair

The fourth objective of this research study is to design and develop a prototype of hot work chair that has been carried out in three stages. Stage 1 is to identify problem and determine the criteria list. Stage 2 is to design and develop the selected prototype and Stage 3 is to conduct the initial testing on the developed hot work chair prototype.

4.5.1 Stage 1: Problem Identification and Determining Criteria List

Stage 1 of this phase had been conducted through reviewing extensive literature, reviewing medical records of workers, feedback from workers and from the ergonomic assessments that had been carried out in phase 1 of this study. There were two assessments conducted earlier to assess muscle discomfort level and ergonomic risk factors among the selected hot work workers. Onsite inspection and observation had also been conducted at the site to get a better view of the current seating practice during the hot works at the selected company. The assessment results in phase 1, feedback from workers and findings from the observation were recorded and taken into consideration to determine the criteria and specification to develop a prototype of the hot work chair. An electromyographic (EMG) study had reported that a chair which is height adjustable and has adjustable backrest and armrests can reduce the muscle activity of the neck, shoulder and back, and also decreases the inter-vertebral disc pressure and therefore, the chair with some of adjustability can be directly associated with the function of the musculoskeletal system (Leivseth G, 1997). The Seat-plane and backrest contours, backrest height and inclination adjustability, padding and covering materials that allow the body to breath (Occhipinti et al., 1993). The input from past research studies have also been reviewed to support the criteria and specification for the prototype as shown in table 4.7.

Table 4.7: Summary of studies on product design specification (PDS) to develop an ideal prototype Hot work chair

No	Criteria	Parameter	References
1	Performance	Easy to be used, impact resistance and involving important points of feet. It also has premium cushioning that gives comfort as it distributes the weight throughout the body. The chair shall provide flexibility for multiple body postures. The chair, and in particular the control features, should be practical and easy to control use.	Noreen (2021), Tahmasebi R (2020), Li W et al., (2020) Occhipinti E. et al., (1993)
2	Environment	It can withstand with hot and cold ground, vibration, shock loading of users, or dirt, slippery oily and dusty environment.	Oscar Hetzg (2017)
3	Product life span	1-2 years with regular maintenance	Noreen (2021)
4	Materials	Ethylene-Vinyl-Acetate insole which was light, dense foam polymer and adapt well to vibration factors	Rodrigues et al., (2008)

Table 4.7: Continued

No	Criteria	Parameter	References
5	Ergonomics	Adjustability of the seat height and the seat pan depth to match the anthropometrics of the user is the most commonly recommended intervention. The seat cushion contour had an impact on pressure parameters and pressure distribution on the seat pan, while the sitting posture affected the location of peak pressure on the seat pan.	Van Niekerk et al, (2012), Li W et., (2020) Leivseth G, 1997).
6	Aesthetics	Not bulky, light,	Collins et al. (2016) Helander M. (2003)
7	Product cost	Affordable	
8	Weight	Light weight and soft	King (2002), Shin et al., (2011)
9	Size	It should fit to present worker's foot length and can to be trimmed	Oscar Hatzg, (2017),
10	Customers	Industrial workers	
11	Durability	The chair should offer good wear and durability of its components and controls	Occhipinti E. et al., (1993)

The identified input and the expected output for the development of the prototype hot work chair had been stated in the figure 4.2. The list of seat features input for the design and development of hot work chair are including adjustable and portable back rest, portable knee support, cushioned seat, back rest and knee support, attached with strong wheels and able to be used for multiple body postures when performing hot works. The expected output from this hot work chair is including relieves muscle discomfort, minimizes discomfort during seating for prolonged hours and maintain good body posture.

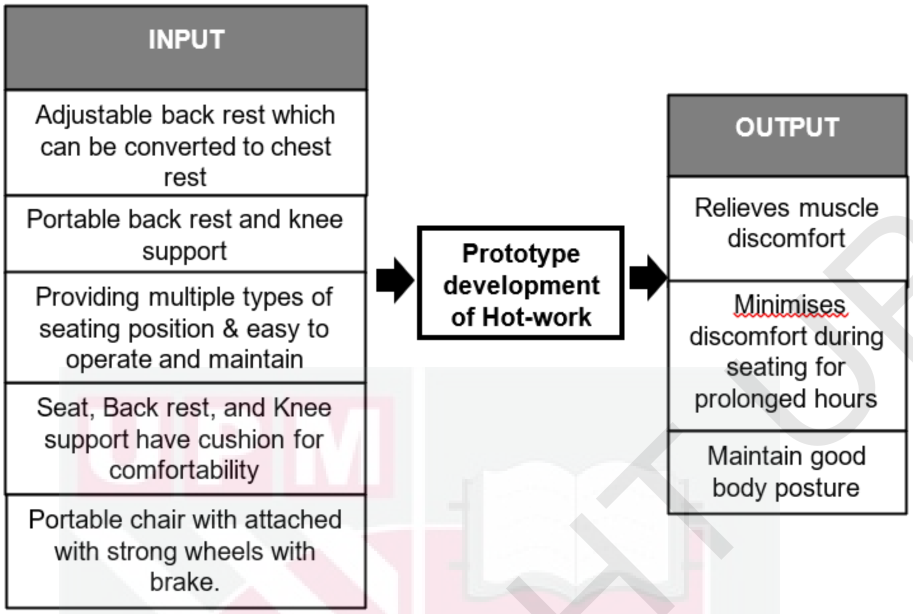


Figure 4.2: Input and output of the prototype hot work chair features

4.5.2 Stage 2: Design and Development of a Prototype

During Stage 2 of the design and development process, the desired product design specification details for the desired hot work chair were established, conceptual design for five different types of hot work chair established, their characteristics compared and evaluated, using a matrix method, choosing the best design, detailed design for the chosen conceptual design established and finally a prototype fabricated based on the finalized detail design done.

4.5.2.1 Product Design Specification

The Product Design Specification or PDS will specify the product to be designed and will place boundaries on the subsequent designs. The PDS formulated will lead the process of developing the conceptual designs based on listed specification of the desired product, in this case a hot work chair. The PDS for the hot work chair established the based findings and results from the first stage and the final concepts, specifications, and criteria in PDS were generated based on consultation from engineering experts through a few detailed discussions and also through prior research in this area of studies. There are in total eighteen criteria in PDS selected which was adapted in previous study and finalized for the development of this prototype (Karmegam et al., 2011). Table 4.8 shows the detailed product design specifications for the desired hot work chair.

Table 4.8: Product Design Specification (PDS) for the hot work chair prototype

No.	Criteria	Description
1	Performance	• The dual layer cushions used in the prototype development is thick and heavy duty. Provides long lasting comfort for users during hot works. • Heavy duty wheel castors ease chair movement in outdoor and indoor environment. Strong brakes on the castor wheels increase its practicality. • Mild steel structure coated with anti-rust paint make the structure strong and rigid. It can withstand static load up to 120kg. • Knee support will provide comfortability to do welding in kneel position • Knee support can be used for seating also for welding at lower level
2	Economy	Reasonable and practical cost
3	Target production cost	Below RM400 (only raw materials and labour cost) For exact production cost, it needs more details on other costs such as consumable production suppliers, hand tools/equipment used, volume of production and fabrication facility required.
4	Product life span	It can withstand up to 10 years depends on the usage
5	Customers	Workers who performing hot works (welding, grinding, metal cutting) at workplace
6	Competition	No significant competition identified
7	Environment	It can withstand both hot and cold temperatures, shock loading, vibration, and dusty environment.
8	Size	Standard size of seating stool which added features like chest rest, knee support and detachable back rest
9	Weight	Light weight material (<15 kg). Average chair weight.
10	Installation	• The chair is fully assembled and can be used instantly. • The back rest can be detached and attached back easily. • Any replacement parts like wheels and seat cushions can be done just using simple tools such as wrench and screwdriver.
11	Maintenance	• Easy maintenance. Leather used to wrap cushions are oil resistant waterproof and spark resistant. • Clean the chair frequently since the hot works involving a lot of dust/sparks

Table 4.8: Continued

No.	Criteria	Description
12	Material	• Structure material – Made up of hollow mild steel. Light but strong frame, robust, less expensive, easy to fabricate. • Cushion material – High density seat foam, memory form concept, increases seating comfort
13	Ergonomics	• Adjustable back rest which can be converted to chest rest • Knee support which can used for seating position • Detachable back rest based on seating needs • Seat, Back rest, and Knee support have cushion with contour shape to support back posture • Movable chair with attached with strong wheels with brake. • Providing multiple types of seating position based on the needs • Easy to operate, handle and maintain
14	Appearance	• The chair is easy to use, looks robust and compact • Curved edges, simple and fulfil the needs • Able to give a real satisfaction and comfort when someone seat • From the looks, it could give confidence for users to use it wisely
15	Finish	Black painted steel structure, black covered seat and back rest exposed with varnished wood as finisher to make the product look sporty, elegant, and attractive.
16	Testing	Initial testing had been conducted - Observation of the seating postures - The discomfort ratings had been evaluated using the VAS after using the chair
17	Safety	• Safety briefing conducted for the users before usage • Recommended seating postures will be displayed on the chair • All sharp edges covered/modified • Avoid direct fire on the cushions.
18	Design time	• Conceptual design – 2 months • Prototype development – 4 months

4.5.2.2 Conceptual Design

The conceptual designs for the desired hot work chair were determined using the Pugh Chart and the previous research review. A datum design was chosen based on an existing normal chair in the market for general activities. The Pugh chart has been used to rank the multi-dimensional options and to compare several design ideas against the criteria determined in Stage 1 of the design process. Several designs were developed, compared, evaluated and the best design was chosen and developed into the prototype of a hot work chair.

<u>Design 1</u>

Figure 4.3 below shows a sleek design of a hot work chair using mild steel painted with anti-rust paint giving a strong structure to this chair. This type of hot work chair will be easier to install, easier for maintenance and lower manufacturing including the raw material costs. The ergonomic detachable back rest will be made with soft cushion which provides good support for the back. The bigger base structure increases the stability of the hot work chair, but it might require larger space to store. The thick dual layer kneeling pad and seat provides comfy feel even if seated for a long duration. However, it will be a fixed seat height and needs additional cushion if one wants to adjust the seat. The heavy-duty PU wheels with brakes which suits both rough and smooth surfaces and the heavy-duty brakes enhance the static working performance. However, the main structure needs to be repainted every 2 years depending on the frequency of usage to prevent it from rusting.

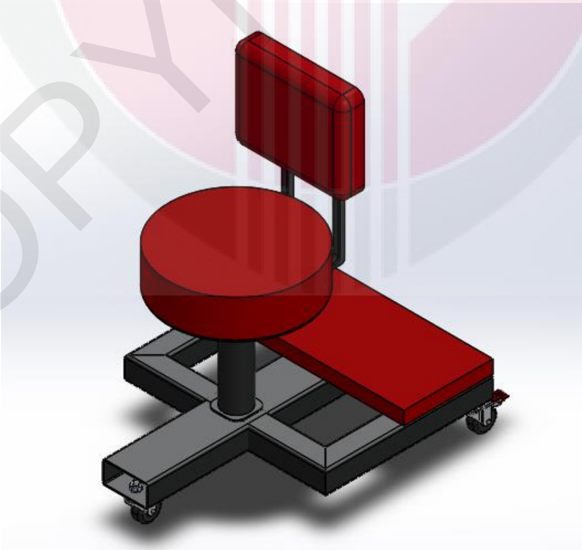


Figure 4.3: A hot work chair – Design 1

Design 2

Figure 4.4 is a robust design of a hot work chair which will be using an aluminium alloy as the main material to fabricate this prototype. The structure of the hot work chair will be stronger with a lighter weight. However, in terms of cost, the aluminium alloy will be more expensive compared to the mild steel. This type of hot work chair design will be installed with the height being adjustable and a swivel seat with a height and angle adjustable backrest for user preference. This chair will be fabricated in standard size and does not require large space to store. However, fabrication and the raw material cost is higher compared with other conceptual designs. The installation of the chair parts will be easier and will be installed with heavy duty PU wheels with brakes that suit both rough and smooth surfaces. The heavy-duty brakes enhance the static working performance. The ergonomic back rest for this design will be made using soft cushion for better lumbar support and chest rest. A thick dual layer seat provides long duration comfort for workers when they need to carry out their job.

Figure 4.4: A hot work chair – Design 2

Design 3

Figure 4.5 shows a simple design of a hot work chair using mild steel painted with anti-rust paint which increases the strength and stability of the chair. This type of hot work chair will be easier to install with low manufacturing cost including the cost of the raw materials used. This type of hot work chair design will have a height adjustable and swivel seat. However, there will be no back rest attached which may cause discomfort for some of the body parts during long working hours. This design of hot work chair will be installed with heavy duty PU wheels with brakes that suit both rough and smooth floor surfaces and the heavy-duty brakes could enhance performance during static working. The huge base structure could increase the chair stability, but it would consume larger space to store. The seat provides a comfy feel for workers during their prolonged working hours. The main structure of the chair needs to be repainted at least two years once depending on the frequency of usage to prevent it from rusting.

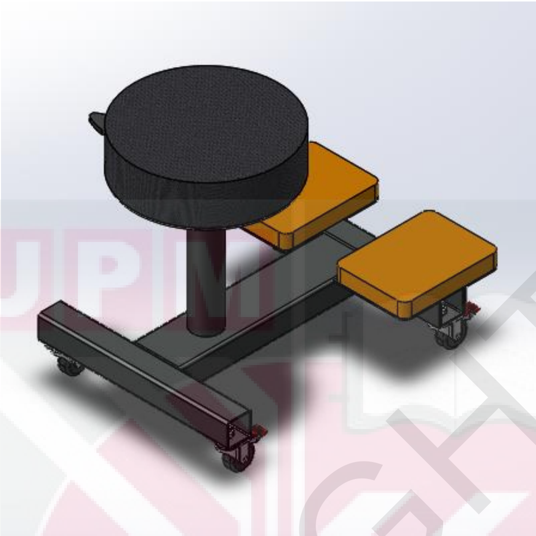


Figure 4.5: A hot work chair – Design 3

<u>Design 4</u>

Figure 4.6 presents a robust design of a hot work chair which will be using an aluminium alloy as the main material to fabricate this prototype. The structure of the hot work chair will be stronger with lighter weight. However, in terms of cost, aluminium alloy will be more expensive compared to mild steel. This backrest will be attached to the chair with fixed height and can be detachable when it is not required for any specific work posture. However, the height and angel of the backrest cannot be adjusted. This type of design will be height adjustable with a swivel thick dual layer of seat which provides a comfy feel for the workers even seating for a long duration. The back rest will be made with soft cushion for better lumbar support and for chest rest. This hot work chair will be in standard size, therefore, a larger space will not be required to store. This hot work chair will be installed with heavy duty PU wheels with brakes that suit both rough and smooth floor surfaces and the heavy-duty brakes could enhance the workers' static working performance. Overall, the manufacturing cost including raw material is lower for this design.

Figure 4.6: A hot work chair – Design 4

Design 5

Figure 4.7 shows a sleek design of hot work chair fixed with a height adjustable and swivel seat. This chair will be fixed with height and angle adjustable backrest for the user's preference and it can be detachable whenever it is not required for certain work posture or under certain work environment. This chair has a special addition of detachable kneeling pad which could be installed when the workers need to use it or remove it whenever it is not required or not suitable for the work environment. This hot work chair will be fabricated with a strong framework structure using mild steel painted with anti-rust paint which could extend the lifespan of this chair. Low-cost material, easy fabrication of the main structure, easy installation of chair parts and materials would reduce the overall manufacturing cost of this chair.

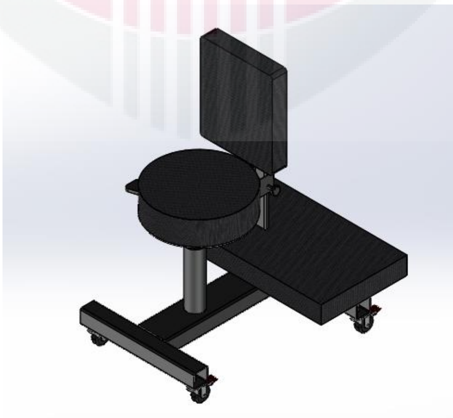


Figure 4.7: A hot work chair – Design 5

This hot work chair will be installed with heavy duty PU wheels with brakes which suit both rough and smooth floor surfaces and the heavy-duty brakes enhance workers' static work performance. The huge base structure could increase the stability of the hot work chair where it will require a larger space to store. The thick dual layer of kneeling pad and seat will provide a comfy feel for users for prolonged hours of seating. The detachable back rest made with soft cushion can be used as lumbar support or as chest rest during various hot work working positions. However, the main structure needs to be repainted every 2 years depending on the frequency of usage to prevent it from rusting.

Table 4.9 shows the list of conceptual designs established and their characteristics. In terms of cost, only design 4 is identified as high cost and the rest of the designs will consume low cost for fabrication. Design 2 and Design 4 will have small base structure (50cm x 50cm) and will be of lighter weight below 15 Kg while the rest of the designs will have a larger base structure (60cm x 50cm) and will be more than 15 kg. In terms of attractiveness, only Design 2 will have a robust design while the rest of the designs will have good contour shapes. Design 1 will be installed with non-adjustable fixed height seat and back rest while Design 3 and 4 will be installed only with adjustable height seat. However, Design 2 and 5 will have adjustable height seat and back rest which are descending and adjustable. In terms of effectiveness, except for Design 3, the rest of the designs could support body postures and relieve discomfort for workers when using the chair for hot works. All the designs established would have heavy duty PU castor wheels to enhance the movement of the chair on rough or smooth floor surfaces. All designs will have a strong structure and heavy-duty castors which increase the durability of the chair. The heavy-duty thick cushion supported with EVA sheet gives high comfort to workers during prolonged work hours and the cushion wrapped with high quality leathers is waterproof, oil proof and fire resistance for all the designs. All the hot work chair designs are easy to install and easy for maintenance. In another investigation, the proposed welding armrest design enhanced the student posture, reduced fatigue and musculoskeletal diseases, and allowed the student to perform welding activities in comfort and safety, resulting in more effective welding performance (Yusof, 2018).

Table 4.10 shows the evaluation of established conceptual designs against datum using a matrix method. All established designs have better mobility, better durability, better ease of maintenance and safety features compared with datum which is the standard chair in the market. In terms of cost, except for Design 2, the rest of the designs are lower than the datum. Design 2 and 4 have the same size as datum while Design 1, 3 and 5 are bigger than the datum. Design 2 and 4 have the same attractiveness as datum while Design 1, 3 and 5 are better than the datum. In terms of performance, Design 2 and 5 are better than the rest of the designs and datum. Design 1, 3 and 5 are easier to install compared with Design 2 and 4 and are the same as datum. Only Design 5 has adjustable back rest, chest rest and knee pad compared with the rest of the designs. Except for Design 3, the rest of the designs show a better effectiveness compared with datum. Overall Design 5 scored a higher number of '+' signs which is 10 and only one '-' compared with the rest of the designs.

Table 4.9. Conceptual designs and their characteristics

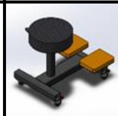
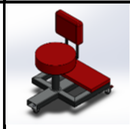
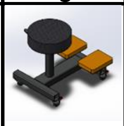
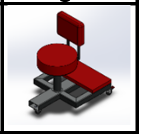
	Design 1	Design 2	Design 3	Design 4	Design 5
Design Criteria (c1 – c18)					
Low cost (c2, c3)	Yes	No	Yes	Yes	No
Small base structure(c8)	No (65 cm x 50 cm)	Yes (50 cm x 50 cm)	No (60 cm x 50 cm)	Yes (50 cm x 50 cm)	No (60 cm x 50 cm)
Lightweight (c9)	No (> 15 kg)	Yes (<15 kg)	No(<15 kg)	Yes (>15 kg)	No (<15 kg)
Attractiveness (c14, c15)	Yes (Best contour shape)	Yes (Robust design)	Yes (Good contour shape)		
Mobility (c13, c14	Yes (easy to move in industrial environment, heavy duty PU castor wheels enhance chair movement on rough and smooth surface)				
Performance (c1, c13)	Heavy duty thick cushion supported with EVA sheet for high comfort during hot works. Cushion wrapped with high quality leather makes it waterproof, oilproof and fire resistance.				
Durable (c12)	Yes, Strong structure and heavy-duty castors				
Environment (c7, c4)	It can withstand hot temperatures, fire spark and dusty environment. It expected can withstand up to 10 years depends on the usage				
Easy to Install (c10	Yes. Can be easily assembled and dissembled. Can be done using simple tools such as wrench, allen key sets and screwdriver				
Ease of maintenance	Yes				
Safety (c17, c12)	Yes (Cushions wrapped with high quality leather act as fire resistant during welding, cutting and grinding work)				
Customer (c5)	Workers who performing hot works (welding, grinding, metal cutting) at workplace				
Competition	No significant competition identified				
Testing (c16)	Initial testing only to be done only after the best design selected and the prototyped developed				
Design time (c18)	Detailed design and Prototype development expected to be completed within 4 months				
Adjustable (c13, c14)	Yes (Adjustable seat height, & adjusting back rest)	Yes (Adjustable seat height, & adjusting back rest)	Yes (Adjustable seat height)	Yes (Adjustable seat height)	No (Fixed seat height and back rest)
Effectiveness (c13)	Yes (Support posture and relieve discomfort)	Yes (Support posture and relieve discomfort)	No (Cannot maintain a good posture)	Yes (Support posture & relieve discomfort)	Yes (Support posture and relieve discomfort)

Table 4.10. Evaluation of conceptual designs using a matrix method

Design Criteria	Design 1	Design 2	Design 3	Design 4	Design 5
					
Low cost	+	+	+	+	+
Size	-	S	-	S	-
Lightweight	+	S	+	S	-
Attractiveness	+	S	+	S	+
Mobility	+	+	+	+	+
Performance	+	+	-	S	+
Durable	+	+	+	+	+
Easy to install	S	S	+	S	+
Ease of maintenance	+	+	+	+	+
Safety	+	+	+	+	+
Adjustable	+	S	-	-	-
Effectiveness	+	+	-	+	+
∑ +	10	7	8	6	9
∑ -	1	1	4	1	4

This concludes the design evaluation and selection process that Design 5 is the best design to be selected for the fabrication of the hot work chair in this research study. The fabricated Design 5 will undergo initial testing and final evaluation of the effectiveness of the developed hot work chair in reducing muscle discomfort level among the selected workers in the selected company.

4.5.2.3 Detail design and prototype development

The conceptual Design 5 which had been finalized and selected was used for fabrication of the hot work chair prototype based on the list of criteria and PDS. The researcher was actively engaged and communicated throughout the phases of the prototype development with consultation from the engineering and fabrication experts. Figure 4.8 shows the dimensions used and its components for the fabricated hot work chair.

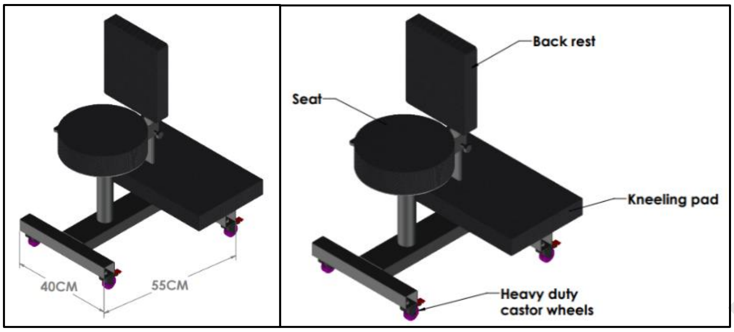


Figure 4.8: A prototype (a) dimensions and (b) its components of the hot work chair

The prototype consisted of back rest, seat height, and angle back rest that can be adjusted according to the required body posture and comfort of the users when carrying out hot works either for short or even for prolonged working duration. Back rest and kneeling pad can be detached whenever not required by users or under certain work conditions. The seat and kneeling pad cushion with 2-inch thickness provides super comfort for the users. The overall dimensions of the chair are 40cm X 55cm. The figure 4.8 shows the overall process of the prototype assembly. The prototype assembly process started with preparation the of the raw materials based on the sizes required, welding of base structure and painted with anti-rust paint. This will be followed by cushions gluing and wrapping with leather sheets. The swivel mechanism, gas lift mechanism and back rest plate had been installed to the base structure fabricated earlier. This process continues with chair seat, kneeling pad and back rest cushion installation. The last diagram shows the full assembly of the hot work chair after installation with back rest support, seat, kneeling pad and castors. Figure 4.10 shows the actual flow pictures of the prototype development. The prototype development process starts with selection and purchasing of raw materials as shown in Picture 1. The measurement of the raw materials is done and arranged accordingly in Picture 2. Picture 3 shows the metal cutting and drilling of the framework metal parts. This is followed with welding and fabrication of framework in Picture 4 and painting works in Picture 5. Next the seat and kneeling pad cushion preparing step shows in Picture 6. The assembly of the hot work chair is in the Picture 7 and Picture 8 shows the final completed hot work chair.

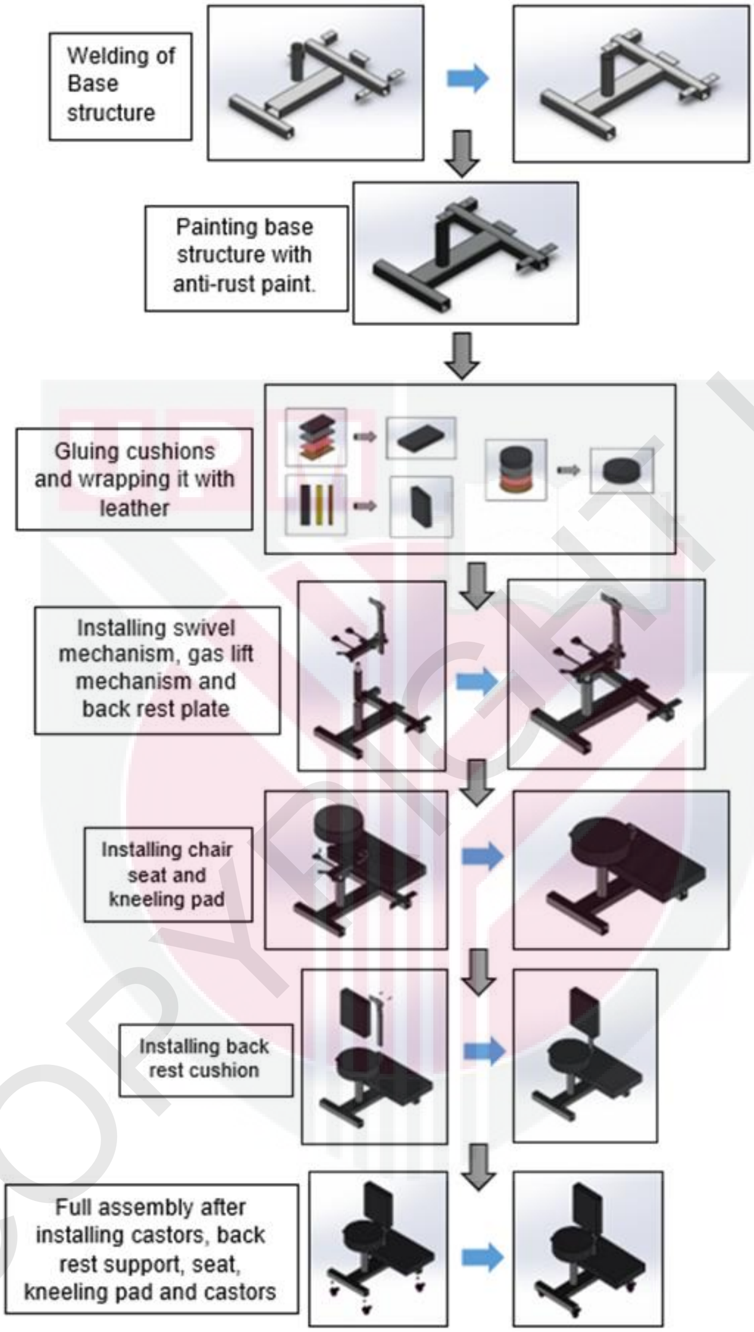


Figure 4.9: Overall overview of the prototype assembly

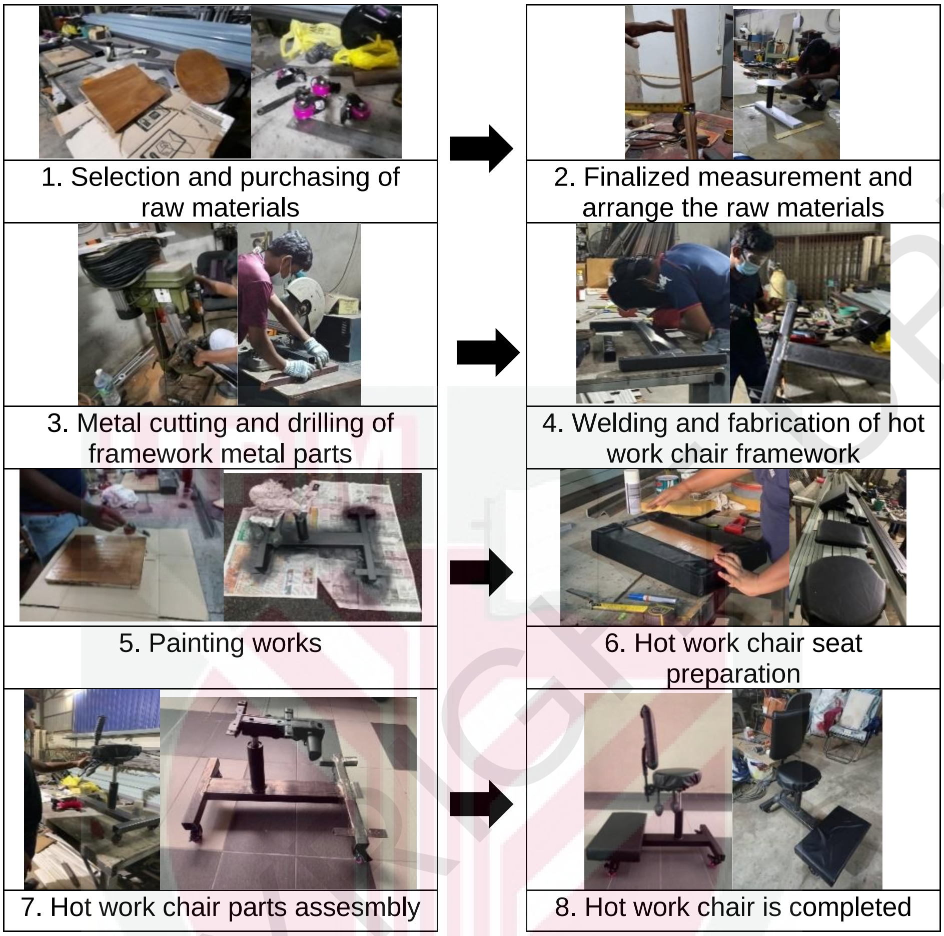


Figure 4.10: Flow of the prototype development

The hot work chair has been successfully designed and developed according to the Pugh design process and product design specification approaches. The consultation and technical advice from engineering experts has helped the design and development process of the prototype especially in selection of materials which suits the hot work job, technical drawing of the desired design, and fabrication of the prototype. Figure 4.11 shows the photos of the developed hot work chair prototype taken from different side views. The hot work chair developed in this research has several significant features that could improve body postures of hot work workers and their work performance at the selected company. The dual layer cushions used is thick and heavy duty provides a long-lasting comfort for users during prolonged hot works. The heavy-duty wheel castors will ease the chair movement in both outdoor and indoor environments. Strong brakes on the castor wheels increase its practicality and will be a good safety feature to prevent slip, trip and fall hazards. Mild steel structure of hot work chairs coated with anti-rust paint make the structure stronger and rigid which can withstand static load up to 120kg. The knee support attached to the designed hot work chair will provide comfortability to do welding in kneeling position and can be used as a seat for welding from low level. Figure 4.12 shows the variety of available seating postures using the hot work chair.

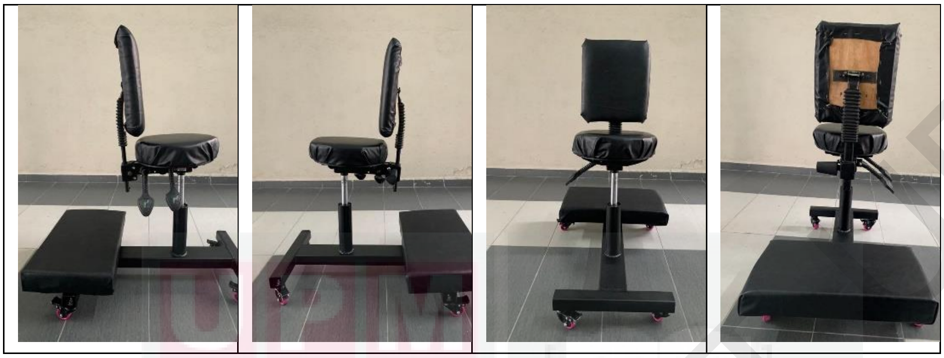
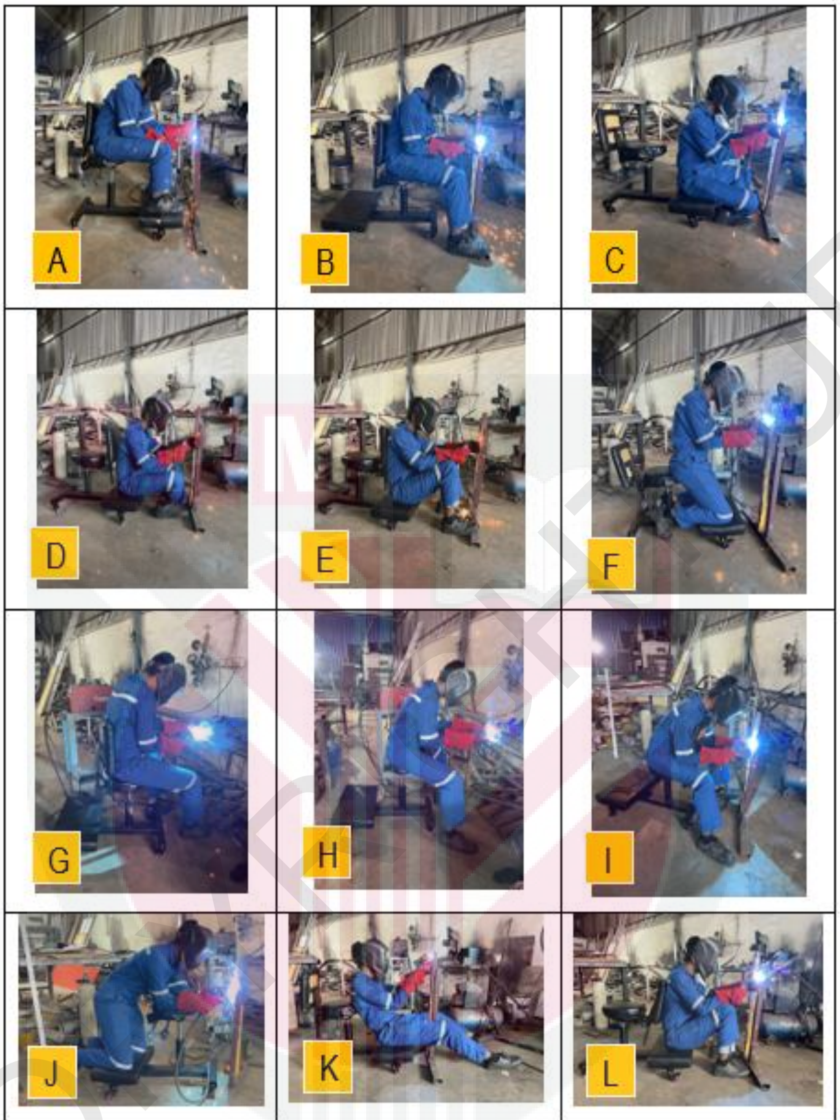


Figure 4.11: Actual view of the prototype at different side views

This hot work chair has an adjustable and detachable back rest which can be converted to chest rest. It also has attached with knee support which can be used for seating position. The seat, back rest, and knee support made with cushion with contour shape to support back posture gives a better comfortability, reduces the discomfort level among the workers and improves the overall ergonomics of the related workers. The chair height is adjustable, and it is a freely movable chair attached with strong wheels with brakes. This designed and developed hot work chair could provide multiple type of seating position based on the needs and it is easy to operate, handle and maintain. An electromyographic (EMG) study had reported that a chair which is height adjustable and has adjustable backrest and armrests can reduce the muscle activity of the neck, shoulder and back, and also decreases the inter-vertebral disc pressure and therefore, the chair with some of adjustability can be directly associated with the function of the musculoskeletal system (Leivseth G, 1997). In a separate study, the unique exercise pattern of the lumbar trunk muscles is the most likely dominant factor in controlling seat movement during active sitting, and the new chair may have a potential positive impact on back health during prolonged sitting (Kuster RP. et., 2020).



A. Seating on the seat and foot on kneeling pad
B. Seating on the seat and foot on the floor
C. Seating on kneeling pad
D. Seating on kneeling pad and leaning on back rest at 90°
E. Seating on the kneeling pad at 90°
F. Seating on the seat and knees on the kneeling pad
G. Seating on the seat and welding on the desk
H. Seating on the seat while leaning on chest rest and welding on the desk
I. Seating on the seat and leaning on chest rest
J. Kneeling on the kneeling pad while arms rested on the seat

Seating on the kneeling pad while leaning on the seat

K. Seating on kneeling pad and leaning on back rest at 45°

Figure 4.12: Different types of seating postures using the developed hot work chair

This developed hot work chair is fully assembled and can be used and disassembled instantly. Any replacement works of chair parts like wheels and seat cushions can be done using simple hand tools such as the wrench and the screwdriver. The seat, back rest, and knee support have curved edges, are simple, fulfil the needs and able to give real satisfaction and comfort when someone sits on it. The input from the literature review, initial testing and feedback from respondents are definitely helpful in determining the suitable design for the hot work chair which is economical and at the same effective in reducing the discomfort level among the hot work workers. Overall, the hot work chair made is successfully completed as designed and expected to pass the initial testing and evaluation of the effectiveness in reducing muscle discomfort ratings among the selected hot work workers.

4.5.3 Stage 3: Initial Testing

For the initial testing stage, five hot work workers randomly were selected to use the developed prototype of the hot work chair at the selected company. Based on the observation, the hot work chair was able to minimise the awkward body posture for continual welding activities that have been tested for 3 hours. The five selected workers had been observed and their feedback about this chair gathered. Based on their feedback, they were very happy and comfortable when using the chair. Surface pressure proved to be affected differently depending on the sitting position and seat cushion contour. The pressure distribution and characteristics on the seat pan had been impacted by the shape of the seat cushion, and the location of the peak pressure on the seat pan has been impacted by the sitting position (Li W. et all., 2020). The respondents also felt no pain on any of the body parts that usually give them pain or discomfort when they work without proper seat. As an initial conclusion or result for this stage, the developed hot work chair is able to improve body postures and to reduce the muscle discomfort affecting hot work workers. There was considerable evidence that chair backrests minimize paraspinal muscle activation and low back disorders in seven studies that reviewed the effect of sitting with and without a backrest using the PEDro scale (Curran M. et al., 2015).

During this testing, the five respondents had answered the muscle discomfort survey with 100-mm VAS for their current seating practices for 3 hours. All of them started with their daily routine job first using the current seating practices before they fill up the provided muscle discomfort survey form. Then they had given one hour rest before proceed with initial testing of the prototype. Then they had been provided with the developed prototype of the hot work chair to be used for another 3 hours to compare the effectiveness of the prototype of the hot work chair. Table 4.12 shows the initial testing mean score obtained for the discomfort ratings before and after using the prototype. The initial testing results show that the muscle discomfort ratings after using the hot work chair had been reduced significantly compared with ratings generated before using the chair. The overall discomfort rating before using the prototype is 70.33mm and for post-test is 35.67mm which is about 49.3% reduction of discomfort rating after using the hot work chair.

Table 4.11: Initial testing mean score obtained for the discomfort ratings before and after use the prototype (N=5)

Body Region	Discomfort ratings (mm)		Average improvement %	Z statistic	p-value
	Existing seat	Prototype seat			
Neck	69.50	39.25	43.5	-3.062	0.002
Shoulder	73.92	36.67	50.4	-3.062	0.002
Hand	50.08	38.92	22.3	-2.941	0.003
Upper back	66.33	40.92	38.3	-3.062	0.002
Lower back	66.50	37.33	43.9	-3.062	0.002
Buttock	77.50	37.00	52.3	-3.062	0.002
Thigh	76.08	38.83	48.9	-3.063	0.002
Calf	69.58	34.75	50.1	-3.061	0.002
Knee	74.17	36.75	50.5	-3.061	0.002
Feet	54.83	36.67	33.1	-3.062	0.002
Overall discomfort	70.33	35.67	49.3	-3.064	0.002

This design and development process had been facilitated with the Pugh design and product design specification approaches based on the literature review, feedback from workers who were involved in the hot works at the company and supported with technical advice from engineering experts. In a previous study conducted, using ergonomic engineering interventions had demonstrated a positive result from respondents that improved their health (Umar et., 2019). Programs for ergonomic intervention may be successful in lowering workers' ergonomic risk factors and, as a result, in the secondary prevention of MSDs (Esmaeilzadeh S. et al., 2012). This study had proven that hot work chair that had been designed and developed as prototype gives a positive impact in reducing the muscle discomfort level affecting hot work workers who carry out job in seating positions. This is supported by the initial testing study and direct observation when they carry out the job. The results from a separate study showed that the suggested on-chair postures had significantly lower mean muscle activity compared with the identified postures ($p < 0.001$) and among the identified postures, kneeling posture had the lowest mean muscle activity ($p < 0.01$), still significantly higher than the mean activity of the on-chair postures ($p < 0.001$). Applying a 15° slope to the seat pad led to a decrease in muscle activity and an increase in usability score (Tahmasebi R. et., 2020).

When using the provided hot work chair, the selected workers were able to sit comfortably with proper seats, back support, arm support, chest arrest and knee support while carrying out the welding activities and had demonstrated that this developed hot work chair was able to support their body position more effectively. This hot work chair prototype is still in the preliminary stage and it requires more additional tests like virtual test (stress analysis, crash analysis) and clinical test (intradiscal pressure of the spine, electromyography) and design iterations (Nurathirah, 2021). However, based on initial stage and evaluation in the third phase of this study, this designed and developed hot work chair is completely functional and able to give support and comfort to the workers when performing hot works. Therefore, it has generated positive feedback among the tested respondents and has high potential in reducing discomfort level and improves the working posture of hot work workers.

4.6 Objective 5 - Evaluation of the developed hot work chair

4.6.1 Sociodemographic and Occupational profile of selected hot work workers

There are twenty-four hot work workers from the chosen company selected as respondents in this last stage of the study to evaluate the effectiveness of the designed and developed hot work chair. They had been divided equally into control and experimental groups which consist of twelve respondents for each group. The respondents' demographic data from both control and experimental group were tabulated in Table 4.11. There is no significant difference identified between workers of each group. The mean age for control group is 36.08 ± 6.37 years while for experimental group is 37.42 ± 6.13 years. Next, the mean height for control group is 161.92 ± 4.36 cm and for experimental group is 164.50 ± 5.68cm. This is followed by the weight range for control group is 70 – 101 kg and for experimental group is 68 – 95kg.

Table 4.12: Distribution of Socio-demographic and occupational profiles between the control group and experimental group (N=24)

Body Region	Control group (n=12)	Experimental group (n=12)	Z statistic	p-value
Age				
Mean ± SD	36.08 ± 6.37	37.42 ± 6.13	-0.445	0.657
Range	26 – 45	28 – 46		
Height				
Mean ± SD	161.92 ± 4.36	164.50 ± 5.68	-1.246	0.213
Range	155 - 171	155 – 172		
Weight				
Mean ± SD	84.00 ± 8.62	80.50 ± 8.50	-1.009	0.313
Range	70 – 101	68 – 95		
BMI (kg/m^2)				
Mean ± SD	32.03 ± 4.14	29.77 ± 3.04	-1.413	0.158
Range	25 - 40	25 – 36		
Working hours/day				
Mean ± SD	10 ± 0.0	10 ± 0.0	0.000	1.000
Range	10	10		

** p-value is significant at p<0.01

There is no significant difference in mean of BMI between control group and experimental group. The average working hours for both control group and experimental group is 10 hours per day. During the study duration, all respondents requested to work for a maximum 10 hours only with approval from their manager to prevent other factors like worker's fatigue or stress to affect the assessment results.

4.6.2 Distribution of Discomfort Ratings

During phase 3 of this study, control and experimental group respondents had answered the questionnaires provided after the shift ended. Figure 4.13 shows that the control group respondents had almost similar discomfort ratings for most of the specified body regions for both pre-test and post-test. In comparison of the body regions, buttocks had scored the highest discomfort rating which is 73.67 ± 12.75mm for pre-test and 72.17 ± 12.58mm for post-test among control group workers. This is followed by thigh and knee. The discomfort ratings for thigh is 71.75 ± 8.99mm for pre-test and 72.75 ± 9.13mm for post-test while the discomfort ratings for knee is 73.08 ± 10.10mm for pre-test and 71.50 ± 10.17mm for post-test. The other body regions which score relatively high discomfort rating more than 60mm are calf, shoulder, neck, upper back, and lower back. The overall discomfort ratings of control group respondents during pre-test are 67.17 ± 8.04mm and for post-test is 67.58 ± 8.039mm. Hot work workers suffer from muscle discomfort due to bending over prolonged duration, sitting on floors or any non-suitable materials, frequent awkward body postures and others (Oanh Nguyen, 2016).

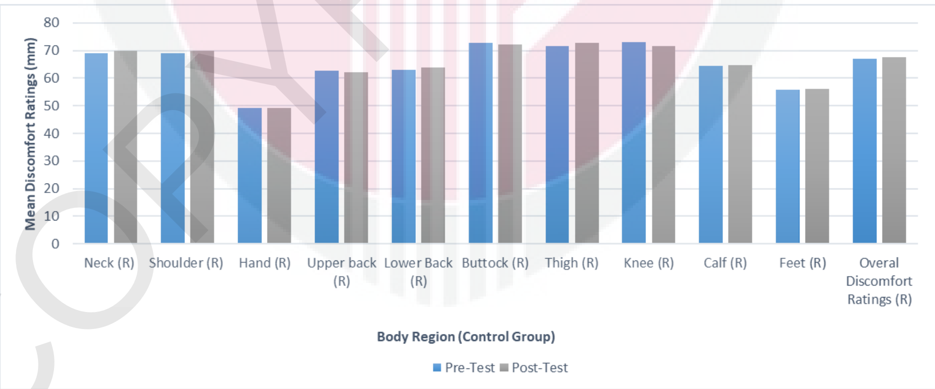


Figure 4.13: Distribution of discomfort ratings based on body regions by control group from Pre-test and Post-test

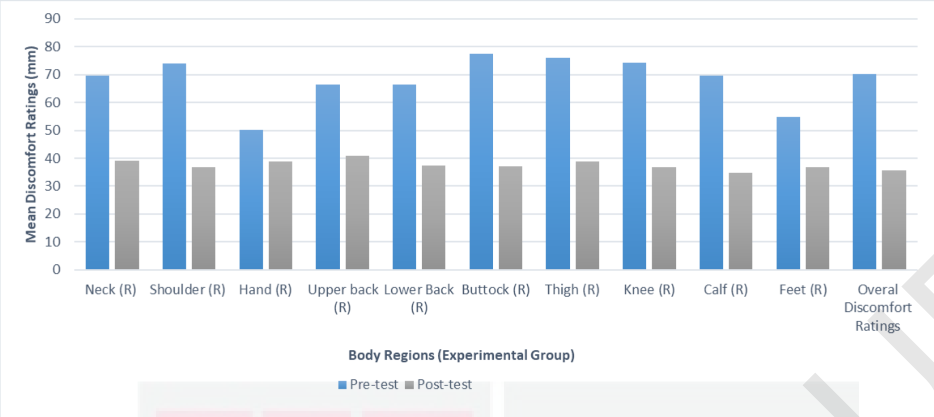


Figure 4.14: Distribution of discomfort ratings based on body regions by experimental group from Pre-test and Post-test

Figure 4.14 shows the results of experimental group which relatively has a significant difference between pre-test and post-test in muscle discomfort ratings for the specified body regions. During the pre-test, buttocks with highest discomfort ratings which is 77.50 ± 4.78mm had been reduced to 37.00 ± 4.13mm during the post-test. This is followed by the discomfort rating of thigh which is 76.08 ± 5.32mm during pre-test had been reduced to 38.83 ± 3.157mm during post-test. This is followed by the discomfort ratings of knee during pre-test which is 74.17 ± 5.65mm and had decreased to 36.75± 5.065 during post-test. The other body regions including calf, shoulder, neck, upper back and lower back previously scored high discomfort ratings during pre-test but then reduced significantly during the post-test. The discomfort ratings of calf reduced from 69.58 ± 9.70mm into 34.75 ± 3.11mm while shoulder had shown a reduction of rating from 73.92 ± 8.21mm to 36.67 ± 6.33mm. The upper back's discomfort ratings for pre-test is 66.33 ± 6.29mm and then reduced into 40.92 ± 5.90mm while lower back's discomfort ratings during pre-test had reduced 43.86% during post-test. The overall discomfort ratings of experimental group recorded during pre-test is 70.33 ± 3.47 compared with 35.67 ± 3.77mm score during post-test which is about 49% reduction of discomfort rating after using the hot work chair. Three ergonomic intervention studies were conducted in a garment factory, workshop and in an office found a significant reduction in self-reported musculoskeletal pain immediately after the intervention (Van Niekerk et al., 2012).

4.6.3 Comparison of Muscle Discomfort ratings between Pre-Test and Post-Test studies

The data analysis using Wilcoxon Signed-rank test showed that the muscle discomfort ratings of all specified body regions for experimental group are significantly different between pre-test and post-test evaluation results including neck (Z = -3.062, p=0.02), shoulders (Z = -3.062, p = 0.02), hand (Z = - 2.941, p

= 0.002), upper back (Z = -3.062, p=0.002), lower back (Z = -3.062, p=0.002), buttocks (Z = -3.062, p=0.002), thigh (Z = -3.063, p=0.002), calf (Z = -3.061, p=0.002), knee (Z = -3.061, p=0.002) and feet (Z = -3.062, p=0.002). The overall discomfort rating for experimental group between pre-test and post-test also shows a significant difference with Z = -3.062, p=0.002. However, there were no significant differences for control group workers between pre-test and post-test for the same specified body regions. The details of the mean and median score for the body discomfort ratings between pre and post-test have been tabulated in table 4.12 below.

Table 4.13: Mean and Median score for the body discomfort ratings between pre-test and post-test (N=24)

Body Region	Group	Mean (Median)		Z statistic	p-value
		Pre-test	Post-test		
Neck	Control	69.00 (70.00)	69.83 (71.50)	-1.852	0.064
	Experimental	69.50 (71.00)	39.25 (36.50)	-3.062	0.002*
Shoulder	Control	68.92 (71.00)	70.00 (74.00)	-0.717	0.474
	Experimental	73.92 (76.00)	36.67 (35.50)	-3.062	0.002*
Hand	Control	49.08 (50.50)	49.33 (51.00)	-0.493	0.622
	Experimental	50.08 (50.00)	38.92 (40.00)	-2.941	0.002*
Upper back	Control	62.75 (64.50)	62.25 (63.50)	-0.902	0.367
	Experimental	66.33 (65.00)	40.92 (40.00)	-3.062	0.002*
Lower back	Control	63.08 (64.50)	63.92 (64.00)	-1.271	0.204
	Experimental	66.50 (67.50)	37.33 (37.50)	-3.062	0.002*
Buttock	Control	72.67 (75.00)	72.17 (73.00)	-0.040	0.968
	Experimental	77.50 (77.00)	37.00 (38.00)	-3.062	0.002*
Thigh	Control	71.75 (73.50)	72.75 (75.00)	-1.438	0.151
	Experimental	76.08 (75.50)	38.83 (39.50)	-3.063	0.002*
Calf	Control	73.08 (72.50)	71.50 (73.00)	-1.041	0.298
	Experimental	74.17 (75.00)	36.75 (35.00)	-3.061	0.002*
Knee	Control	64.50 (67.00)	64.83 (69.00)	-0.238	0.812
	Experimental	69.58 (70.50)	34.75 (35.00)	-3.061	0.002*
Feet	Control	55.83 (56.50)	56.17 (57.50)	-0.449	0.653
	Experimental	54.83 (54.50)	36.67 (38.00)	-3.062	0.002*
Overall discomfort	Control	67.17 (69.00)	67.58 (70.00)	-0.583	0.560
	Experimental	70.33 (70.00)	35.67 (35.00)	-3.064	0.002*

** p-value is significant at p<0.01

The third phase which is the final phase of this research study has been conducted successfully to investigate the effectiveness of the designed and developed prototype of the hot work chair among the selected respondents. During pre-test, most of the respondents from both control and experimental group had experienced high level of discomfort ratings for buttocks, thigh, knee, calf, shoulder, neck, upper and lower back. This is due to ergonomic risk factors which had been identified from during phase one of this study. Based on the initial ergonomic risk assessment conducted, the awkward body postures, repetitive motions, static and sustained work postures were identified as ergonomics risk factors affecting the selected hot work workers. The Quick Exposure Check (QEC) assessment also showed that selected workers scored very high risk for body parts including back, shoulder, arm parts and neck. During the pre-test, workers continually followed the current seating practices of workers using metal sheets and plastic containers to sit for welding, grinding and other hot works for long hours which increases the muscle discomfort ratings and muscle pains on their body parts. Without a proper seat, without knee support, without back and chest support and carrying out work in awkward body positions had increased the ergonomic risk factors among the workers. However, the newly designed and developed hot work chair has proved the discomfort level before using the hot work chair could be reduced significantly with the aid of hot work chair. Through this research study, it was found that there is a significant difference in muscle discomfort ratings between pre-test and post-test between the experimental group for buttocks, thigh, knee, neck, calf, shoulder, upper and lower back. The overall discomfort ratings of experimental group during pre-test is 70.33 ± 3.47 and for post-test is 35.67 ± 3.77mm which is about 49% reduction of discomfort rating after using the hot work chair. Cham and Redfern, (2001) has studied about the effect of several mat to muscle discomfort and fatigue. The findings revealed a statistically significant difference in discomfort and leg tiredness after the third hour for everyone (p 0.05). Reduced discomfort was also associated with mats with higher elasticity, decreased energy absorption, and improved stiffness (r=0.4-0.9) (Cham and Redfern, 2001).

Most of the discomfort ratings showed that this intervention of the hot work chair is very effective on almost all parts of the body and this shows that workers felt more comfortable and experienced lesser muscle discomfort or pain when using the designed and developed prototype of the hot work chair. The intervention of the hot work chair seat also resulted a positive impact on the buttock and thigh area which had been identified as main affected area on workers because it reduced the pressure on the ischium. The buttock-thigh tissues have the most pressure on the body during seating and it could worsen the situation without the presence of back or chest support where the pressure couldn't be distributed effectively (Tang et al, 2010). The new developed hot work chair has been made with a strong seat covered with cushion material that gives real satisfaction and comfort for workers. The development of musculoskeletal diseases brought on by intense muscle activity as a result of awkward positions can be mitigated by using a proper chair or support for multiple work postures (Tahmasebi R. et al., 2020). This flexible hot work chair has improved the muscle discomfort level at other parts of body like the lower and upper back, knee, calf, shoulder, and neck. This hot work chair has an adjustable back rest which can be detached and attached in opposite ways as a chest rest. There is a knee support which can be used for seating position giving a comfortable environment for workers to carry out welding or other hot jobs while kneeling for longer time.

The seat, back rest, and knee support have cushion with contour shape that could support the body's different postures. This is a movable chair which has attached strong wheels and easy to operate, handle and maintain. The flexibility of this chair provides the user for multiple types of seating positions based on their needs and working environment. This helps workers to maintain their body postures ergonomically while working and could give real satisfaction and comfort to them while doing their jobs. The results of a review done have shown a consistent pattern supporting the use of a chair intervention to lessen musculoskeletal problems in workers who have to sit for extended periods of time. The effectiveness of a chair intervention, particularly with regard to musculoskeletal problems, as well as the recurrence of symptoms and the resulting cost of care, are unknown until more trials are undertaken (Van Niekerk et al., 2012). It is also important to enforce and ensure all affected workers use the designed chair accordingly and effectively to get better results. The advantages of ergonomics are obtained through teamwork, which eventually results in a comfortable work environment and safe working postures, which leads to a more productive and lucrative hot work operation and maintains the long-term health of hot work personnel.

4.7 Summary

The research study has been completed successfully as per the methodology described in Chapter 3. The study has been conducted in three phases. Phase 1 to assess the muscle discomfort level among the workers and ergonomic risk assessment including initial ergonomic assessment, muscle fatigue assessment, REBA and QEC was conducted and the result obtained showed the workers are affected with ergonomic risk factors associated with their current seating practices when they perform hot works that increase the overall muscle discomfort level. Phase 2 of the study to design and develop is completed successfully establishing product design specifications, conceptual designs, selection of the best design, development process of the prototype and initial testing for the prototype. Initial testing based on observation and muscle discomfort assessment has proven that the developed hot work chair has reduced muscle discomfort ratings among the hot work workers and improved their working body postures. The last phase of the study which is to evaluate the effectiveness of the hot work chair based on pre-test and post-test assessment carried out among the experimental group respondents shows the muscle discomfort level for all the specified body regions has been reduced significantly compared with control group respondents with no significant changes.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Research

The research study based on the objectives and hypothesis set in the early stage have been summarized below.

I. Objective 1: To identify the muscle discomfort among hot work workers

During the initial observation, past ill-health records and medical leaves statistics review, it was found workers in the hot work section of the company suffered with muscle pain and discomforts at multiple body parts. An assessment was conducted to assess the muscle discomforts ratings among the hot work workers based on the body discomfort chart. In total 110 hot work workers from the company were included as samples in this assessment. A set of questionnaires was used in this study. Out of 110 respondents, only 7 workers are from Malaysia and the balance 103 workers are foreigners. The workers were selected mainly from three hot works section which are welding, grinding and from metal cutting section. Out of 110 workers, 50% of the respondents are welders and this followed by 35% from the grinding section and balance 25% are from metal cutting section. Buttocks is the main body part that affects hot work workers with the highest mean of muscle discomfort which is 71.28 ± 9.91mm for left buttocks and 72.07 ± 8.87mm for right buttocks. The next highest rating recorded for muscle discomfort is the right knee with mean 72.41 ± 8.60mm and the right thigh with mean 72.07 ± 8.87mm. This was followed by the right shoulder, left knee, left thigh, right neck, left neck, and left shoulder accordingly. The overall mean of body discomfort level experienced by respondents is 67.98 ± 6.90mm. There is a strong positive significant correlation found between the years of hot work experiences and age of workers ($p < 0.01$, $r = 0.763$) and moderate positive correlation between years of hot work experiences and overall discomfort ratings ($p < 0.01$, $r = 0.374$). There is also a significant correlation between age of workers and overall discomfort ratings ($p < 0.01$, $r = 0.300$).

II. Objective 2: To conduct the initial risk assessment among the hot work workers

Hot work workers had raised multiple complaints on the current seating and working posture when carrying out hot works at the company that could cause the muscle pains and discomforts. The three workers from each hot work divisions in this company—the welding, grinding, and cutting sections—were each subjected to an initial ergonomic risk assessment. Initial ERA scores were calculated using each component observed and examined in accordance with the 2017 Guidelines on Ergonomics Risk Assessment at Workplace published by DOSH Malaysia. As proof for reporting, both video and photographic images were taken. Overall, the three chosen workers had scores of 18, 18, and 17, respectively. Awkward postures, repetitive motions, static and continuous work positions, vibration, poor ventilation, noise exposure, and working in excessive heat are among the ergonomic risk factors that have been identified based on assessment. The advanced ergonomic risk assessment was used to further assess the identified ergonomic risk factors for those risk variables that had scores above the minimum score required by the guidelines.

III. Objective 3: To conduct advanced ergonomic risk assessment among hot work workers during seating position through Rapid Entire Body Assessment (REBA), Quick Exposure Check (QEC) and Muscle Fatigue Assessment.

The advanced ergonomic risk assessment which consists of REBA, QEC and Muscle Fatigue Assessment was conducted on the selected hot work workers from the three hot work units in this company including welding, grinding, and cutting section. The results of the muscle fatigue assessment for the chosen workers indicated that the right shoulders, right wrist/hand/finger, right legs/knees, and left legs/knees all scored very high fatigue. The results of the Rapid Whole-Body Assessment (REBA) form, which included ratings for body posture, forces applied, the type of movement or action, repetition, and coupling activities, were compiled to produce a final REBA score. One employee was identified as having a total score of "10," placing him in the "High Risk" category, while two other employees were found to have total scores of "12," placing them in the "Very High Risk" category. Quick Exposure Checklist (QEC) had two parts to be completed by the observer for the first part and the worker for the second part. Their answers were transferred into a scoring table and the results show that the respondents had been identified with ‘very high risk’ for Shoulder or Arm and Neck with average score of 47 and 16 respectively. This was followed by back in static position with average score of 23 and wrist or hand with an average score of 38 are classified as ‘high risk’. Overall, all the body parts evaluated scored within the range from moderate risk to very high risk which showed that workers in this hot work section are really exposed to ergonomic risk factors that need immediate attention to prevent any muscle discomforts or MSDs.

IV. Objective 4: To develop a hot work chair for the workers

The fourth objective of this study is to design and develop a hot work chair for workers which had been completed successfully in three stages. Stage 1 of this design process had been conducted through reviewing extensive literature, muscle discomfort survey, ergonomic risk assessments, reviewing medical records of workers, feedback from workers and interview session with workers taken into the consideration to determine the criteria and specification to develop the prototype of the hot work chair. In Stage 2 of the development of hot work chair, a product design specification (PDS) had been established that consists of 18 elements where the final concepts, specifications and criteria were generated based on literature review and through consultation from engineering experts. Five conceptual designs were developed and compared using the Pugh Chart and the best design has been selected and developed into prototype of hot work chair. In stage 3, the developed hot work chair has been evaluated with initial testing with five selected workers based on the direct observation and muscle discomfort scale form. The initial testing results show that the muscle discomfort ratings after using the hot work chair had been reduced significantly compared with discomfort ratings before using the chair. In overall muscle discomfort score after using the prototype is lower and reduced about 42% from the scores obtained before using the prototype.

V. Objective 5: To compare the muscle discomfort level between the pre-test and post-test session (experimental and control groups) among hot work workers.

The final phase of this research study is to evaluate and compare the muscle discomfort level between the control group workers that had continued performing their job without any changes and experimental group workers that used the developed hot work chair. A total of 24 respondents had been selected and divided into two groups (control group and experimental group) with 12 respondents for each group respectively. The Experimental group had been introduced with hot work chair and the control group continued with their current seating practices. Pre-test and post-test had been conducted to these control and experimental groups to obtain the muscle discomfort ratings before and after using the hot work chair. The data of muscle discomfort ratings collected for experimental group showed all body regions indicated with significant difference between pre-test and post-test. Buttocks with highest discomfort ratings which is 77.50 ± 4.78mm had been reduced into 37.00 ± 4.13mm during the post-test. This is followed by thigh, knee and other body regions including calf, shoulder, neck, upper back and lower back previously have scored high discomfort ratings during pre-test but then reduced significantly during the post-test. The overall discomfort ratings of experimental group recorded during pre-test is 70.33 ± 3.47 compared with 35.67 ± 3.77mm score during post-test which is about 49% reduction of discomfort rating after used the hot work chair. There were no significant differences had been notified between pre-test and post-test for control group for the same body regions.

5.2 Conclusions

This research study has been conducted to assess muscle discomfort level among the hot work workers, to design and develop a hot work chair and to evaluate the effectiveness of the developed hot work chair in reducing muscle discomfort on the affected workers. The final conclusions that could be generated based on the results obtained and statistical analysis are as below:

1. This research study demonstrates that there are high muscle discomfort ratings associated with hot works in seating position among hot work workers. Buttocks, knee, and thigh are the most affected body parts with the highest discomfort level among the workers due to awkward body postures when they carry out hot works such as welding and grinding using improper seating tools or without seats for prolonged work duration. Thus, an ergonomic hot work chair that suits the needs of hot work workers and their working environment has been developed in this study.

2. The initial ergonomic risk assessment which had been conducted at this company also supports the fact that the current seating postures had caused muscle discomfort and muscle pain among the hot work workers. Some of the ergonomic risk factors identified through initial ergonomic risk assessment are awkward postures, repetitive motions, static and sustained work postures and working in extreme temperature.

3. Almost everybody component, including the shoulders, right legs/knees, neck, left shoulders, back, and left legs/knees, exhibits high or extremely high risk of fatigue, according to the muscle fatigue assessment performed on selected workers. One respondent received a Rapid Whole-Body Assessment (REBA) score of "High Risk," while two more employees received a "Very High Risk" rating. All responders were found to be at "extremely high risk" for back (movement) and shoulder/arm components, according to the Quick Exposure Check (QEC) results. Overall, these ergonomic risk assessments showed that hot work workers at this organisation are exposed to a high risk of musculoskeletal illnesses and muscular pain due to awkward body postures, improper seating tools, lengthy periods of sitting, and static positions for extended periods of time. So, their working posture must be improved soon to prevent further discomfort level which may lead to MSD as well as to improve their work performance and productivity. As a result, the newly designed hot work chair developed in this study is anticipated to lower ergonomic risk factors impacting hot work workers and enhance their body postures.

4. A prototype of hot work chair has been successfully designed and developed in this research study based on feedback from workers, extensive literature review and the product design specification. The operational, structural, and functional expects of the prototype were successfully tested with selected workers and shown the initial potential

to reduce the muscle discomfort ratings and to improve the working body postures of hot work workers

5. There is a significant difference in the muscle discomfort ratings between the pre-test and post-test sessions in the experimental group. The usage of the hot work chair when they carry out their job, the type of materials used for the seating cushions, the special features added to the hot work chair such as back rest, chest rest, kneeling pad and stable moving chair have improved the body postures and provided better comfortability that may cause the reduction in muscle discomfort ratings.

6. Overall, the designed and developed hot work chair has proven the effectiveness in reducing the muscle discomfort ratings among the workers performing hot works like welding, grinding, metal cutting in seating position and therefore has potential in reducing the risk of developing MSD or other ergonomic disorders.

Improvement in ergonomics of workers will not only give protection to hot works from musculoskeletal injuries but also increase the productivity and profits of the company through effective welding operations. Stressful body postures and motions which are improper and inefficient can be eliminated or improved by using the developed hot work chair. This developed hot work chair is expected to improve the overall efficiency and productivity of the workers in all heavy industries that have the same working environment.

5.3 Study Limitations

There are a few unavoidable limitations involved throughout this study as below:

1. This study only involves hot work workers from one of the offshore manufacturing companies. Thus, the samples utilized in this research study cannot be used to generalise the whole population of hot work workers.

2. The designed and developed hot work chair is the new element that has been introduced to the selected workers. So, they were fully aware and excited on the hot work chair provided to them which may cause dishonest feedback when answering the evaluation. But the selected workers had been briefed on the importance of answering the question honestly for the improvement of the chair.

3. The next limitation is the number of the prototypes that had been developed in this research study. Due to the limited financial aid and limited resources like materials and equipment, only one prototype was developed for this study.

4. The time constraints also became one of the limitations in this study due to the heavy production period at the company and the workers took turns one by one to participate in the assessment and for evaluation of the hot work chair.

5. Due to Covid-19 restrictions, not all the workers were able participate at the time for this research study to prevent social distance issues and spreading of any Covid-19 disease among the respondents. That is the reason why 12 weeks has been consumed to conduct the evaluation of hot work chair among the selected respondents.

5.4 Recommendations for future Research

There are a few recommendations to be highlighted for future improvement of the developed hot work chair and for future related research studies as below:

1. The first recommendation is to include more hot work workers from other companies that have similar work environment to increase the accuracy and to obtain more generalised findings for the whole targeted sample population. Bigger the sample size utilized in the research; the results will be more reliable compared with a smaller sample size.

2. Apart from analysing the worker's work posture during hot works, it is also recommended to consider other contributing risk factors like the worker's stress level, workload, and worker's social or personal life that might affect their health that could cause muscle pains.

3. The effectiveness evaluation of the developed hot work chair could be done in an artificial laboratory that has clinical settings (i.e electromyography test) and virtual testing facility like specific software (i.e crash analysis, comfort analysis) to support the research findings with more variation in the measurement done among the users.

4. The designed and developed hot work chair could be improved in many ways. More studies should be done to the type of materials used to fabricate this hot work chair. The improvised cushion, the better leather and steels, and other raw materials with better quality could be used to enhance the current hot work chair to increase the efficiency and able to reduce more muscle discomforts ratings when carrying out the hot works.

5. The design of the hot work chair can be improved with additional ergonomic features like installation of detachable armrest, adjustable base of the chair, bigger chest arrest, and others special features which could make this chair able to be used not only in metal fabrication industry but also in other various industries.

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ETHICS COMMITTEE FOR RESEARCH INVOLVING HUMAN SUBJECTS
(JKEUPM)
UNIVERSITI PUTRA MALAYSIA

Research Title	:	**Ergonomic Risk Assessment and Development of a Hot-Work Chair at Selected Company.**
Study Site	:	**VG Metal Technology Sdn. Bhd., Taman Perindustrian Pulau Indah, Port Klang, Selangor.**
JKEUPM Ref No.	:	**JKEUPM-2022-214**
Researcher	:	**Sivabalan A/L Sanmugum**
Supervisor	:	**Assoc. Prof. Dr. Karmegam A/L Karuppiah**

Documents received and reviewed with reference to the above study:

1. Ethics Application Form, Version 1 dated 18/03/2022
2. Respondent's Information Sheet / Consent (English), Version 1 dated 18/03/2022
3. Respondent's Information Sheet / Consent (Malay), Version 1 dated 18/03/2022
4. Proposal (English), Version 1 dated 18/03/2022
5. Questionnaire / Interviews (English), Version 1 dated 18/03/2022
6. Questionnaire / Interviews (Malay), Version 1 dated 18/03/2022
7. Curriculum Vitae of:
   a. Assoc. Prof. Dr. Karmegam A/L Karuppiah
   b. Assoc. Prof. Dr. Irniza Binti Rasdi
   c. Dr. Vivien How
   d. Dr. Sivasankar A/L Sambasivam
   e. Sivabalan A/L Sanmugum

The University Research Ethics Committee, Universiti Putra Malaysia (JKEUPM) operates in accordance to the ICH-GCP Guidelines.
Decision by JKEUPM:

[X] Approved

[X] **Permission MUST BE OBTAINED from the respective hospitals/ institutions before conducting the research**

[ ] Disapproved

Please note that the approval is **VALID UNTIL 15 JUNE 2023**

Researchers should comply with the following:

I. Complete a Study Final Report upon study completion (Form 3.2).

II. Ethical approval is required in the case of amendments/ changes to the study documents/ study sites/ study team.

III. Applicable for Clinical Trial Studies and Clinical Interventional Studies only: Progress Report has to be submitted to JKEUPM at every 6 months from the date of approval (Form 3.1). Report

Appendix B: Information sheet in English

JAWATANKUASA ETIKA UNIVERSITI UNTUK PENYELIDIKAN MELIBATKAN MANUSIA (JKEUPM)
UNIVERSITI PUTRA MALAYSIA, 43400 UPM SERDANG, SELANGOR, MALAYSIA

FORM 2.4: RESPONDENT'S INFORMATION SHEET AND INFORMED CONSENT FORM

Please read the following information carefully and do not hesitate to discuss any questions you may have with the researcher.

1. STUDY TITLE :

Ergonomic Risk Assessment and Development of an ergonomic hot work chair at selected company

2. INTRODUCTION:

This is a research study to conduct ergonomic risk assessment at hot work section and develop a hot work chair which can improve the sitting and working position during the work works, which gave a comfort environment for work, reducing number of ergonomic complain by workers and also to provide a better space for workers to place personal protective equipment. The workers currently use metal sheets and plastic tools to sit for welding, grinding and other hot works for long hours with awkward positions which leaded to many ergonomic issues including muscle cramps, back pain, leg and ankle pain and many of them under medication as per in medical records and employee feedback forms. This designed hot work chair also needed to increase the efficiency of the hot works and also productivity of individual and company. The researcher also believed that the results of this study can reduce ergonomic incidents at hot work section, improving overall workers' health and quality of hot work in selected company mainly and also can be implemented generally in other industries which involving hot works as main core in their business

3. WHAT WILL YOU HAVE TO DO?

Sign the consent form which indicates your interest to participate in this study after you read and understand all the explanation given. You will need to answer a set of questionnaire to obtain the information about this study. The questionnaire set covers several sections which include personal data, occupational information, and perceived discomfort level on current practice of hot works. Then, the consent form and questionnaires should be returned to the researcher before the ergonomic risk assessment been carried out. The expected time to answer a set of questionnaires is 20 minutes only. Besides, you will be also asked to wear your usual uniform and usual PPE which currently being provided during the assessment. Then, a control group will be carried out hot work task as usual as per in current practice. The intervention group will be used the developed hot work chair when performing their hot works. Both groups should perform their daily task at hot work section. There are 24 hot work workers are needed for this study. However, this participation is voluntary, and that participant may withdraw anytime without penalty or loss of benefit to which the participant is entitled.

4. WHO SHOULD NOT PARTICIPATE IN THE STUDY?

This study only involves workers from metal fabrication section who are asigned for hot works at this company. Those workers who never involved in hot works less than 12 months and has history of musculoskeletal disease or injuries before joining this company as hot work workers should not participate in this study

5. WHAT WILL BE THE BENEFITS OF THE STUDY:

(a) TO YOU AS THE SUBJECT?

This study will provide the information about your health status, especially in related to Musculoskeletal Disorders. Several assessments on ergonomic risk factors will be conducted on you and no cost will be imposed to every participant. The ergonomic risk assessment will be conducted while you are performing hot works to identify and understand the ergonomic risk factors that affecting your job. Information and knowledge in related to safety and health will also be shared with the participants by the researchers throughout the study. The baseline data from this study may be used by the employer to provide programs towards a healthier work condition in the future including providing of hot work chair for their hot work workers.

(b) TO THE INVESTIGATOR?

A new design and development of a hot work chair which can improve the sitting and working position during the work works, gave a comfort environment for work, reducing number of ergonomic complain by workers and also to provide a better space for workers to place personal protective equipment. This designed hot work chair expected will increase the efficiency of the hot works and productivity

Appendix C: Information sheet in Malay

JAWATANKUASA ETIKA UNIVERSITI UNTUK PENYELIDIKAN MELIBATKAN MANUSIA (JKEUPM)
UNIVERSITI PUTRA MALAYSIA, 43400 UPM SERDANG, SELANGOR, MALAYSIA

BORANG 2.4: PENERANGAN DAN PERSETUJUAN RESPONDEN

Sila baca maklumat berikut dengan teliti. Sekiranya anda mempunyai sebarang pertanyaan, sila kemukakan kepada penyelidik.

1.TAJUK KAJIAN

Penilaian risiko ergonomik dan pembentukkan prototaip tempat duduk yang ergonomik bagi pekerja kerja-kerja panas.

2. PENGENALAN

Ini adalah kajian penyelidikan untuk menjalankan penilaian risiko ergonomik di bahagian kerja panas dan membangunkan kerusi kerja panas yang boleh meningkatkan kedudukan duduk dan bekerja semasa kerja kerja, yang memberikan persekitaran yang selesa untuk bekerja, mengurangkan bilangan pengadu ergonomik oleh pekerja dan juga menyediakan ruang yang lebih baik bagi pekerja untuk meletakkan peralatan pelindung diri. Para pekerja kini menggunakan helaian logam dan alat plastik untuk duduk untuk kimpalan, pengisaran dan lain-lain kerja panas untuk waktu yang lama dengan janggal kedudukan yang membawa kepada banyak masalah ergonomik termasuk kejang otot, sakit belakang, kaki dan sakit pergelangan kaki dan banyak daripada mereka di bawah ubat seperti dalam rekod perubatan dan borang maklum balas pekerja. Kerusi kerja yang direka khas ini juga diperlukan untuk meningkatkan kecekapan kerja panas dan juga produktiviti individu dan syarikat. Penyelidik juga percaya bahawa hasil kajian ini dapat mengurangkan insiden ergonomik di seksyen kerja panas, meningkatkan kesihatan keseluruhan pekerja dan kualiti kerja panas di kilang ini terutamanya dan juga boleh dilaksanakan di industri-industri lain yang melibatkan kerja-kerja panas sebagai teras utama dalam perniagaan mereka

3. APAKAH YANG PERLU ANDA LAKUKAN?

Tandatangani borang kebenaran yang menunjukkan minat anda untuk mengambil bahagian dalam kajian ini selepas anda membaca dan memahami semua penjelasan yang diberikan. Anda perlu menjawab satu set soal selidik untuk mendapatkan maklumat mengenai kajian ini. Set soal selidik meliputi beberapa bahagian yang merangkumi data peribadi, maklumat pekerjaan, dan tahap ketidakselesaan yang dirasakan pada amalan semasa kerja panas. Kemudian, borang persetujuan dan soal selidik hendaklah dikembalikan kepada penyelidik sebelum penilaian risiko ergonomik dijalankan. Masa yang dijangkakan untuk menjawab satu set soal selidik adalah 20 minit sahaja. Selain itu, anda juga akan diminta untuk memakai PPE seragam biasa dan biasa yang sedang disediakan semasa penilaian. Kemudian, kumpulan kawalan akan menjalankan tugas kerja panas sebagaimana biasa dalam amalan semasa. Kumpulan intervensi akan menggunakan kerusi kerja panas yang dibangunkan ketika melakukan kerja panas mereka. Kedua-dua kumpulan itu harus melakukan tugas harian mereka di bahagian kerja panas. Terdapat 24 pekerja 'hot works' diperlukan untuk kajian ini. Bagaimanapun, penyertaan ini adalah secara sukarela, dan peserta boleh menarik balik bila-bila masa tanpa penalti atau kehilangan manfaat yang menjadi hak peserta. boleh menarik balik bila-bila masa tanpa penalti atau kehilangan manfaat yang mana peserta berhak

4. SIAPA YANG TIDAK BOLEH MENYERTAI KAJIAN INI?

Kajian ini hanya melibatkan pekerja-pekerja dari bahagian fabrikasi logam yang ditugaskan untuk kerja-kerja panas di syarikat ini. Pekerja-pekerja yang tidak pernah terlibat dalam kerja 'hot works' kurang dari 12 bulan dan mempunyai sejarah penyakit otot atau kecederaan sebelum bergabung dengan syarikat ini sebagai pekerja panas tidak seharusnya terlibat dalam kajian ini

5. APAKAH FAEDAH MENYERTAI KAJIAN INI?

a) KEPADA ANDA SEBAGAI PESERTA?

Kajian ini akan memberikan maklumat mengenai status kesihatan anda, terutamanya berkaitan dengan Gangguan Muskuloskeletal. Beberapa penilaian mengenai faktor risiko ergonomik akan dijalankan ke atas anda dan tiada kos akan dikenakan kepada setiap peserta. Penilaian risiko ergonomik akan dijalankan semasa anda melakukan kerja panas untuk mengenal pasti dan memahami faktor risiko ergonomik yang mempengaruhi pekerjaan anda. Maklumat dan pengetahuan yang berkaitan dengan keselamatan dan kesihatan juga akan dikongsi bersama para peserta penyelidik sepanjang kajian. Data asas dari kajian ini boleh digunakan oleh majikan untuk menyediakan program ke arah keadaan kerja yang lebih baik pada masa akan datang termasuk menyediakan kerusi kerja untuk pekerja mereka.

Appendix D: Consent form

JAWATANKUASA ETIKA UNIVERSITI UNTUK PENYELIDIKAN MELIBATKAN MANUSIA (JKEUPM)
UNIVERSITI PUTRA MALAYSIA, 43400 UPM SERDANG, SELANGOR, MALAYSIA

BORANG 2.4: INFORMED CONSENT FORM

I …………………………………............... Identity Card Num/ Passport Num.

……………………………...address…………………………………………………….

…………………………………………………......... hereby voluntarily agree to take part in the research stated above *(clinical /drug trial/video recording/ focus group/interview-based/ questionnaire-based/ assessment).

I have been informed about the nature of the research in terms of methodology, possible adverse effects and complications (as written in the Respondent's Information Sheet). I understand that I have the right to withdraw from this research at any time without giving any reason whatsoever. I also understand that this study is confidential and all information provided with regard to my identity will remain private and confidential.

I* wish / do not wish to know the results related to my participation in the research

I agree / do not agree that the images/photos/video recordings/voice recordings related to me be used in any form of publication or presentation (if applicable)
* delete where necessary

Signature……..……………… (Respondent)   Signature ……..……………………… (Witness)

Date :…………………………   Name :………………………………

I/C No. :……………………………......

I confirm that I have explained to the respondent the nature and purpose of the above-mentioned research.

Date : ……..…………………   Signature ……..………………………… (Researcher)

BORANG 2.4: PERSETUJUAN RESPONDEN

Saya……………………………… No Kad Pengenalan. ……………………………

beralamat……………………………………………………………………………

……………………………………………………..dengan ini bersetuju untuk mengambil bahagian secara sukarela dalam penyelidikan yang tersebut di atas *(kajian klinikal/percubaan ubat-ubatan/rakaman video/kumpulan sasaran/temuduga/ soal selidik).

Saya telah diberi penjelasan secara menyeluruh mengenai penyelidikan ini dari segi metodologi, risiko dan komplikasi (seperti tertulis pada Helaian Penerangan Responden). Saya memahami bahawa saya berhak menarik diri dari penyelidikan ini pada bila-bila masa tanpa memberi sebarang alasan.Saya juga memahami bahawa sebarang maklumat yang berkaitan identiti saya akan dirahsiakan.

Saya* berminat / tidak berminat untuk mengetahui keputusan kajian yang melibatkan saya.

I setuju/tidak bersetuju untuk imei/gambar/rakaman video/ rakaman suara digunakan dalam apa jua bentuk penerbitan atau pembentangan. (sekiranya berkaitan).

*potong yang tidak berkenaan

Tandatangan ……..…………………… Tandatangan ……..……………………
(*Responden*) (*Saksi*)

Tarikh :………………………… Nama :………………………………….…..

No. K/P:……………………………….…..

Saya mengesahkan bahawa saya telah menerangkan kepada responden ini sifat dan tujuan penyelidikan yang tersebut di atas.

Tarikh ……..………………… Tandatangan ……..…………………………
(*Penyelidik*)

Appendix E: Questionnaire in English

ID NUM : ....

DATE : ....

SIGNATURE : ....

<u>INSTRUCTION:</u>

1. This questionnaire contains several parts which are:

PART A	Background Details
PART B	Work and Medical History details
PART C	Self-Assessment on Musculoskeletal pain
PART D	Body parts discomfort rating (Pre and Post)

2. You are required to answer all the questions available in this questionnaire

3. To answer, please tick the answer in the reply section that has been prepared.

4. The questionnaire should be returned to the researcher upon completion of answering all questions.

BAHAGIAN A: MAKLUMAT LATAR BELAKANG DIRI

1. Age: ☐☐ years

2. Race:
   - ☐ Malay
   - ☐ Indian
   - ☐ Chinese
   - ☐ Others

2. Nationality:
   - ☐ Malaysian
   - ☐ Bangladeshi
   - ☐ Nepalese
   - ☐ Indian
   - ☐ Lain-Lain

3. Marital status:
   - ☐ Single
   - ☐ Married
   - ☐ Divorced

4. Education level:
   - ☐ Never attended schools
   - ☐ Primary / UPSR
   - ☐ Secondary / PMR / SPM / STPM
   - ☐ Certificate / Diploma / Bachelor

5. Height: ☐☐ cm

6. Weight: ☐☐ kg

PART B: WORKING EXPERIENCE AND MEDICAL HISTORY

1. What is the previous job/post and how long you worked?

   ____

2. List all the hot work activities you carried out here such as welding, grinding, or metal cutting.

   ____

3. What is your current job/position?

   ____

4. How many years (experience) you have as a hot work worker including welding, grinding, or metal cutting?

   ___________________ years

5. What is your average of total hours you are working in one day?

   ___________________ hours

6. Do you have any past or current musculoskeletal disorders, back pain, muscle pain, or other parts of body?

   _____ If yes, list down: ______________________________________

7. Have you thought on why you getting the pain or disorders as stated in above?

   ____

8. Do you have any other medical disease or illness other than stated in above?

   _____ If yes, list down : ______________________________________

PART C: BODY PARTS DISCOMFORT RATINGS

PRE - TEST

BAHAGIAN C(i): TAHAP KETIDAKSELESAAN ANGGOTA BADAN **BAGI PRA-UJIAN**
PART C(i): Body parts discomfort ratings for pre-test
Tandakan pada garisan [/] di setiap soalan mengikut tahap ketidakselesaan di setiap bahagian anggota badan anda

	Tiada Ketidakselesaan /*No discomfort*		Ketidakselesaan melampau/*Extreme discomfort*
1. Leher/*Neck*			
2. Bahu/*Shoulder*			
3. Tangan/*Hand*			
4.Belakang atas/*Upper back*			
5. Belakang bawah/*Lower back*			
6.Punggung/*Buttock*			
7.Peha/*Thigh*			
8. Lutut/*Knee*			
9. Betis/*Calf*			
10. Kaki/*Feet*			
11.Tahap ketidakselesaan keseluruhan/*Overall discomfort rating*			

POST – TEST

BAHAGIAN C(ii): TAHAP KETIDAKSELESAAN ANGGOTA BADAN **BAGI PASCA-UJIAN**

PART C(ii): Body parts discomfort ratings for post-test
Mark on the [/] line in each question according to the discomfort level for each body parts

	Tiada Ketidakselesaan /*No discomfort*		Ketidakselesaan melampau/*Extreme discomfort*
1. Leher/*Neck*			
2. Bahu/*Shoulder*			
3. Tangan/*Hand*			
4.Belakang atas/*Upper back*			
5. Belakang bawah/*Lower back*			
6.Punggung/*Buttock*			
7.Peha/*Thigh*			
8. Lutut/*Knee*			
9. Betis/*Calf*			
10. Kaki/*Feet*			
11.Tahap ketidakselesaan keseluruhan/*Overall discomfort rating*			

Appendix F: Questionnaire in Malay

BORANG SOAL-SELIDIK

NO. ID : ....

TARIKH : ....

TANDATANGAN : ....

ARAHAN SOALAN:

1. Borang soal selidik ini mengandungi beberapa bahagian iaitu:

BAHAGIAN A	Maklumat latar belakang diri
BAHAGIAN B	Maklumat pekerjaan dan Masalah Kesihatan
BAHAGIAN C	Tahap ketidakselesaan anggota badan
BAHAGIAN D	Tahap ketidakselesaan tempat duduk motorsikal

2. Anda diminta untuk menjawab semua soalan yang ada di dalam borang soal selidik ini.

3. Untuk menjawab, sila tandakan jawapan di bahagian jawapan yang telahdisediakan.

4. Borang soal selidik hendaklah dikembalikan kepada penyelidik setelah selesai menjawab semua soalan.

BAHAGIAN A: MAKLUMAT LATAR BELAKANG DIRI

1. Umur : ☐☐ Tahun

2. Bangsa:
   - ☐ Melayu
   - ☐ India
   - ☐ Cina
   - ☐ Lain-Lain

2. Warganegara:
   - ☐ Malaysia
   - ☐ Bangladesh
   - ☐ Nepal
   - ☐ India
   - ☐ Lain-Lain

3. Status Berkahwin:
   - ☐ Bujang
   - ☐ Berkahwin
   - ☐ Bercerai

4. Tahap Pendidikan:
   - ☐ Tidak Bersekolah
   - ☐ Rendah / UPSR
   - ☐ Menengah / PMR / SPM / STPM
   - ☐ Sijil / Diploma / Ijazah

5. Tinggi: ☐☐ cm

6. Berat: ☐☐ kg

BAHAGIAN B: MAKLUMAT PEKERJAAN DAN SEJARAH KESIHATAN

1. Apakah pekerjaan/jawatan dahulu dan berapa tahun telah bekerja?

   ____

2. Senaraikan aktiviti kerja panas yang anda lakukan seperti kimpalan, pengisaran, atau memotong logam

   ____

3. Apakah jawatan anda sekarang?

   ____

4. Berapa tahun (pengalaman) anda sebagai perkerja 'hot work' termasuk aktiviti kimpalan, pengisaran, atau memotong logam?

   ____________________ tahun

5. Berapa jamkah secara purata anda bekerja dalam sehari?

   ____________________ jam

6. Adakah anda pernah atau sedang mengalami apa-apa masalah gangguan musculoskeletal, sakit otot/tendon/sendi/belakang atau apa-apa sakit di anggota badan?

   _____ Jika Ya, senaraikan : ________________________________

7. Anda rasa kenapa anda dapat masalah kesihatan seperti di atas?

   ____

8. Adakah anda pernah atau sedang mengalami apa-apa masalah kesihatan umum yang lain selain daripada senarai di atas?

   _____ Jika Ya, senaraikan : ________________________________

BAHAGIAN C: TAHAP KETIDAKSELESAAN ANGGOTA BADA

PRE-UJIAN

BAHAGIAN C(i): TAHAP KETIDAKSELESAAN ANGGOTA BADAN **BAGI PRA-UJIAN**
PART C(i): Body parts discomfort ratings for pre-test
Tandakan pada garisan [/] di setiap soalan mengikut tahap ketidakselesaan di setiap bahagian anggota badan anda

	Tiada Ketidakselesaan /*No discomfort*		Ketidakselesaan melampau/*Extreme discomfort*
1. Leher/*Neck*			
2. Bahu/*Shoulder*			
3. Tangan/*Hand*			
4.Belakang atas/*Upper back*			
5. Belakang bawah/*Lower back*			
6.Punggung/*Buttock*			
7.Peha/*Thigh*			
8. Lutut/*Knee*			
9. Betis/*Calf*			
10. Kaki/*Feet*			
11.Tahap ketidakselesaan keseluruhan/*Overall discomfort rating*			

POS-UJIAN

BAHAGIAN C(ii): TAHAP KETIDAKSELESAAN ANGGOTA BADAN **BAGI PASCA-UJIAN**

PART C(ii): Body parts discomfort ratings for post-test
Mark on the [/] line in each question according to the discomfort level for each body parts

	Tiada Ketidakselesaan /*No discomfort*		Ketidakselesaan melampau/*Extreme discomfort*
1. Leher/*Neck*			
2. Bahu/*Shoulder*			
3. Tangan/*Hand*			
4.Belakang atas/*Upper back*			
5. Belakang bawah/*Lower back*			
6.Punggung/*Buttock*			
7.Peha/*Thigh*			
8. Lutut/*Knee*			
9. Betis/*Calf*			
10. Kaki/*Feet*			
11.Tahap ketidakselesaan keseluruhan/*Overall discomfort rating*			

LIST OF PUBLICATIONS

Sivabalan S., Karmegam K., & Sivasankar. (2020). Ergonomic Risk Assessment on selected Hot-work workers at company XXX. *Malaysian Journal of Public Health Medicine, 20* (Special 1): 176-185. (Published)

Sivabalan S., Karmegam K., Sivasankar S, Vivien H., & Irniza R. (2024). Effectiveness of the Developed Hot-work Chair Prototype for Hot-work Workers: A Preliminary Study in the View of Ergonomics, *Malaysian Journal of Medicine and Health Sciences (2024) 20(2): 218-225.* (Published)