# ERGONOMIC DESIGN OF HAND GLOVE FOR IMPROVING GRIP STRENGTH OF MALE ADULTS

Submitted in accordance with the requirement of the Universiti Teknikal Melaka Malaysia (UTeM) for the Bachelor Degree of Industrial Engineering (Hons.)

by

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# APPROVAL

This report is submitted to Faculty of Industrial and Manufacturing Technology and Engineering of Universiti Teknikal Melaka Malaysia as a partial fulfilment of the requirements for the degree of Bachelor of Industrial Engineering (Hons.). The members of the supervisory committee are as follows:

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**(Dr. Isa Bin Halim)**

# ABSTRAK

Permintaan yang semakin meningkat terhadap produk ergonomik yang fokus kepada kesejahteraan dan keselesaan telah menjadi jelas dalam beberapa tahun kebelakangan ini. Kekurangan sarung tangan ergonomik khusus untuk Shielded Metal Arc Welding (SMAW) menimbulkan kebimbangan keselamatan, menghalang prestasi, dan menyumbang kepada keletihan di kalangan tukang kimpal. Kajian ini bertujuan mereka bentuk sarung tangan ergonomik untuk meningkatkan kekuatan genggaman lelaki dewasa Malaysia. Projek ini menangani masalah kekuatan genggaman yang tidak mencukupi, yang boleh menjejaskan aktiviti harian dan pekerjaan. Objektif termasuk menganalisis kekuatan genggaman tangan dan hubungannya dengan pelbagai postur tangan dan badan, serta membangunkan prototaip sarung tangan SMAW yang meningkatkan prestasi genggaman. Metodologi melibatkan penciptaan set data dengan mengukur dimensi antropometrik tangan dan kekuatan genggaman dalam pelbagai postur (2x3=6 kombinasi: berdiri dan duduk untuk postur neutral, supinasi, dan pronasi), menjalankan analisis korelasi, dan membuat prototaip berdasarkan keperluan pengguna. Hasil kajian menunjukkan korelasi yang kuat (r = 0.93 hingga 0.95) antara kekuatan genggaman dan postur tertentu, yang membimbing ciri-ciri reka bentuk sarung tangan SMAW. Prototaip akhir menunjukkan penurunan 6.51% dalam pengurangan prestasi genggaman berbanding dengan sarung tangan SMAW tradisional, meningkatkan kepuasan pengguna untuk kegunaan peribadi dan profesional. Kajian ini menyumbang kepada reka bentuk sarung tangan SMAW yang ergonomik dan menawarkan penyelesaian praktikal untuk meningkatkan prestasi tukang kimpal dalam proses SMAW. Cadangan untuk kajian lanjut termasuk meneliti kesan bahan yang berbeza terhadap prestasi sarung tangan, menilai kepuasan pengguna jangka panjang, dan memperluas kajian untuk merangkumi faktor-faktor kekuatan genggaman yang lain.

# ABSTRACT

The growing demand for ergonomic products focusing on well-being and comfort has been evident in recent years. The observation of a lack of specialized ergonomic gloves for Shielded Metal Arc Welding (SMAW) raises safety concerns, hinders performance, and contributes to fatigue among welders. This study aims to design an ergonomic glove to enhance the grip strength of Malaysian male adults for SMAW process. The study focuses on Malaysian male adults to tailor the ergonomic glove design to local physiological characteristics and occupational needs in SMAW tasks. The project addresses the problem of inadequate grip strength, which can affect daily and occupational activities. The objectives of this study include analyzing hand grip strength and its correlation with various hand and body postures, and developing a prototype of SMAW glove that improves grip performance. The methodology involves creating a dataset by measuring hand anthropometric dimensions and grip strength, considering various postures (2x3=6 combinations: standing and sitting for neutral, supination, and pronation forearm postures), conducting a correlation analysis between grip strength and different postures, and prototyping an ergonomic glove based on user needs and product specifications. Results indicate strong correlations ($r = 0.93$ to 0.95) between grip strength and specific postures, guiding the design features of the SMAW glove. The final prototype shows a 6.51% reduction in grip impairment compared to traditional SMAW gloves, enhancing user satisfaction for personal and professional use. This study contributes to ergonomic SMAW glove design and offers practical solutions for enhancing welders performance in SMAW process. Recommendations for further study include exploring the impact of different materials on glove performance, assessing long-term user satisfaction, and expanding the study to include other grip strength factors.

# DEDICATION

I wholeheartedly dedicate this report to my father, Chai Yoon Jun, and my mother, Anne Tan Lee Peng, whose unwavering support, and boundless love have shaped my journey. To my elder sister, Yvonne Chai Yi Wen, and my elder brother, Webster Chai Meng Sheng, who have enriched my life as mentors and confidants. Their love, guidance, and unwavering support are the driving forces behind my academic achievements.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ABSI | - | A Body Shape Index |
| ANOVA | - | Analysis of Variance |
| ANSI | - | American National Standards Institute |
| BMI | - | Body Mass Index |
| CMP | - | Customized Measurement and Patternmaking |
| CRF | - | Chronic Renal Failure |
| CRs | - | Customer Requirements |
| DBP | - | Diastolic Blood Pressure |
| EDA | - | Exploratory Data Analysis |
| EDC | - | Extensor Digitorum Communis |
| FDR | - | False Discovery Rate |
| FDS | - | Fraction of Design Space |
| GMV | - | Gray Matter Volume |
| HGS/GS | - | Hand Grip Strength/Grip Strength |
| HOQ | - | House of Quality |
| ICFDH | - | International Classification of Functioning, Disability, and Health |
| MCP | - | Metacarpophalangeal |
| ME/CFS | - | Myalgic Encephalomyelitis/Chronic Fatigue Syndrome |
| NaN | - | Not a Number (used in computing) |
| NHANES | - | National Health and Nutrition Examination Survey |
| PPE | - | Personal Protective Equipment |
| QFD | - | Quality Function Deployment |
| SBP | - | Systolic Blood Pressure |
| SES | - | Socioeconomic Status |
| SMAW | - | Shielded Metal Arc Welding |
| SOP | - | Standard Operating Procedure |
| UTeM | - | Universiti Teknikal Malaysia Melaka |
| WHO | - | World Health Organization |

# CHAPTER 1
# INTRODUCTION

The first chapter introduces the study's background, problem statement, objectives, and scope. The background of the study explains the necessity for ergonomic hand glove design to enhance the grip strength of adult males. The problem statement identifies the ergonomic issues experienced by SMAW welding operators currently. The objectives of this study include assessing hand anthropometric dimensions and grip strength in Malaysian males, exploring the correlation between grip strength and various postures, and creating a prototype for an ergonomic glove to improve gripping ability. At the end of this chapter, significant of study highlights the importance of the study.



## 1.1 Background of Study

Research on grip strength has a longstanding history, spanning several years (Spottswood & Burghardt, 1976; Newman et al., 1984; Fransson & Winkel, 1991; O'Driscoll et al., 1992). However, discrepancies and disagreements persist in the existing body of knowledge. These disparities may arise due to variations in research scope, encompassing factors such as age, gender (Ramakrishnan et al.,1994; Davies et al., 1988), and variations in hand (Petersen et al., 1989) and arm dimensions (Su et al., 1994). In the realm of ergonomics, the complexities within grip strength research necessitate a thorough investigation. Ongoing debates emphasize the importance of a nuanced examination that considers various factors. This approach aims to achieve a conclusive understanding of grip strength dynamics, crucial for informing ergonomic design principles (Halim et al., 2019).

Ergonomics is a fundamental consideration in the design and use of gloves within various settings (Yu et al., 2019). Ergonomic gloves are specially crafted to fit the natural contours of the hand, promoting comfort and reducing the risk of strain or fatigue during prolonged tasks (Muralidhar et al., 1999). By enhancing the ergonomic aspects of gloves, they ensure better hand health and overall work performance. These gloves are tailored to provide a balance between protection and dexterity, allowing workers to maintain a secure grip and precise control over tools or materials. In essence, the ergonomic design of gloves is pivotal in aligning hand protection with the principles of ergonomics, which focus on optimizing the interaction between workers and their tools or environment to enhance safety, comfort, and efficiency in the workplace.

In this study, the focus is on the development of an ergonomic glove tailored for users or workers who are performing Shielded Metal Arc Welding (SMAW) tasks. The study explores the complexities of hand grip strength among Malaysian adult males, with the aim of providing valuable insights for a future that is safer, comfortable, and better performance (Yu et al., 2019). Gloves are essential primarily for safety and performance reasons in SMAW. They serve to protect the hands of welders from various hazards, including electric shock, flames, hot parts, sharp or flying metal, and arc rays during the welding process (ANSI Standard Z49.1, 2021). Additionally, they provide a secure grip on welding tools and materials, enhancing the welder's control and precision. Figure 1.1 illustrates an example of SMAW process at workplace that requires an ergonomically designed hand glove for hand protection.

Figure 1.1: Shielded metal arc process (Global Institute of Studies, 2022)

This project not only to offer protection but also to improve on enhancing grip strength in adult males through the development of an ergonomic glove design, with a primary aim of aligning the design of gloves with the physiological characteristics of industrial workers to reduce user discomfort and fatigue. It involves gathering data on hand and arm dimensions, analyzing correlations with grip strength, and developing a predictive model for grip strength. Data from 125 male adults will be collected using the Jamar hand dynamometer and subjected to statistical analysis. The expected outcomes extend to practical applications in engineering (Choong et al., 2021) and hand tools design (Halim et al., 2019), ultimately improving user experience, reducing discomfort, and benefiting both workers and employers. Elements such as material selection, fit, ergonomic design, padding, finger and palm design, and moisture management are considered in the glove design to enhance grip strength in various industrial tasks. Figure 1.2 shows an example of glove designed for welding purposes.

Figure 1.2: Example of welding glove (GlobalSpec)

The study anticipates substantial benefits by aligning glove design with industrial workers' physiological characteristics. It seeks to enhance user comfort, reduce fatigue, and improve safety. The developed regression model provides engineers and designers with a valuable tool for creating ergonomically optimized hand tools and machinery (S Rostamzadeh et al., 2019). Additionally, the study extends its impact to healthcare (Sánchez-Torralvo et al., 2020), aiding occupational therapists in early issue identification for improved occupational health. Overall, the goal is to create a safer, more efficient, and healthier future for individuals in various industrial tasks.



## 1.2 Problem Statement

The absence of specifically designed ergonomic gloves customized for the unique demands of SMAW tasks poses a significant challenge. This deficiency in the availability of safety equipment not only heightens safety hazards but also hampers overall performance and productivity. It increases the susceptibility to accidents and adds to the physical fatigue experienced by welders. As a result, safeguarding the well-being and efficiency of SMAW welders becomes a critical focal point within the scope of this final year research project.

a) Lack of ergonomically fitted design:

The lack of specialized ergonomic gloves for SMAW results in discomfort and affect welders' performance, compromising safety. The absence of ergonomically fitted designs leads to workers avoiding safety gloves, as the discomfort negatively impacts performance (Khanlari et al., 2021). Subsequently, operators may end up wearing inconvenient gloves that are oversized and not user-friendly. This situation could lead to worker injuries or harm. Figure 1.3 depicts an oversized glove that does not correspond to hand dimensions.

Figure 1.3: Oversized gloves



b) Lack of optimally grip design:

Insufficient glove design diminishes precision and control, compromising a welder's accuracy in handling tools. The absence of an optimized grip impacts both the safety and efficiency of the welding process. Moreover, prior research has revealed a negative correlation between the problematic design of hand tools and the duration of grip strength decrement (Halim et al., 2019). Extensive problematic design often compels users to employ hand tools in awkward postures, leading to increased contact stress, particularly in the palm and wrist. Figure 1.4 represents the correlation of the use of problematic hand tools design with grip strength.

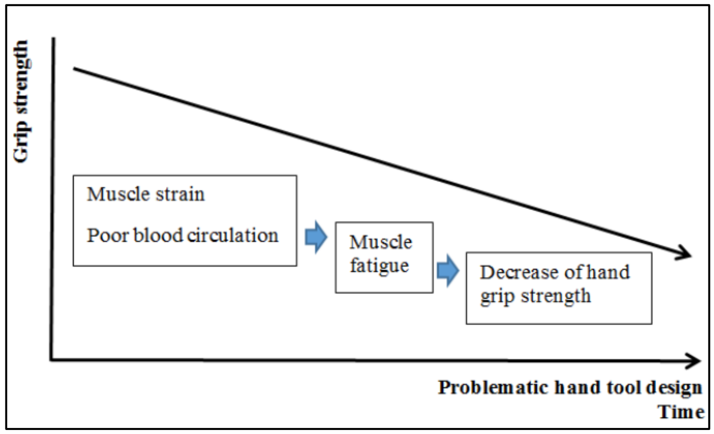



Figure 1.4: Correlation problematic design and HGS (Halim et al., 2019)

c) Insufficient Variety in Task-Specific Glove Options:

A limited selection of task-specific gloves leads to inefficiency and increased fatigue among SMAW welders. The lack of design elements tailored to specific tasks undermines productivity, highlighting the need for gloves customized for the unique demands of welding. Challenges arise in finding perfectly fitted gloves due to the limited sizes available in the market, where many gloves may only offer a single size for all customers (Yu et al., 2019). Operators tend to select impractical and unsafe gloves for the sake of convenience. Figure 1.5 represents inappropriate glove selection while performing SMAW.

Figure 1.5: Inappropriate glove selection

## 1.3 Objectives

Acknowledging the significance of addressing the above-mentioned problems, this study endeavors to attain the subsequent objectives:

i. To measure the hand anthropometric dimensions and grip strength of Malaysian male adults.

ii. To analyze the correlation between the hand grip strength and various hand and body postures among Malaysian male adults.

iii. To develop a prototype of an ergonomic glove that enhances the ability of Malaysian male adults to perform gripping tasks effectively.

### 1.3.1 Relationship between Objectives and Problem Statement



Table 1.1 outlines the specific alignment between each research objective and its corresponding problem statement, indicating how addressing each objective contributes to resolving the identified issues.

Table 1.1: Relationship between objectives and problem statement

| Objectives | Problem Statement |
| --- | --- |
| To measure the hand anthropometric dimensions and grip strength of Malaysian male adults. | Addressing this objective aims to provide quantitative data on hand anthropometric dimensions and grip strength, contributing to the development of specialized ergonomic gloves for SMAW. |
| To analyze the correlation between the hand grip strength and various hand and body postures among Malaysian male adults. | Achieving this objective involves exploring the relationship between grip strength and postures, providing insights into optimal grip design, and addressing issues related to precision, control, and ergonomic aspects. |

| | |
|---|---|
| To develop a functional prototype of an ergonomic glove that enhances the ability of Malaysian male adults to perform gripping tasks in SMAW process. | This objective is directly related to the identified problem of a limited selection of task-specific gloves, aiming to develop a prototype that caters to the unique demands of welding tasks, improving efficiency, and reducing fatigue. |

## 1.4 Scope of Study

This study centers on enhancing the ergonomics and optimization of SMAW gloves, considering the grip strength of Malaysian male adults. The study establishes key scopes to ensure the fulfillment of its objectives.

For the first objective, information pertaining to hand anthropometric dimensions and grip strength will be acquired from a diverse sample of 125 Malaysian male adults aged between 21 and 40. Ensuring inclusivity within the adult range and maintaining participants' healthy and stable physical conditions. The testing protocol encompasses an evaluation of three distinct grip types—neutral, supination, and pronation—in both standing and sitting positions.



Next, second objective entails a comprehensive analysis of the correlation between hand grip strength and various hand and body postures among Malaysian male adults. This analysis need the collection of relevant data, the application of statistical methodologies, and the derivation of correlations. This robust examination is paramount to effectively address concerns pertaining to precision, control, and the ergonomic aspects associated with various postures.

The third objective centers on developing a prototype of ergonomic gloves. The consideration of users' hand anthropometric dimensions is pivotal in designing a good ergonomic glove. The aim of this ergonomic glove design is to enhance grip dynamics, thereby catalyzing advancements in grip strength, precision, control, and overall muscle activity, contributing to an elevated user experience.

However, there are limitations to this study. It exclusively focuses on designing and fabricating the prototype of ergonomic gloves, excluding the overall design. Additionally, a fidelity prototype of the gloves will be crafted, with no actual product production. The orientation of the prototype handle will not be analyzed in this study, providing an avenue for future investigations and enhancements.

## 1.5 Significance of study

Grip strength plays a vital role in the daily manual activities of workers. Ergonomists must prioritize this aspect when designing equipment for workers, considering its essential role in their tasks. This research is highly significant as it addresses crucial challenges in SMAW, emphasizing the optimization of gloves tailored to the grip strength of Malaysian male adults. The study holds importance in enhancing workplace safety and efficiency for individuals engaged in various industrial tasks. Moreover, the outcome of study can yield advantages, as outlined below:



a) Bridging the gap in glove variety

The limited selection of task-specific gloves in the market contributes to inefficiency and increased fatigue among SMAW welders. This research addresses this issue by exploring the development of gloves customized for the unique demands of welding, aiming to provide a variety of options that cater to different tasks and user preferences.

b) Engineering and occupational health impact

The outcomes of this study extend beyond the immediate realm of welding. Engineers and designers can leverage the developed regression model to create ergonomically optimized hand tools and machinery, impacting various industries. Additionally, occupational health institutions can benefit from the study's methodology for research and training related to hand tools design and ergonomics.

c) Academic contribution

The study contributes to the academic understanding of ergonomics, grip strength, and glove design. Academicians and students can use the findings for research, teaching, and learning activities, fostering continuous improvement in the field.

# CHAPTER 2
## LITERATURE REVIEW

This chapter encompasses a review of literature pertaining to research conducted by previous scholars in preceding years, aligning the gathered information with the objectives of the current study. It integrates discussions from past studies encompassing hand grip strength, product development, focus group considerations, and other aspects. These insights were sourced from various relevant materials, including journals, articles, books, and online resources.



### 2.1 An Overview of Hand Grip Strength - Measurements and Establishing Datasets

Hand grip strength serves as a measurement of the maximal force exerted by the muscles during hand flexion and is typically evaluated using a hand dynamometer (Larson & Ye, 2017). Evaluating grip strength is a quick, easily conducted, and reliable test, providing a straightforward result that is simple to document (Innes., 2002). It can serve as a valuable method for forecasting physical fitness (Vaidya & Nariya, 2021). Hand grip strength data are extensively applied across multiple disciplines and endorsed by the World Health Organization (WHO, 2001) for the International Classification of Functioning, Disability, and Health (ICFDH). The assessment of hand grip strength has garnered interest as an uncomplicated and non-intrusive indicator of the muscle strength in the upper limbs (Norman et al.,2011). In addition, one single attempt suffices for gauging the maximum handgrip strength. A single attempt exhibits similar test reliability compared to three trials and is less fatiguing (Lee et al., 2021).

### 2.1.1 Evaluation of the literature review related to hand grip strength

Table 2.1 outlines the assessment of the literature review on hand grip strength, encompassing details such as the participant range, age group, independent variables or predictors studied, and distinctions from the current study.

Table 2.1: Evaluation of the past studies related to hand grip strength study

| Studies (Countries) | Participants of study | Age group | Predictors studied | Difference with the current study |
|---|---|---|---|---|
| Jaafar et al., 2023 (Malaysia) | Malay ethnicity | 35 to 70 years | Age, gender, occupation type, socio-economic status (SES), physical activity level, and BMI | The study links higher BMI to increased handgrip strength in various occupations. In contrast, my research focuses on correlating posture with hand anthropometry. |
| Ong et al., 2017 (Singapore) | Singapore older adults | 60 years and above | Height, weight, upper arm circumference, and waist circumference | The uniqueness of the study lies in its emphasis on establishing a connection with waist circumference. Additionally, the research specifically targets the older adult age group. |
| Prasetyo et al., 2020 (Philippine) | Filipino teenagers | 15 to 18 years | Gender, hand anthropometry, hand dominance, and high school grade | This study shares similarities with the present investigation; however, its distinctive feature lies in its exploration of the association between school grade and handgrip strength. |
| Kim et al., 2017 (UK) | UK Biobank Data | 40 to 69 years | BMI and waist circumference | The study aims to explore the link between grip strength and physical activity, analyzing BMI and waist circumference as factors. |

| | | | | |
|---|---|---|---|---|
| Wang et al., 2018 (USA) | Community-dwelling and non-institutionalized | 18 to 85 years | Sex, side, age, BMI, and ethnicity | The study reveals variations in physical fitness across age groups, examining how individuals of different ages, genders, and BMI levels exhibit distinct fitness levels. |
| Chen et al, 2017 (China) | Chinese university students | 16 to 30 years | Sleep quality, duration, muscle strength, BMI, daily activity, depressive symptoms, and various factors (age, sex, grade, living status, smoking, drinking, and hypnotics use) were considered. | This study is distinctive in that it incorporates an examination of the correlation between status of participant including smoking, life quality, sleep quality and duration with muscle strength, a unique research angle not commonly explored in relation to other variables. |
| Nara et al., 2023 (India) | Indian adolescents | 12 to 16 years | BMI, body stature, economic status, side, and gender | This study uniquely highlights that individuals with lower economic status tend to have weaker grip strength in their daily lives. |
| Prasitsiriphon & Weber, 2019 (Thailand) | Older Thai's adult | 60 to 79 years | Age, gender, body weight, body height, and health variables | The study validated cutoff points for predicting functional limitations in the elderly using measures like handgrip strength and walking speed. |
| Current study | Malaysian male adults | 21 to 40 years | Hand anthropometry, body posture and hand posture | This study assesses hand dimensions and grip strength in Malaysian adult males, exploring correlations with various hand and body postures to gain insights into their physical capabilities. |



### 2.1.2 Hand grip strength measurement tools

Grip strength is commonly employed in diverse fields, including sports, rehabilitation, and geriatrics, to gauge muscle strength and identify conditions like sarcopenia and frailty in the elderly. The potential for measurement discrepancies exists among different dynamometers, and studies comparing GS measurements using various tools have yielded conflicting findings (Savas et al., 2023). Commencing with an acknowledgment of the diverse range of available measuring tools, it is crucial to underscore that not all alternatives are equally reliable for grip strength assessment.

#### 2.1.2.1 Types of commonly used hand dynamometer

Hand dynamometers are crucial tools in assessing grip strength, offering valuable insights into an individual's hand and forearm muscular capabilities (McGrath et al., 2022). Various types of hand dynamometers are commonly employed for clinical, research, and ergonomic purposes. This section provides an overview of the types of hand dynamometers frequently utilized in diverse settings, emphasizing their significance in evaluating and understanding grip strength dynamics:

a) Jamar hydraulic hand dynamometer

The Jamar hydraulic dynamometer shown in figure 2.1 is a widely used device for assessing grip strength in clinical (De Dobbeleer et al., 2019) and research settings (Yu et al., 2017). Known for its reliability and precision, it measures the maximum isometric force applied by an individual during a squeezing motion. The hydraulic system ensures consistent and accurate readings, making it a standard tool in hand strength evaluations.



Figure 2.1: Jamar hydraulic dynamometer (Huang et al., 2022)

b) Camry Digital Hand Dynamometer

The Camry digital dynamometer as shown in figure 2.2 is recognized for its digital capabilities, providing a modern approach to grip strength assessment. It offers an easy-to-read digital display, making it suitable for both clinical (Tai et al., 2023) and personal use. Also, the ability to measure grip strength in various units. The digital interface allows for precise and efficient grip strength evaluations.




Figure 2.2: Camry digital dynamometer (Huang et al., 2022)

d) Takei Digital Grip Strength Dynamometer

The Takei digital dynamometer as shown in figure 2.3 is a renowned device for measuring grip strength with the added advantage of digital technology. It combines accuracy with user-friendly features, making it suitable for clinical assessments (Gatt et al.,2017) and research studies (Amo-Setién et al., 2020). The device often includes additional features for comprehensive hand strength evaluation.


Figure 2.3: Takei digital dynamometer (Lee et al., 2020)

In the myriads of choices, the JAMAR Hydraulic Hand Dynamometer takes precedence as the gold standard (Uysal et al., 2022). While more economical alternatives are present, their effectiveness in a hospital setting remains uncertain. The Jamar dynamometer, well-regarded for its widespread acknowledgment and utilization in both research and clinical realms, emerges as the preferred choice within the confines of this study (Guerra et al., 2017). Valued for its unwavering reliability and consistency, it serves as a benchmark, ensuring precise and reproducible measurements. The elevated status of the Jamar dynamometer is attributed to its extensive validation and standardization procedures, solidifying its position as the quintessential method for grip strength evaluations. Given its widespread acceptance, reliability, and rigorous validation, the Jamar dynamometer rightfully earns the distinguished title of the "gold standard" within the context of this research (Alison et al., 2022).

### 2.1.2.2 Evaluation of the literature review related to advantages and disadvantages of various dynamometer model used

Table 2.2 presents a synthesis of findings from various studies, outlining the distinct advantages and disadvantages of different dynamometers. The models reviewed include the Camry, Smedley, Squegg, Takei 5401, Jamar, and Jamar Plus+. Each dynamometer offers unique benefits and limitations, such as weight, ease of use, reliability, precision, and potential for misdiagnosis. This overview aids in selecting the most suitable dynamometer based on specific requirements and contexts.

Table 2.2: Evaluation of the pros and cons of various dynamometers from past studies

| Dynamometer Model | References | Advantages | Disadvantages |
|---|---|---|---|
| Camry | Díaz Muñoz et al., 2019 | -Statistically significant concordance with the Jamar Dynamometer, particularly in the 40-59 age group.<br><br>-Lighter and designed with distinct ergonomics in comparison to the Jamar dynamometer. | -Consistently displayed lower mean grip strength values than the Jamar dynamometer, indicating a potential limitation in delivering weaker grip strength measurements. |
| Smedley | Benton et al., 2022 | -Commonly employed in research settings, the Smedley dynamometer is widely utilized, especially for evaluating handgrip strength, due to its ease of use and reliability. | The Jamar and Smedley dynamometers show inconsistent handgrip strength measurements, suggesting potential divergence in outcomes and a risk of misdiagnoses, especially in conditions like sarcopenia. |
| Squegg | Stamate et al., 2023 | - The app automates analysis and tracking of grip strength parameters, simplifying the process for clinicians, and providing comprehensive insights.<br><br>-The app linked to the device offers automated analysis and tracking of diverse grip strength parameters, streamlining the process for clinicians, and delivering thorough insights. | -Psychological factors may affect measurements with alternative devices, as participants might apply less force to devices that seem more fragile. This suggests a potential limitation linked to participant perception and behavior during testing. |

| | | | |
|---|---|---|---|
| Takei 5401 | Savas et al., 2023 | -The Takei dynamometer is characterized as a spring-type dynamometer equipped with a digital screen. The digital interface allows for accurate and easily legible measurements.<br><br>-Spring-type dynamometers, such as the Takei model, see widespread usage in Asian countries, indicating a notable acceptance and familiarity with this dynamometer in specific regions. | -The Takei dynamometer displayed a tendency to overestimate grip strength in comparison to the Jamar dynamometer. |
| Jamar | Savas et al., 2023 | - The Jamar dynamometer stands out as a highly utilized and standardized tool for hand grip strength measurement. Its widespread adoption in clinical and research settings contributes to maintaining consistency and comparability in studies.<br><br>-The Jamar dynamometer has been extensively employed in research to evaluate hand grip strength, leading to the establishment of reference values, and enabling comparisons across diverse populations. | -The newer models of Jamar dynamometers could yield higher grip strength values, potentially attributed to the friction of the handles. |
| Jamar Plus+ | Savas et al., 2023 | -The Jamar+ dynamometer is a digital device that utilizes electronic measurements, providing benefits like precise readings and enhanced usability.<br><br>-The Jamar+ is noted to have a lighter weight compared to the standard Jamar dynamometer, offering advantages in terms of portability and user comfort. | -Minor differences between the Jamar+ and the standard Jamar dynamometer, without providing specific details about these variances.<br><br>-The Jamar+ dynamometer is limited in availability and is not widely used in clinics. This could present a practical disadvantage in specific settings. |

### 2.1.3 Comprehensive analysis of grip strength influencing postures

Extensive practical research has been carried out to establish reliable and accurate methodologies for gauging grip strength. Numerous studies have investigated grip strength under different conditions, examining variations in shoulder, elbow, forearm, and wrist angles (Su et al.,1994; Oxford et al., 2000; Lamoreaux & Hoffer, 1995), as well as diverse postures (Watanabe T, 2005; Richards, 1997) and grip spans (Firrell et al., 1996; Fransson & Winkel,1991) The overarching goal of these investigations is to devise procedures that consistently generate results that are both reproducible and valid (Watanabe et al., 2005).

#### 2.1.3.1 Grip postures in past research

Various grip postures provide individuals with the flexibility to optimize hand configurations for different tools, enhancing overall usability. Varied grip postures significantly improve precision and control, especially in activities involving fine motor skills. Customized for different tasks, these grips enhance efficiency and ease in daily activities (Lesourd et al., 2020). Having multiple grip options fosters functional independence, enabling individuals to proficiently tackle diverse tasks without constraints on specific hand configurations (Reina et al., 2017). The subsequent sections elaborate on the different hand grip postures investigated in prior research related to the measurement of hand grip strength. The following subsections describe the variety of grip postures.



##### 2.1.3.1.1 Pinch posture

The configuration of the hand and the grasp patterns involved characterize pinch postures, with a primary emphasis on utilizing the thumb and fingers (Lee & Jung, 2017).

Throughout history, the development of pinch postures has been shaped by technological advancements and the evolution of tools (Tidke et al., 2019). These postures play a vital role in daily activities, significantly contributing to activities of daily living. The adaptation of pinch postures is intricately connected to technological progress, as the hand adjusts to diverse configurations for the optimal utilization of tools (Shurrab et al., 2017).

The illustration in figure 2.4 depicts the configuration of a chuck pinch posture. In the realm of grip postures, Chuck Pinch is notable for its precision and control in securing objects (Dierick et al., 2020). It involves using the thumb's pad against the pads of the index and middle fingers, resembling actions like holding a key or turning a doorknob. This nuanced technique, vital for achieving dexterity and command, places Chuck Pinch at the forefront of grip methods.

Figure 2.4: A chuck pinch posture (Shurrab et al., 2017)



Next, the diagram in figure 2.5 depicts an example of a lateral pinch posture. It is characterized by the utilization of the thumb's sides and index finger to secure an object (Hock & Lindstrom, 2021), shares a resemblance to holding a pencil or similar cylindrical items with the thumb on one side and the index finger on the other (Shurrab et al., 2017). This grip posture frequently finds application in tasks requiring the retrieval of small items, such as grasping the edge of a sheet of paper or holding compact tools.

Figure 2.5: A lateral pinch posture (Shurrab et al., 2017)

In figure 2.6, you can see the pulp-2 pinch posture, a precise grip involving a delicate pinch with the tips of the thumb and index finger. This grip resembles holding a small object between the fingertips, allowing controlled pressure with the thumb and index finger pads. It is particularly useful for tasks demanding meticulous precision, such as handling tiny beads or manipulating small electronic components with precision.



Figure 2.6: A pulp-2 pinch posture (Shurrab et al., 2017)

#### 2.1.3.1.2 Crush grip posture

A crush grip is a potent hand posture involving a forceful, comprehensive grasp using the entire hand (Madankumar, 2018) as shown in figure 2.7. Applied in weightlifting and rock climbing as it offers a strong grip. Engaging various hand muscles, this posture is versatile and effective in tasks requiring substantial strength, such as carrying heavy objects (Reina et al., 2017).

Figure 2.7: A crush grip posture (Blomkvist., 2016)



### 2.1.3.2 Biomechanics principles associated with various body positions

The biomechanics aspects associated with distinct body positions play a crucial role in influencing muscle engagement and, by extension, grip strength (Csapo et al., 2020). For instance, the way muscles are activated varies between standing and sitting postures. Furthermore, neurological factors, including the stimulation of specific neural pathways, exert an impact on grip strength across different postures. Notably, adopting a standing position, particularly with the elbow fully extended, facilitates improved coordination between the muscles of the upper and lower extremities, leading to heightened grip strength (Xu et al., 2021). Figure 2.8 depicts four stances used for evaluating grip strength.

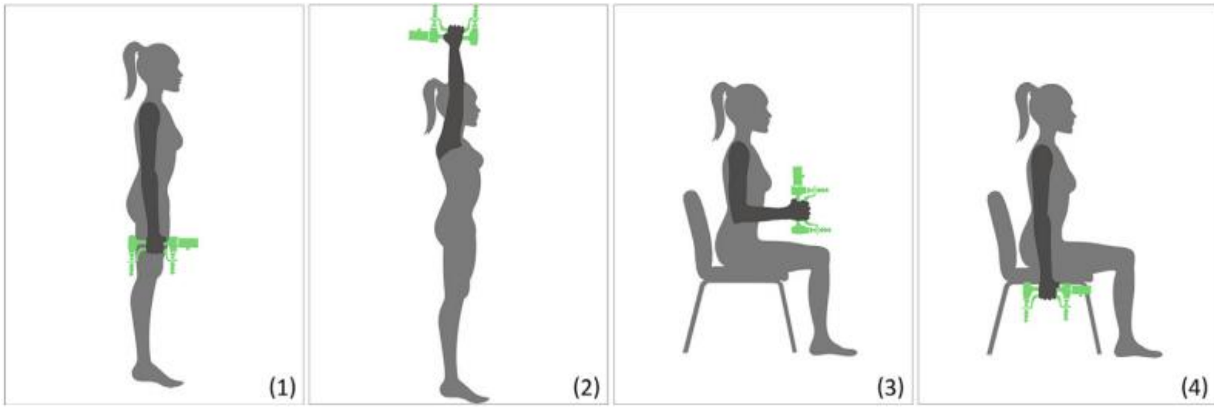



Figure 2.8: Four stances for assessing grip strength include: (1) standing with the elbow fully extended, (2) standing with arms elevated, (3) sitting with a 90˚ elbow flexion, and (4) sitting with the elbow extended (Xu et al., 2021).

In the first posture, "Standing with Elbow Fully Extended," the grip strength measurements showed a statistically significant increase compared to other postures. This indicates that adopting the stance of standing with the elbow fully extended resulted in the highest grip strength among the study participants. The biomechanics associated with this posture may allow for optimal engagement of upper and lower extremity muscles, contributing to enhanced grip strength.



Moving on to "Standing with Arms Elevated," grip strength values did not significantly differ from the standing position with full elbow extension. Despite the act of raising the arms, there was no significant improvement in grip strength, suggesting minimal impact on measured strength compared to standing with the elbow fully extended. This insight adds nuance to the understanding of body posture dynamics.

In the "Sitting with a 90˚ Elbow Flexion" posture, seated with flexed elbow, grip strength significantly reduced, suggesting biomechanical adjustments in sitting and flexed elbow impact strength negatively. Intriguingly, no significant difference was found compared to the sitting position with the elbow extended ("Sitting with Elbow Extension"), raising questions about the impact of elbow positioning when sitting relative to grip strength in standing postures.

Speaking of "Sitting with Elbow Extension," grip strength in this sitting posture did not significantly differ from the sitting posture with 90˚ elbow flexion. The consistent trend of lower grip strength in sitting positions, compared to standing postures, suggests a biomechanical relationship between body position and grip strength generation. These insights contribute to understanding how postures influence grip strength and may inform clinical considerations related to musculoskeletal health.

### 2.1.4 Hand grip strength measurement procedure

Guided by established principles in biomechanics and muscle physiology, the hand grip strength measurement procedure employs a systematic approach to assess reliability, validity, and responsiveness through meta-analyses, utilizing a random-effect model (P Bobos, 2020). This methodology is firmly grounded in the fundamental principles of isometric muscle contraction and force assessment (Manthar et al., 2019). The systematic nature of the procedure mirrors common conventions seen in systematic reviews and meta-analyses (Labott et al., 2019).

Drawing from four references (Manthar et al., 2019; Labott et al., 2019; Amaral et al., 2019; Bobos et al., 2020), the widely acknowledged method for measuring hand grip strength in the subsequent section, ensures standardized assessment across diverse populations through participant preparation, dynamometer adjustment, and systematic data analysis.

#### 2.1.4.1 Participant preparation

Validating the suitability of the selected demographic for the study involves a meticulous process in line with project management principles. This includes confirming that participants align with relevant criteria and undergo screening to ensure their appropriateness for the study objectives. The screening process not only contributes to data integrity but also aligns with project management principles to enhance the overall organization and coordination of the study.

Following participant confirmation, a detailed plan is developed, resembling project management scheduling, to outline when and where participants will be engaged in the study. This strategic plan also incorporates considerations for sample size, ensuring statistical robustness. This careful and comprehensive participant preparation further strengthens the study's alignment with project management principles, fostering effective execution.

##### 2.1.4.1.1 Sample size



Ensuring an appropriate sample size is pivotal for obtaining reliable research outcomes. Making arbitrary choices or being constrained by resource limitations in sample size selection can introduce bias and compromise result validity (Kang et al., 2021). To address observed issues of low statistical power in gerontology studies, researchers are encouraged to expand their sample sizes, thereby enhancing the ability to detect true effects (Brydges, 2019). In the context of inductive, exploratory research, it is deemed illogical to define the sample size a priori (Sim et al., 2018). To optimize sample quality, recommendations include refining participant screening, unevenly allocating participants to conditions, utilizing reliable measures with minimal error variance, and incorporating intelligent preregistered covariates (Lakens, 2022).

#### 2.1.4.1.1.1 2-Sample t-Test analysis

The 2-sample t-test is a statistical test used to compare the means of two independent groups to determine if there is a significant difference between them (Jim, 2018). The 2-sample t-test is integral to assessing the power of a chosen sample size. By comparing the means of two groups, it determines if the selected sample size is sufficient to detect a meaningful difference. Adequate sample sizes enhance the statistical power of the test, ensuring a higher likelihood of detecting true differences when they exist. The formula for the 2-sample t-test is as shown in figure 2.9 below:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

$$s^2 = \frac{\sum_{i=1}^{n_1}(x_i - \bar{x}_1)^2 + \sum_{j=1}^{n_2}(x_j - \bar{x}_2)^2}{n_1 + n_2 - 2}$$

Figure 2.9: 2-sample t-test formula (statsdirect)



Where:

- $\bar{x}_1$ and $\bar{x}_2$ are the sample means of the two groups.
- $s_1^2$ and $s_2^2$ are the sample variances of the two groups.
- $n_1$ and $n_2$ are the sample sizes of the two groups.

Analyze a power curve by examining the x-axis for effect sizes and the y-axis for corresponding statistical power. Focus on the dot representing chosen parameters and observe how power changes across the curve, providing insights into the test's sensitivity to different effect sizes. Figure 2.10 and 2.11 show examples of power curve for 2-sample t-test.

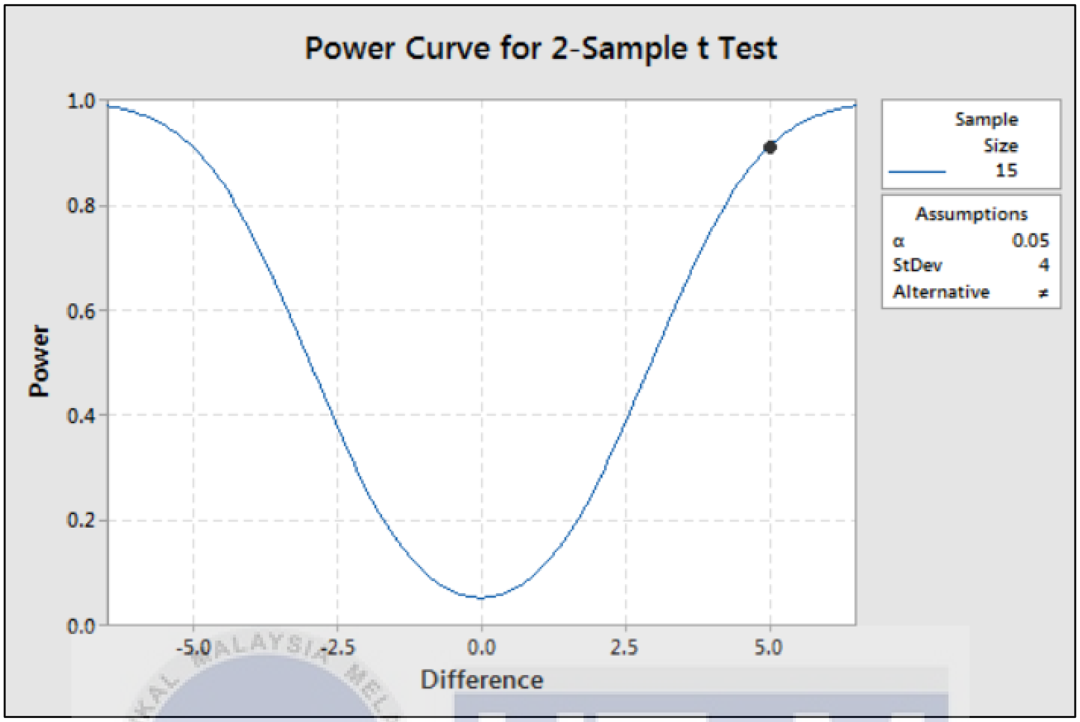



Figure 2.10: Power curve for 2-Sample t-Test [1]

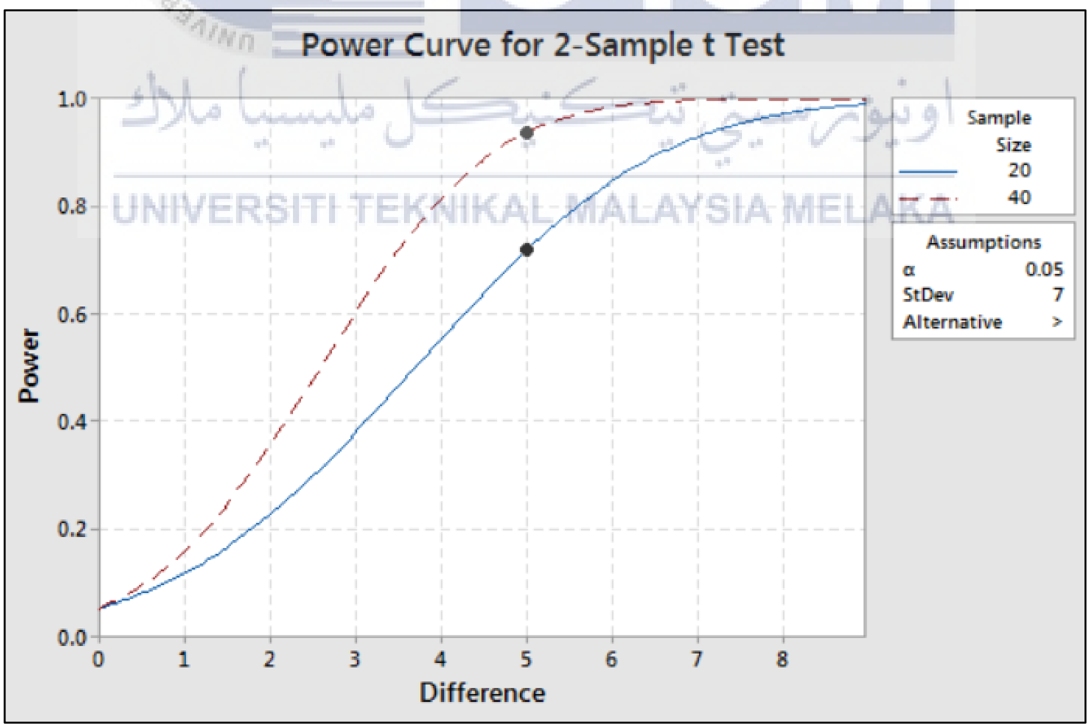



Figure 2.11: Power curve for 2-Sample t-Test [2]

#### 2.1.4.1.1.2 G*power analysis

G*Power is a tool for statistical sample size and power analyses, covering various tests like t-tests, ANOVA, correlation, and chi-square tests. The procedures from Hyun Kang's 2021 study are outlined in table 2.3, offering detailed steps. These instructions and practical examples enhance understanding of the analytical processes.

Table 2.3: Type of analyses and procedures (Kang, 2021)

| Analyses | Procedures |
|---|---|
| Two-Independent Sample t-Test | i. Use of G*Power: The researcher should use G*Power, a statistical power analysis tool.<br>ii. Effect Sizes: Understand and incorporate effect sizes into the calculation. Effect size measures the magnitude of a phenomenon.<br>iii. Step-by-Step Instructions: Give detailed G*Power instructions, covering means, standard deviations, and test parameters. |
| Dependent t-Test | i. Calculation of Sample Size: Explain how to calculate sample size with or without a determined effect size.<br>ii. Practical Scenario: Demonstrate the process using practical scenarios involving dependent samples. |
| One-way Analysis of Variance (ANOVA) | i. Scenarios: Explore different scenarios where the effect size is either known or needs to be estimated.<br>ii. Calculation: Provide step-by-step guidance on calculating sample size for one-way ANOVA. |
| Correlation – Pearson r | i. Scenario: Describe the context of a correlation study.<br>ii. G*Power Usage: Explain how to use G*Power for sample size determination in correlation studies. |
| Two Independent Proportions – Chi-square Test | i. Chi-square Test: Explain the chi-square test for comparing proportions.<br>ii. A Priori and Post Hoc Analysis: Demonstrate both a priori (before data collection) and post hoc (after data collection) power analysis. |



### 2.1.4.2 Dynamometer adjustment

Calibrate both the dynamometer weight meter indicator and handles with precision to align accurately with the participant's hand size. This crucial step ensures precise and reliable measurements, as meticulous calibration is pivotal for maintaining accuracy in grip strength assessments. Proper adjustment minimizes errors, enhances data consistency, and ensures that the grip strength evaluation of the participant's dominant hand is accurate, reproducible, and reflective of true muscle strength.

#### 2.1.4.3 Dominant hand selection

Select the dominant hand for measuring grip strength in participants. Confirm each participant's dominant hand to maintain measurement consistency, ensuring accuracy and reliability. This reduces variability and provides standardized data for comparative analysis, resulting in more precise and meaningful comparisons of hand grip strength across different individuals and groups.

#### 2.1.4.4 Proper grip instruction

Provide thorough guidance on the correct grip technique, emphasizing the importance of a firm and consistent squeeze throughout the measurement process. Instruct participants to maintain a 90-degree angle at the elbow while holding the dynamometer. This ensures optimal execution, leading to accurate and reliable assessment of hand grip strength. Proper technique is crucial for obtaining consistent and valid measurements.



#### 2.1.4.5 Trial squeezes

Encourage participants to conduct initial trial squeezes, fostering familiarity with the process and allowing for crucial grip adjustments. This step not only enhances participant comfort but also ensures they are well-prepared for subsequent official attempts. The provision for initial adjustments contributes to an optimal approach in subsequent measurements, refining the precision and reliability of hand grip strength assessments.

#### 2.1.4.6 Official attempts

Conduct a defined number of official attempts, commonly three, interspersed with brief rest intervals to mitigate participant fatigue. Capture the maximum force exerted during each squeeze, meticulously documenting the participant's hand grip strength. This method ensures a comprehensive and accurate assessment while allowing participants to showcase their optimal performance. Strategic rest intervals enhance consistency, minimize fatigue impact, and boost reliability in recorded measurements for increased precision.

#### 2.1.4.7 Recording measurements

Document the highest force reached during official attempts, recording the peak measurement. Ensure transparency in indicating units—whether kilograms or pounds—alongside their respective values for precision. This detailed recording not only maintains accuracy but also aids in the precise interpretation of measurements. Ensures comprehensive understanding of participants' grip strength for reliable analysis in research and clinical applications. The clear presentation of measurements is essential for the accuracy and credibility of the recorded data.

#### 2.1.4.8 Data analysis

Apply systematic review methodologies to ensure a comprehensive and robust analysis. Follow established guidelines such as COSMIN for systematic reviews, meticulously extracting data on various measurement properties—ranging from validity and reliability to responsiveness. This inclusive approach facilitates a nuanced understanding of the measurement tools. Employ advanced statistical methods to conduct meta-analyses, synthesizing data from numerous studies.

This rigorous analytical process enhances the depth, reliability, and applicability of the findings, providing crucial insights for both research and clinical practice. Such thorough analysis ensures that conclusions drawn are well-founded and widely applicable.

### 2.1.4.9 Report findings

Presenting outcomes derived from data analysis involves articulating correlations with health parameters clearly and effectively. By clearly communicating the results and offering contextual information, such as demographic details and health conditions of participants, the study's findings are contextualized, and their significance is elucidated. This approach ensures effective dissemination of the results and provides a comprehensive understanding of how grip strength relates to various health parameters, highlighting its potential implications for health assessment and intervention strategies.



### 2.1.4.10 Data extraction and analysis

Adhering to established systematic review protocols, such as COSMIN, ensures a methodical extraction of relevant details from studies. Employing statistical tools like the random-effects model facilitates rigorous data analysis. Including studies that meet predefined criteria ensures meticulous extraction of valuable data. This systematic approach provides a robust foundation for data synthesis, contributing to a comprehensive understanding of the subject matter. Emphasis is placed on thorough data extraction and rigorous statistical analysis, which are essential for deriving meaningful insights and drawing reliable conclusions in research and clinical contexts.

#### 2.1.4.10.1 Statistical Tools

Statistical tools, including software like Python and Excel, are essential in research, providing means to analyze data and reveal meaningful patterns or relationships. These tools empower researchers to interpret data, identify trends, and draw informed conclusions, significantly contributing to the advancement of knowledge across various scientific disciplines. The correlation tools within these platforms further enhance the ability to explore relationships among variables systematically.

##### 2.1.4.10.1.1 Correlation analysis

The study employed correlation coefficients to scrutinize the relationships among variables, including the correlation between HGS and SBP or DBP. This analytical approach facilitated the exploration of potential associations between HGS and blood pressure measures, shedding light on the intricate interconnections between muscular strength and cardiovascular health. Understanding these physiological correlations is vital for comprehending the broader implications of hand grip strength on overall health and well-being.



##### 2.1.4.10.1.2 Analysis of Variance (ANOVA)

The critical utilization of ANOVA was integral in scrutinizing the disparities in mean SBP and DBP across tertiles of hand grip strength. Through meticulous adjustments for covariates such as age, gender, smoking, drinking, body mass index, physical activity, fasting glucose level, and lipid profile, this comparative analysis provided a thorough comprehension of the relationship between variations in hand grip strength and blood pressure measures. By accommodating diverse influencing factors, this approach not only bolstered the reliability of findings but also contributed to a nuanced understanding of their broader implications for cardiovascular health.

#### 2.1.4.10.1.3 Logistic Regression Analysis

The investigation employed logistic regression analysis to assess the link between hand grip strength and hypertension risk, estimating odds ratios and 95% confidence intervals. Employing diverse models that accounted for multiple covariates ensured a thorough examination of the intricate relationship between hand grip strength and the probability of hypertension development. This statistical methodology delivered nuanced insights into the interplay of hand grip strength with various factors influencing the risk of hypertension.

#### 2.1.4.10.1.4 Meta Analysis



Meta-analysis, a robust statistical technique, amalgamates diverse study findings to provide a more precise overall effect estimate. Key tools in this analytical approach include the Standardized Mean Difference (SMD), quantifying treatment effect size relative to study variability, and the Forest Plot, a graphical representation showcasing individual study results with point estimates and confidence intervals. Heterogeneity Analysis, represented by $I^2$, evaluates variability among study effect sizes, aiding in assessing result consistency. The Funnel Plot visually depicts the distribution of study effect sizes, assisting in identifying potential biases, while Z-Test or T-Test rigorously examines the overall significance of the combined effect size. These tools collectively elevate the robustness and depth of meta-analytical insights, contributing to a more nuanced understanding of research outcomes.

#### 2.1.4.11 Conclusion

Summarize primary findings derived from data analysis and meta-analysis. Share perspectives on the implications of the results. Recommend potential avenues for future research or refinements in measurement protocols.

#### 2.1.4.12 Flow chart of the standardizes hand grip strength measurement procedure

Figure 2.12 depicts a streamlined flowchart outlining the standardized procedure for measuring Hand Grip Strength (HGS). It begins with participant preparation and dynamometer calibration, ensuring accuracy and fit. Dominant hand selection and proper grip instructions follow, leading to trial squeezes and official attempts. Recorded measurements undergo rigorous data analysis, culminating in findings reporting and conclusion drawing for comprehensive HGS assessment.



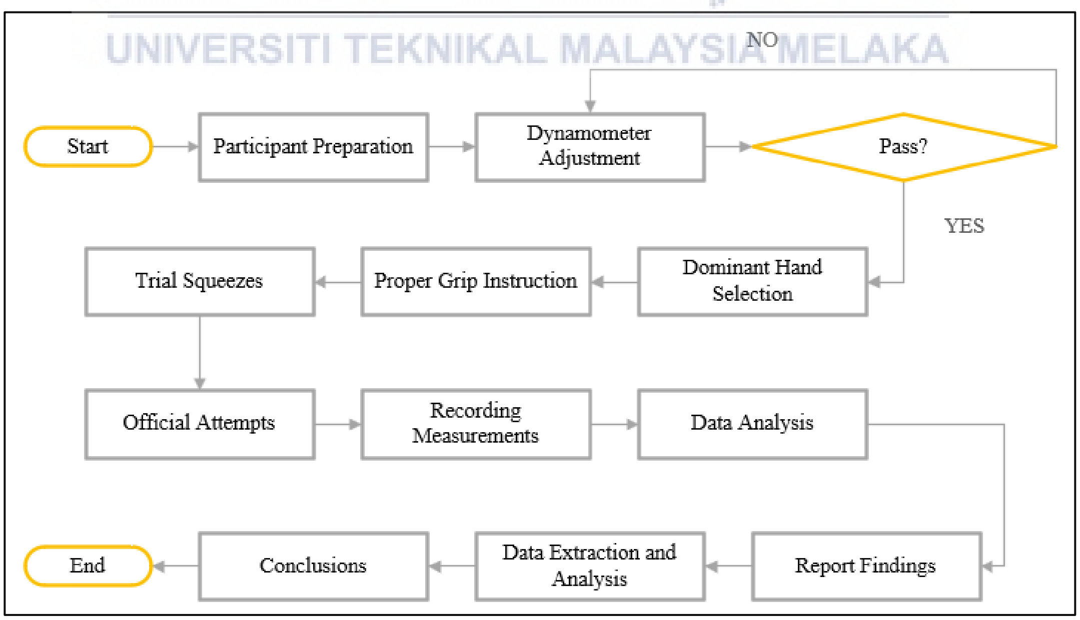



Figure 2.12: Flow chart of the standardizes HGS measurement procedure

### 2.1.5 The importance of hand grip normative dataset

A hand grip normative dataset holds significance as it provides a standardized reference for evaluating hand grip strength across diverse demographics (Wang et al., 2018). This metric is crucial for health assessments (Lim et al., 2019), aiding healthcare professionals in identifying potential health issues (Ong et al., 2017), setting rehabilitation goals (Larson & Ye, 2017), and monitoring progress. Particularly relevant in the elderly population, and it serves as a predictor of frailty and functional decline (Olguín et al., 2017). In sports, it enables coaches to gauge athletes' performance (Gledson et al., 2018) and tailor training programs, while in occupational settings, it informs ergonomic interventions for promoting workplace health (Lee & Hwang, 2019). Additionally, the dataset's utility extends to research, allowing for consistent comparisons across studies and populations. Overall, a hand grip normative dataset is crucial for interpreting and applying hand grip strength as a comprehensive measure of health and performance.

### 2.1.6 Analysis of the factors affecting hand grip strength



Hand grip strength can be influenced by various factors. These factors including the age (Massy-Westropp et al., 2011), gender (Ahrenfeldt et al., 2019), race (Chiles Shaffer et al., 2020), sleep duration (Grandou et al., 2019), health condition (McGrath et al., 2020), posture (Jain et al., 2019), and hand-forearm dimensions (Rostamzadeh et al., 2020).

#### 2.1.6.1 Age

Challenges with hand functioning and manual dexterity are commonly encountered by elderly individuals, necessitating precise fine grip, and often accompanied by a decline in hand strength that impacts daily activities (Carmeli et al., 2003). While functional ability typically remains stable until the age of 65, a gradual decline becomes evident thereafter, attributed to factors such as chronic diseases, hand osteoarthritis, reduced physical activity, diminishing motivation, and age-related muscle changes (Kalman et al., 1990). The late-life deterioration in physical functioning is a significant concern due to its widespread prevalence, impact on morbidity, imposition of functional limitations, and influence on overall quality of life (Frederiksen et al., 2002). Notably, the long-acknowledged decline in muscle mass and strength during aging is a phenomenon that can only be partially mitigated through ongoing resistance-type training (Goldspink, 2012).

#### 2.1.6.2 Gender

Muscle cross-sectional area (CSA) is influenced by both the size and quantity of muscle fibers. Existing research, as documented by various studies (MacDougall, 1983; Henriksson-Larsen, 1985; Sale, 1987), consistently indicates that untrained women generally possess smaller fiber areas compared to untrained men in muscles of both the upper and lower limbs. In a comparative analysis of individuals with similar body mass, the observed greater strength in men's muscles, both in absolute units and relative to lean body mass, is primarily attributed to the larger muscle fibers (Miller et al., 1993).



#### 2.1.6.3 Race

Differences in hand grip and muscle strength among various races can be influenced by genetic and environmental factors. Previous studies (Bhat et al., 2021; Germain et al., 2016) emphasize the role of genetic variations in muscle composition and function. Additionally, environmental factors, including lifestyle and physical activity patterns, contribute to disparities.

These findings underscore the complexity of interpreting grip and muscle strength data across diverse racial groups due to intricate interplay between genetics and environmental influences.

#### 2.1.6.4 Sleep duration

Variations in sleep duration impact hand grip strength, as evidenced by prior research (Chen et al., 2017; Wang et al., 2018). Both excessive and insufficient sleep have been associated with a decline in hand grip strength. Optimal strength is achieved with an adequate amount of sleep, with around 8 hours being the optimal duration, as indicated by previous studies. However, it's important to note that sleep patterns are also influenced by individuals past lifestyles (Sinha et al., 2020), contextualizing sleep duration and hand grip strength improves our understanding.

#### 2.1.6.5 Health condition

Decreased muscle function in illness significantly impacts functional status, disease recovery, and clinical outcomes, with additional interacting factors (Norman et al., 2011). In earlier research, malnourished IBD patients experienced a 15% increase in hand grip strength within the initial week after a 14-day TPN intervention (Christle & Hill, 1990). Another study (Norman et al., 2008) focused on malnourished patients with benign gastrointestinal disease, revealing that oral nutritional supplements for three months resulted in improved hand grip strength and quality of life exclusively among intervention patients.

#### 2.1.6.6 Posture

The influence of different testing postures, including body posture, wrist posture, and forearm posture, on hand grip strength has been explored in various studies (Sais et al., 2014;

Boadella et al., 2005; Liao, 2014). The consistent findings across these studies indicate that posture significantly affects grip strength, with differing outcomes observed between standing and sitting positions. A recent study (Xu et al., 2021) specifically highlights a slightly higher grip strength in the standing position compared to sitting. This emphasizes the critical consideration of testing posture in the assessment of hand grip strength. Figure 2.13 represents an example of hand grip strength test with standing and sitting posture.

Figure 2.13: Standing and sitting HGS posture (Keener et al., 2022)



#### 2.1.6.7 Hand circumference

Hand circumference as shown in figure 2.14, is the measure of the distance around the hand at its widest point, has been correlated with hand grip strength in various studies (Harries, 1985; Fraser et al., 1999; Gunther et al., 2008). The relationship between hand circumference and grip strength suggests that individuals with larger hand circumferences tend to exhibit greater hand grip strength. This association can be attributed to the physiological aspect that a larger hand circumference often implies a larger hand size and, consequently, a greater distribution of muscle mass, which contributes to enhanced grip strength. Studies in this line of research, including one conducted (Li et al., 2010), continue to emphasize the significant impact of hand circumference on hand grip strength.

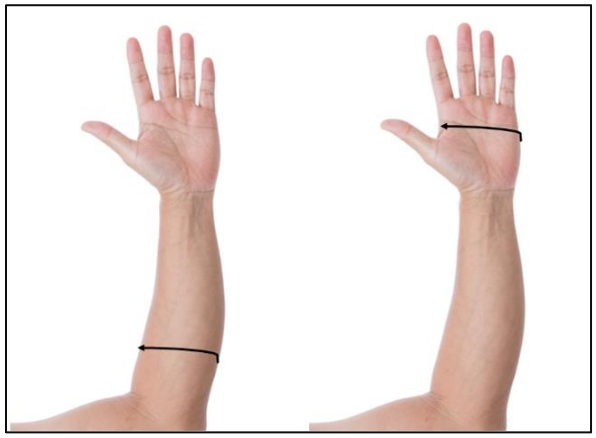


Figure 2.14: Hand circumference

### 2.1.7 Summary

This literature review covers hand grip strength, its measurements, influencing factors, and the importance of a normative dataset. It highlights grip strength as a quick, reliable method endorsed by the World Health Organization. The study uniquely explores the correlation between hand anthropometry, body posture, and grip strength in Malaysian male adults.

The subsequent section systematically assesses hand grip strength measurement tools, spotlighting the Jamar Hydraulic Hand Dynamometer as the gold standard, known for its reliability. A comparative analysis of different dynamometers underscores the need for careful selection based on their nuanced advantages and disadvantages.

The literature review explores how different postures, such as Chuck Pinch and lateral pinch, impact grip strength and their relevance in daily activities and fine motor skills. It covers crush grip postures, biomechanical principles, and how body positions influence muscular engagement, offering a comprehensive view of posture's role in grip strength.

Then, the next section meticulously outlines the hand grip strength measurement procedure, drawing from established principles in biomechanics and muscle physiology. The systematic approach, encompassing participant preparation, dynamometer adjustment, dominant hand selection, proper grip instruction, trial squeezes, official attempts, recording measurements, data analysis, and reporting findings, ensures standardized assessment across diverse populations.

Underlining the vital role of a hand grip normative dataset, the review emphasizes its significance as a standardized reference for assessing grip strength across demographics. Crucial for health assessments, rehabilitation goals, and diverse applications, the analysis of factors affecting grip strength reveals the intricate nature of this physiological metric, considering age, gender, race, sleep duration, health condition, posture, and hand circumference.

In conclusion, this literature review provides a comprehensive understanding of hand grip strength, from its measurement tools and influencing factors to the significance of a normative dataset. The detailed exploration sets the stage for the subsequent chapters, contributing valuable insights for both researchers and practitioners in the fields of health, sports, and ergonomics.



## 2.2 An Overview of Correlation Analysis – Statistical Evaluation Method

In quantitative research, the meticulous execution of data cleaning is essential to guarantee that the insights derived from the data hold a high level of generalizability (Osborne, 2010). Correlation analysis is both popular and useful in several social networking research, particularly in exploratory data analysis (Xiao, 2015). Then, it is crucial to visually represent correlation analyses to gain a clear understanding of the relationships. For instance, consider visualizing the correlation between grip strength and another variable (Wichelhaus et al., 2018; Jäkel et al, 2021).

### 2.2.1 Data cleaning

Data scientists spend a significant portion, often 50% to 80%, of their work time on data cleaning and organization, limiting time for actual analysis. Poor data quality, highlighted as the main adversary of machine learning, was discussed in a 2018 Harvard Business Review article. Effective data cleaning is paramount for businesses leveraging data analysis tools, echoing the principle "garbage in, garbage out," underscoring the requirement for clean data to ensure valid outputs (Chai, 2000). Data errors often result from human factors like typos and misinterpretation of sources, as well as issues in measuring physical phenomena and errors introduced during data preprocessing. Challenges in data merging from diverse sources with varying representations further complicate data quality (Hellerstein, 2022).

The era of "big data" introduces challenges in qualitative data cleaning, necessitating the creation of scalable methods. Acknowledging the significance of data cleaning's influence on statistical analysis becomes progressively vital (Chu et al., 2016). Negotiating these intricacies, businesses find that ensuring data quality stands out as a strategic necessity in the field of data science. Combining insights from Chai (2000), Chu et al. (2016), and Hellerstein (2022), we can establish key steps in a standardized data cleaning process: initial assessment, handling missing values, unit standardization, and numerical error correction.



#### 2.2.1.1 Data cleaning techniques

A dataset consists of individual records, each serving as the fundamental unit of information for a program. Grouping and naming these records form a dataset. The main goal is to refine the dataset using various techniques, ensuring it is ready for subsequent data analysis (Dasari & Varma, 2022). Regardless of the quality and timeliness of the analysis performed, if the dataset's quality is subpar, the outcomes will likely be unsatisfactory. The following section explores two prevalent techniques employed for data cleaning and analysis.

#### 2.2.1.1.1 Python

Python, a user-friendly and robust programming language, features efficient high-level data structures and a straightforward approach to object-oriented programming. Its elegant syntax, dynamic typing, and interpretive nature make it ideal for scripting and rapid application development across platforms (Rossum & Jr, 2011). Table 2.4 represents several data cleaning tasks and command/library in Python.

Table 2.4: Data cleaning techniques using Python (Dasari & Varma, 2022)

| Data Cleaning Tasks | Python Commands/ Library Apply |
|---|---|
| Detection of Missing Values<br>Issue: Data may contain missing values (null or NaN).<br>Solution:<br>-Replace null values with a space or a specified value.<br>-Replace null values with the mean, median, or mode of the respective columns.<br>-Delete records/rows containing null values. | *dc1.dropna()* |
| Get Rid of Extra Spaces<br>Issue: Data may contain extra spaces in column names or values.<br>Solution:<br>-Replace column spaces with underscores.<br>-Remove extra spaces in column values. | *dc1.columns = dc1.columns.str.replace(' ', '_')*<br><br>*dc1['Gender'] = dc1['Gender'].str.replace(' ', '')* |
| Convert Numbers Stored as Text into Numbers<br>Issue: Numbers may be stored as text, causing calculation and sorting problems.<br>Solution:<br>Convert object type values to numeric type. | *dc1['Emp_id'] = pd.to_numeric(dc1['Emp_id'])* |
| Remove Duplicates<br>Issue: Duplicate records in the dataset.<br>Solution:<br>Identify and remove duplicate records. | *print(dc1.drop_duplicates())* |
| Highlight Errors<br>Issue: Structural errors, inconsistent naming conventions, typos, etc.<br>Solution:<br>Highlight null values in the dataset. | *dc1.style.highlight_null(null_color='yellow')* |
| Change Text to Lower/Upper/Proper Case<br>Issue: Inconsistent text case.<br>Solution:<br>Convert text to upper case | *dc1.apply(lambda x: x.astype(str).str.upper())* |

These Python implementations showcase the practical steps to clean and preprocess data using the mentioned techniques. Data cleaning is crucial for ensuring data accuracy, consistency, and usability in analysis and decision-making processes.

#### 2.2.1.1.2 Microsoft Excel

In the realm of data science, there are various stages, including crucial data preparation. During this phase, efforts are made to transform raw, unclean data into a refined form suitable for modeling. Excel, a Microsoft application, is among the tools offering convenience for processing data in preparation for modeling, despite its limitations (Setiyanto & Setiawan, 2022). Table 2.5 represents steps used to clean data using Excel. These steps help ensure the accuracy, consistency, and usability of the data, making it ready for analysis in the field of data science.

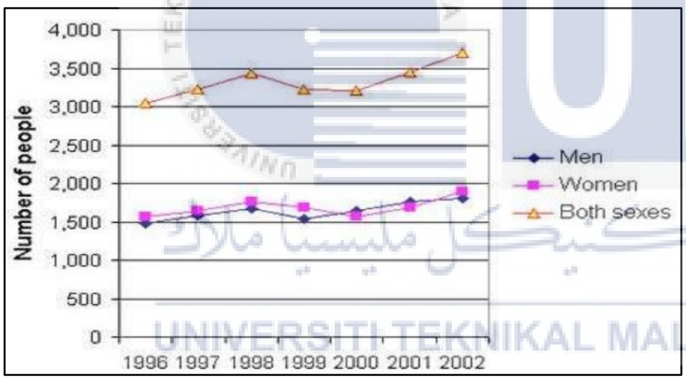
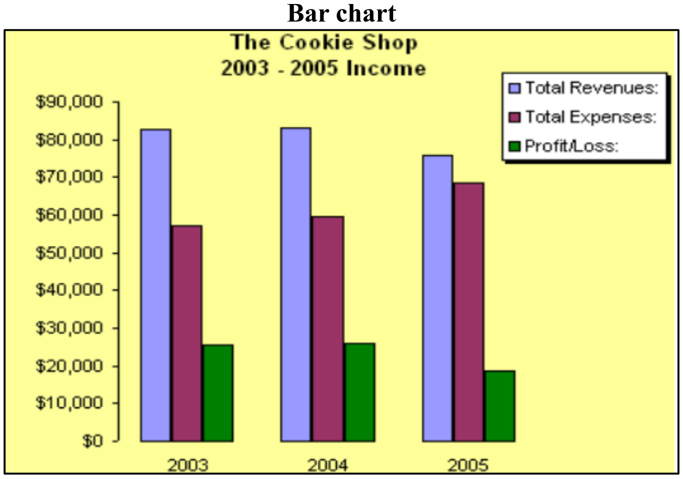
Table 2.5: Steps of data cleaning in excel (Setiyanto & Setiawan, 2022)

| Steps | Explanation |
|---|---|
| Detecting Errors | -Use the "Go To" feature to identify error cells in Microsoft Excel.<br>-Navigate to Home → Conditional Formatting → Highlight Cells Rules → Duplicate Values to find and highlight duplicate data. |
| Fixing Structure Errors | -Differentiate between numeric and text data using Excel's built-in functions like replace and substitute. |
| Removing Duplicate or Unnecessary Data | -Utilize Conditional Formatting to identify and highlight duplicate values.<br>-Select the data range, go to Home → Conditional Formatting → Highlight Cells Rules → Duplicate Values. |
| Handling Unwanted Outliers | -Calculate mean and standard deviation to identify outliers in the dataset.<br>-Use the Z-score or other statistical measures to determine if a data point is an outlier. |
| Handling Missing Data | -Address missing values by using techniques like linear interpolation.<br>-Use formulas to fill in missing values based on surrounding data. |
| Data Validation | -Apply data validation to restrict the type of data entered in a cell or range.<br>-Select the cell or range, go to Data → Data Tools → Data Validation, and set the desired validation criteria. |

### 2.2.2 Data visualization

Data Visualization serves as a crucial approach in comprehending large datasets and uncovering valuable insights. Due to the extensive range of visualization techniques available, selecting the most suitable method for presenting data can be challenging. The primary objective of visualizing data is to offer a clear interpretation of insights seamlessly. Over time, diverse visualization techniques have been employed for various tasks, each conveying distinct levels of understanding. Table 2.6 represents the type of data visualization we can do in data exploratory.

Table 2.6: Data visualization techniques with explanation

| Methods | Explanation |
|---|---|
| **Line chart**<br><br><br>Figure 2.15: Example of line chart | A line chart is a visual tool for displaying relationships between variables, often used for comparing multiple items and trends. It connects data points with straight lines, making it suitable for showcasing changes in variables. The choice of a line chart depends on the number of data points, and specific symbols represent these points in the chart. Figure 2.15 shows an example line chart. |
| **Bar chart**<br><br><br>Figure 2.16: Example of bar chart | A bar chart, also known as a column chart, is utilized for comparing items across different groups. It employs bars to represent values within a group, either horizontally or vertically. Bar charts are effective when differences between values are easily perceptible, but they may be challenging for large datasets. They commonly depict discrete data and present single data series, grouping related data points. Figure 2.16 shows an example bar chart. |

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**Pie chart**

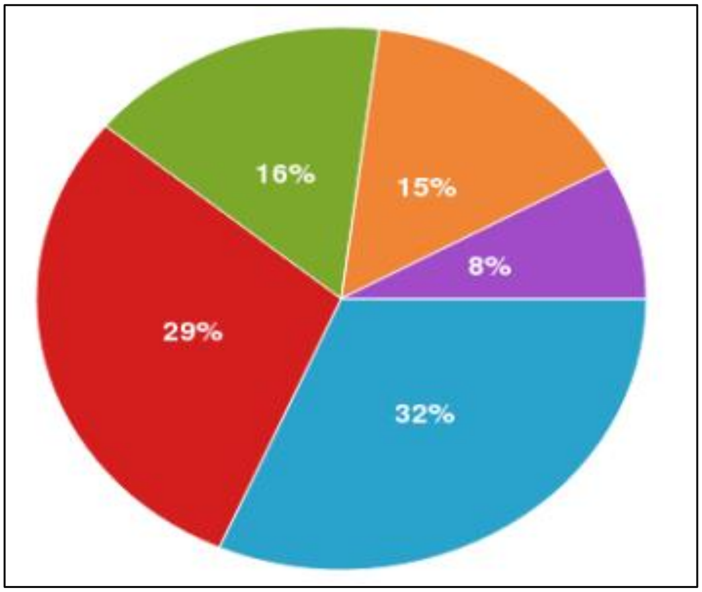


Figure 2.17: Example of pie chart

</td>
<td>

A pie chart, or circle graph, visually displays data in pie-slice form, showcasing each element's proportion. Larger slices indicate higher representation, aiding in value comparison. Effective with few components and percentages, it provides clear information. Variations include the Doughnut chart with a hollow center and Exploding pie chart for altered wedge sizes. Figure 2.17 shows an example pie chart.

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***Scatter plot***

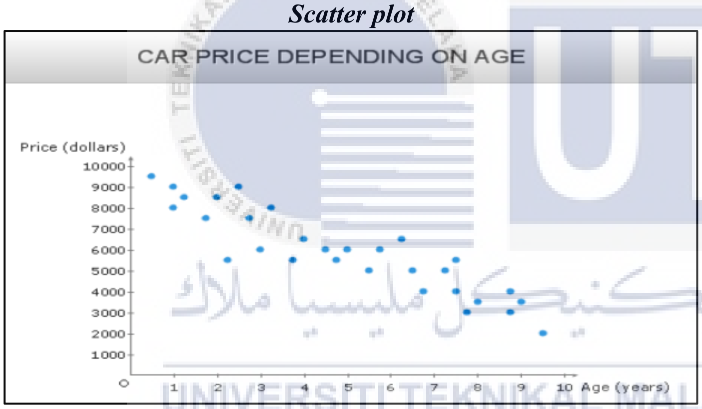


Figure 2.18: Example of scatter plot

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<td>

A scatter plot, also known as a scatter chart, visually represents the joint variation of two data items in a 2-dimensional plot. Observations are marked to indicate their values, offering insights into the relationship and dispersion of data points, helping assess correlation strength and scatter. Figure 2.18 shows an example scatter chart.

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***Bubble chart***

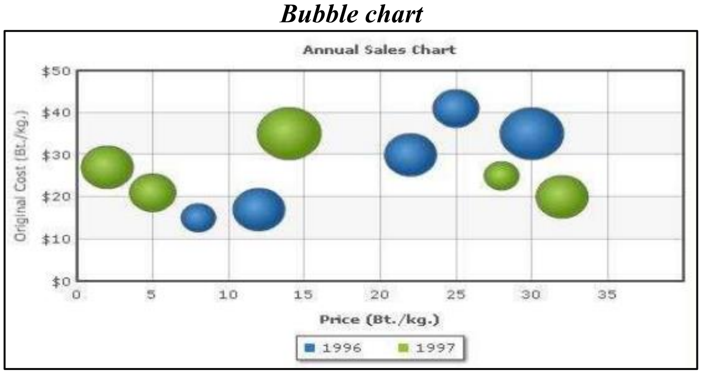


Figure 2.19: Example of bubble plot

</td>
<td>

A bubble plot, a variant of a scatter plot, uses bubbles to represent data points with three values each—two on plot axes and the third determining bubble size. Suitable for numerous or varied-magnitude values, it employs colors for additional measures. Animated bubbles show data changes over time. Useful in project management, it compares risk and success rates, with bubble size determined by values like net present values, success probability, and total sum. Figure 2.19 shows an example bar chart.

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</table>

### 2.2.3 Common correlation coefficients used

Correlation and regression, although distinct, are not mutually exclusive statistical techniques. Generally, regression is employed for prediction purposes, with the caveat that it doesn't extend beyond the data used in the analysis. In contrast, correlation serves to assess the degree of association between variables (AG Asuero, 2006). Correlation specifically measures the strength of the linear relationship between a pair of variables (Viv Bewick, 2003). Pearson correlation coefficient, Spearman rank correlation coefficient, and Kendall rank correlation coefficient is the three well-known and frequently utilized correlation coefficients (Chengwei Xiao, 2015). The subsequent sections elaborate on the mechanisms underlying these three correlation coefficients.

#### 2.2.3.1 Pearson correlation coefficient

The Pearson correlation coefficient assesses linear relationships between two variables and finds applications in statistics, data analysis, classification, decision-making, clustering, finance analysis, and biological research (Zhou et al., 2016). The formula of Pearson correlation coefficient, r, is as shown in figure 2.20 below (Bewick et al., 2003).

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Figure 2.20: Formula of Pearson correlation coefficient

where $\bar{x}$ is the mean of the x values, and $\bar{y}$ is the mean of the y values.

- r close to +1 indicates a strong positive linear relationship.
- r close to -1 indicates a strong negative linear relationship.
- r close to 0 indicates no linear relationship.

### 2.2.3.2 Spearman rank correlation coefficient

Spearman's rank correlation coefficient is a nonparametric statistic measuring the strength of an association between two variables, especially when the data distribution renders Pearson's correlation coefficient unsuitable (Hauke & Kossowski, 2011). The formula of Spearman rank correlation coefficient, $d_i$, is as shown in figure 2.21 below (Xiao et al, 2015).

$$r_s = 1 - \frac{6\sum d_i^2}{N(N^2 - 1)},$$

Figure 2.21: Formula of Spearman rank correlation coefficient

where $d_i = X'_i - Y'_i$ is the difference between each pair of the ranked variables and N is the total number of the samples.

- $r_s = 1$ indicates a perfect positive monotonic relationship.
- $r_s = -1$ indicates a perfect negative monotonic relationship.
- $r_s = 0$ indicates no monotonic relationship.



### 2.2.3.3 Kendall rank correlation coefficient

The Kendall rank correlation coefficient assesses the similarity between two sets of ranks for the same objects, considering the number of inversions required to transform one rank order into the other (Hervé, 2007). The formula of Kendall rank correlation coefficient, $n_c$, is as shown in figure 2.22 below (Xiao et al., 2015).

$$\tau = \frac{n_c - n_d}{\frac{1}{2}N(N-1)}$$

Figure 2.22: Formula of Kendall rank correlation coefficient

where $n_c$ = number of concordant pairs, $n_d$ = number of discordant pairs and N = total number of pairs.

- ➢ τ = 1 indicates a perfect positive correlation.
- ➢ τ = -1 indicates a perfect negative correlation.
- ➢ τ = 0 indicates no correlation.

**2.2.3.4 R-squared analysis**

In the research by Nurul Shahida et al. (2015) and Flood et al. (2014), the R squared ($R^2$) value is used to measure the proportion of variance in the dependent variable explained by the independent variables. Nurul Shahida et al. (2015) demonstrate that a higher $R^2$ value indicates a better fit between the model and the data, with the model explaining more of the variability in hand grip strength based on anthropometric dimensions and gender. Similarly, Flood et al. (2014) use $R^2$ to quantify how well hand grip strength predicts nutritional status, as measured by the Patient-Generated Subjective Global Assessment (PG-SGA) score. An $R^2$ of 1 signifies perfect prediction, while an $R^2$ of 0 indicates no predictive power. Additionally, Flood et al. (2014) illustrate the correlation visually through graphs, which further emphasize the relationship between hand grip strength and nutritional status. Figure 2.23 illustrates an example of R-squared analysis, showing the correlation between the percent of ideal HGS and PG-SGA score.



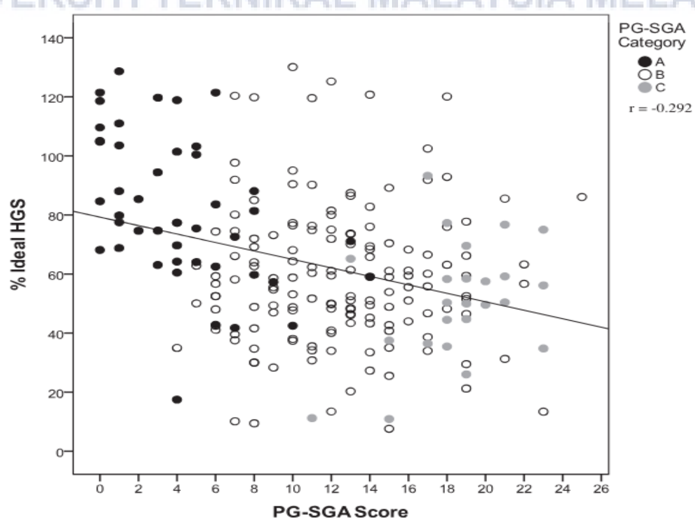


Figure 2.23: Correlation between percent of ideal HGS and PG-SGA score by PG-SGA nutrition status category

### 2.2.4 Evaluation of literature review of visualized correlation/comparison method and the independent variables of study

Table 2.7 provides a comprehensive summary and evaluation of previous studies, specifically focusing on the methods used for visualizing correlations and comparisons, as well as the diverse independent variables examined across these studies.

Table 2.7: Evaluation of visualized correlation application and independent variables in previous studies

<table>
<tr><th>Studies</th><th>Example of visualization correlation application used in the previous study</th><th>Independent variables or predictors studied</th></tr>
<tr><td>Alex et al., 2013</td><td>The study found mild to moderate correlations between dominant hand grip strength and height, as well as weight, in men. This emphasizes the complex nature of factors influencing grip strength and underscores the need for further research. Figure 2.24 displays two scatter plots: (A) shows a mild and positive correlation between height and dominant HGS, while (B) depicts a moderate and positive relationship between weight and dominant HGS.

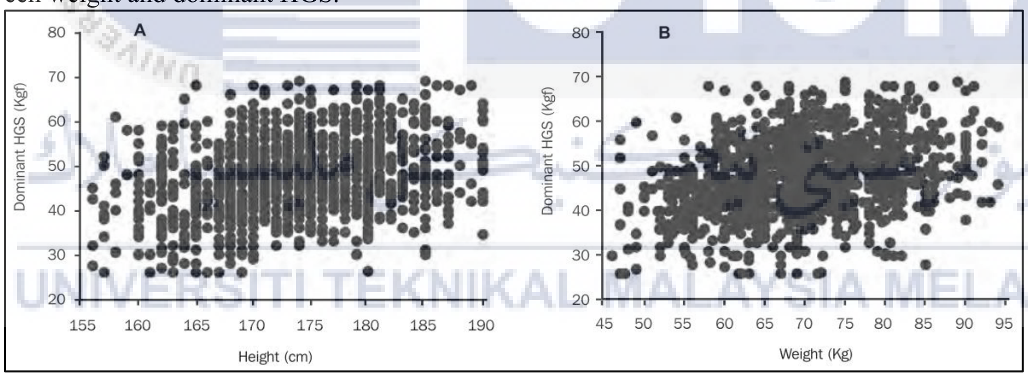


Figure 2.24: Scatter plots: dominant HGS and height (left); dominant HGS and weight disc(right)</td><td>Age, height, weight, BMI, and grip strength (left and right hand; dominant and non-dominant hand)</td></tr>
<tr><td>Wichelhaus et al., 2018</td><td>Figure 2.25 displays maximum strength results for different manual loading conditions using the monography system (200-mm cylinder) and Biometrics system (handle position 4). It visually compares the distribution of strength values for activities with and without manual loading.</td><td>Sex, hand length, manual loading, measurement system, handle size, and grip position.</td></tr>
</table>

| | | |
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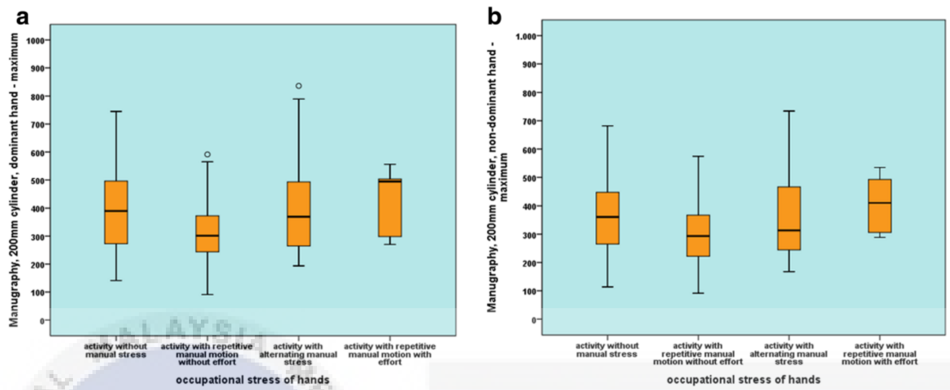
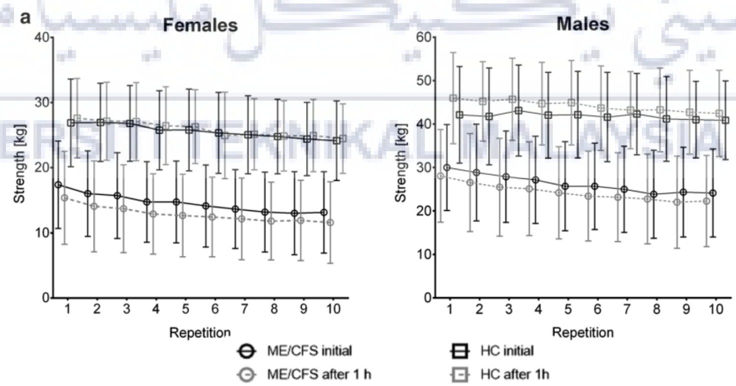
| | <br>Figure 2.25: Box and whiskers: dominant HGS by Manugraphy and occupational stress of hands (left); dominant HGS by Biometrics and occupational stress of hands (right) | |
| Jäkel et al, 2021 | Figure 2.26, 2.27 and 2.28 depicts HGS in male and female patients with ME/CFS, female patients with CRF, and healthy controls. ME/CFS patients exhibit consistently lower HGS than controls, with more pronounced differences in the second session, implying impaired recovery and increased fatigability. CRF patients also display lower HGS, suggesting non-specific effects. The figure visually conveys the impact of repeated measurements and recovery intervals on HGS in the studied groups, highlighting the distinctive patterns in ME/CFS and broader fatigue-related implications.<br><br>Figure 2.26: Forrest plot with handgrip strength (HGS) measurements in different groups (ME/CFS patients, cancer-related fatigue patients, and healthy controls). | Group membership, session, handedness, age, BMI, disease duration, fatigue severity, and pain severity. |

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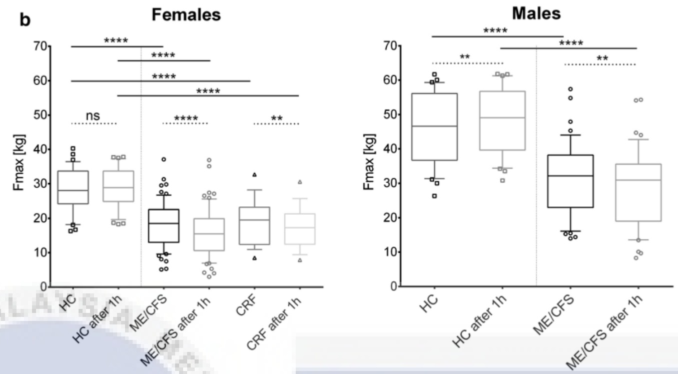


Figure 2.27: Boxplot comparing HGS in male and female ME/CFS patients, female cancer-related fatigue patients, and healthy controls.

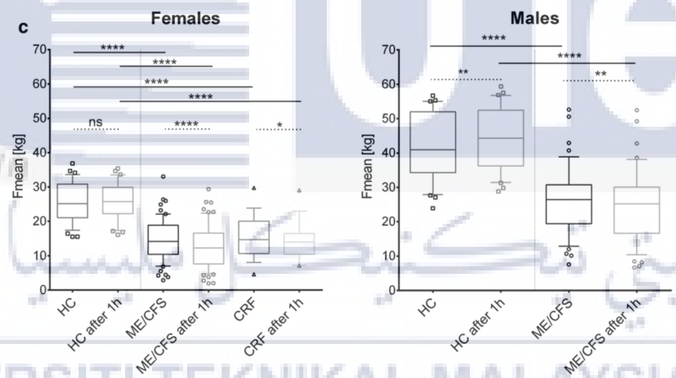


Figure 2.28: Boxplot depicting HGS variations due to repeated measurements and recovery intervals across diverse study populations.
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<td>Krakauer & Krakauer, 2020</td>
<td>Figure 2.29(a) illustrates the correlation of grip strength with ABSI, showing an inverse linear association. Figure 2.29(b) displays the relationship between grip strength and BMI Z score, indicating a nonlinear association with grip strength leveling off at higher BMI values. These figures visually represent the significant correlations and associations found between grip strength, ABSI, BMI, and mortality hazard in the NHANES 2011–2014 population. The dashed black lines represent least-squares linear fits, while the solid blue lines depict local polynomial (LOESS) fits with 95% confidence intervals.</td>
<td>ABSI, BMI, grip strength, sex, age, and ethnicity</td>
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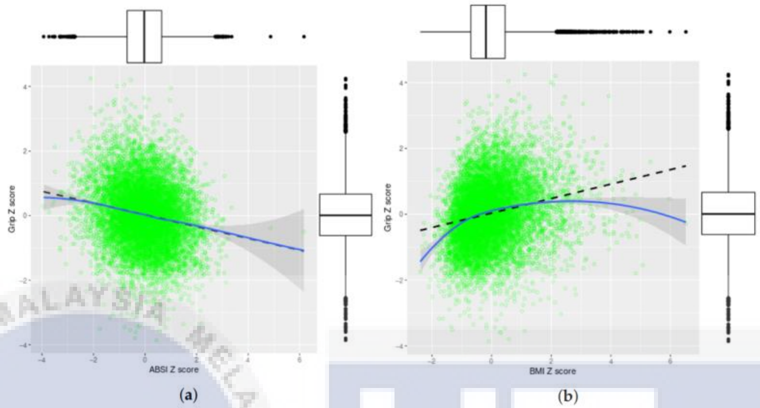
<td>

Figure 2.29: Combination of scatter and boxplot of grip strength against (a) ABSI and (b) BMI Z score in NHANES 2011–2014.</td>
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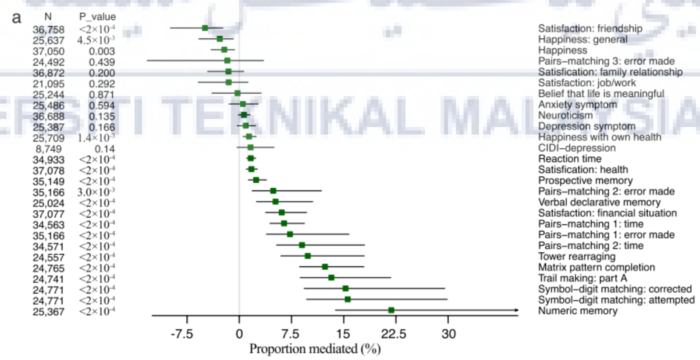
<td>Jiang et al., 2022</td>
<td>Figure 2.30 shows the mediation effect of mean GMV on the relationship between grip strength and behavioral outcomes. The strong correlation between mean GMV and grip strength ($r = 0.485$, $P < 10^{-30}$) indicates a significant indirect effect ($a \times b$) in 16 out of 27 behavioral outcomes (FDR corrected $P < 0.05$). The mediated effect size ranged from 1.40% to 21.83%, demonstrating that mean GMV partially mediates the association between grip strength and specific mental health outcomes. The figure displays the proportion of variance explained by the mediation, along with the 95% confidence interval bounds for each mediated effect.


Figure 2.30: Forest plot of mediation effect of mean GMV on the association between grip strength and behavioral outcomes.</td>
<td>Grip strength, cognitive functioning, life satisfaction, subjective well-being, depression, and anxiety symptoms</td>
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<td>Barry et al., 2021</td>
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Figure 2.31 show the paretic hand's substantial weakness is evident, registering an average grip strength of only 12.1% compared to the nonparetic hand. This weakened grip strongly correlates with overall upper extremity motor control, as indicated by the Fugl-Meyer Upper Extremity (FMUE) score. Additionally, the data reveal significant challenges in generating voluntary finger extension torque, with the majority of participants struggling to produce any net extension torque. These findings underscore the profound impact of weakness and coordination deficits on hand function in stroke survivors with severe chronic impairment, emphasizing the critical need for targeted interventions to improve motor outcomes and enhance overall functionality.

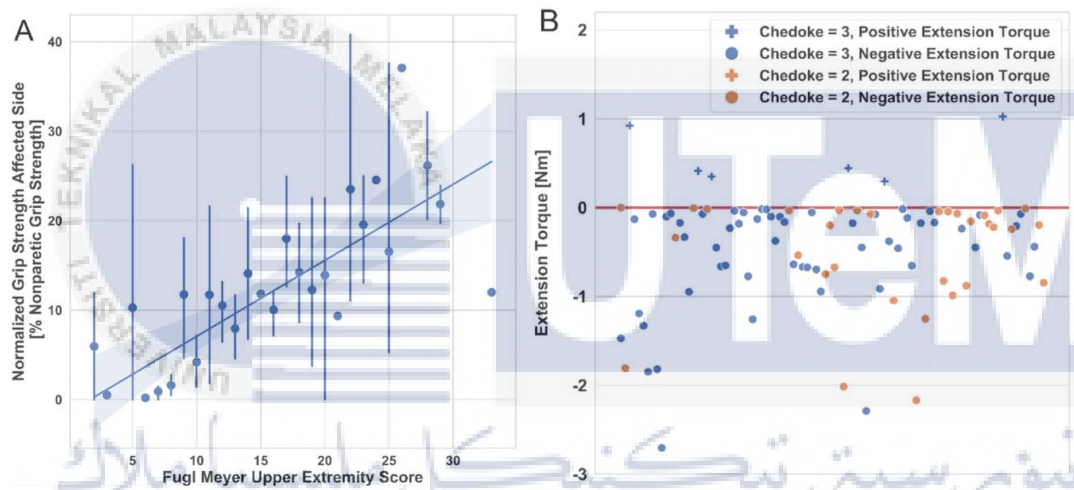


Figure 2.31: Figure: (a) Forrest plot and predictive of grip strength of the affected hand, as a percentage of the unaffected hand's grip strength. (b) Bland altman plot of maximum voluntary extension torque around the finger MCP joints



Figure 2.32 depicts a density map of EDC activation during voluntary finger extension and flexion. The x-axis represents extension activation, the y-axis represents flexion activation, and the red line marks equal activation. Most data points fall below the line, signifying increased EDC activation during voluntary flexion versus extension. This heightened flexor activation may contribute to grip force deficits and abnormal MCP flexion torque in individuals with severe chronic hand impairment post-stroke.
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<td>Severity of hand impairment, time since stroke onset, age, gender, hand dominance, demographic characteristics, grip strength, MCP flexion torque, FDS response, and spasticity measures.</td>
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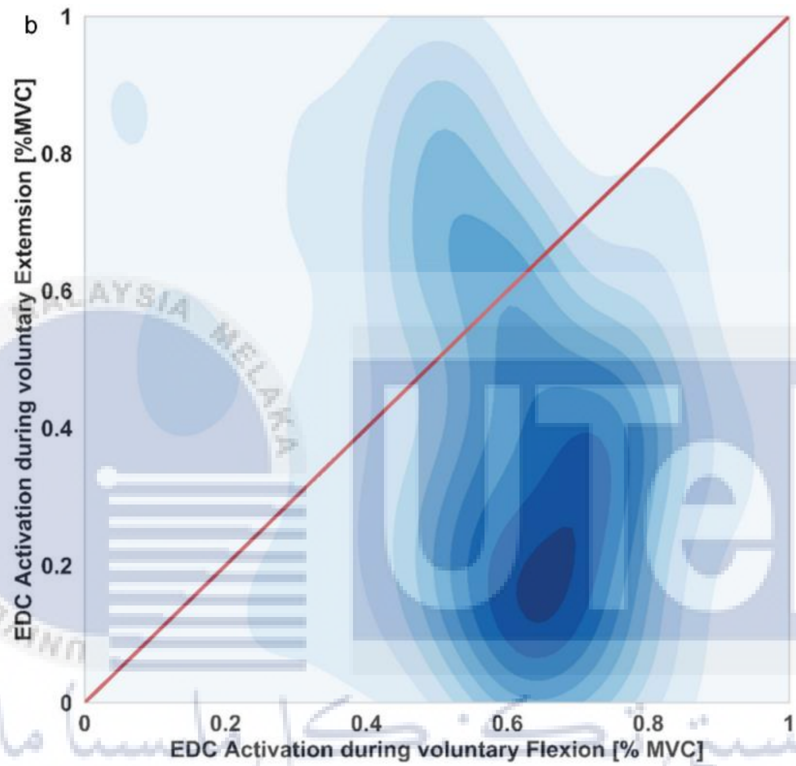
| |   Figure 2.32: Density map of EDC activation during voluntary finger extension and flexion | |

### 2.2.5 Summary

This literature review covers the foundational aspects of correlation analysis, emphasizing the crucial role of data cleaning in ensuring accurate and reliable insights from quantitative research. It highlights challenges related to poor data quality and emphasizes the necessity of clean datasets for meaningful analysis.

The subsequent exploration of data visualization techniques enhances the review, emphasizing the importance of visual representations in understanding large datasets and extracting valuable insights. It introduces a range of visualization methods: line charts, bar charts, pie charts, scatter plots, and bubble charts, each ideal for specific data exploration tasks.

Moving beyond data cleaning and visualization, the literature review provides an in-depth examination of common correlation coefficients—Pearson, Spearman, and Kendall. The review elucidates their formulas, interpretations, and distinct applications in assessing the strength and nature of relationships between variables.



The synthesis of information culminates in an evaluation of literature related to the visualization of correlation, offering examples from various studies. These examples span health, biomechanics, and cognitive science, illustrating how correlation analysis reveals relationships between variables like grip strength, height, weight, BMI, and others across diverse populations and conditions.

In essence, this literature review is a comprehensive guide to the foundational principles and practical applications of correlation analysis in quantitative research. It covers data cleaning, visualization techniques, and correlation coefficients, providing a holistic understanding of their collective role in deriving meaningful conclusions from data.

## 2.3 An Overview of the Prototype Development – Ergonomic Hand Glove Design Development

The prototype development for the ergonomic hand glove focuses on creating a design that prioritizes user comfort and functionality (Muralidhar et al., 1999). This process involves iterative testing and refinement to ensure optimal performance. Incorporating advanced materials and innovative features, the design aims to enhance user experience and performance (Cerqueira et al, 2022). The engineering analysis involves rigorous testing and validation processes to assess the performance and structural integrity of the ergonomic hand glove design (Dianat et al, 2012).

### 2.3.1 Ergonomic hand glove

There has been a growing demand for ergonomic products, driven by a heightened emphasis on health and comfort in recent years. The field of ergonomics is particularly critical in the development of PPE to mitigate risks in the workplace, with a specific focus on the essential role played by protective gloves in safeguarding the hands and arms (Irzmańska, 2014). However, the intricate nature of hand anatomy poses challenges in designing effective gloves (Irzmańska, 2014). Ensuring that gloves offer protection from the environment is a top priority, with efforts directed towards preventing any negative impact on performance (Muralidhar et al., 1995; Burak et al., 2023). The subsequent section will explore the prototype development of glove design.

The concept of prioritizing employee well-being through safety-focused gloves is commendable, yet in today's business landscape, balancing this with cost-effectiveness is equally crucial. Recognizing the inherent variability in hand dimensions, the availability of diverse and high-quality glove options provides a valuable opportunity to enhance comfort and safety across various workplace settings, fostering a positive impact on both individuals and businesses (Anne, 2012).

### 2.3.2 Evaluation of the literature review related to key steps and major considerations of glove prototype design

Table 2.8 consolidates insights from a variety of sources, providing a comprehensive summary of critical stages and primary considerations integral to the design of glove prototypes, as elucidated by past studies in the field.

Table 2.8: Key steps and major considerations of glove prototype design

| Studies | Glove type | Key steps | Major considerations |
|---|---|---|---|
| Maitre et al., 2021 | Daily activities (prototype is sensor-equipped glove) | Developing the glove design entails defining goals, selecting appropriate sensors, prioritizing wearability, establishing a robust data acquisition system, and applying signal processing for feature extraction. Machine learning or deep learning algorithms are chosen based on data characteristics, and the prototype undergoes rigorous testing and optimization for accurate object recognition. Considerations for usability, scalability, and ethical standards are integrated into the process, resulting in a well-documented, reproducible prototype. | User requirements, sensor selection, wearability, efficiency, participant engagement, and usability |
| Cerqueira et al, 2022 | Sensorial glove prototype | The glove prototype underwent key phases, testing UDP connectivity and handling continuous data streams using Python. Utilizing Unity's serialization tools, custom quaternion serialization managed efficient data transfer, addressing reference frame disparities. A tangible prototype with a wool glove navigated challenges, exploring wireless communication. Empirical testing evaluated the IMU-based orientation estimation solution. Future improvement include overcoming glove size limitations and refining calibration for improved precision. | User experience, glove design, solution, orientation estimation, user experience, future expandability, and empirical testing. |
| Kim et al., 2023 | Customized gloves (different hand shape) | The glove prototype development using the CMP method involves 3D hand scanning, grid creation, surface length measurement, transition to a 2D pattern, and fit adjustment. The process emphasizes the trapezoidal hand structure and C-curve finger side panels. Prototype testing includes wear tests, functional assessments, and user evaluations, leading to iterative improvements. The CMP method effectively tailors' gloves to individual hand dimensions and requirements. | 3D figure, 2D block pattern, comfort, material selection, user evaluation, functional testing, and analysis result |

| | | | |
|---|---|---|---|
| Biggar et al., 2017 | Therapy robotic glove | The prototype development involve user-centered design, including needs analysis and feedback integration. Identifying core features, ensuring functionality, and considering cost-efficiency are crucial. Technical feasibility, rapid prototyping, and iterative design enhance the process. Prioritizing ease of use, safety, and compliance, along with testing and validation, ensures a robust prototype. Legal and ethical considerations, scalability planning, and sustainability are vital for a successful development journey. | User need analysis, functionality, performance, cost-efficiency, technical feasibility, ease of use, safety, future development, and validation |
| Muralidhar et al., 1999 | Ergonomic glove | The prototype development involved several key steps: defining selective protection criteria based on hand anatomy studies, designing gloves with varying thickness for critical areas, validating prototypes through dexterity and strength tests, and evaluating safety using an algometer. The results supported the hypothesis that selectively applying protective materials improves glove design. | Hand condition, gender, material selection, selective protection criteria, biomechanical data, and performance evaluation |

### 2.3.3 Standard procedure of glove development

By examining the studies on glove prototype design in section 2.3.1, a clear understanding of the commonly adopted steps and considerations in glove development has been gained. The subsequent section delineates the components deemed appropriate for the design of an ergonomic glove, aligning with the focus of my title.



#### 2.3.3.1 User need survey

Examining studies conducted by Maitre et al. (2021), Cerqueira et al. (2022), Biggar et al. (2017), and Kim et al., it becomes evident that a crucial aspect in their key considerations involves the analysis of user requirements or the evaluation of users' feedback. In contrast, the study by Muralidhar et al. (1999) focuses on gathering data directly from users to inform the design of an ergonomic glove.

Prioritizing usability, ergonomic criteria, and adherence to design guidelines is essential for creating a positive user experience. Interfaces that are user-friendly, efficient, and enjoyable contribute significantly to user satisfaction (García et al., 2008). Understanding user preferences and satisfaction is vital for the success of any assistive technology. The user need requirement, which considers these factors, ensures that the technology is not only effective in controlled environments but also in real-world applications (Soviak et al., 2016).

Derived from a previous study, the focus is on former therapy patients' experiences and preferences, ensuring the patient-centric design of a robotic glove prototype aligns with the actual needs of those with upper limb impairments. Using a questionnaire and follow-up interviews, the study identifies critical functions integral to the success of the glove prototype (Biggar et al., 2017). Figure 2.33 provides an example questionnaire on natural rubber latex sensitization.



I. Demographic Characteristics

| | | | |
|---|---|---|---|
| Name | Job category | Sex: Female Male | Age (years old) |
| Latex glove use | 1-3 hours/day | 3-5 hours/day | > 6 hours/day |

II. Risk Factor Assessment/ Exposure History

| | | |
|---|---|---|
| Are you a health care worker? | Y | N |
| Do you wear latex gloves regularly or are you otherwise exposed to latex regularly? | Y | N |
| Do you have any history of eczema or other rashes on your hands? | Y | N |
| Do you have a medical history of frequent surgery or invasive medical procedures? | Y | N |
| Did these take place when you were an infant? | Y | N |
| Do you have a history of "hay fever" or other common allergies? | Y | N |
| Do your fellow workers wear latex gloves regularly? | Y | N |
| Do you take a beta-blocker medication? | Y | N |

III. Circle any foods below that cause hives, itching of the lips or throat, or more severe symptoms when you eat or handle them
Apple, apricot, avocado, banana, carrot, celery, cherry, chestnut, fig, kiwi, grape, hazelnut, melon, nectarine, papaya, passion fruit, pear, peach, pineapple, plum, potatoes, tomatoes

IV. Hand Dermatitis Assessment

| | | |
|---|---|---|
| Do you have rash, itching, cracking, chapping, scaling, or weeping of the skin from latex glove use? | Y | N |
| Have these symptoms recently changed or worsened? | Y | N |
| Have you used different brands of latex gloves? If so, have your symptoms persisted? | Y | N |
| Have you used non-latex gloves? If so, have you had the same or similar symptoms as with latex gloves? | Y | N |
| Do these symptoms persist when you stop wearing all gloves? | Y | N |
| When you wear or are around others wearing latex gloves do you get hives, red itchy swollen hands within 30 minutes or, "water blisters" on your hands within a day? | Y | N |

V. Aerosol Reaction Assessment
When you wear or are around others wearing latex gloves, have you noted any:

| | | |
|---|---|---|
| • Itchy, red eyes, fits of sneezing, runny or stuffy nose, itching of the nose or palate? | Y | N |
| • Shortness of breath, wheezing, chest tightness or difficulty breathing? | Y | N |
| • Other acute reactions, including generalized or severe swelling or shock | Y | N |

VI. History of Reactions Suggestive of Latex Allergy

| | | |
|---|---|---|
| Do you have a history of anaphylaxis or of intra-operative shock? | Y | N |
| Have you had itching, swelling or other symptoms following dental, rectal or pelvic exams? | Y | N |
| Have you experienced swelling or difficulty breathing after blowing up a balloon? | Y | N |
| Do condoms, diaphragms or latex sexual aids cause itching or swelling? | Y | N |
| Do rubber handles, rubber bands or elastic bands or clothing cause any discomfort? | Y | N |

Figure 2.33: Questionnaire on natural rubber latex sensitization, (Buss et al., 2008)

### 2.3.3.2 Material selection

If a hazard assessment indicates potential hand and arm injuries that engineering and work controls cannot eliminate, employers must ensure proper protection. One method is installing a barrier to prevent contact between employees' hands and a table saw blade during cutting.

A wide range of gloves is available to protect against various hazards, and the selection depends on the nature of the hazard and specific tasks. Choosing the right gloves is crucial due to the diverse occupational hand injuries. Employees must use gloves tailored to their workplace hazards, as gloves designed for one function may not safeguard against different risks, even if they seem suitable (OSHA, 2023). Table 2.9 represents the information from OSHA documents about material types of protection glove with its function and weakness.

Table 2.9: Protective glove material type with its function and weakness

| Material type | Protection against | Weakness |
|---|---|---|
| Leather, Canvas, or Metal Mesh Gloves | Cuts, burns, sparks, moderate heat, blows, chips, rough objects. | Limited protection against chemicals, may not be suitable for tasks involving strong acids, alkalis, and solvents. |
| Fabric and Coated Fabric Gloves | Dirt, slivers, chafing, abrasions. Coated fabric gloves offer slip-resistant qualities. | Limited protection for rough, sharp, or heavy materials. Effectiveness against specific chemicals may vary, and it is important to check with the manufacturer. |
| Chemical- and Liquid-Resistant Gloves | Various chemicals, including peroxide, rocket fuels, corrosive acids, bases, alcohols, aldehydes, ketones, esters, and nitro compounds. | Thicker gloves may impair grip and dexterity. Material thickness influences chemical resistance. Some materials may not perform well with specific chemicals. |
| Insulating Rubber Gloves | Electrical hazards | May not provide protection against other hazards |

### 2.3.3.3 Conceptual design

Conceptual design is critical for transforming a concept into an actual prototype. The engineering design process involves turning a concept into a tangible device or technique, and a key step in this process is the conceptual design phase (Huang et al., 2014). Conceptual design is pivotal in enhancing the gloves production lines, emphasizing mechanical innovation. Prototypes validate cost-effective solutions, contributing to streamlined processes and improved industry competitiveness (Yongyingsakthavorn et al., 2019). Figure 2.34 effectively illustrates conceptual design with clear visual concepts while also incorporating clear labeling.

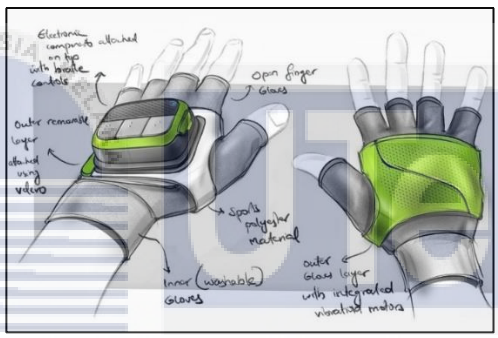



Figure 2.34: Example of a conceptual design (Torres, 2023)



### 2.3.3.4 Glove simulation

Simulation is pivotal, expediting robotic glove development while mitigating risks and costs. It optimizes performance, serves as an educational tool, and ensures reproducibility, fostering advancements in research through controlled and iterative refinement of prototypes (Morozova et al., 2021). Simulation is crucial in optimizing the performance of systems, processes, and designs. It helps in fine-tuning parameters, predicting outcomes, and achieving efficiency improvements without the need for costly and time-consuming physical tests (Cerqueira, 2022). Figure 2.35 showcases an example of glove simulation system for hand tracking in Unity.

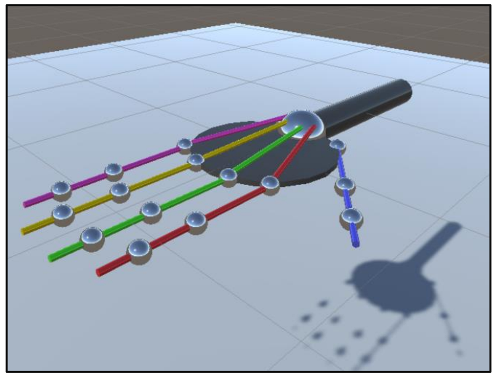


Figure 2.35: Glove simulation system for hand tracking (Cerqueira, 2022)

### 2.3.3.5 Quality function deployment (QFD)

QFD is a systematic approach, originating from Japan, that connects user needs with design requirements. It enhances customer understanding and facilitates customer-oriented development of products, services, and processes (Biggar et al., 2017; Tutik Lestari, 2018). The QFD method, employing the HOQ, aligns both customer and engineering requirements (Ismail et al., 2023).

The House of Quality as shown in figure 2.36 visually encapsulates the relationships between customer requirements and engineering characteristics. It involves a matrix with critical elements such as CRs, ECs, their importance, interrelations, competitive assessment, inner dependencies, and overall priorities. Collaboratively filled by an expert group, the HOQ aligns technical features with customer needs, fostering effective product planning and development. The provided text introduces an integrated approach utilizing hesitant fuzzy sets and MCDM techniques to enhance traditional QFD methodologies for more accurate expert opinions and prioritization of ECs (Wu et al., 2016).

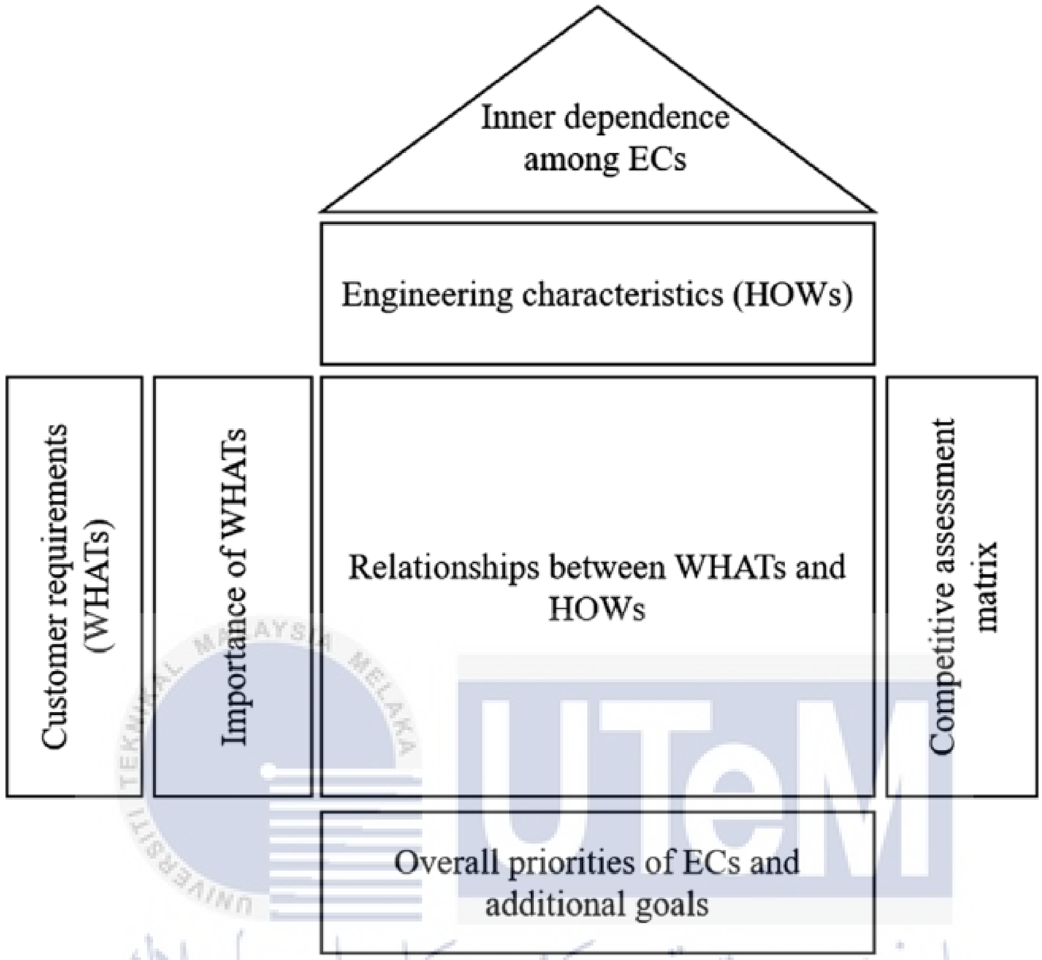



Figure 2.36: House of quality (HOQ), (Wu et al., 2016)



### 2.3.3.6 Glove performance engineering analysis

Engineering analysis based on input is vital for optimizing glove design, enhancing performance (Han et al., 2019), and ensuring safety (Dianat, 2012). By analyzing forces, and ergonomic factors (Burak, 2023), engineers can customize gloves for specific tasks, improve user comfort (Yu et al., 2019), and meet industry standards (OSHA, 2023). This iterative process fosters continuous improvement, cost-efficiency, and innovation in hand protection. The succeeding segment details the kinds of engineering analyses that can be conducted as measures of performance.

#### 2.3.3.6.1 Coefficient of friction

The evaluation of friction in gloves is crucial for understanding how the glove material interacts with different surfaces. Friction testing is instrumental in gauging the glove's capacity to ensure a firm grip, prevent slipping, and retain tactile sensitivity across various tasks (O'Hara et al., 1988; Carré et al., 2017). As indicated by a prior study, the findings reveal that users may experience variations in performance based on the glove material, with the possibility of reduced effectiveness, especially in aspects such as grip and tactile sensitivity (Carré et al., 2017).

#### 2.3.3.6.2 Hand grip strength comparison

Comparing hand grip strength with and without gloves can serve as an engineering analysis and performance indicator. The difference in grip strength provides valuable insights into how gloves may affect the muscular performance of the hand (Dianat et al. 2014), which is crucial information for various applications, including ergonomics, occupational safety, and the design and evaluation of protective gear.



#### 2.3.3.6.3 Pinch strength measurement

Pinch strength measurement involves using specialized equipment like pinch gauges or strain gauges. Subjects perform specific pinch grips (e.g., lateral, chuck, pulp) while the device records the force exerted between the thumb and fingers. Input parameters include grip type, gauge calibration, and hand positioning (Shurrab et al., 2017). Analysis considers factors influencing pinch strength, such as glove use, providing insights into hand performance and ergonomic considerations (Dianat et al. 2014).

### 2.3.4 Summary

The prototype development for an ergonomic hand glove emphasizes user comfort and functionality through iterative testing and engineering analysis. Drawing insights from diverse studies on glove design, the process covers key considerations such as sensor-equipped gloves, customized gloves for different hand shapes, therapy robotic gloves, and ergonomic gloves.

The standard procedure for glove development includes user need surveys, material selection based on workplace hazards, conceptual design, glove simulation, QFD, and glove performance engineering analysis. These steps ensure alignment with user requirements, optimal material choices, efficient design, simulation for cost-effective development, and a systematic approach to connecting user needs with design requirements.

The document provides a comprehensive overview of the development process, integrating findings from various studies to create gloves that prioritize safety, user satisfaction, and efficiency in diverse workplace settings.

# CHAPTER 3
# METHODOLOGY

This chapter outlines the methodology employed in the study, providing details on the methods and tools employed to meet the study's goals. The focus involves evaluating the hand anthropometric dimensions and grip strength of adult males in Malaysia, exploring the connection between hand grip strength and various hand and body postures in Malaysian adult males, and designing a prototype for an ergonomic glove to enhance the gripping capabilities of adult males in Malaysia across different tasks.



## 3.1 Measure the Hand Anthropometric Dimensions and Grip Strength of Malaysian Male Adults

This section provides a detailed overview of the data collection process for hand anthropometric dimensions and grip strength. It encompasses various stages, including the calibration procedure and the subsequent steps taken post-calibration to ensure accurate and reliable measurements. The explanation aims to offer comprehensive insights into the methodology employed during the data collection phase of the study.

### 3.1.1 Developing the study methodology concept

This study adopts a holistic approach, merging original ideas, insights from extensive literature review, and guidance from experienced lecturers. Collaborative method ensures thorough exploration of glove design's impact on adult males' grip strength, ensuring reliability.

### 3.1.2 Pre-study - review of existing literature

The literature review encompasses diverse information on hand grip strength, measurement tools, influencing factors like age, gender, and health conditions, various grip postures, and biomechanics principles associated with body positions. Additionally, it explores different dynamometers and their advantages and limitations. This wealth of information forms the foundation for the study's methodology, providing a comprehensive understanding of the existing knowledge landscape and guiding the investigation into the ergonomic design of hand gloves to enhance grip strength in adult males.



### 3.1.3 Calibrate the Jamar hand dynamometer

Calibrating the Jamar hand dynamometer is a crucial step to ensure the accuracy of maximum hand grip strength measurements. This process involves preparing apparatus such as two same height table, hand dynamometer, weight balance, screwdriver, and fixed loads of 5 kg and 10 kg. The fixed load is suspended on the adjustable handle using a stronger rope during calibration. The dynamometer needles are adjusted to middle of "0". After calibration, a comparison is made with another hand dynamometer. The entire calibration procedure is validated by the supervisor and technician to ensure its accuracy and reliability. Figure 3.1 shows the calibration of Jamar and the position of dynamometer needles.

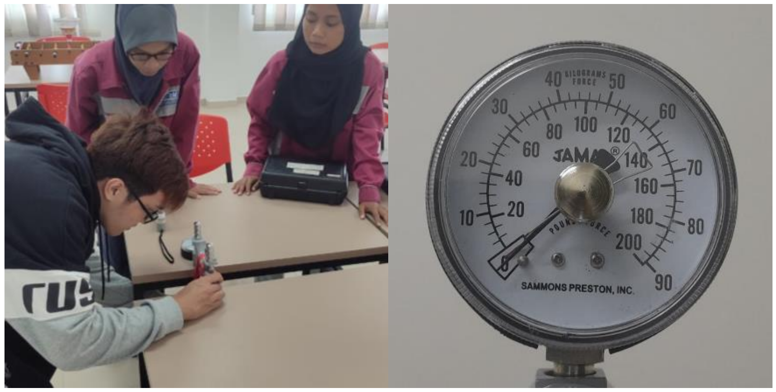



Figure 3.1: Calibration of Jamar and position of calibrated dynamometer

### 3.1.4 Questionnaire

In the questionnaire, it is expressly stated that the confidentiality of all sensitive information disclosed by participants will be strictly upheld. The collection of particulars such as participant names, ages, and identities serves the primary purpose of fortifying the credibility of the ensuing report. This transparent communication regarding data usage reflects our unwavering commitment to ethical practices and responsible management of participant data throughout the research endeavor.

### 3.1.5 Standard operating procedure (SOP)

Provide participants with a comprehensive overview of the standardized procedures involved in the study. It includes visual aids, such as images illustrating various postures, to facilitate participant understanding during both the registration process and subsequent explanations. The SOP serves the dual purpose of familiarizing participants with the entire process and ensuring clarity on the number of postures involved. Additionally, it emphasizes the importance of participants being aware of any limitations, contributing to the confirmation of data accuracy and the overall reliability of the obtained information.

### 3.1.6 Experiment procedures

The experimental procedures will be concisely presented and captured in a video for convenient reference by researchers and participants alike. This aims to ensure strict adherence to standardized steps in hand grip force measurements, promoting consistency and reliability throughout the study. Figure 3.2 represents the demonstration of standard experiment in standing posture. Essentially, the hand grip experiment involves the following steps:



i. In the sitting position, participants sit comfortably on a standard chair without arm support, with back support. Feet should be flat on the floor, and the non-dominant hand rests on the respective thigh. In the standing position, participants stand anatomically straight, facing forward, with feet pointing forwards and slightly apart, and the non-dominant hand hanging down by the side.
ii. A card is positioned under the participant's armpit to prevent arm abduction during the hand grip experiment.
iii. Participants are asked to comfortably hold the handle of the Jamar dynamometer, positioning the thumb on one side and the four fingers on the other. Adjustment of the handle position is allowed, with the default position set at the 2nd level.
iv. An L-square ruler is used to ensure that the participant's elbow is flexed at a 90° angle. Once the angle is established, the L-square ruler is removed.

v. Researchers support the weight of the dynamometer to counteract the effect of gravity on peak strength, taking care not to restrict its movement.

vi. Hand grip force data is collected, with participants gradually squeezing the dynamometer handle. Participants should avoid sudden squeezes to prevent needle jumping.

vii. Participants are prompted to squeeze tightly until the gauge needle stops rising, after which they cease squeezing. An example of encouragement is provided (Robert et al., 2011): ‘Are you ready? Squeeze as hard as you can’. As the participant begins to squeeze, the researcher says, ‘Go! … Go! … Relax'.

viii. Researchers record grip force data and participants rest for 1 minute before the second trial. Reading from the outside dial and recorded to the nearest 1 kg on part D of the participant form. If the reading needle rests between the dial, the middle kilogram is recorded.



Figure 3.2: Demonstration of standard posture

### 3.1.7 Pilot study

A pilot study is an initial investigation that involves a small-scale real experiment, primarily conducted to assess the feasibility of the main study or real experiment. In this study, a pilot study was carried out with a total of 10 male adult participants. These participants underwent two trials for each forearm position, considering both standing and sitting body positions: neutral, supination, and pronation, resulting in a total of 6 test combinations (2x3).

During this phase, participants were briefed on the purpose of the measurement. To ensure understanding of the measurement protocol of the Southampton Hand Assessment Procedure (SHAP), a demonstration of the hand grip strength test for the three wrist positions (neutral, supination, and pronation) was provided. Additionally, a light trial was conducted with each participant for familiarization. The illustration in Figure () depicts a light trial of hand grip strength measurement performed by a participant. This approach aimed to acquaint participants with the hand grip strength measurement using the Jamar hand dynamometer, promoting optimal performance in the actual measurement.

Following the analysis of the pilot study results, a crucial next step involves engaging in discussions with other researchers and lecturers who share a similar focus or expertise in the topic. This collaboration seeks input, feedback, and suggestions to improve the study. Figure 3.3 and 3.4 illustrates both sitting and standing positions with neutral, supination and pronation forearm posture.

Figure 3.3: Sitting body positions: neutral forearm posture (left), supination forearm posture (middle), and pronation forearm posture (right)

Figure 3.4: Standing body positions: neutral forearm posture (left), supination forearm posture (middle), and pronation forearm posture (right)

### 3.1.8 Participant preparation

For participant selection, a varied group of adult males will be recruited, considering factors such as age, hand size, and occupation. It is essential that participants have no pre-existing hand injuries or medical conditions that might impact grip strength. The initial discussion between myself and the supervisor focused on confirming the inclusion of male adults from Malaysia. To streamline recruitment, most participants will be targeted within UTeM. To enhance engagement, an informal hand grip strength test contest was initiated at UTeM, serving as an unofficial event to attract more participants.



#### 3.1.8.1 Sample size power analysis

Determining the sample size is a pivotal aspect of research design, exerting a direct impact on the credibility and dependability of study outcomes. An appropriately calculated sample size is instrumental in providing the study with adequate statistical power, enabling the identification of significant effects with precision.

The selected approach to gauge the sufficiency of the chosen sample size utilizes power curve analysis, a statistical method assessing the study's statistical power across diverse effect sizes. By plotting a power curve, researchers visually grasp how statistical power varies with different effect sizes, offering insights into the study's ability to detect different magnitudes of effects.

Integrating the two-sample t-test, this analytical technique provides a nuanced understanding of the interplay between effect size and statistical power. Executed through Python coding as figure 3.5, this method aids in determining an optimal sample size aligned with research objectives, enhancing overall study robustness.



```python
# Import the necessary library for power analysis
from statsmodels.stats.power import TTestIndPower

# Set parameters based on your collected data
sample_size = 125
population_size = 1800
alpha = 0.05
effect_size = 0.5  # Effect size is unknown for post hoc analysis
sd_grip_strength = 7.623975  # Standard deviation is unknown for post hoc analysis
allocation_ratio = 1  # Assuming equal sample sizes

# Perform post hoc power analysis
analysis = TTestIndPower()
result = analysis.solve_power(
    effect_size=effect_size,
    nobs1=sample_size,
    alpha=alpha,
    ratio=allocation_ratio,
    alternative='two-sided'
)
```

Figure 3.5: Python power analysis test

#### 3.1.8.2 Participant screening

The screening form, Part I of google form is designed to ensure the integrity of grip strength data by establishing specific criteria for participant inclusion or exclusion. Participants must meet certain conditions for nationality, sleep duration, current health status, upper extremity condition, and alcohol/drug consumption. By implementing these measures, the screening process ensures that participants meet the necessary criteria for accurate and reliable grip strength data. This is essential for maintaining the study's integrity and ensuring the collected data aligns with the objectives of the research, facilitating accurate analysis.

- Nationality: Participants must be Malaysian to qualify for the test.
- Sleep Duration: Participants with 6 hours or less sleep will be excluded from the study.
- Current Health Condition: Participants showing signs of illness (fever, cold, migraine, sinus, etc.) will be excluded.
- Current Condition of Upper Extremity: Exclusion criteria include injuries or breaks in the upper extremity, health problems affecting the upper extremity, or any other condition limiting strength in the upper extremity.
- Alcohol & Drug Consumption: Exclusion applies to those who consume alcohol or drowsiness medication use 24 hours before the session.

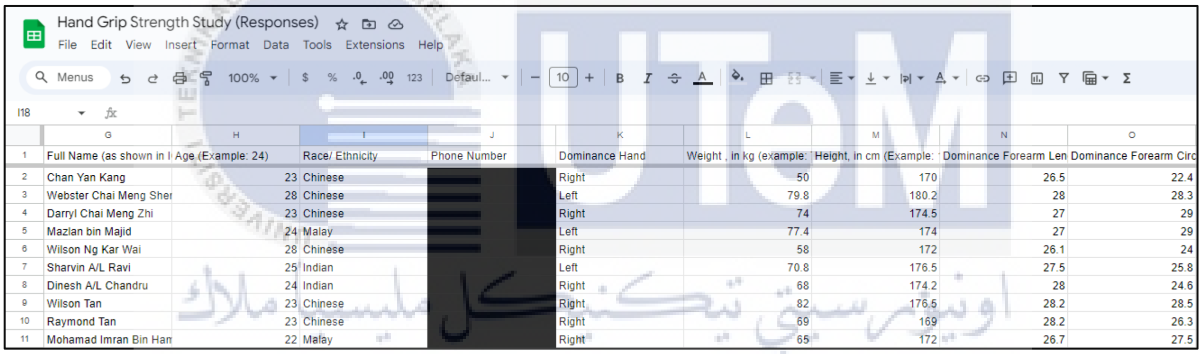


#### 3.1.8.3 Proper grip instructions and trial squeezes

To maintain data consistency and standardization, participants receive instructions before the actual hand grip strength test, ensuring they comprehend and execute the grip technique uniformly. Subsequently, trial squeezes are conducted to confirm participants' full understanding of the required posture. This systematic approach minimizes measurement variability and guarantees the quality and reliability of the collected data. By clarifying instructions and allowing trial squeezes, the study aims to enhance participant confidence, engagement, and cooperation while mitigating factors that could impact the accuracy of grip strength measurements.

### 3.1.9 Data collection and building database

After providing instructions and conducting trial squeezes, the data collection commenced. Building on the validated reliability of the pilot study, the actual data collection scaled up to include 125 exclusively male participants, replicating the pilot study's framework. Given its magnitude, the data collection extended over an extended period. The collected data was systematically organized into a comprehensive database for analysis. The use of Google Forms streamlined the process, removing the necessity for physical survey forms and automatically generating a filled data sheet as shown in figure 3.6, enhancing the efficiency in the data collection process.



Hand Grip Strength Study (Responses)

| | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Full Name (as shown in I | Age (Example: 24) | Race/ Ethnicity | Phone Number | Dominance Hand | Weight , in kg (example: | Height, in cm (Example: | Dominance Forearm Len | Dominance Forearm Circ |
| 2 | Chan Yan Kang | 23 | Chinese | [redacted] | Right | 50 | 170 | 26.5 | 22.4 |
| 3 | Webster Chai Meng Sher | 28 | Chinese | [redacted] | Left | 79.8 | 180.2 | 28 | 28.3 |
| 4 | Darryl Chai Meng Zhi | 23 | Chinese | [redacted] | Right | 74 | 174.5 | 27 | 29 |
| 5 | Mazlan bin Majid | 24 | Malay | [redacted] | Left | 77.4 | 174 | 27 | 29 |
| 6 | Wilson Ng Kar Wai | 28 | Chinese | [redacted] | Right | 58 | 172 | 26.1 | 24 |
| 7 | Sharvin A/L Ravi | 25 | Indian | [redacted] | Left | 70.8 | 176.5 | 27.5 | 25.8 |
| 8 | Dinesh A/L Chandru | 24 | Indian | [redacted] | Right | 68 | 174.2 | 28 | 24.6 |
| 9 | Wilson Tan | 23 | Chinese | [redacted] | Right | 82 | 176.5 | 28.2 | 28.5 |
| 10 | Raymond Tan | 23 | Chinese | [redacted] | Right | 69 | 169 | 28.2 | 26.3 |
| 11 | Mohamad Imran Bin Han | 22 | Malay | [redacted] | Right | 65 | 172 | 26.7 | 27.5 |

Figure 3.6: Part of HGS study google form responses



### 3.1.10 Perform statistical analysis

The research employed statistical analyses, incorporating both descriptive and regression methods, to scrutinize the measurements of hand grip strength. Descriptive analysis extracted key statistics, such as mean, standard deviation, and variance, from the extensive hand grip strength dataset, detailed in the descriptive statistics section. Regression analysis, particularly in generating a normal probability plot, offered insights into variable relationships. The R-squared value in the plot indicates the degree of fit of the regression line, with 1 signifying a perfect fit. Figure 3.7 illustrates the statistical summary presented in tabular format, while the 3.8 depicts the R-Squared analysis.

```
import pandas as pd
from tabulate import tabulate

# Load the dataset
df = pd.read_csv("dataset pilot.csv")

# Display basic statistics
summary_statistics = df.describe().transpose()

# Display the summary in a colorful table
print(tabulate(summary_statistics, headers='keys', tablefmt='fancy_grid',
               showindex=True, numalign="center"))
```

Figure 3.7: Python statistic summary in table form

```
import pandas as pd
import matplotlib.pyplot as plt
from scipy.stats import probplot

# Columns for analysis
columns_for_analysis = df.columns

# Create subplots
fig, axes = plt.subplots(nrows=len(columns_for_analysis), ncols=1,
                         figsize=(8, 2 * len(columns_for_analysis)))

# Iterate through each column
for i, column in enumerate(columns_for_analysis):
    # Create normal probability plot
    _, (slope, intercept, r_sq) = probplot(df[column], plot=axes[i])

    # Add title with R-squared value
    axes[i].set_title(f"{column} - R-squared: {r_sq**2:.4f}")

# Adjust layout
plt.tight_layout()
plt.show()
```

Figure 3.8: Python R-Squared analysis

### 3.1.11 Summary

The study on hand dimensions and grip strength in Malaysian men adopts a comprehensive approach, guided by an extensive literature review. Focusing on the influence of glove design on adult male grip strength, the methodology involves precise calibration of the Jamar hand dynamometer. A pilot study with 10 male participants assesses feasibility, and rigorous recruitment, sample size analysis using Python, and clear instructions enhance data integrity. Data collection from 125 male participants via Google Forms contributes to a robust database, while Python statistical analyses thoroughly explore grip strength, ensuring study robustness. Figure 3.9 outlines block diagram of sequential steps for achieving objective 1 in this investigation.

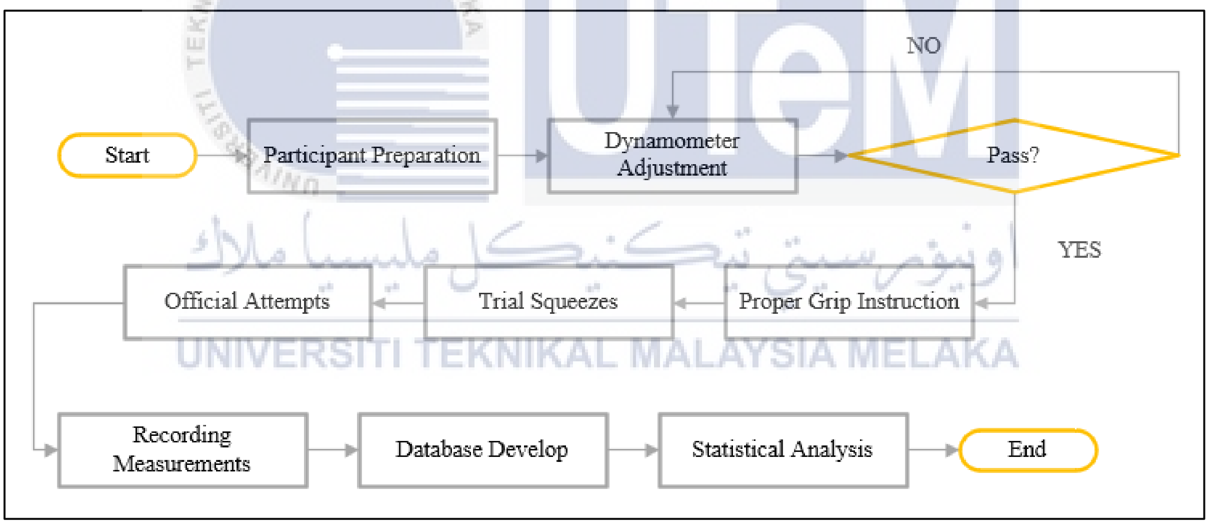



Figure 3.9: Block diagram of Methodology 1

## 3.2 Analyze the Correlation Between Hand Grip Strength and Various Hand and Body Postures Among Malaysian Male Adults

This section focusing on analyzing the correlation between grip strength and various hand and body postures among Malaysian male adults. The process involves data preparing, cleaning, and reshaping, conducting exploratory analysis, interpreting results, and documenting findings. A summary encapsulates the key insights derived from the correlation analysis.

### 3.2.1 Data preparation: pre-processing, transformation, and management

In the data preparation phase, emphasis is on pre-processing, transforming, and managing data. This involves cleaning outliers and reshaping variables for various correlation tests between grip strength, posture, and anthropometric measurements.



#### 3.2.1.1 Data outliers checking

Detecting outliers is crucial in data analysis, as they may signal errors in data collection or entry. Addressing outliers is essential for enhancing the dataset's quality and integrity, ensuring accurate data. In Python, code can be implemented to identify and count outliers using methods like z-scores. This step is vital for maintaining the accuracy and reliability of the data throughout the analysis process. Figure 3.10 represent Python code for identifying and counting outliers within a dataset. Upon identifying outliers, we will promptly reach out to participants for a reassessment of the hand grip strength test. If communication fails, we will proceed to eliminate the outlier data.

```python
import pandas as pd
import numpy as np

def count_outliers(df, threshold=3):
    outliers_count = {}
    for column in df.columns:
        z_scores = np.abs((df[column] - np.mean(df[column])) / np.std(df[column]))
        outliers_count[column] = np.sum(z_scores > threshold)

    return outliers_count

outliers_count = count_outliers(df)
print(outliers_count)
```

Figure 3.10: Python outliers checking

#### 3.2.1.2 Data reshaping

Reshaping data is vital for diverse purposes, entailing the reorganization of dataset structures to suit specific analysis or modeling needs. In our context, with six combinations (2x3) of HGS and hand dimension data, we categorize the data into two sets: HGS vs Posture and HGS vs Anthropometry. This segregation enables the exploration of unique correlations between hand grip strength and various factors, simplifying the process of analyzing different variables associated with hand grip strength data.

### 3.2.2 Exploratory data analysis & data interpretation and visualization

EDA helps grasp the dataset's structure and characteristics, offering insights into variables, distributions, and possible patterns. It reveals connections between variables, allowing researchers to pinpoint potential correlations, dependencies, or trends. EDA's visualization aspect facilitates the representation of intricate patterns in a visually understandable way, simplifying the communication of research findings.

### 3.2.2.1 Graphical representation of the distribution of a dataset

Graphical representation of a dataset, incorporating line plots, histograms, box plots, and other visualizations, holds paramount importance in data analysis. These visual tools provide an intuitive and comprehensive understanding of key aspects such as central tendency, variability, and the overall shape of the data distribution. Through these graphical representations, patterns, trends, and outliers within the dataset become readily identifiable, enabling the detection of any unusual or unexpected behaviors in the data. Visualizations are powerful tools for communicating complex information to diverse audiences, offering a more accessible way for stakeholders to comprehend and interpret results than raw data or statistical summaries.



#### 3.2.2.1.1 Line plots

Line plots excel in portraying trends and changes, offering valuable insights into the nuanced dynamics of grip strength across various hand postures. Particularly beneficial for datasets with repeated measurements, these plots provide a dynamic representation of posture-specific patterns, facilitating a comprehensive understanding of how grip strength evolves over multiple observations and contributing to a more nuanced analysis of hand-related metrics. Figure 3.11 and 3.12 represents the example of Python coding of line plot and its result respectively.

```
import matplotlib.pyplot as plt

plt.figure(figsize=(10, 6))

for posture in ['AVGSit.Neutral', 'AVGSit.Pronation', 'AVGSit.Supination',
                'AVGStand.Neutral', 'AVGStand.Pronation', 'AVGStand.Supination']:
    plt.plot(df[posture], label=posture)

plt.title('Line Plot of Grip Strength Across Postures')
plt.xlabel('Sample')
plt.ylabel('Grip Strength')
plt.legend()
plt.grid(True)
plt.show()
```

Figure 3.11: Python line plot coding

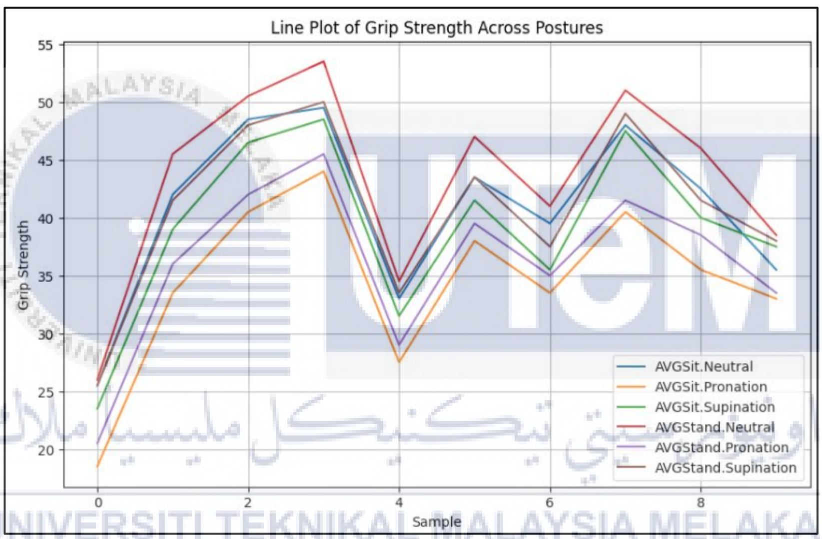





Figure 3.12: Python line plot

### 3.2.2.1.2 Histogram

Histograms are valuable tools for illustrating the distribution of continuous variables like hand dimensions and grip strength in the dataset. By generating individual histograms for each posture, it effectively compare and analyze the distribution patterns, gaining insights into the variation of these metrics across different hand postures in a visually informative manner. Figure 3.13 and 3.14 represents the example of Python coding of histogram and its result respectively.

```python
import matplotlib.pyplot as plt
import pandas as pd


selected_column = 'selected_colunn'

# Plotting the histogram for the selected column
plt.figure(figsize=(8, 6))
plt.hist(df[selected_column], bins=10, alpha=0.5, color='blue', edgecolor='black')

# Adding labels and title
plt.title(f'Histogram of {selected_column}')
plt.xlabel(selected_column)
plt.ylabel('Frequency')
plt.grid(True)
plt.show()
```

Figure 3.13: Python histogram coding

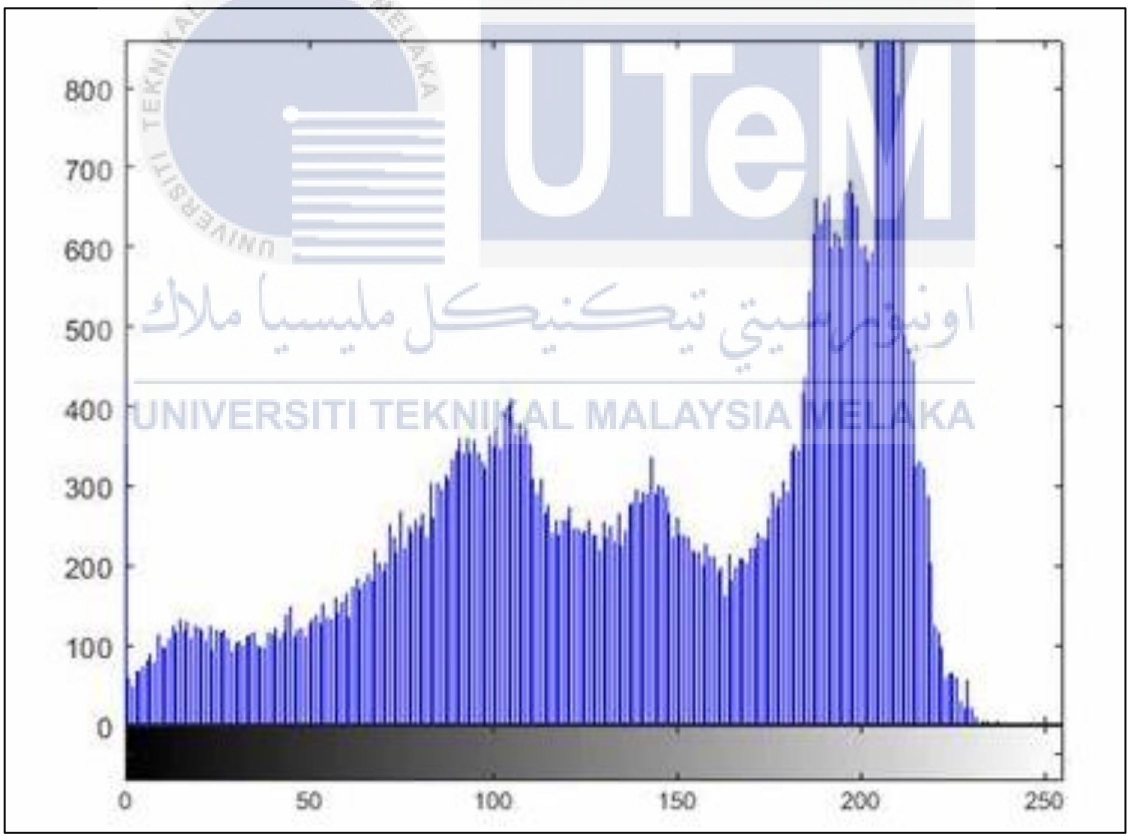



Figure 3.14: Python histogram

#### 3.2.2.1.3 Box plots

Box plots as shown in figure 3.16, also known as box-and-whisker plots, serve as excellent tools to portray the summary statistics of your hand-related data. These plots encapsulate key metrics like median and quartiles, offering a concise snapshot of grip strength variations across diverse hand postures. They provide a clear visual representation, facilitating the comparison of central tendencies and identifying potential outliers within the context of your dataset. Figure 3.15 represents the example of Python coding of box plots.

```
import matplotlib.pyplot as plt
import pandas as pd

# Column for grip strength
selected_column = 'selected_column'

# Creating a boxplot for the selected column
plt.figure(figsize=(8, 6))
plt.boxplot(df[selected_column], vert=False, patch_artist=True)

# Adding labels and title
plt.title(f'Boxplot of {selected_column}')
plt.xlabel(selected_column)
plt.grid(True)
plt.show()
```



Figure 3.15: Python box plots coding

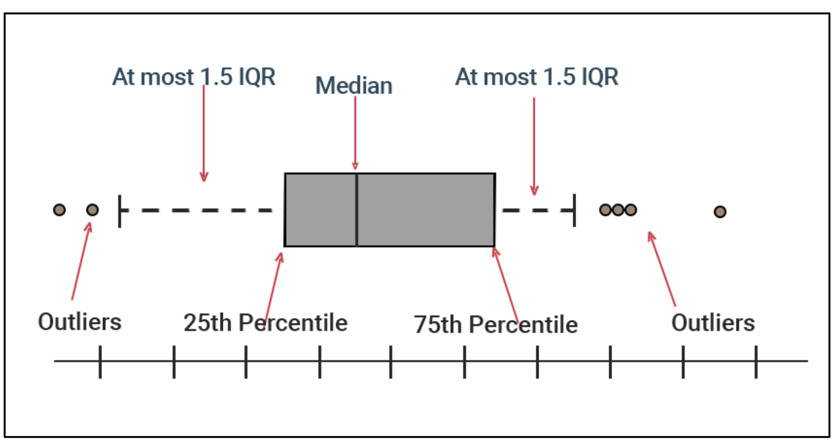



Figure 3.16: Box plots example (360DigiTMG Group, 2023)

### 3.2.2.2 Perform correlation analysis

Correlation analysis is a statistical technique crucial for evaluating the strength and direction of linear relationships among variables. It gauges how fluctuations in one variable coincide with those in another, offering valuable insights into data patterns and dependencies. Recognizing correlations assists in predicting one variable from another, guiding decision-making. Additionally, this analysis supports hypothesis validation, aids in variable selection for detailed investigations, and enhances comprehension of underlying patterns in datasets.

#### 3.2.2.2.1 Pearson correlation coefficient

The Pearson correlation coefficient, often denoted as "r," is a statistical measure that quantifies the strength and direction of a linear relationship between two continuous variables. It ranges from -1 to 1, where 1 indicates a perfect positive linear correlation, -1 indicates a perfect negative linear correlation, and 0 suggests no linear correlation. The coefficient is calculated by dividing the covariance of the two variables by the product of their standard deviations as shown in figure 3.17, providing a standardized measure of the linear association between them.



$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

Where,

r = Pearson Correlation Coefficient

$x_i$ = x variable samples    $y_i$ = y variable sample

$\bar{x}$ = mean of values in x variable    $\bar{y}$ =mean of values in y variable

Figure 3.17: Standardized measure of the linear association

#### 3.2.2.2.2 Correlation matrix heatmap

Correlation matrix heatmap as shown in figure 3.18 is a visual representation of the correlation matrix, which displays the correlation coefficients between multiple variables in a dataset. Each cell in the heatmap represents the correlation between a pair of variables, with colors indicating the strength and direction of the correlation. This graphical representation provides a quick and intuitive way to identify patterns, relationships, and dependencies among variables. Typically shades of that color are used to represent the correlation strength. A darker shade of the color may indicate a stronger correlation, while a lighter shade signifies a weaker correlation.




Figure 3.18: Example structure of a correlation heatmap

### 3.2.3 Documentation

Effective documentation plays a pivotal role across diverse fields by facilitating clear communication among researchers, analysts, and stakeholders. It serves as a medium to articulate methodologies, findings, and insights comprehensively. Additionally, thorough documentation supports result reproducibility, a foundational aspect in scientific research and data analysis. Replicating work boosts research credibility, ensuring the reliability of findings.

### 3.2.4 Summary

This section focuses on analyzing the correlation between hand grip strength and various hand and body postures among Malaysian male adults. It encompasses data preparation, cleaning, and reshaping, followed by exploratory analysis, interpretation, and documentation. Key steps include outlier detection to enhance data quality, reshaping variables for correlation tests, and employing EDA for insights. Graphical representations like line plots, histograms, and box plots aid in visualizing patterns. Correlation analysis, including Pearson correlation coefficients and heatmap visualization, reveals relationships between variables. Effective documentation ensures clear communication, method reproducibility, and research credibility, encapsulating the study's key insights. Figure 3.19 represents the block diagram of the sequential steps to achieve objective 2.



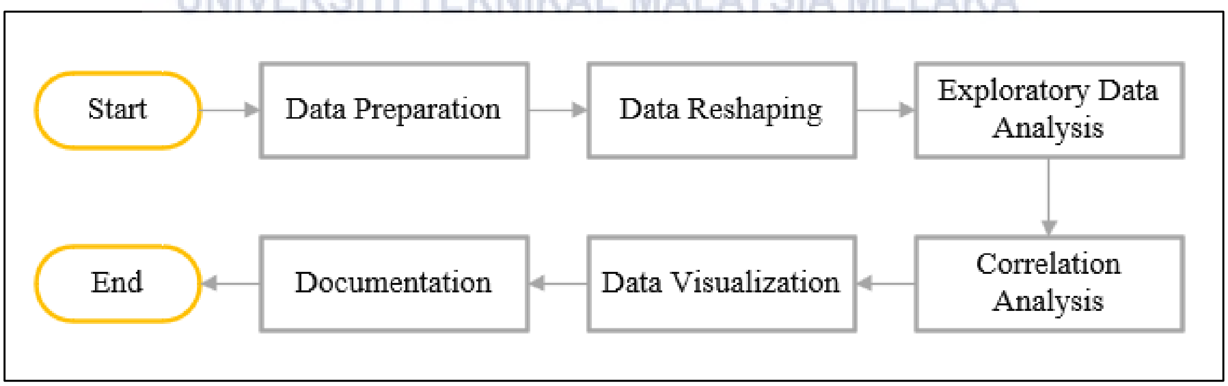



Figure 3.19: Block diagram of Methodology 2

## 3.3 Develop a Prototype of an Ergonomic Glove That Enhances the Ability of Malaysian Male Adults to Perform Gripping Tasks Effectively

The data analysis provided essential information for making an appropriate ergonomic hand glove prototype. To prioritize user demands and preferences, the development methodology included numerous ways. This entails measuring hand anthropometry, interviewing users, prioritizing design components using the House of Quality (HOQ) and comparing design proposals using a Weighted Decision Matrix. Conceptual sketches were created to show design features and materials before prototyping.

### 3.3.1 User need survey

Performing a user needs analysis is essential for developing an ergonomic glove prototype specifically designed for adult males in Malaysia. This approach guarantees that the design is focused on user preferences, challenges, and functional requirements. Collecting data on comfort, fit, and specific grasping tasks allows the prototype to effectively meet the unique requirements of users. In addition, considering cultural and environmental factors ensures that the glove is suitable and fitting for the Malaysian context.



#### 3.3.1.1 Interview

Interviews were conducted to ascertain the anticipated parameters for the ergonomic glove. These interviews necessitated direct interaction with prospective consumers to obtain comprehensive feedback regarding their requirements and preferences. The data obtained from these interviews was converted into comprehensive product specifications, guaranteeing that the ultimate design fulfilled user expectations and substantially enhanced gripping performance.

#### 3.3.1.2 Comfortable rating

Data was collected from potential users using a questionnaire to assess their comfort ratings. Participants evaluated many aspects of glove comfort, such as the fit, texture, and pliability of the material. This feedback played a crucial role in transforming consumer preferences into measurable product specifications. The findings influenced the design process, resulting in enhanced overall comfort of the glove.

### 3.3.2 Product benchmark



The product benchmark involved analyzing glove designs from different industries to produce new thoughts for the ergonomic glove prototype. Participants evaluated three distinct glove designs selected from diverse applications, rating them according to their comfort, durability, and functionality. This comprehensive comparison yielded valuable insights into the advantages and limitations of alternative products to the traditional cowhide long leather gloves that are routinely employed in shielded metal arc welding (SMAW). The benchmarking approach helped to identify new features and materials that may be used to improve the new ergonomic glove prototype. This approach guaranteed that design improvements were not limited by pre-existing stereotypes, stimulating creativity and stretching the boundaries of traditional glove design to address the specific needs of Malaysian male adults doing gripping jobs.

### 3.3.3 House of Quality (HoQ)

The HOQ technique incorporates user preferences and technical needs into new product design. It shows how customer choices affect product performance as a fundamental design strategy. The ergonomic hand glove was made by HOQ as shown in figure 3.20 for shielded arc welding operators. In this research, customer expectations were utilized for rating. Engineer-voiced technical parameters were translated from participant needs. The study linked participant needs to technical factors using interrelationship matrix symbols. Table 3.1 explained matrix symbols in these interrelationships. Their weight affects the HOQ matrix.

Table 3.1: Weightage of interrelationship symbols

| Symbols | Weightage | Level of interrelationship |
|---|---|---|
| ⊙ | +5 | Strong |
| ○ | +3 | Medium |
| △ | +1 | Weak |



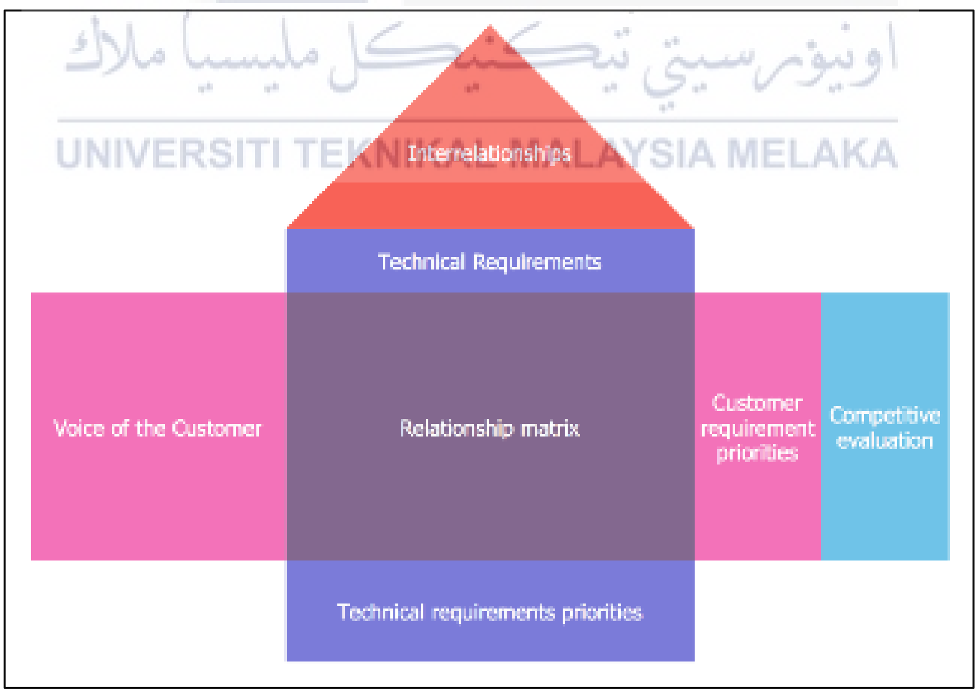



Figure 3.20: Components of a house of quality (ConceptDraw)

### 3.3.4 Weighted decision matrix

The weighted decision matrix was utilized to objectively evaluate and compare different design concepts, taking into consideration many factors such as comfort, durability, cost, and user preferences. Each criterion was assigned a weight based on its importance, and each design was assessed against these criteria. The methodical methodology substantially facilitated the selection of the most suitable design concept for the ergonomic glove. Table 3.2 presents an example format for a weighted decision matrix.

Table 3.2: Example format for weighted decision matrix

| Requirement | Weightage | Options | | | | | |
|---|---|---|---|---|---|---|---|
| | | Synthetic Leather Glove | | Microfiber Glove | | Long Leather Glove | |
| | | Rating | Score | Rating | Score | Rating | Score |
| | | | | | | | |
| | | | | | | | |
| … | … | … | … | … | … | … | … |
| Total | | | | | | | |
| Ranking | | | | | | | |



### 3.3.5 Material selection

Material selection influences product performance, durability, and operation, making it an important design step. Mechanical qualities, cost, availability, and suitability for the purpose influence decision-making. When constructing an ergonomic glove, materials must be chosen carefully. This is required for maximum comfort, flexibility, and durability. User needs and ergonomics must also be considered while choosing materials. Glove materials usually include fabrics, synthetic materials, and carefully developed coatings for hand protection and performance.

Material selection is vital for making a shielded metal arc welding glove. Materials with high heat resistance and protection are prioritized. These materials must provide thermal insulation and protect against sparks and molten metal at welding temperatures. To improve the user's ability to weld securely and effectively, the glove's materials must address flexibility, dexterity, and comfort.

### 3.3.6 Conceptual design

The significance of conceptual design in developing a prototype for a specialized glove that enhances the grasping abilities of adult males in Malaysia cannot be overstated. The main emphasis of this initial design phase is on users, with the objective of developing a prototype that effectively caters to the special needs and challenges encountered when performing jobs that require manual dexterity. Conceptual design functions as a space for creative exploration, promoting innovation to enhance efficiency and user-friendliness. A process of exploration, considering multiple options and testing various features and materials to customize the glove to meet the individual needs of the users.



Furthermore, conceptual design surpasses mere brainstorming; it is an expedition of problem-solving. It facilitates the recognition of potential difficulties associated with jobs that require a strong grip and motivates designers to create innovative solution. The iterative process of refinement, along with a feasibility assessment, guarantees that the final prototype not only fulfills the functional and ergonomic criteria but also stands out as an innovative solution that addresses the specific requirements of Malaysian adult males in their gripping activities.

### 3.3.7 Conceptual drawing

The conceptual drawing in this project entails producing intricate designs that effectively convey the characteristics and materials employed in the design of the ergonomic glove. These sketches function as a visual plan to improve the design prior to moving on to the prototype phase. Conceptual sketches are essential in effectively capturing and expressing my design ideas in an individual undertaking.

The designs primarily depict the sophisticated characteristics and materials of the glove, highlighting specific improvements designed to boost the gripping ability for adult males in Malaysia. The figure 3.21 showcase the example of fundamental structure and form of the glove, emphasizing inventive elements like ergonomic curves, material choices for enhanced comfort and longevity, and any distinctive characteristics aimed at maximizing usability. Conceptual sketches clearly depict the elements of the glove's design, enabling a precise and thorough comprehension of its intended requirements and ensuring compliance with my desired direction.



Conceptual sketching plays a crucial role in the iterative refinement of the ergonomic glove design and acts as a valuable tool for personal reflection and enhancement of the prototype's functionality.

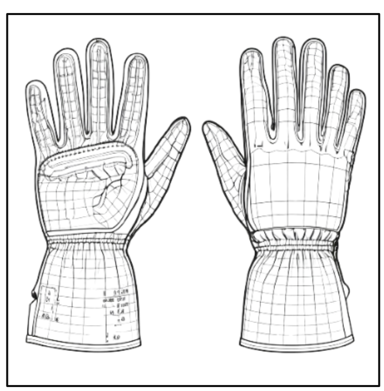


Figure 3.21: Example of glove 3D modelling

### 3.3.8 Prototype making

Prototype fabrication is the iterative procedure of developing an initial product prototype for the purpose of evaluating its design and practicality prior to commencing mass production. This practical approach allows for hands-on experimentation and refinement using a variety of materials and techniques. The process of creating an ergonomic hand glove for shielded arc welding includes transforming the design into a physical prototype, conducting thorough tests to ensure ergonomic characteristics, durability, and compatibility, and providing guidance for final improvements. Figure 3.22 is an example of a welding glove.

Figure 3.22: Example of welding glove



### 3.3.9 User testing

Glove compatibility was assessed by user testing conducted on shielded metal arc welding (SMAW) procedures. The testing encompassed practical usage scenarios to evaluate the glove's efficacy. Interviews were conducted to get feedback to identify areas that could be enhanced. In addition, a comfort rating survey, like the one conducted in section 3.3.1.2, was carried out to compare the new prototype with the currently available gloves. This ensured a thorough evaluation of the glove's performance and comfort.

### 3.3.10 Engineering analysis

The engineering investigation entailed utilizing the Jamar hand grip strength test and a Digital Torque Gauge Mark-10 with Jacobs chuck attachment to evaluate and compare the novel glove design with the currently available gloves. This investigation yielded quantitative data regarding the enhancements in the performance of the glove.

#### 3.3.10.1 Comparison of hand grip strength

The Jamar hand grip strength test was utilized to quantitatively measure the improvement in grip strength afforded by the newly designed prototype glove. This assessment aimed to evaluate the effectiveness of the ergonomic enhancements incorporated into the prototype. By comparing the hand grip strength (HGS) of users wearing the new ergonomic glove against those wearing existing gloves, the test provided a clear indication of the prototype's performance benefits. The results from this comparison were then visually represented in a bar chart, allowing for an intuitive and straightforward analysis of the grip strength differences. This graphical representation highlighted the relative effectiveness of the new design in enhancing grip strength, thereby validating the ergonomic improvements and demonstrating the prototype's superiority over traditional glove designs.

#### 3.3.10.2 Comparison of wrist torque with digital torque gauge Mark-10 with Jacobs chuck attachment

The Mark-10 Digital Torque Gauge, equipped with the Jacobs chuck attachment used for this measurement is shown in figure 3.23, was employed to quantitatively measure the impact of the new glove design on wrist torque and movement. This experiment aimed to collect precise data on how the glove affected the angle and force of wrist movements during various gripping tasks. By comparing these results with those obtained from users wearing existing gloves, the study sought to determine whether the new design impaired wrist movement or enhanced it.

The findings from this investigation, presented in a bar chart, provided a clear visual representation of the differences in wrist torque and movement angles. This graphical comparison highlighted the ergonomic advantages of the new glove design, demonstrating its effectiveness in maintaining or improving wrist mobility and reducing strain. The data underscored the prototype's potential to enhance task performance by ensuring that wrist movements were not impeded, thereby contributing to better overall ergonomics compared to traditional gloves.


Figure 3.23: Digital torque gauge Mark-10 with Jacobs chuck attachment

### 3.3.11 Summary

Developing a prototype of an ergonomic glove for Malaysian male adults involves several critical steps, as illustrated in figure 3.25. The process begins with a user need survey to ensure the prototype meets user preferences, challenges, and functional requirements. Following this, a product benchmark is conducted to compare existing glove designs and gather ideas. The House of Quality (HoQ) methodology is then used to align customer preferences with technical specifications. A weighted decision matrix helps evaluate and select the best design concepts based on various criteria. Material selection focuses on comfort, flexibility, and durability, particularly for shielded arc welding applications. The conceptual design phase emphasizes innovation and problem-solving tailored to user needs, while conceptual drawings visualize and refine the design before prototype creation. The prototype making phase is iterative, involving testing and refinement with different materials. User testing assesses the glove's performance in real-world scenarios, and engineering analysis, including grip strength and wrist torque tests, confirms the glove's effectiveness and suitability for shielded arc welding.

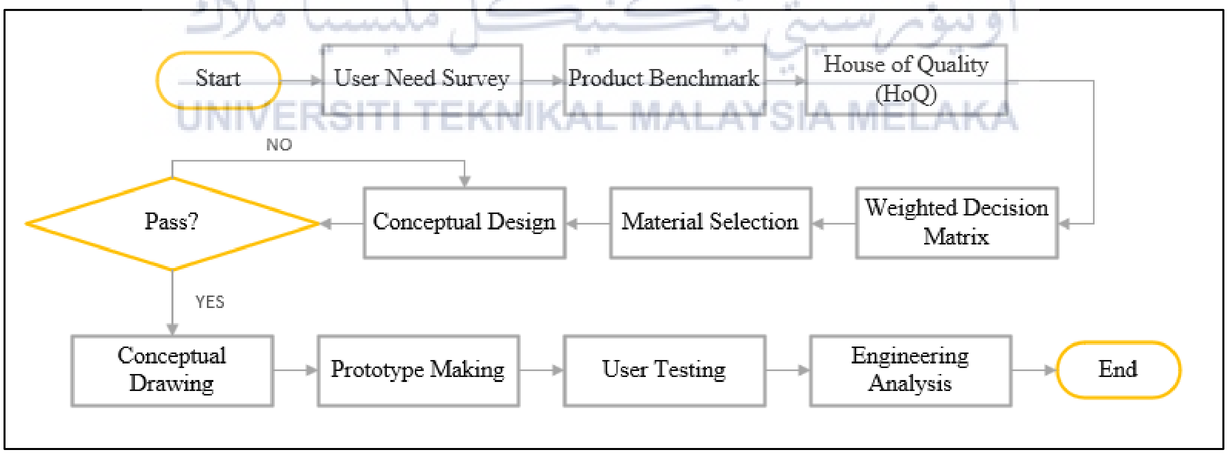



Figure 3.24: Block diagram of methodology 3

# CHAPTER 4
# RESULTS AND DISCUSSION

This chapter presents the study's results and discussion, covering data collection on hand anthropometry and grip strength. It includes correlation analyses. Furthermore, the chapter details the development of a prototype glove using interviews, House of Quality (HoQ), and material selection. It concludes with the development of a prototype glove and an engineering analysis, including performance ratings and comparisons.



## 4.1 Measurement of Hand Anthropometric Dimensions and Grip Strength in Malaysian Male Adults

In this section, the findings of the study are presented in two parts: experimental data and main findings. The experimental data provides a detailed account of the demographic characteristics of the participants, including age, ethnicity, and other relevant background information, establishing a comprehensive understanding of the participant profile. The main findings focus on key outcomes related to hand grip strength and hand anthropometric measurements, analyzing grip strength across different conditions and specific hand dimensions. This dual approach aims to draw meaningful conclusions about the ergonomic glove's design and its effectiveness in enhancing grip performance for Malaysian male adults.

### 4.1.1 Demographic of participants

According to the Malaysian population, the main ethnic groups are Malay, Chinese, and Indian. In this section, the demographic data collected consists of age, ethnicity, weight, height, and Body Mass Index (BMI). Malaysian youth aged between 20 to 29 years participated in this study. Furthermore, this section focuses solely on the male population since the hand grip strength of male participants will serve as the baseline for the results. Other genders will be covered by sub-studies at the national level.

Figure 4.1 illustrates the distribution of participants across various ages. Most participants are 24 years old, as the study was primarily conducted among students and staff within UTeM. According to previous research by Carmeli et al. (2003), elderly individuals face challenges with hand functioning. However, this study focuses on young adults, and different age groups are not covered.



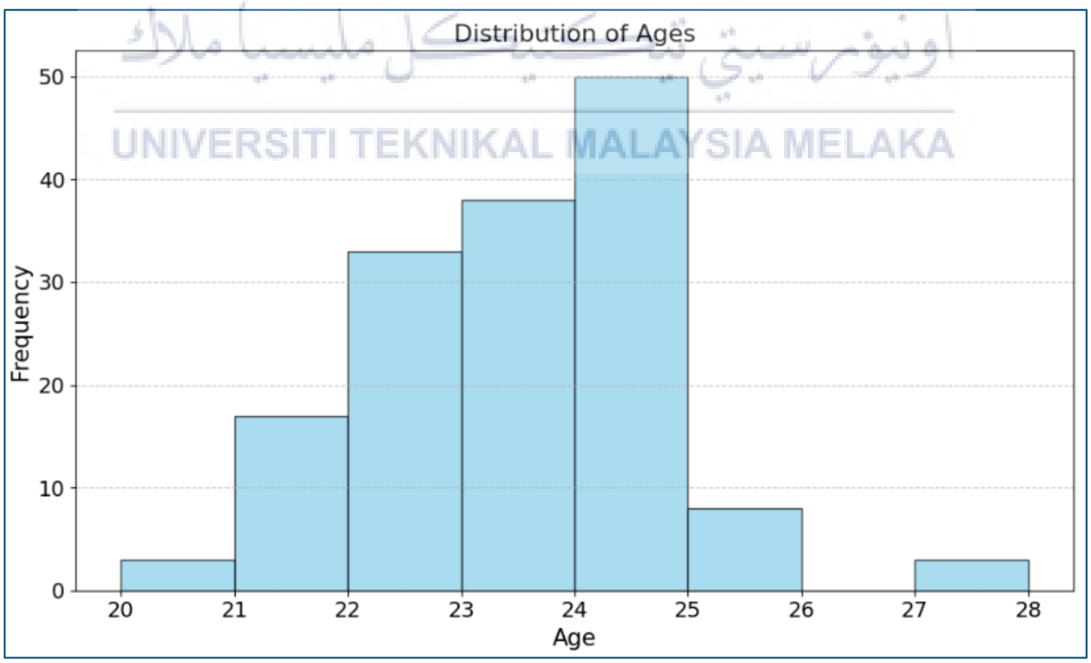



Figure 4.1: Distribution of ages

In Malaysia, the primary ethnic groups are Malays, Chinese, and Indians (DOSM, 2023). Despite similar dietary and environmental factors, there are slight variations in hand grip strength among these groups. This discrepancy may be attributed to diverse sporting activities and genetic differences (Bhat et al., 2021; Germain et al., 2016). While the data collected in this study can be utilized for subsequent analysis, such investigations are beyond the scope of this research endeavor. Table 4.1 and Figure 4.2 display the number and percentage of participants across the various ethnic groupings.

Table 4.1: Ethnicity of participants

| Ethnic | Malay | Chinese | Indian | Others | Total |
|---|---|---|---|---|---|
| No. of Participants | 81 | 38 | 32 | 1 | 152 |

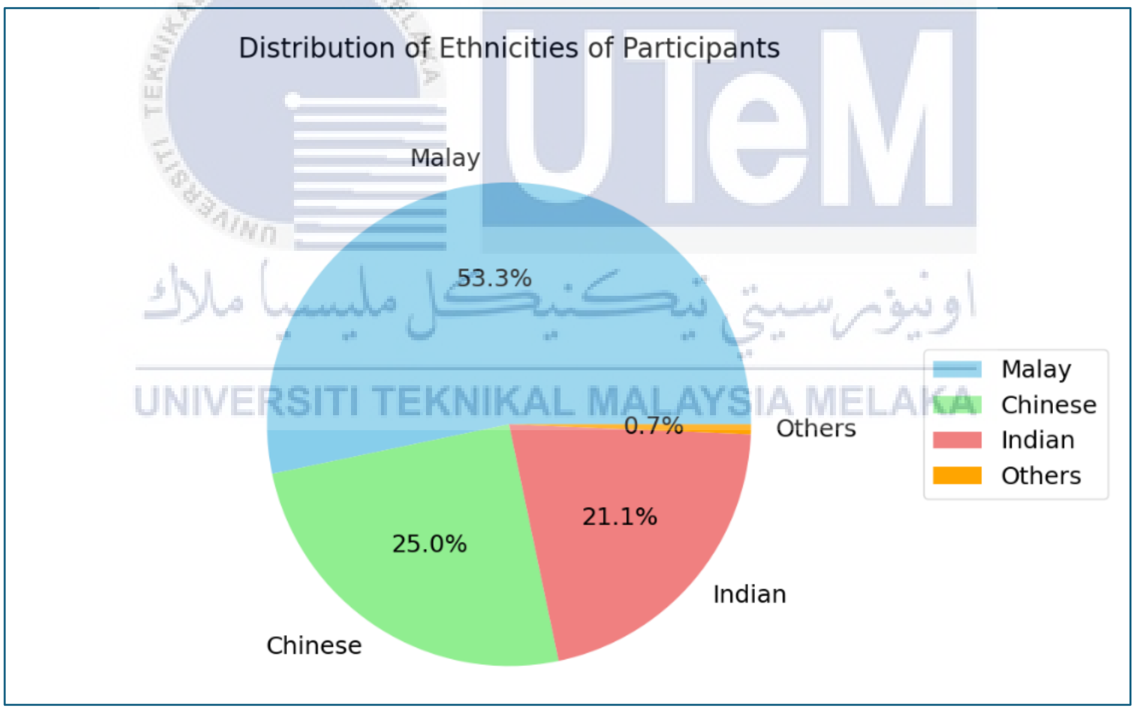



Figure 4.2: Distribution of ethnicities of participants

The distribution of the participants' dominant hands is shown in Figure 4.3. Based on the data, it can be observed that 21.1% (n = 32) of the participants were left-handed, while 78.9% (n = 120) were right-handed. The findings showed that none of the 152 participants in the study were ambidextrous. Larson and Ye (2017) asserted that the dominant hand had greater strength than the non-dominant hand. However, handedness is outside the purview of the study, so additional analysis and research will not be conducted.

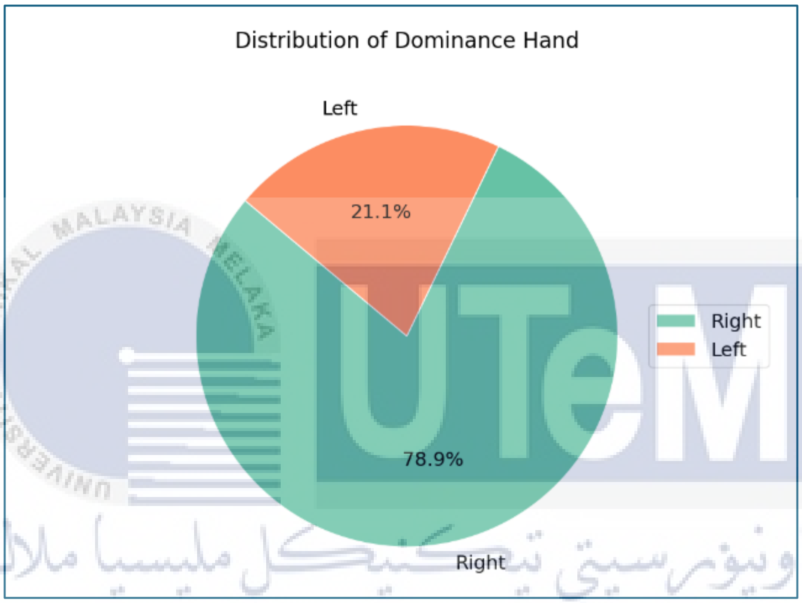



Figure 4.3: Distribution of dominance hand

In addition, the individuals' height, weight, and BMI are recorded in this section. The participants' descriptive statistics for those factors are displayed in Table 4.2. The participant's average height is 171.49 cm (SD = 4.93), average weight is 68.72 kg (SD = 9.60), and average BMI is 23.35 kg/m2 (SD = 3.10). The responders' weight ranges from 45 kg to 130 kg, maximum and lowest. The respondents' height ranges from 150 cm at the least to 185 cm at the maximum. Also, the participants' BMI ranges from 17.30 kg/m2 to 44.98 kg/m2, the maximum and minimum values. While there were some underweight and overweight participants in this study, the average BMI (23.35 kg/m2) falls between 18.5-24.9, which is recognized by the World Health Organization (WHO) as a normal weight range.

Table 4.2: Descriptive statistics of height, weight, and BMI

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Weight (kg) | 68.72 | 9.60 | 45.00 | 130.00 |
| Height (cm) | 171.49 | 4.93 | 150.00 | 185.00 |
| BMI (kg/m$^2$) | 23.35 | 3.10 | 17.30 | 44.98 |

### 4.1.2 Hand anthropometric data

Table 4.3 presents the descriptive statistics of hand anthropometric data. The forearm length has a mean of 26.7743 cm with a standard deviation of 1.1016 cm. The measurements span a range from a minimum of 23.00 cm to a maximum of 28.50 cm. The interquartile range (IQR) for forearm length extends from 26.40 cm (Q1) to 27.50 cm (Q3), suggesting that most individuals have forearm lengths clustered closely around the median value of 27.00 cm. This relatively narrow range and small standard deviation indicate a high degree of consistency in forearm length among the participants.

In contrast, forearm circumference exhibits greater variability. The mean forearm circumference is 27.2276 cm with a standard deviation of 1.8684 cm. Measurements range from a minimum of 21.30 cm to a maximum of 34.50 cm. The IQR spans from 26.20 cm (Q1) to 28.53 cm (Q3), highlighting a broader distribution of values. This suggests that there is more variation in forearm circumference compared to forearm length, reflecting differences in muscle and fat distribution among individuals.

The palm circumference has a mean value of 20.7013 cm and a standard deviation of 1.4432 cm. The range of measurements extends from a minimum of 16.50 cm to a maximum of 24.50 cm. The IQR for palm circumference is from 20.00 cm (Q1) to 21.63 cm (Q3), indicating that most measurements are centered around the median of 21.20 cm. This moderate level of variability suggests that while there is some variation in palm circumference, it is not as pronounced as in forearm circumference.

The length of the palm-wrist shows the lowest variability among the measured parameters. The mean palm-wrist length is 18.8684 cm with a standard deviation of 0.5667 cm. The range of measurements spans from 16.50 cm to 21.00 cm, and the IQR extends from 18.60 cm (Q1) to 19.10 cm (Q3). This tight range and low standard deviation indicate that palm-wrist length is highly consistent among participants, with most values clustering closely around the median.

Previous studies Karmegam et al. (2011), Shahida et al. (2015), Kiat et al. (2013), and Daruis et al. (2021) provide corroborative evidence with similar datasets regarding male hand anthropometry. Their studies align closely with the findings presented here, validating the consistency and reliability of the anthropometric measurements obtained. These references contribute to a broader understanding of hand dimensions among males across different studies, reinforcing the importance of accurate and standardized data in ergonomic design and related fields.



Table 4.3: Descriptive statistics of hand anthropometric data

| Variable | Mean | Standard deviation | Min | Q1 | Q2 | Q3 | Max |
|---|---|---|---|---|---|---|---|
| Forearm Length | 26.7743 | 1.1016 | 23.00 | 26.40 | 27.00 | 27.50 | 28.50 |
| Forearm Circumference | 27.2276 | 1.8684 | 21.30 | 26.20 | 27.15 | 28.53 | 34.50 |
| Palm Circumference | 20.7013 | 1.4432 | 16.50 | 20.00 | 21.20 | 21.63 | 24.50 |
| Length of Palm-Wrist | 18.8684 | 0.5667 | 16.50 | 18.60 | 19.00 | 19.10 | 21.00 |

### 4.1.3 Hand grip strength

In terms of hand grip strength, measurements were taken in both sitting and standing positions across different wrist positions: neutral, pronation, and supination. Table 4.4 presents the descriptive statistics of hand grip strength data for both sitting and standing positions. In the sitting position, the highest mean grip strength was observed in the neutral wrist position at 33.7635 kg, with a standard deviation of 6.5005 kg. This was followed by the supination position at 32.6480 kg (standard deviation of 6.0232 kg) and the pronation position at 29.1118 kg (standard deviation of 5.9614 kg). In the standing position, the neutral wrist position again showed the highest mean grip strength at 34.0411 kg (standard deviation of 6.7739 kg), followed by supination at 32.9803 kg (standard deviation of 6.0307 kg) and pronation at 29.3586 kg (standard deviation of 6.1196 kg). Overall, the data suggest that hand grip strength is generally higher in the neutral wrist position and slightly increases when transitioning from a sitting to a standing position. These findings align with the research by Kamarul and Ahmad (2006), who reported similar hand grip strength data for young male adults, confirming the reliability of this data set for further analysis.



Table 4.4: Descriptive statistics of hand grip strength data for both sitting and standing

| Body Position | Wrist Position | Mean | Standard deviation | Min | Q1 | Q2 | Q3 | Max |
|---|---|---|---|---|---|---|---|---|
| Sitting | Neutral | 33.7635 | 6.5005 | 22.50 | 28.75 | 31.75 | 38.13 | 53.25 |
| | Pronation | 29.1118 | 5.9614 | 17.00 | 24.69 | 27.50 | 33.56 | 51.00 |
| | Supination | 32.6480 | 6.0232 | 21.50 | 28.00 | 31.00 | 36.75 | 51.50 |
| Standing | Neutral | 34.0411 | 6.7739 | 22.50 | 29.00 | 32.00 | 38.50 | 55.00 |
| | Pronation | 29.3586 | 6.1196 | 19.50 | 24.75 | 27.50 | 34.00 | 49.00 |
| | Supination | 32.9803 | 6.0307 | 21.50 | 28.50 | 31.50 | 37.00 | 52.25 |

## 4.2 Analysis of the Correlation Between Hand Grip Strength and Various Hand and Body Postures Among Malaysian Male Adults

The following section demonstrates the data cleaning process and correlation analyses of hand grip strength among Malaysian male adults, featuring box plots, a bar chart, Pearson correlation coefficients, and R-squared values for anthropometric predictors.

### 4.2.1 Check outliers

Table 4.5 showcases three box and whiskers graphs that provide a comprehensive visual analysis of the data collected for hand anthropometry, hand grip strength in the sitting position, and hand grip strength in the standing position. Each graph illustrates the central tendency, variability, and any outliers within the respective datasets.

Table 4.5: Box and whiskers graphs of hand anthropometry and hand grip strength

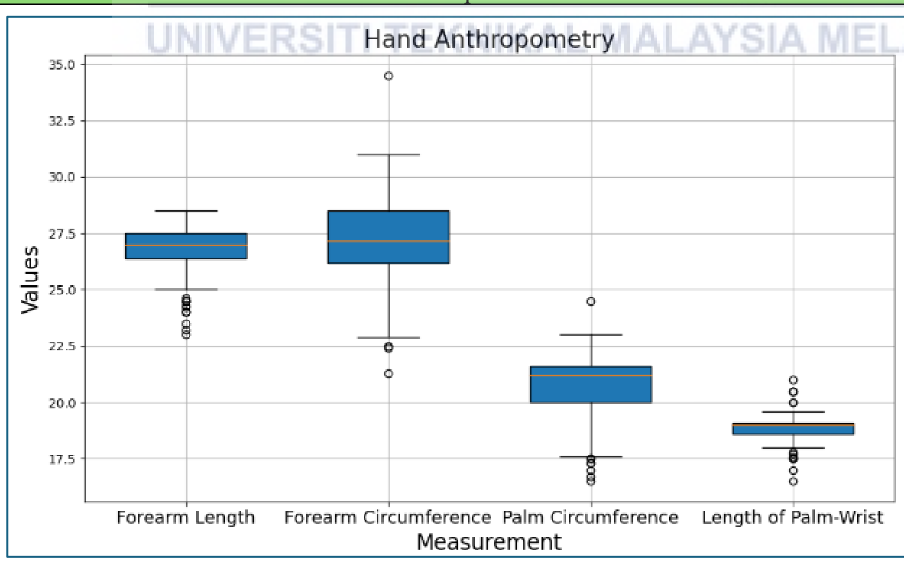
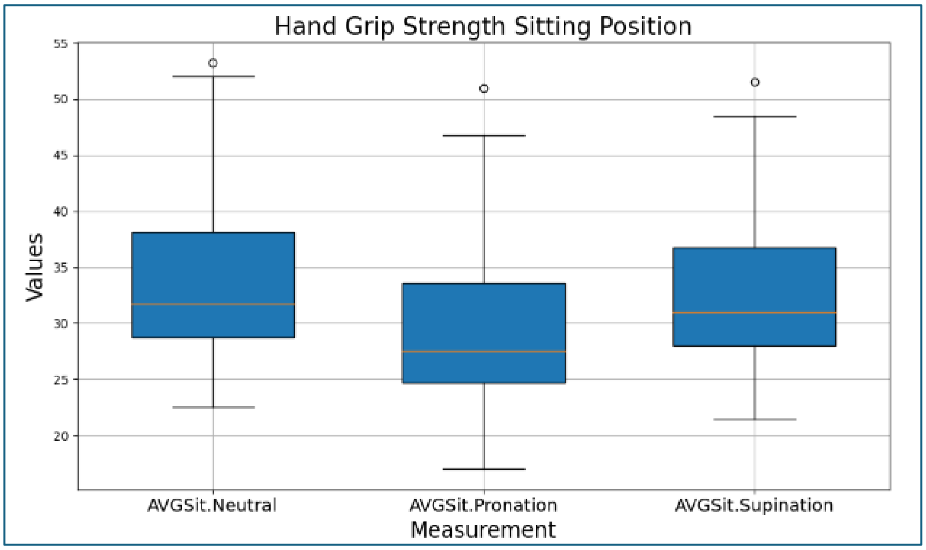
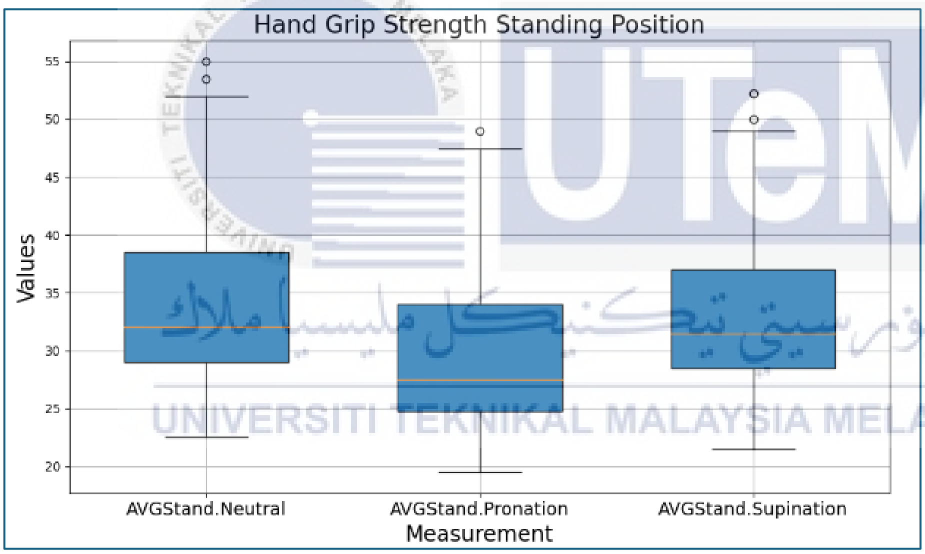
<table>
<tr><th>Graph</th><th>Explanation</th></tr>
<tr><td>


Figure 4.4: Box and whiskers: hand anthropometry
</td><td>Figure 4.4 shows the box and whiskers plot for hand anthropometry. The data distributions for these measurements appear normal, with most values concentrated around the median and a few outliers observed. These outliers are not extreme and fit within the expected range, suggesting a reliable dataset.</td></tr>
<tr><td></td><td>Figure 4.5 shows the box and</td></tr>
</table>

| | |
|---|---|
|  <br>Figure 4.5: Box and whiskers: HGS sitting position | whiskers plot for hand grip strength in the sitting position. It shows median grip strength values are consistent across different sitting positions, with slight variations. Outliers in these measurements are minimal and do not significantly deviate from the main data distribution, indicating the dataset's stability. |
|  <br>Figure 4.6: Box and whiskers: HGS standing position | Figure 4.6 shows the box and whiskers plot for hand grip strength in the standing position. It is like the sitting position, the distribution of the data is normal, with median values showing consistency across different positions. The outliers observed are within a reasonable range, further validating the dataset's integrity. |



Overall, the analysis proceeded with all 152 data entries. The minimal presence of outliers and the normal distribution of the data reinforce the dataset's robustness and reliability. This comprehensive evaluation underscores the dataset's suitability for further analysis.

### 4.2.2 Correlation analysis

The section below presents findings from the correlation analysis based on various measurements related to hand grip strength (HGS) among Malaysian male adults. The analysis includes data on body posture (sitting vs. standing) and wrist position (neutral, pronation, and supination), highlighting significant correlations.

#### 4.2.2.1 Bar chart-HGS

The bar chart in figure 4.7 highlights the correlation between hand grip strength and various hand and body postures among Malaysian male adults. It shows that hand grip strength is influenced by both body posture (sitting vs. standing) and wrist position (neutral, pronation, and supination).

In terms of body posture, the chart reveals that grip strength is consistently higher in the standing position compared to the sitting position across all wrist postures. Specifically, in the neutral wrist position, the average grip strength is 34.04 kg when standing, compared to 33.76 kg when sitting. In the pronation position, standing grip strength is 29.36 kg versus 29.11 kg when sitting. Similarly, in the supination position, standing grip strength is 32.98 kg, while sitting grip strength is 32.65 kg. This pattern indicates that standing posture generally enhances grip strength slightly more than sitting posture.

Regarding wrist positions, the neutral position consistently shows the highest average grip strength in both sitting and standing postures. This position yields an average grip strength of 34.04 kg when standing and 33.76 kg when sitting, indicating it is the most favorable for maximizing grip strength. The supination position follows, with average grip strengths of 32.98 kg in the standing position and 32.65 kg in the sitting position, indicating it is moderately favorable. The pronation position results in the lowest average grip strength, with 29.36 kg when standing and 29.11 kg when sitting, suggesting it is the least favorable for grip strength.

Cho et al. (2007) support the trend that the neutral wrist position yields the highest grip strength, followed by supination, and finally pronation for male data. The neutral grip strength values are very close to those of the supination position. Murugan et al. (2013) confirm that sitting hand grip strength is slightly lower than standing hand grip strength. The data is aligned with previous studies, reinforcing the reliability of these findings and providing a strong foundation for further analysis and application in ergonomic glove design.

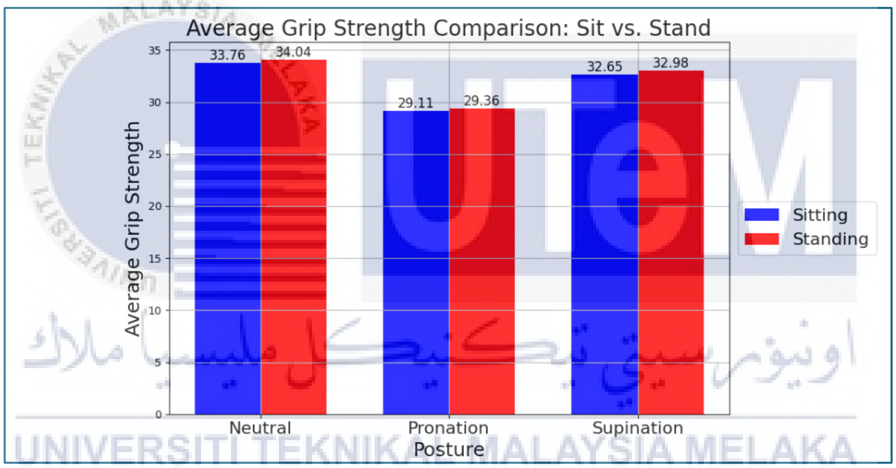



Figure 4.7: Bar chart: HGS sitting and standing

**4.2.2.2 Correlation matrix heatmap - Pearson correlation coefficient**

Based on the correlation heatmap analysis of grip strength and hand anthropometry shown in figure 4.8, several significant relationships have been identified. The grip strength measurements in neutral, pronation, and supination wrist positions exhibit very high positive correlations (0.93 to 0.95), indicating consistent strength performance across different wrist orientations. Among the anthropometric variables, forearm circumference shows a moderate to strong correlation with grip strength (0.65 to 0.75), suggesting greater forearm girth enhances grip strength. Palm circumference also has moderate correlations (0.5 to 0.57), while forearm length shows a moderate influence (0.35 to 0.42). Conversely, palm-wrist length has low correlations (0.24 to 0.29), implying it is less influential. These findings highlight the importance of forearm and palm characteristics in grip strength capabilities, while suggesting other factors might also contribute to grip strength variance.

Sirajudeen et al. (2012) found that forearm circumference had the highest correlation with grip strength, which aligns with our data. However, their study indicated that the palm-wrist length had a higher correlation with grip strength than hand breadth, which differs from our findings. This discrepancy may be due to the smaller sample size in their research. Similarly, Fuentes-Manrique et al. (2018) and Hemberal et al. (2014) reported differing results from each other. Therefore, a larger sample size is needed to draw definitive conclusions about these correlations, as there is still some debate in this area of research.

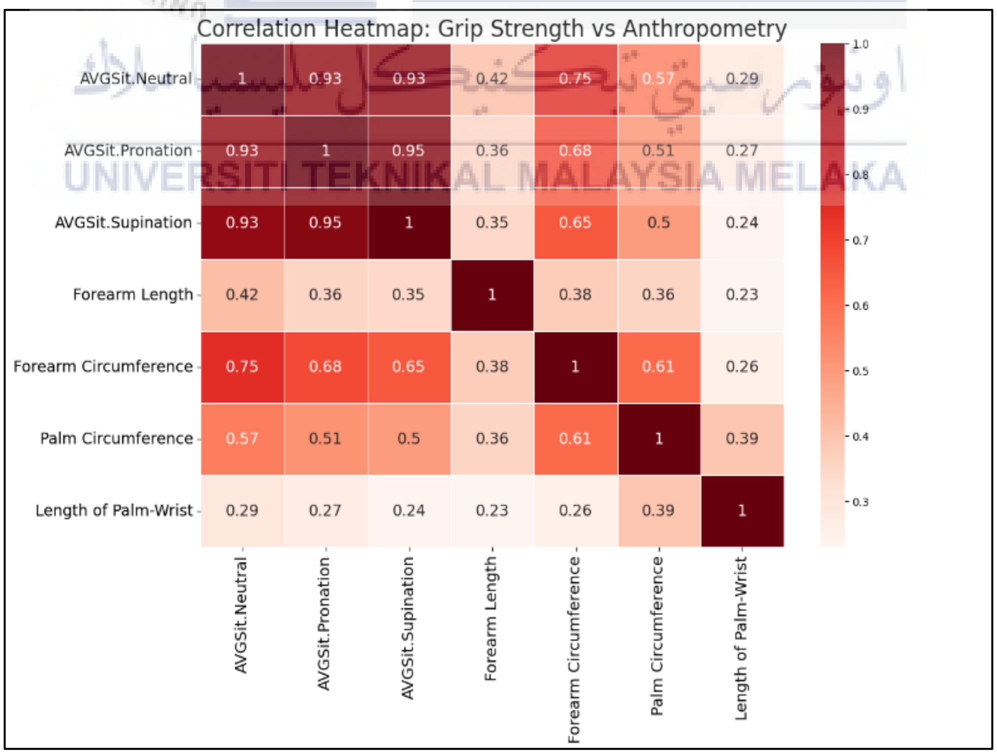



Figure 4.8: Correlation heatmap: grip strength vs anthropometry

#### 4.2.2.3 R-Squared analysis

Relationship between grip strength and various hand anthropometry measures by analyzing R-squared values to identify which anatomical features most significantly affect grip strength performance. The R-squared data, presented in the table 4.6 below, provide clear insights into these relationships.

Table 4.6: R-Squared: anthropometry variable with HGS

| Anthropometry Variable | R-Squared Value | | |
|---|---|---|---|
| | Average Sitting Neutral HGS | Average Sitting Pronation HGS | Average Sitting Supination HGS |
| Forearm Length | 0.1727 | 0.1274 | 0.1196 |
| Forearm Circumference | 0.5626 | 0.4606 | 0.4275 |
| Palm Circumference | 0.3238 | 0.2642 | 0.2462 |
| Length of Palm-Wrist | 0.0854 | 0.0734 | 0.0566 |

Based on the R-squared analysis, several important insights have emerged. The R-squared values for forearm length, shown in figure 4.9, indicate that it has a modest explanatory power regarding grip strength, with values of 0.1727, 0.1274, and 0.1196 for the neutral, pronation, and supination positions, respectively. This indicates that forearm length explains between 11.96% to 17.27% of the variance in grip strength, suggesting some influence but not a strong predictive factor.

In contrast, the R-squared values for forearm circumference, illustrated in figure 4.10, demonstrate a much stronger relationship with grip strength. The values are 0.5626 for the neutral position, 0.4606 for the pronation position, and 0.4275 for the supination position. These values indicate that forearm circumference explains between 42.75% to 56.26% of the variance in grip strength, highlighting it as a significant predictor.

Palm circumference also shows moderate explanatory power, as shown in figure 4.11, with R-squared values of 0.3238, 0.2642, and 0.2462 for the neutral, pronation, and supination positions, respectively. This indicates that palm circumference can explain roughly 24.62% to 32.38% of the variance in grip strength, underscoring its relevance.

Lastly, the length of the palm-wrist exhibits the lowest R-squared values, presented in figure 4.12, with 0.0854, 0.0734, and 0.0566 for the neutral, pronation, and supination positions, respectively. These values suggest that the length of the palm-wrist explains only 5.66% to 8.54% of the variance in grip strength, indicating a minimal impact.

Overall, forearm circumference emerges as the most significant anthropometric predictor of grip strength, followed by palm circumference and forearm length, while the length of the palm-wrist shows the least impact. These findings emphasize the importance of certain forearm and hand dimensions in determining grip strength performance.

There are differences in R-squared analysis results between this study and previous research, which can be attributed to several factors. Li et al. (2010) found a strong positive correlation between forearm circumference and grip strength, aligning with our findings. However, other results differ from our data. Previous studies, such as those by Shahida et al. (2015) and Fuentes-Manrique et al. (2018), also show varying levels of correlation.

Inconsistencies can arise due to several factors. First, sample size affects reliability and variability of results. Differences in data processing methods, like data cleaning and outlier handling, also contribute to discrepancies. These factors underscore the importance of standardizing methodologies to achieve consistent and comparable results across studies.

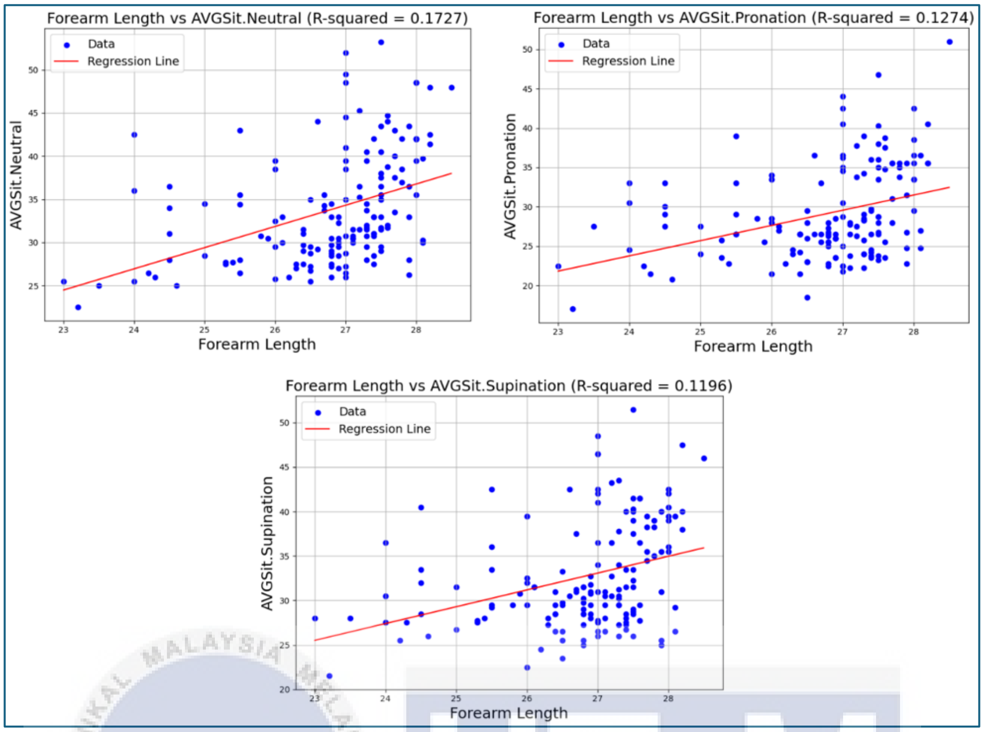



Figure 4.9: Forearm length R-squared graph

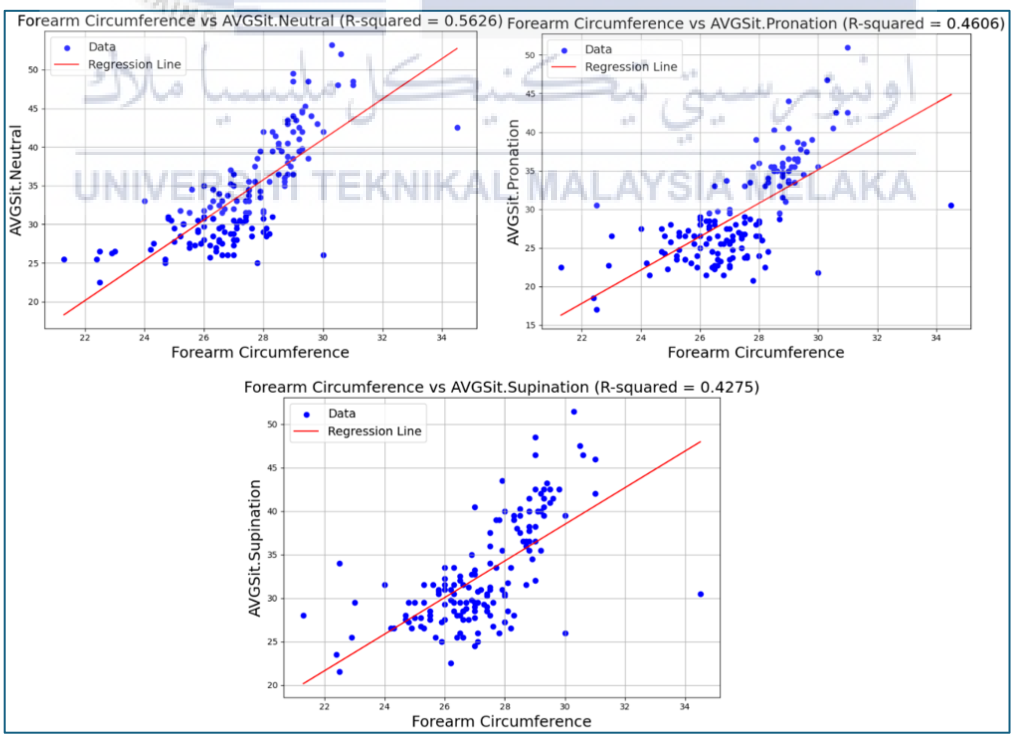



Figure 4.10: Forearm circumference R-squared graph

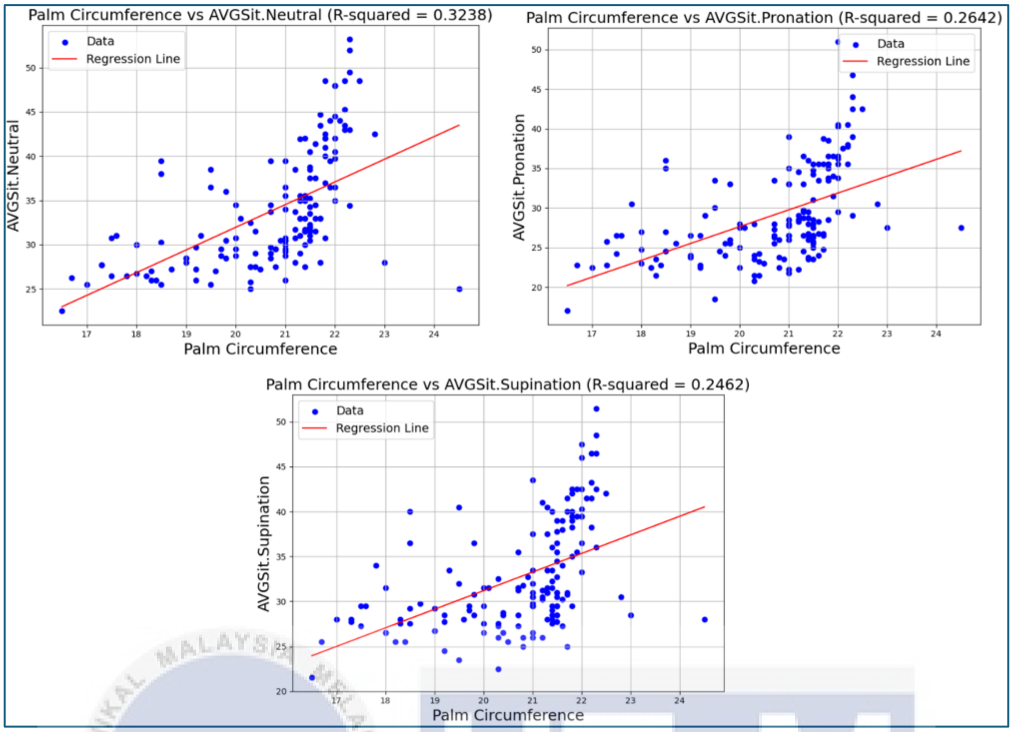



Figure 4.11: Palm circumference R-squared graph



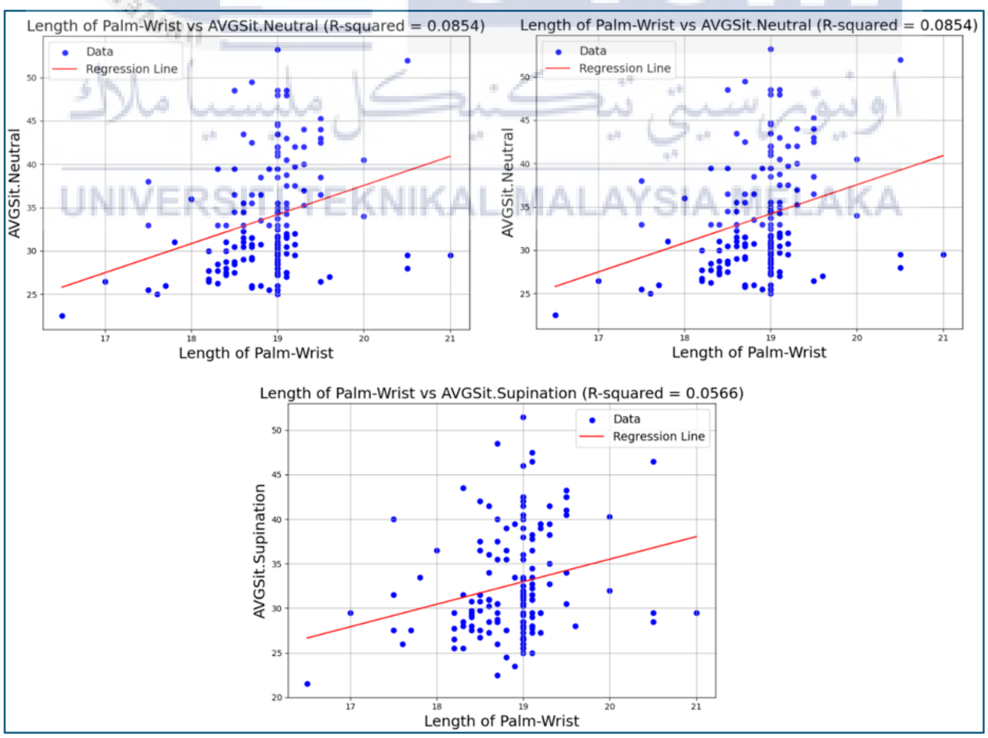



Figure 4.12: Length of palm-wrist R-squared graph

## 4.3 Prototype Development of an Ergonomic Glove for Improved Gripping Performance in Malaysian Male Adults

The study findings, based on interviews with six young adults (three males, three females), identified key user needs for SMAW welding gloves. These insights informed the development of a prototype and subsequent engineering analysis. The prototype was compared against existing market benchmarks, integrating user preferences with technical requirements to refine the design for optimal performance.

### 4.3.1 User need analysis

Based on the interview sessions conducted with six participants, three males and three females, all of whom are young adults, insights were gathered regarding their expectations for SMAW welding gloves. Each participant highlighted specific criteria that they prioritize for optimal glove performance and comfort during welding tasks. The participant background and their expectation criteria are shown in table 4.7. Overall, the participants' expectations for SMAW welding gloves focus on a combination of comfort, fit, durability, and safety. Additionally, figure 4.13 illustrates one of the participant interviews.


Figure 4.13: Interview session

Table 4.7: Participants' expectation criteria

| Participant | Background | Expectation criteria |
|---|---|---|
| Ms. Fatin | -Female<br>-Malay<br>-24 years old | -Requires gloves that provide better force transmission for effective handling<br>-Needs better fitted to avoid discomfort |
| Ms. Syazwani | -Female<br>-Malay<br>-23 years old | -Requires gloves that can fit various hand shapes<br>-Needs gloves that allow for precise force control during tasks |
| Ms. Aina | -Female<br>-Malay<br>-23 years old | -Prefers gloves that are of high quality and durability<br>-Requires gloves with improved heat and cut resistance for enhanced safety |
| Mr. Yap | -Male<br>-Chinese<br>-24 years old | -Requires gloves that are comfortable to wear for extended periods<br>-Needs gloves that allow for a full range of finger and wrist movement without restriction |
| Mr. Dinesh | -Male<br>-Indian<br>-23 years old | -Requires gloves that are better fitted to avoid discomfort<br>-Maintain the force after wearing glove |
| Mr. Chan | -Male<br>-Chinese<br>-24 years old | -Requires gloves that maintain high force transmission for effective handling<br>-Prefers gloves that prioritize safety, including heat and cut resistance |

### 4.3.2 Product specification

Table 4.8 summarizes the product specifications concluded from interview sessions, aligning expected criteria with specific technical targets. The specifications focus on key aspects such as force, angle of motion, comfort, size, and quality, ensuring the gloves meet diverse user needs.

Table 4.8: User needs: technical specifications and target

| User needs | Technical specifications | Target |
|---|---|---|
| Force | -Grip strength (measured in Kilograms)<br>-Torque capacity (measured in Newton-centimeters) | -Maintain at least 90% of natural grip strength<br>-Maintain at least 85% of natural wrist torque |
| Angle of motion | -Range of motion (degrees) | -Allow full range of motion (0-180° for fingers, 0-90° for wrist) |
| Comfort | -Temperature regulation | -Keeps hands cool and dry in hot conditions |
| Size | -Fit<br>-Adjustability (features such as straps or elastic) | -Adjustable features to fit different hand shapes |
| Quality | -Durability<br>-Heat resistance<br>-Cut resistance | -Long-lasting without significant wear<br>-Strong and tear-resistant materials |

Table 4.9 presents the important ratings for various specifications. According to the results, force and quality are the most important specifications, each with an average rating of 23.33%. Size follows with 20.00%, while comfort and angle of motion are both rated at 16.67%. This indicates that participants prioritize force and quality in the glove design.

Table 4.9: Importance specification rating

| Participant | Force | Angle of Motion | Comfort | Size | Quality |
|---|---|---|---|---|---|
| 1 | 25% | 15% | 15% | 20% | 25% |
| 2 | 30% | 15% | 20% | 15% | 20% |
| 3 | 25% | 20% | 15% | 15% | 25% |
| 4 | 25% | 15% | 10% | 20% | 30% |
| 5 | 20% | 20% | 15% | 25% | 20% |
| 6 | 15% | 15% | 25% | 25% | 20% |
| Average | 23.33% | 16.67% | 16.67% | 20.00% | 23.33% |

### 4.3.3 Product benchmark

In this section, comprehensive benchmark analysis performed of numerous types of gloves that are relevant to the scope of the study, across diverse sectors. As specified in Section 3.3.2, the choice of gloves was determined by their suitability for important industrial areas that demand protective characteristics. The benchmark comparison in table 4.10 displays three distinct categories of gloves: synthetic leather (figure 4.14), microfiber (figure 4.15), and long leather gloves (figure 4.16). This comparative analysis offers crucial insights into the suitability and efficacy of these gloves in various working settings, facilitating the selection and implementation of suitable hand protection measures.

Table 4.10: Types of gloves and specification

| Glove | Specifications |
|---|---|
|  Figure 4.14: Synthetic leather glove | • Suitable industry: Manufacturing, automotive, construction<br>• Main material: Polyurethane (PU) and nitrile blend<br>• Features: Enhanced grip in wet and oily conditions, excellent abrasion resistance, long-lasting comfort with a seamless knitted nylon liner, and elasticated knit wrist for a secure fit.<br>• Protection: Hands from oils, abrasions, and general wear. |
|  Figure 4.15: Microfiber glove | • Suitable industry: Welding, heavy industrial applications<br>• Main material: Microfiber<br>• Features: Durable with high mechanical strength and good heat resistance, suitable for prolonged wear, and offers excellent durability and comfort.<br>• Protection of: Hands from heat, mechanical hazards, and abrasions in welding and industrial environments. |
|  Figure 4.16: Long leather glove | • Suitable industry: Construction, heavy-duty work, SMAW welding<br>• Main material: Cow leather<br>• Features: Provides strong abrasion resistance, insulation, and flame resistance, offers comfortable fit and flexibility.<br>• Protection of: Hands from abrasions, heat, and mechanical hazards in construction and heavy-duty industries. |

In the following section, these three types of gloves underwent participant rating assessments, grip strength tests, and wrist torque (figure 4.17) evaluations to facilitate a comprehensive comparison. These tests aimed to objectively measure aspects such as comfort, usability, and ergonomic performance. These assessments are crucial for understanding the practical advantages and limitations of each glove type, thereby informing informed decisions regarding their deployment in industrial settings.


Figure 4.17: Wrist torque test



### 4.3.3 Participant rating assessment

Based on the ratings in table 4.11, the Microfiber Glove excels with a top score of 7.2, particularly in force impairment (7.3) and comfort (7.3). These strengths highlight its ability to minimize hand strain and provide ergonomic comfort, crucial for prolonged use. In contrast, the Long Leather Glove, despite a strong product quality rating (7.5), received the lowest average score of 5.3 due to lower comfort (4.3) and size (3.0) ratings. This indicates potential drawbacks in ergonomic fit and wearer comfort compared to the Microfiber and Synthetic Leather Gloves. The Synthetic Leather Glove closely follows with an average score of 7.0, emphasizing comfort (7.7) and size (8.5), making it a solid choice for users prioritizing fit and satisfaction.

Table 4.11: Participant rating assessment

| Glove Type | Specification | Participant | | | | | | Average | Overall score |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | | |
| Synthetic Leather Glove | Force Impairment | 7.0 | 7.0 | 5.0 | 7.0 | 8.0 | 7.0 | 6.8 | 7.0 |
| | Impaired Angle of Motion | 8.0 | 8.0 | 7.0 | 8.0 | 9.0 | 8.0 | 8.0 | |
| | Comfort | 7.0 | 7.0 | 8.0 | 9.0 | 8.0 | 7.0 | 7.7 | |
| | Size | 7.0 | 9.0 | 9.0 | 9.0 | 8.0 | 9.0 | 8.5 | |
| | Product Quality | 3.0 | 3.0 | 5.0 | 4.0 | 4.0 | 4.0 | 3.8 | |
| Microfiber Glove | Force Impairment | 8.0 | 8.0 | 6.0 | 7.0 | 8.0 | 7.0 | 7.3 | 7.2 |
| | Impaired Angle of Motion | 8.0 | 7.0 | 7.0 | 8.0 | 8.0 | 7.0 | 7.5 | |
| | Comfort | 6.0 | 8.0 | 7.0 | 7.0 | 8.0 | 8.0 | 7.3 | |
| | Size | 8.0 | 9.0 | 9.0 | 8.0 | 9.0 | 8.0 | 8.5 | |
| | Product Quality | 4.0 | 6.0 | 5.0 | 5.0 | 6.0 | 5.0 | 5.2 | |
| Long Leather Glove | Force Impairment | 6.0 | 5.0 | 5.0 | 7.0 | 5.0 | 6.0 | 5.7 | 5.3 |
| | Impaired Angle of Motion | 6.0 | 5.0 | 7.0 | 7.0 | 7.0 | 5.0 | 6.2 | |
| | Comfort | 3.0 | 4.0 | 4.0 | 6.0 | 5.0 | 4.0 | 4.3 | |
| | Size | 2.0 | 3.0 | 2.0 | 4.0 | 5.0 | 2.0 | 3.0 | |
| | Product Quality | 9.0 | 7.0 | 7.0 | 8.0 | 8.0 | 6.0 | 7.5 | |

### 4.3.4 House of Quality (HoQ)

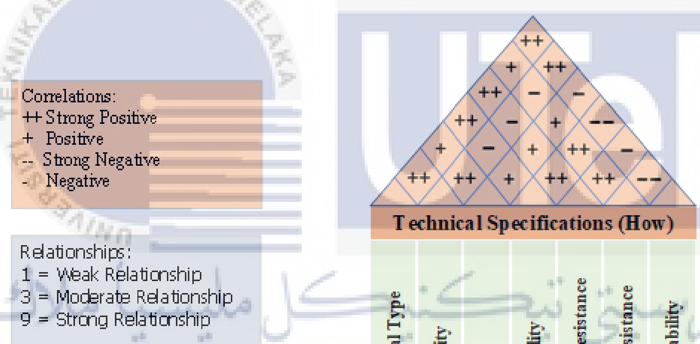
The House of Quality (HoQ) analysis depicted in Figure 4.18 elucidates the crucial specifications for developing an ergonomic glove tailored for SMAW welding. This analysis bridges the gap between customer requirements and technical specifications, ensuring the glove meets both performance standards and user expectations.



From the customer requirements perspective, force and product quality emerged as the most critical factors, each holding an importance weight of 23.33%. This underscores the necessity for the glove to enable adequate force application while maintaining high durability and overall product integrity. Size is also a significant consideration, with a 20.00% importance weight, indicating the need for a range of glove sizes to accommodate different hand shapes and sizes for better fit and comfort. Comfort and range of motion are equally important, each with an importance weight of 16.67%. These factors highlight the need for the glove to facilitate unrestricted movements and provide comfort during prolonged use, which are essential for maintaining efficiency and reducing fatigue in welding tasks.

On the technical specifications front, the material type stands out as a critical factor due to its strong relationship with durability and heat resistance, essential for protecting against the harsh conditions of welding. Flexibility and grip are also paramount, as they directly impact the welder's ability to perform precise movements and maintain control over tools. Durability and cut resistance are crucial for ensuring the glove can withstand wear and potential hazards. Additionally, breathability, although rated lower in importance, remains significant for enhancing comfort during long working hours.

The comparison of the three gloves highlights their respective advantages in specific specifications. However, determining the foundational design to proceed with requires additional comparisons. The following section will outline how to proceed with this assessment.




| | Customer Requirements (What) | Importance | Material Type<br>1 | Flexibility<br>2 | Grip<br>3 | Durability<br>4 | Heat Resistance<br>5 | Cut Resistance<br>6 | Breathability<br>7 | Competitive Assessment<br>1 | <br>2 | <br>3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Force | 23.33% | 3 | 9 | 9 | | | | | 6.8 | 7.3 | 5.7 |
| 2 | Range of motion | 16.67% | 1 | 9 | 3 | | | | | 8.0 | 7.5 | 6.2 |
| 3 | Comfort | 16.67% | 3 | 9 | 3 | | | | 9 | 7.7 | 7.3 | 4.3 |
| 4 | Size | 20.00% | | 3 | | | | | | 8.5 | 8.5 | 3.0 |
| 5 | Product Quality | 23.33% | 9 | | 3 | 9 | 9 | 9 | | 3.8 | 5.2 | 7.5 |
| | | Target | High quality, durable | Unrestricted movements | Reliable user control | Long-lasting | High resistance to temperatures | Strong restance to cut | Comfort during prolonged use | | | |
| | | Importance Rating | 3.47 | 5.7 | 3.8 | 2.1 | 2.1 | 2.1 | 1.5 | | | |
| | | Ranking | 3 | 1 | 2 | 4 | 4 | 4 | 5 | | | |

Figure 4.18: House of quality (HoQ)

### 4.3.5 Performance evaluation matrix

The weighted decision matrix in Table 4.12 ranks the three types of gloves based on various criteria such as force, range of motion, comfort, size, and product quality. The microfiber glove emerges as the top choice with the highest total score of 7.08, indicating superior performance across the evaluated factors. In contrast, the synthetic leather glove follows closely behind with a total score of 6.79, securing the second position. The long leather glove ranks third with a total score of 5.43, showing lower performance compared to the other two options. This ranking suggests that while each glove type has its strengths and weaknesses across different attributes, the microfiber glove stands out as the most balanced and effective choice overall according to the weighted criteria.

Table 4.12: Weighted decision matrix

| Requirement | Weightage | Options | | | | | |
|---|---|---|---|---|---|---|---|
| | | Synthetic Leather Glove | | Microfiber Glove | | Long Leather Glove | |
| | | Rating | Score | Rating | Score | Rating | Score |
| Force | 23.33% | 6.8 | 1.59 | 7.3 | 1.70 | 5.7 | 1.33 |
| Range of motion | 16.67% | 8.0 | 1.33 | 7.5 | 1.25 | 6.2 | 1.03 |
| Comfort | 16.67% | 7.7 | 1.28 | 7.3 | 1.22 | 4.3 | 0.72 |
| Size | 20.00% | 8.5 | 1.70 | 8.5 | 1.70 | 3.0 | 0.60 |
| Product Quality | 23.33% | 3.8 | 0.89 | 5.2 | 1.21 | 7.5 | 1.75 |
| | Total | 34.8 | 6.79 | 35.8 | 7.08 | 26.7 | 5.43 |
| | Ranking | 2 | | 1 | | 3 | |

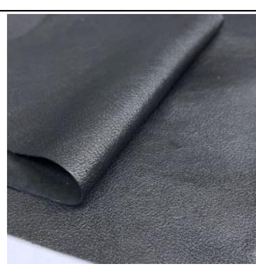
### 4.3.6 Detail conceptualization

Based on the findings from section 4.3.5, where the microfiber glove ranked highest in participant ratings, it has been chosen as the foundation for further development in this study. The decision stems from its superior performance. Given the intense heat, sparks, and spatter involved in SMAW welding operations (John Tillman Co.), necessitating enhanced heat insulation, the concept design integrates the synthetic leather glove's elastic wrist design and draws upon the long leather glove's high-quality cut and heat resistance features. These modifications and description are detailed in figure 4.19 and table 4.13, the conceptual drawing of the glove.


Figure 4.19: Conceptual drawing of new glove



Table 4.13: Conceptual design parts and description

| Parts | Description |
|---|---|
|  Figure 4.20: Microfiber lining | Microfiber used as a welding lining provides excellent heat resistance, high tensile strength, and good abrasion resistance. Its lightweight and flexibility enhance dexterity and reduce hand fatigue during welding operations. |
|  Figure 4.21: Genuine leather | Genuine leather improves safety through its exceptional resistance to cuts and heat. It provides durable protection against sharp objects and high temperatures, specifically applied to the palm and finger areas of the glove. The choice of leather type is tailored to meet precise industrial requirements, ensuring reliable performance in demanding work environments. |

| | |
|---|---|
|  Figure 4.22: Elastic strap | An elastic strap for the glove wrist, inspired by synthetic leather glove designs, improves fit and usability. It ensures a secure, comfortable fit without needing to adjust or remove the glove, enhancing convenience and safety in industrial environments. |

#### 4.3.6.1 Material selection

Table 4.14 showcases the properties of various leather types, highlighting their unique advantages for different welding applications. Sheep leather provides natural insulation and flexibility; deer leather offers superior cut resistance and flexibility; goat leather combines tensile strength and dexterity; pig leather ensures breathability and durability; elk leather provides exceptional heat and abrasion resistance; and cow leather, the most common in welding, offers excellent durability and affordability. (Hardin, 2023; Waylanderwelding, 2022) These leathers are among the most used in welding processes, and this overview aids in selecting the most suitable leather for specific industrial needs, ensuring optimal safety and performance.



Table 4.14: Leather type with properties

| Leather Type | Properties |
|---|---|
|  Figure 4.23: Sheepskin | • Tanned with wool intact, providing natural insulation and resistance to flame and static electricity.<br>• Thin and elastic, allowing for great flexibility and sensitivity.<br>• Wool fibers draw perspiration away from the skin, enhancing comfort during use. |

| | |
|---|---|
| <br>Figure 4.24: Deerskin | • Naturally tough and resistant to cuts and abrasion.<br>• Lightweight, spongy, and one of the softest and warmest leathers available.<br>• It can spring back to its original shape and softness after getting wet, which is unique among leathers.<br>• Thicker cuts of deerskin leather are suitable for MIG welding, while thinner cuts are an excellent choice for TIG welding. |
| <br>Figure 4.25: Goatskin | • High tensile strength, durability, dexterity, and flexibility.<br>• Although it is thin leather, goatskin is soft, pliable, and offers great protection against cuts and abrasion.<br>• The higher lanolin content in goatskin provides a natural barrier against moisture, while the thin nature of the material allows for excellent fingertip control.<br>• Kidskin, very soft and lightweight, superior fingertip sensitivity along with durability and abrasion resistance. |
| <br>Figure 4.26: Pigskin | • Dense leather, which makes it less flexible compared to other leathers on the market.<br>• Small pores in pigskin allow the wearer's skin to breathe, making pigskin gloves one of the most durable options.<br>• Supple feel and remains soft even after getting wet, though it is not recommended for use in jobs with consistently high moisture levels.<br>• Excellent for MIG and stick welding, high durability. |
| <br>Figure 4.27: Elkskin | • Thickest, soft leathers available, is very durable and provides exceptional resistance to heat, flame, and abrasion.<br>• It maintains its softness and flexibility even in hot and wet conditions, conforming to the hand and offering great movement and flexibility for the wearer.<br>• Withstand high temperatures makes it particularly suitable for stick welding, where heat resistance is crucial. |

| | |
|---|---|
| <br>Figure 4.28: Cowhide | • Most common leather used in welding due to its abundance and durability.<br>• Its robust structure offers excellent resistance to abrasion, sparks, and spatter.<br>• It is slightly more durable than elkskin but not quite as soft, although it is still preferred for comfort over other non-leather materials, allowing for longer wear periods.<br>• The combination of durability and abundance makes cowhide leather both a practical choice and a great value for welders. |

Elkskin and cowhide leather are excellent choices for stick welding and driver's gloves due to their superior safety features and durability. According to Fisher, elkskin is highly regarded for its heat and abrasion resistance, making it ideal for intense welding conditions. Similarly, cowhide is prized for its robustness and ability to withstand sparks and spatter. However, both leathers are heavy, which can reduce dexterity.

In contrast, sheepskin and deerskin are valued for their flexibility, softness, and comfort, making them suitable for applications requiring fine motor skills and prolonged wear. However, they lack the robustness and heat resistance needed for stick welding.



Goatskin and pigskin offer a superior balance of durability, protection, and flexibility. Goatskin is known for its high tensile strength, natural moisture resistance, and excellent fingertip control, making it versatile for various welding applications. Pigskin provides strong protection against cuts and abrasion and remains soft even when wet, making both leathers suitable for the demanding environment of stick welding.

Additionally, in accordance with the guidelines set by the ‘Pejabat Mufti Wilayah Persekutuan’ (2019), the use of swine leather is prohibited, thereby eliminating pigskin from consideration. Considering that the majority ethnic group in Malaysia is Malay, goatskin emerges as the optimal choice, offering reliable protection without compromising on the comfort and maneuverability needed for precision tasks.

After evaluating the options, goatskin is the final recommendation for stick welding gloves. Its exceptional durability, protection, and flexibility meet the study's criteria for better precision and force control, making it the ideal material to ensure both safety and dexterity.

### 4.3.7 Prototype making and user testing

Figure 4.29 illustrates the modified glove prototype, developed and tested with six participants simulating the SMAW welding process. The participant rating assessment data is presented in Table 4.15, with a comparison of glove ratings against the other three designs shown in Figure 4.30. The modified glove achieved the highest overall performance score of 7.7, outperforming the microfiber glove (7.2), synthetic leather glove (7.0), and long leather glove (5.3). Despite its top rating, participants noted that while the modified glove effectively covers the wrist, the intense heat, sparks, and spatter characteristic of the SMAW welding process demand even greater protection. Suggestions for improvement included extending the glove's length.



The additional leather layer slightly reduced the angle of motion because it made the glove thicker. However, this also increased contact friction compared to the microfiber surface, allowing for greater applied force and providing better safety. The glove received particularly high marks for grip and force (7.8). Additionally, while the added leather reduced breathability and lowered comfort, the microfiber still provided good contact with the hand. The elastic strap enhanced comfort and stability during welding by preventing the glove from shifting while holding the tool. Overall, the modified glove's performance was commendable, with room for minor enhancements.

Figure 4. 29: Modified glove prototype

Table 4.15: Participant rating assessment: modified glove

| Specification \ Participant | 1 | 2 | 3 | 4 | 5 | 6 | Average |
|---|---|---|---|---|---|---|---|
| Force Impairment | 8.0 | 8.0 | 7.0 | 8.0 | 9.0 | 7.0 | 7.8 |
| Impaired Angle of Motion | 7.0 | 7.0 | 6.0 | 7.0 | 8.0 | 7.0 | 7.0 |
| Comfort | 9.0 | 8.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.5 |
| Size | 8.0 | 9.0 | 9.0 | 8.0 | 9.0 | 8.0 | 8.5 |
| Product Quality | 5.0 | 8.0 | 8.0 | 7.0 | 7.0 | 6.0 | 6.7 |
| Average | 7.4 | 8.0 | 8.0 | 7.8 | 8.2 | 7.4 | 7.7 |



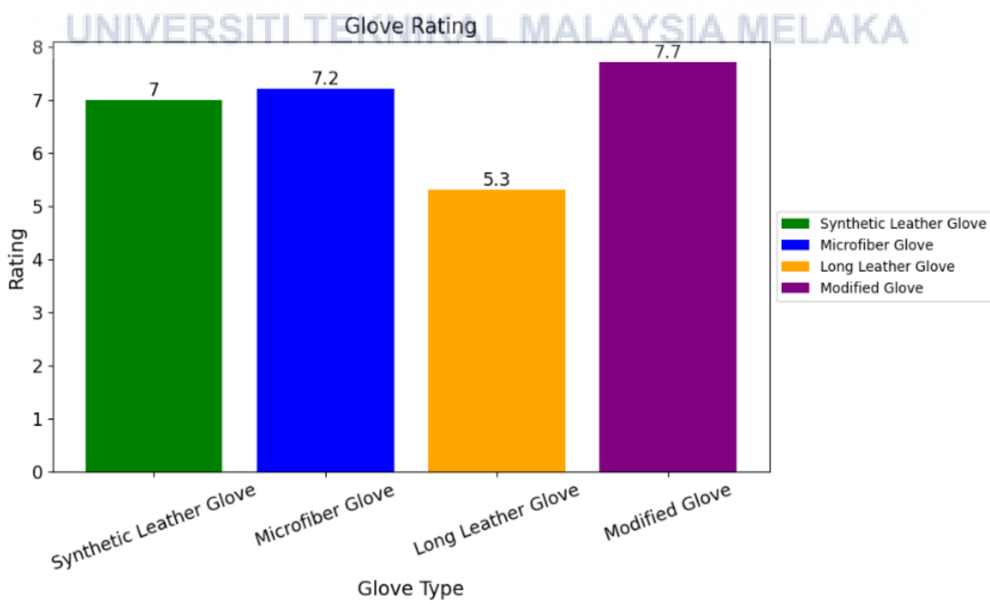



Figure 4.30: Bar chart: glove rating

### 4.3.8 Engineering analysis: wrist torque and grip strength comparison

Participant rating assessments provide valuable data, but they don't fully reveal the improvements of the modified glove. To address this, an engineering analysis was conducted on the prototype with six participants, comparing grip strength and wrist torque. Before testing the glove, wrist torque measurements were taken from 30 male and 30 female participants, as shown in Table 4.16, to understand wrist torque trends. Figures 4.31 and 4.32 illustrate that, although not all patterns are identical, the neutral posture consistently exhibits the highest wrist torque. Notably, female participants displayed higher pronation wrist torque compared to supination, a different pattern from grip strength. Further analysis is needed to explore these wrist torque variations. This preliminary data helps estimate wrist torque trends for subsequent glove testing.

Table 4.16: Average wrist torque of various position for both male and female

| Position / Gender | Pronation, Flexion | Pronation, Extension | Supination, Flexion | Supination, Extension | Neutral, Flexion | Neutral, Extension |
|---|---|---|---|---|---|---|
| Male | 528.03 | 490.90 | 512.97 | 556.57 | 604.47 | 629.57 |
| Female | 285.33 | 300.83 | 293.67 | 280.83 | 299.23 | 319.23 |



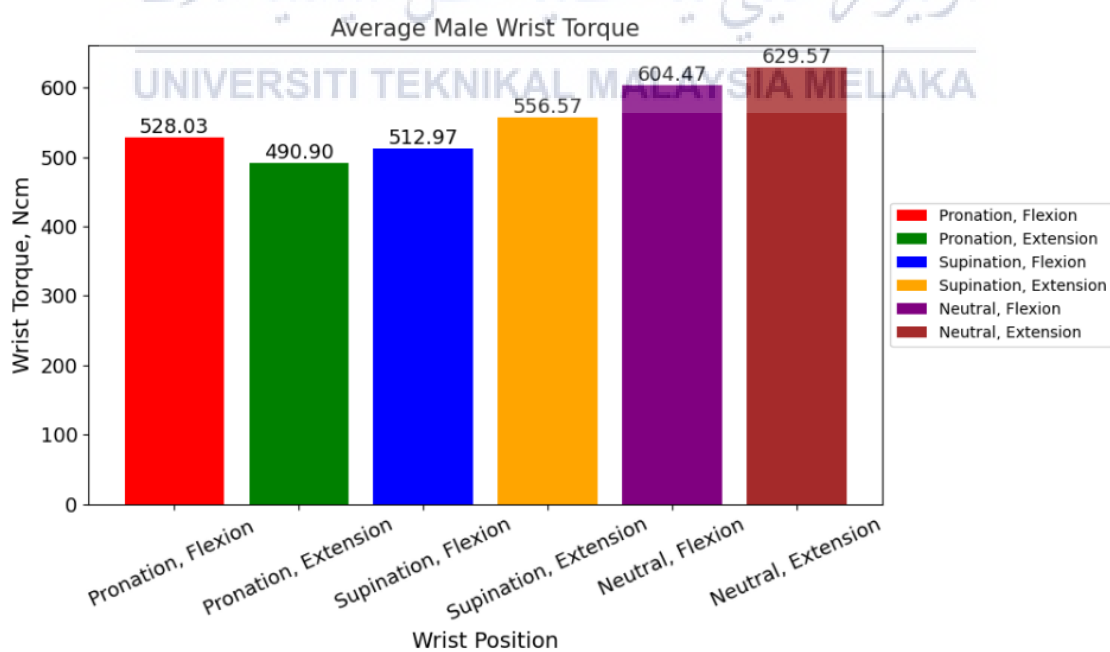



Figure 4.31: Average male wrist torque for various positions

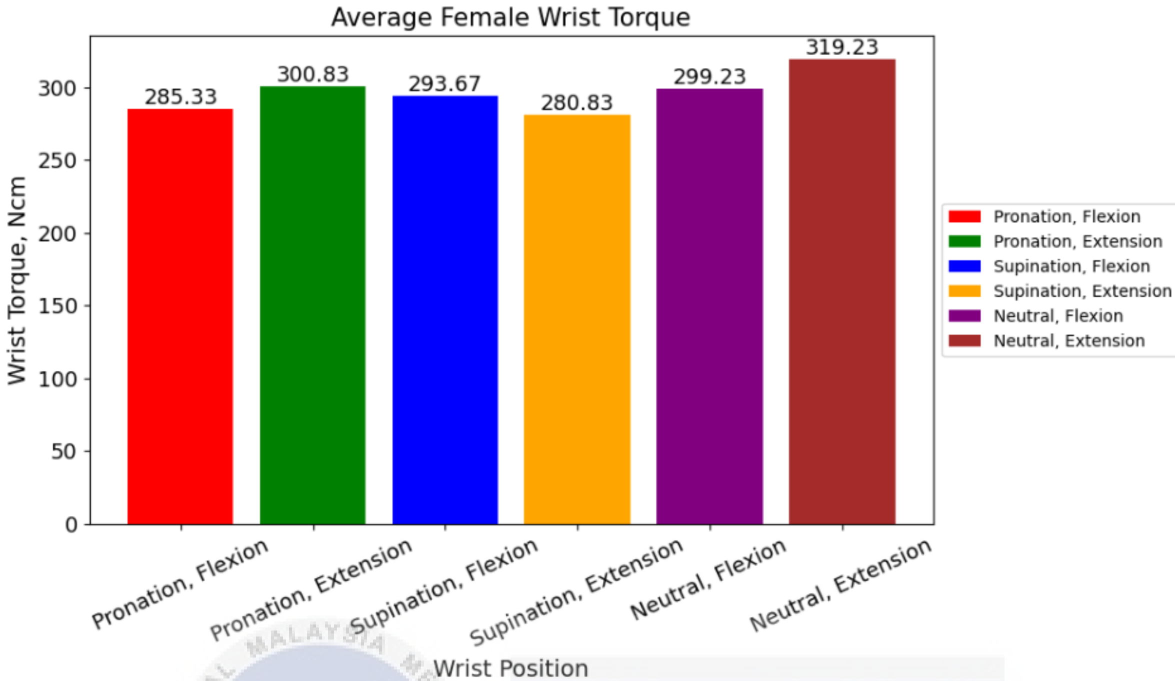



Figure 4.32: Average female wrist torque for various positions

Figure 4.33 shows the Wrist Torque test conducted using a Digital Torque Gauge Mark-10 with a Jacobs chuck attachment, ensuring precise and consistent measurements across all conditions. The results of the wrist torque measurements for the six participants across different glove types are presented in Table 4.17 and visually depicted in Figure 4.34. The data provides a comprehensive comparison of the average wrist torque (WT) values when participants performed tasks barehanded and while wearing various types of gloves, including synthetic leather gloves, microfiber gloves, long leather gloves, and a newly developed modified glove prototype.

From the data, it is evident that the average wrist torque recorded when participants used their bare hands was the highest, at 454.97 Ncm. This high value suggests that performing tasks without any gloves requires more wrist torque compared to using gloves. Among the different glove types, the long leather glove resulted in the lowest average wrist torque of 382.53 Ncm, indicating it has the most resistance during tasks, thus obtaining the least wrist torque.

The modified glove prototype, designed as part of this study, showed an average wrist torque of 425.97 Ncm. This value is higher than those for the synthetic leather glove (409.97 Ncm), microfiber glove (407.39 Ncm), and long leather glove (382.53 Ncm) but lower than the bare hand condition. This positioning suggests that the modified glove prototype offers the best performance by requiring more wrist torque, indicating greater support and effectiveness compared to other gloves.

The synthetic leather and microfiber gloves yielded similar average wrist torques, with the synthetic leather glove at 409.97 Ncm and the microfiber glove at 407.39 Ncm. These values indicate that both glove types provide moderate wrist torque, suggesting a balance between support and flexibility compared to bare hands but are less effective than the modified glove.



Figure 4.33: Wrist torque test with Digital torque gauge Mark-10 with Jacobs chuck attachment

Table 4.17: Average wrist torque: comparison barehand with gloves

| Participant \ Average WT | Bare Hand | Synthetic Leather Glove | Microfiber Glove | Long Leather Glove | Modified Glove |
|---|---|---|---|---|---|
| 1 | 279.33 | 237.83 | 209.67 | 169.00 | 252.67 |
| 2 | 337.83 | 303.83 | 322.83 | 289.83 | 316.50 |
| 3 | 370.50 | 330.17 | 354.17 | 312.00 | 345.83 |
| 4 | 725.83 | 659.67 | 627.67 | 692.00 | 683.33 |
| 5 | 526.00 | 516.50 | 501.67 | 445.50 | 522.17 |
| 6 | 490.33 | 411.83 | 428.33 | 386.83 | 435.33 |
| Average | 454.97 | 409.97 | 407.39 | 382.53 | 425.97 |

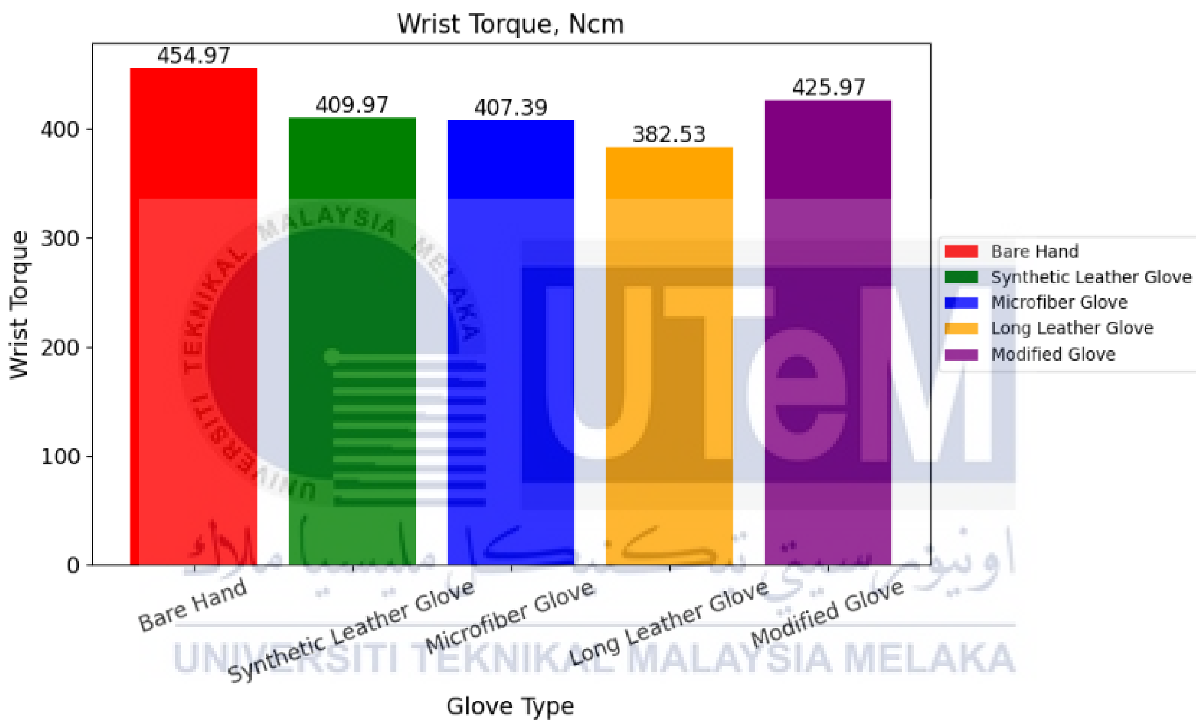



Figure 4.34: Bar chart: comparison wrist torque of barehand with gloves

The data presented in Table 4.18 and Figure 4.35 illustrate the average grip strength comparisons between bare hand use and various types of gloves, including synthetic leather gloves, microfiber gloves, long leather gloves, and a modified glove prototype developed during the study. The analysis focuses on determining which glove design best approximates the grip strength of a bare hand.

From the table, it is evident that the bare hand condition yields the highest average grip strength, with a value of 28.72 kg. This is followed by the modified glove prototype, which demonstrates an average grip strength of 26.50 kg. Among the existing glove designs, the microfiber glove achieves the highest average grip strength at 26.17 kg, closely followed by the synthetic leather glove at 26.00 kg. The long leather glove shows the lowest average grip strength among the gloves tested, at 24.88 kg.

The bar chart in Figure 4.35 visually reinforces these findings, showing a clear distinction between the grip strength of a bare hand and that of each glove type. The bare hand's grip strength is notably higher than all glove conditions. However, the modified glove prototype, represented by the purple bar, comes closest to matching the bare hand's grip strength, indicating its superior performance compared to the other glove designs tested.

Overall, the study's prototype modified glove shows promise in enhancing grip strength performance and closely mimicking the grip strength of a bare hand. This positions it as a preferable option among the gloves tested, particularly for applications where maintaining high grip strength is crucial. The synthetic leather and microfiber gloves, although slightly behind the modified glove, still provide relatively high grip strength values, making them suitable alternatives. In contrast, the long leather glove's lower grip strength indicates a less favorable performance in tasks requiring strong grip.

Table 4.18: Average grip strength: comparison barehand with gloves

| Average GS / Participant | Bare Hand | Synthetic Leather Glove | Microfiber Glove | Long Leather Glove | Modified Glove |
|---|---|---|---|---|---|
| 1 | 19.83 | 16.67 | 17.00 | 15.33 | 17.50 |
| 2 | 26.50 | 24.00 | 25.33 | 22.50 | 25.50 |
| 3 | 23.83 | 21.17 | 22.33 | 20.33 | 22.50 |
| 4 | 43.83 | 39.67 | 37.17 | 41.67 | 37.83 |
| 5 | 36.00 | 34.50 | 34.00 | 30.67 | 34.33 |
| 6 | 22.33 | 20.00 | 21.17 | 18.80 | 21.33 |
| Average | 28.72 | 26.00 | 26.17 | 24.88 | 26.50 |

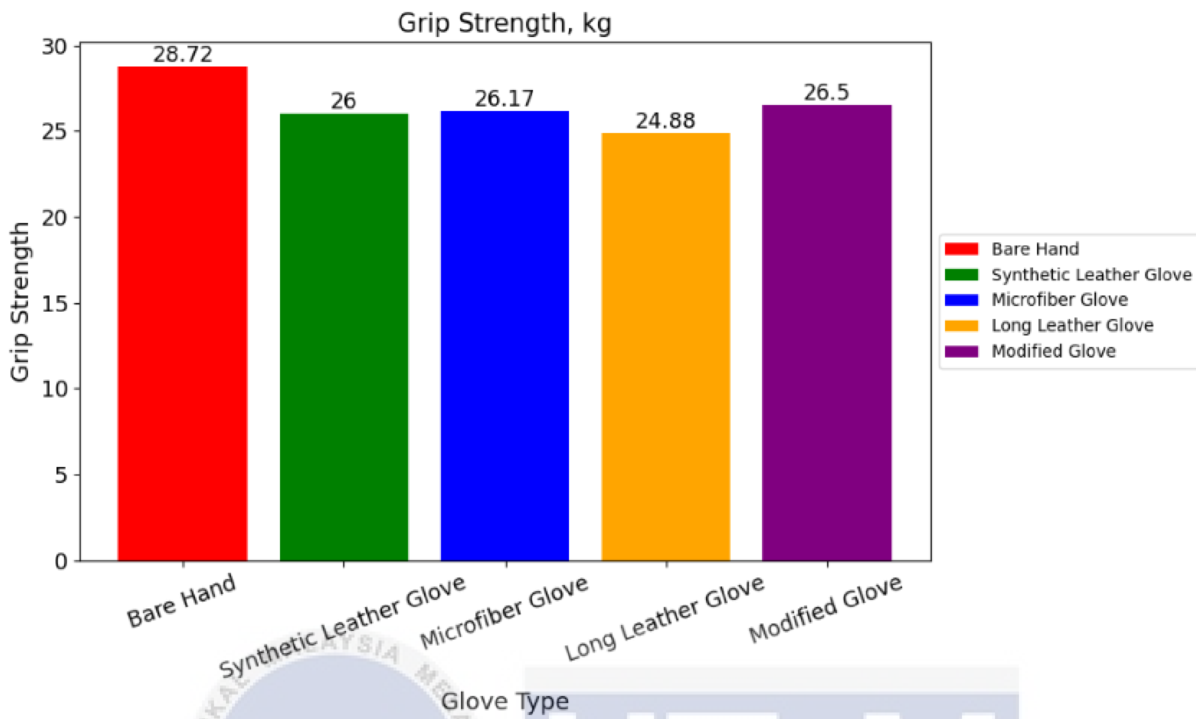



Figure 4.35: Bar chart: comparison grip strength of barehand with gloves

# CHAPTER 5
## CONCLUSION AND RECOMMENDATIONS

This chapter concludes findings on Malaysian male adults' hand dimensions and grip strength correlations in conjunction with the study's objectives. It details the development of an ergonomic glove prototype that enhances gripping performance, validated through user testing. Lastly, the recommendations for future research are also included in this section.



### 5.1 Hand Anthropometric Dimensions and Grip Strength of Malaysian Male Adults

This study assessed hand anthropometric dimensions and maximum hand grip strength in various wrist positions vertical, supination, and pronation among 152 male participants aged 20 to 29 years. The analysis revealed the following average hand anthropometric measurements: forearm length of 26.7743 cm, forearm circumference of 27.2276 cm, palm circumference of 20.7013 cm, and length of palm-wrist of 18.8684 cm. Regarding grip strength in the sitting position, the averages were 33.7635 kg in a neutral position, 29.1118 kg in pronation, and 32.6480 kg in supination. For the standing position, the average grip strengths were 34.0411 kg in neutral, 29.3586 kg in pronation, and 32.9803 kg in supination.

## 5.2 Correlation Between Hand Grip Strength and Various Hand and Body Postures Among Malaysian Male Adults

A box and whisker plot was utilized to ensure the collected data was normal and reliable for further analysis. Next, the correlation analysis began with a bar chart of hand grip strength in both sitting and standing positions, across three wrist postures: neutral, pronation, and supination. This chart revealed higher grip strength values in the standing position across all wrist postures, with the neutral position yielding the highest grip strengths.

Additionally, a correlation matrix heatmap of Pearson correlation coefficients identified significant relationships between grip strength and hand anthropometry. Grip strength in different wrist positions (neutral, pronation, and supination) exhibited very high positive correlations with each other, indicating consistent strength performance across wrist orientations. Among the anthropometric variables, forearm circumference showed the strongest correlation with grip strength, followed by palm circumference and forearm length, while the length of the palm-wrist had the least influence.



Furthermore, an R-squared analysis quantified these relationships. Forearm circumference emerged as the most significant predictor of grip strength, explaining the difference between 42.75% to 56.26% of the variance in grip strength. Palm circumference also had moderate explanatory power, whereas forearm length showed a modest influence. The length of the palm-wrist had minimal impact on grip strength, explaining only a small fraction of the variance.

Overall, the study concluded that certain forearm and hand dimensions, particularly forearm circumference, are significant predictors of grip strength performance. Additionally, the study confirmed that standing posture generally enhances grip strength more than sitting posture, with the neutral wrist position being the most favorable for maximizing grip strength.

## 5.3 Development of an Ergonomic Glove Prototype for Enhanced Gripping Performance in Malaysian Male Adults

This study designed and developed a prototype of an ergonomic glove aimed at enhancing the gripping ability of Malaysian male adults. The new glove design incorporated all customer expectation criteria obtained through interviews. These expectations were translated into technical specifications, and a questionnaire was used to identify which specifications needed more focus, particularly on quality and reducing force impairment.

During the product benchmarking phase, three gloves—Synthetic Leather, Microfiber, and Long Leather—were evaluated. Participant feedback identified the Microfiber Glove as the most preferred design. A detailed analysis using a house of quality highlighted its alignment with customer requirements, leading to its selection as the foundational design. Conceptual drawings were subsequently refined to integrate enhancements, including an added leather layer and elastic wrist strap. Once material suitability was confirmed, a prototype was developed for testing and further refinement.



During user testing, the newly developed modified glove prototype demonstrated superior performance compared to existing designs, particularly in enhancing safety, mitigating force impairment, and improving grip strength during SMAW welding tasks. Participants consistently rated the glove highest for its effective balance of comfort and protective functionality, which includes an additional leather layer that enhances friction and stability. Analysis of hand grip strength and wrist torque confirmed the glove's competitive edge, closely approximating bare hand capabilities while reducing wrist strain compared to performing tasks without gloves. Valuable user feedback underscored the importance of enhancing breathability, optimizing fit for improved maneuverability, and exploring additional ergonomic features to further elevate safety and performance in industrial environments. Participants also suggested extending the glove's length for enhanced protection against the intense heat, sparks, and spatter typical in SMAW welding processes.

## 5.4 Recommendations for Future Research

Further study has the potential to enhance our comprehension of the correlation between hand grasp strength and participant demographics. By considering factors such as age, ethnicity, dominant hand, height, weight, and BMI, researchers can gain valuable insights into the design of gloves that cater to the unique requirements of users. Furthermore, widening the scope of engineering study beyond grip strength and wrist torque comparisons allows for a more comprehensive assessment of glove performance. A more extensive review could include an examination of the material's durability, flexibility, temperature resistance, cut resistance, and rigorous friction testing. These would be extremely useful in determining the best glove materials, ensuring that they effectively meet the needs of various work environments.

Furthermore, it is critical to prioritize safety improvements in glove designs, particularly in high-risk environments such as SMAW welding. Although current glove designs can boost grip strength and wrist torque more efficiently than before, their shorter length may jeopardize overall safety. As a result, future research efforts should prioritize the integration of resilient safety systems to provide better protection to users. By putting safety and performance first, we can ensure that gloves not only boost productivity but also protect workers' well-being in dangerous conditions.



## 5.5 Sustainable Design

In conclusion, this study has successfully developed an ergonomic glove prototype that enhances grip strength for Malaysian male adults. A critical aspect of this development is the emphasis on sustainable design. Recognizing the growing environmental concerns and the need for sustainable practices, the glove's design process prioritized the selection of eco-friendly and durable materials. The use of microfiber lining and goat skin leather serves as supporting evidence for sustainable design.

Microfiber is known for its durability and lower environmental impact compared to traditional materials. It is lightweight, strong, and requires less energy and water during production. Additionally, microfiber's long-lasting nature reduces the need for frequent replacements, thereby minimizing waste. Goat skin leather, on the other hand, is a byproduct of the meat industry, making it a more sustainable choice compared to other leathers. It is also durable, flexible, and provides excellent grip and comfort, aligning well with the ergonomic requirements of the glove.

By integrating these materials, the glove not only meets performance and ergonomic standards but also adheres to sustainability principles. The use of eco-friendly materials ensures that the entire lifecycle of the glove, from production to disposal, aligns with environmental stewardship. This approach contributes to reducing the overall environmental footprint, promoting long-term sustainability in product design. Thus, this project not only addresses immediate ergonomic needs but also sets a precedent for environmentally responsible design in the industry, supporting global efforts to combat environmental degradation and promote sustainable development.



## 5.6 Complexity

The complexity inherent in ergonomic design became evident throughout the various stages of this project. One of the most challenging aspects was finding participants for the data collection process. Recruiting a sufficient number of participants who fit the specific criteria was time-consuming and required significant effort. This step was crucial for obtaining reliable data to inform the design process.

Once the participants were secured, the next challenge was the data collection itself. Gathering accurate and comprehensive data on grip strength and other relevant metrics necessitated meticulous planning and execution. The correlation analysis to understand the relationship between hand anatomy and grip strength further added to the complexity. Establishing these correlations required advanced statistical methods and a deep understanding of biomechanics.

Finally, the actual glove design had to incorporate the insights gained from the data analysis. This required a multidisciplinary approach, integrating principles from biomechanics, material science, and user-centered design. The iterative nature of the design process involved continuous testing, feedback, and refinement to achieve the optimal balance of comfort, functionality, and safety. This project underscores the importance of a thorough and collaborative design process to address the multifaceted challenges of ergonomic product development.



## 5.7 Life-long Learning

Finally, this research underscores the principle of life-long learning, which is vital in the ever-evolving field of industrial design. The insights and data generated from this study serve as a foundation for ongoing education and future research. Staying updated with the latest research, trends, and technological advancements is crucial for continuous improvement and adaptation in ergonomic design.

This project has provided a significant learning experience, illustrating the importance of embracing new knowledge and technologies. By fostering a culture of continuous education and research, designers and engineers can remain responsive to new challenges and opportunities. This commitment to life-long learning ultimately enhances the quality and efficacy of ergonomic products, contributing to improved user well-being and satisfaction.

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# APPENDICES

## Appendix A: Gantt Chart

Gantt Chart: PSM 1

| Activities | Week | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Submission of FYP Title | ■ | | | | | | | | | | | | | | |
| **Introduction** | | | | | | | | | | | | | | | |
| Discuss details about the project | ■ | | | | | | | | | | | | | | |
| Background Study | | ■ | ■ | | | | | | | | | | | | |
| Finding the Problem Statements | | | ■ | ■ | | | | | | | | | | | |
| Objectives | | | | ■ | ■ | | | | | | | | | | |
| **Progress** | | | | | | | | | | | | | | | |
| Calibration of Jamar Hand Dynamometer | | | | | ■ | ■ | ■ | ■ | | | | | | | |
| Pilot Study | | | | | | | | ■ | ■ | ■ | | | | | |
| Pilot Study Data Analysis | | | | | | | | | | ■ | ■ | ■ | | | |
| Construct Expected Result PSM 2 | | | | | | | | | | | | ■ | ■ | ■ | |
| Actual Data Collection | | | | | | | | | | | | ■ | ■ | ■ | ■ |
| **Submission/Important Deadline for FYP 1** | | | | | | | | | | | | | | | |
| Logbook | | | | | | | | | | | | ■ | | | |
| Poster Presentation | | | | | | | | | | | | | | ■ | |
| Final Report | | | | | | | | | | | | | | | ■ |
| **FYP 1 Write-up** | | | | | | | | | | | | | | | |
| Draft of Introduction | | | | ■ | ■ | ■ | | | | | | | | | |
| Draft of Literature Review | | | | | | ■ | ■ | ■ | | | | | | | |
| Draft of Methodology | | | | | | | | | ■ | ■ | ■ | | | | |
| Draft of Poster Presentation | | | | | | | | | | | ■ | ■ | | | |
| Draft of Expected Result PSM 2 | | | | | | | | | | | | ■ | ■ | ■ | ■ |
| Finalize PSM 1 Report | | | | | | | | | | | | | | ■ | ■ |

Gantt Chart: PSM 2

| Activities | Week | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| PSM 1 Comment | | | | | | | | | | | | | | | |
| **Objective 1** | | | | | | | | | | | | | | | |
| Actual Data Collection | | | | | | | | | | | | | | | |
| Build Database | | | | | | | | | | | | | | | |
| Statical Analysis | | | | | | | | | | | | | | | |
| **Objective 2** | | | | | | | | | | | | | | | |
| Data Reshaping | | | | | | | | | | | | | | | |
| Data Analysis & Data Visualization | | | | | | | | | | | | | | | |
| Correlation Analysis | | | | | | | | | | | | | | | |
| **Objective 3** | | | | | | | | | | | | | | | |
| User Need Survey | | | | | | | | | | | | | | | |
| Conceptual Design | | | | | | | | | | | | | | | |
| House of Quality | | | | | | | | | | | | | | | |
| Prototype Making | | | | | | | | | | | | | | | |
| Engineering Analysis | | | | | | | | | | | | | | | |
| **Submission/Important Deadline for FYP 1** | | | | | | | | | | | | | | | |
| Logbook | | | | | | | | | | | | | | | |
| Poster Presentation | | | | | | | | | | | | | | | |
| Final Report | | | | | | | | | | | | | | | |
| **FYP 2 Write-up** | | | | | | | | | | | | | | | |
| Draft of Objective 1 | | | | | | | | | | | | | | | |
| Draft of Objective 2 | | | | | | | | | | | | | | | |
| Draft of Objective 3 | | | | | | | | | | | | | | | |
| Draft of Poster Presentation | | | | | | | | | | | | | | | |
| Draft of Conclusion | | | | | | | | | | | | | | | |
| Finalize PSM 2 Report | | | | | | | | | | | | | | | |

# Appendix B: Standard Operating Procedures

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## Standard Operating Procedures

The experimental procedures will be concisely presented and captured in a video for convenient reference by researchers and participants alike. This aims to ensure strict adherence to standardized steps in hand grip force measurements, promoting consistency and reliability throughout the study. Figure below represents the demonstration of standard experiment in standing posture. Essentially, the hand grip experiment involves the following steps:

i. In the sitting position, participants sit comfortably on a standard chair without arm support, with back support. Feet should be flat on the floor, and the non-dominant hand rests on the respective thigh. In the standing position, participants stand anatomically straight, facing forward, with feet pointing forwards and slightly apart, and the non-dominant hand hanging down by the side.

ii. A card is positioned under the participant's armpit to prevent arm abduction during the hand grip experiment.

iii. Participants are asked to comfortably hold the handle of the Jamar dynamometer, positioning the thumb on one side and the four fingers on the other. Adjustment of the handle position is allowed, with the default position set at the 2nd level.

iv. An L-square ruler is used to ensure that the participant's elbow is flexed at a 90° angle. Once the angle is established, the L-square ruler is removed.

v. Researchers support the weight of the dynamometer to counteract the effect of gravity on peak strength, taking care not to restrict its movement.

vi. Hand grip force data is collected, with participants gradually squeezing the dynamometer handle. Participants should avoid sudden squeezes to prevent needle jumping.

vii. Participants are prompted to squeeze tightly until the gauge needle stops rising, after which they cease squeezing. An example of encouragement is provided (Robert et al., 2011): ‘Are you ready? Squeeze as hard as you can’. As the participant begins to squeeze, the researcher says, ‘Go! … Go! … Relax'.

viii. Researchers record grip force data and participants rest for 1 minute before the second trial. Reading from the outside dial and recorded to the nearest 1 kg on part D of the participant form. If the reading needle rests between the dial, the middle kilogram is recorded.

Figure: Demonstration of standard experiment in standing posture

Familiarization (gentle trial) using the Jamar hand dynamometer:

1. The participants will receive a demonstration of the gripping exercise from the researchers.
2. Participants will have an opportunity to engage in the gripping exercise for practice and familiarization.
3. A minimum rest period of 1 minute is advised for participants before the commencement of the experiment.

## Appendix C: Consent Form

---

**INFORMED CONSENT FORM**

I, the undersigned, hereby agree to participate in this experiment. My details are as follows: Name: ______________________, Phone number: ______________________. The purpose of this document is to provide a clear understanding of the terms associated with my involvement in this experiment.

1. I acknowledge that I have received a thorough briefing from the researcher and fully comprehend the overall procedures of this experiment.
2. I am aware that my participation is entirely voluntary, and I willingly accept any associated risks involved in the execution of this experiment.
3. I acknowledge that all information provided by me for this experiment will be handled with strict confidentiality.
4. I understand that I have the right to withdraw from the experiment if I feel uncomfortable at any point during its execution.



By signing below, I confirm that I have been adequately informed about the study and consent to be a participant. If any questions arise during the study or concerning my participation, or in the case of an experiment-related injury, I may contact Dr. Isa bin Halim at 012 5142756 or email isa@utem.edu.my.

Signature of subject: Signature of researcher:

________________________

________________________

Date: ___________________ Date:

____________________

**Appendix D: Participant Screening & Survey Form (https://forms.gle/c4HysetaYiRs9wuU8)**

# Hand Grip Strength Study

Dear participants,

I am Darryl Chai, a current student pursuing a degree in Industrial Engineering at Universiti Teknikal Malaysia Melaka (UTeM) within the Faculty of Industrial and Manufacturing Technology and Engineering. This research is conducted as part of my Final Year Project under the supervision of Dr. Isa Halim.

Your participation in this survey is crucial for obtaining the necessary dataset. The completion of the survey is estimated to take approximately 15 to 20 minutes. Please be assured that your demographic information will be kept confidential. Your support and cooperation in contributing to this data collection are highly appreciated.

If you have any questions or inquiries regarding the study, please do not hesitate to contact me:
Name: Darryl Chai
Email: B052010206@student.utem.edu.my
Tel: 011-56363892

* Indicates required question



***Part I: Participant Screening***

(to be excluded from the experimental session if any of these conditions apply)

1. **Nationality**

   *Mark only one oval.*

   ⬭ Non-Malaysian

2. **Sleep Duration**

   *Mark only one oval.*

   ⬭ Less than or equal to 6 hours

3. **Current Health Condition**

*Mark only one oval.*

- ◯ Unhealthy (e.g. shows a sign of fever, cold, migraine, sinus, or etc.)

4. **Current Condition of Upper Extremity**

*Mark only one oval.*

- ◯ Injured/broken of upper extremity
- ◯ Health problem with upper extremity
- ◯ Other condition limiting strength on upper extremity

5. **Alcohol & Drug Consumption**

*Mark only one oval.*

- ◯ Consume alcohol within 24 hours prior to the experimental session
- ◯ Consume any prescribed/ drowsiness medication 24 hours prior the session



***Part II: Demographic***

6. **Full Name (as shown in IC)** *

_______________________________

7. **Age (Example: 24)** *

_______________________________

8. **Race/ Ethnicity** *

*Mark only one oval.*

- ⬭ Malay
- ⬭ Chinese
- ⬭ Indian
- ⬭ Others

9. **Phone Number** *

____________________________________

***Part III: Experimental Data***

10. **Dominance Hand** *

*Mark only one oval.*

- ⬭ Left
- ⬭ Right
- ⬭ Ambidextrous



11. **Weight , in kg (example: 73.5)** *

____________________________________

12. **Height, in cm (Example: 174.5)** *

____________________________________

***Part IV: Experimental Data II***

**The dimensions of the palm and forearm, including the length and circumference.**

13. **Dominance Forearm Length, in cm (Example: 27.0)** *

14. **Dominance Forearm Circumference, in cm (Example: 29.0)** *



15. **Palm Circumference of Dominance Hand, in cm (Example: 22.0)** *

16. **Length of Palm-Wrist of Dominance Hand, in cm (Example: 19.1)** *



***Part V: Grip Strength Data***

**There are a total of six test combinations, involving neutral, pronated, and supinated hand postures in both sitting and standing positions.**

**Sitting Posture**

17. **Neutral Posture 1st Trial, in kg force (Example: 40.0)** *

18. **Neutral Posture 2nd Trial, in kg force (Example: 40.0)** *

19. **Pronation Posture 1st Trial, in kg force (Example: 40.0)** *



20. **Pronation Posture 2nd Trial, in kg force (Example: 40.0)** *

21. **Supination Posture 1st Trial, in kg force (Example: 40.0)** *

22. **Supination Posture 2nd Trial, in kg force (Example: 40.0)** *

**Standing Posture**

23. **Neutral Posture 1st Trial, in kg force (Example: 40.0)** *

24. **Neutral Posture 2nd Trial, in kg force (Example: 40.0)** *

25. **Pronation Posture 1st Trial, in kg force (Example: 40.0)** *

26. **Pronation Posture 2nd Trial, in kg force (Example: 40.0)** *

27. **Supination Posture 1st Trial, in kg force (Example: 40.0)** *

28. **Supination Posture 2nd Trial, in kg force (Example: 40.0)** *

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# Appendix E: Surat Kelulusan CRIM

UTeM

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**PEJABAT PENGURUSAN PENYELIDIKAN DAN INOVASI**
Tel : +606 270 1307 | Faks : +606 270 1040

Rujukan Kami (Our Ref): UTeM.11.02/500-25/1/4 Jilid 3 (4 )
Rujukan Tuan (Your Ref):
Tarikh (Date): 4 Rejab 1445H / 16 Januari 2024

**Dr. Isa Bin Halim**
Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan
Universiti Teknikal Malaysia Melaka

**KELULUSAN JAWATANKUASA ETIKA (MANUSIA) PENYELIDIKAN, UTeM**

**Tajuk Penyelidikan :**

*Regression Model Of Hand Grip Strength Of Malaysian Young Adults*

Perkara di atas adalah dirujuk

2. Dimaklumkan bahawa, pihak kami telah menerima permohonan kelulusan etika daripada pihak Tuan, bagi menjalankan kajian kepada manusia.

3. Oleh itu, setelah meneliti, Mesyuarat Jawatankuasa Etika (Manusia) Penyelidikan, UTeM yang dilaksanakan telah bersetuju memberi kelulusan dengan meletakkan syarat seperti berikut:

a. Adalah menjadi tanggungjawab penyelidik untuk menggunakan sebarang maklumat secara beretika.



b. Kutipan data adalah dikelaskan sebagai sulit dan persendirian dan hanya digunakan untuk tujuan akademik sahaja.

c. Perlu mendapat persetujuan responden sebelum kajian dijalankan dan perlu menjelaskan kepada responden secara verbal dan bertulis atas segala syarat yang telah ditetapkan. Ini termasuk tanggungjawab penyelidik kepada responden dari aspek keselamatan diri dan risiko yang akan dihadapi.

**'MALAYSIA MADANI'**
**'BERKHIDMAT UNTUK NEGARA'**
**'KOMPETENSI TERAS KEGEMILANGAN'**

Saya yang menjalankan amanah,

**PROFESOR TS. DR. NOREFFENDY BIN TAMALDIN**
Pengarah
Pusat Pengurusan Penyelidikan dan Inovasi (CRIM)

**Appendix F: Participant Rating Assessment**
**(https://forms.gle/jEMpYxqHXeFogRxh8)**

# Hand Grip Strength Study

User Survey Analysis Data

Type of Glove (1-3 from left to right)
1 - Rubber Glove 10.0"
2 - Microfiber Glove 10.5"
3 - Long Leather Glove 13"



1. Name

___________________________

2. Hand Length

___________________________

3. Hand Circumference

___________________________

4. Hand Width

5. Wrist Circumference

6. Grip strength (Neutral)

7. Grip strength (Pronation)

8. Grip strength (Supination)

9. Wrist Torque (Neutral, Flexion)

10. Wrist Torque (Neutral, Extension)

11. Wrist Torque (Pronation, Flexion)

12. Wrist Torque (Pronation, Extension)

13. Wrist Torque (Supination, Flexion)

________________________

14. Wrist Torque (Supination, Extension)

________________________

Hand Comfort Rating: 1 - Rubber Glove 10.0"

Rate the performance of the glove based on rating (1-10, 10 being the best)

15. Grip Strength (Neutral)

________________________

16. Grip Strength (Pronation)

________________________

17. Grip Strength (Supination)

________________________



18. Wrist Torque (Neutral, Flexion)

________________________

19. Wrist Torque (Neutral, Extension)

________________________

20. Wrist Torque (Pronation, Flexion)

________________________

21. Wrist Torque (Pronation, Extension)

________________________________

22. Wrist Torque (Supination, Flexion)

________________________________

23. Wrist Torque (Supination, Extension)

________________________________

Rate the performance of the glove based on rating (1-10, 10 being the best)

24. Force Impaired

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higl | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Low |



25. Angle of motion Impaired (Supination, Pronation)

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higl | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Low |

26. Comfort level

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unc | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Comfortable |

27. Size

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Too | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Fit |

28. Product quality

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | High |

Hand Comfort Rating: 2 - Microfiber Glove 10.5"

Rate the performance of the glove based on rating (1-10, 10 being the best)

29. Grip Strength (Neutral)

_______________

30. Grip Strength (Pronation)

_______________

31. Grip Strength (Supination)

_______________

32. Wrist Torque (Neutral, Flexion)

_______________

33. Wrist Torque (Neutral, Extension)

________________________

34. Wrist Torque (Pronation, Flexion)

________________________

35. Wrist Torque (Pronation, Extension)

________________________

36. Wrist Torque (Supination, Flexion)

________________________

37. Wrist Torque (Supination

________________________



38. Force Impaired

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higl | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Low |

39. Motion Impaired (Supination, Pronation)

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higl | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Low |

40. Comfortable to wear

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unc | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Comfortable |

41. Size

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Too | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Fit |

42. Product quality

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | High |



Hand Comfort Rating: 3 - Long Leather Glove 13"

Rate the performance of the glove based on rating (1-10, 10 being the best)

43. Grip Strength (Neutral)

____________________

44. Grip Strength (Pronation)

____________________

45. Grip Strength (Supination)

________________________________

46. Wrist Torque (Neutral, Flexion)

________________________________

47. Wrist Torque (Neutral, Extension)

________________________________

48. Wrist Torque (Pronation, Flexion)

________________________________

49. Wrist Torque (Pronation, Extension)

________________________________



50. Wrist Torque (Supination, Flexion)

________________________________

51. Wrist Torque (Supination, Extension)

________________________________

52. Force Impaired

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higl | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Low |

53. Angle of motion Impaired (Supination, Pronation)

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higl | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Low |

54. Comfortable to wear

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unc | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Comfortable |

55. Size

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Too | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Fit |



56. Product quality

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | High |

## Appendix G: Specification Importance Level

(https://forms.gle/3PTkGC4h5Jy61DmD6)

# Specification Importance Level

- **Force Impairment**: Ensures ease of use and reduces fatigue.
- **Impaired Range of Motion (Supination, Pronation)**: Maintains necessary wrist and hand movements.
- **Comfort**: Enhances focus and productivity by reducing discomfort and fatigue.
- **Size**: Ensures a secure fit for safety and control.
- **Product Quality**: Provides durability and long-term protection, ensuring safety and cost-efficiency.

* Indicates required question

1. Name *

_______________________________

Importance level rating

- 10% - Minimal
- 15% - Low
- 20% - Moderate
- 25% - Significant
- 30% - High



2. Rate the importance level (not exceeding 100% in total) *

*Mark only one oval per row.*

| | 10% | 15% | 20% | 25% | 30% |
|---|---|---|---|---|---|
| **Force** | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ |
| **Angle of Motion** | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ |
| **Comfort** | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ |
| **Size** | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ |
| **Quality (safety)** | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ |

## Appendix H: Hand Anthropometry and Hand Grip Strength Data of 152 Participants

| Participant | Full Name | Age | Race/ Ethnicity | Phone Number | Dominance Hand | Weight , in kg | Height, in cm |
|---|---|---|---|---|---|---|---|
| 1 | [redacted] | 24 | Chinese | [redacted] | Right | 74.0 | 174.0 |
| 2 | [redacted] | 24 | Malay | [redacted] | Right | 68.0 | 172.0 |
| 3 | [redacted] | 24 | Malay | [redacted] | Left | 75.0 | 176.0 |
| 4 | [redacted] | 22 | Malay | [redacted] | Right | 76.0 | 178.0 |
| 5 | [redacted] | 24 | Malay | [redacted] | Left | 70.0 | 173.0 |
| 6 | [redacted] | 22 | Malay | [redacted] | Right | 69.0 | 174.0 |
| 7 | [redacted] | 25 | Malay | [redacted] | Right | 66.0 | 177.0 |
| 8 | [redacted] | 28 | Malay | [redacted] | Right | 65.3 | 170.5 |
| 9 | [redacted] | 24 | Malay | [redacted] | Left | 67.0 | 170.0 |
| 10 | [redacted] | 23 | Indian | [redacted] | Right | 71.0 | 175.0 |
| 11 | [redacted] | 24 | Malay | [redacted] | Right | 65.0 | 171.0 |
| 12 | [redacted] | 22 | Malay | [redacted] | Right | 60.0 | 161.0 |
| 13 | [redacted] | 23 | Malay | [redacted] | Left | 66.0 | 170.0 |
| 14 | [redacted] | 24 | Malay | [redacted] | Left | 58.0 | 170.0 |
| 15 | [redacted] | 22 | Indian | [redacted] | Right | 78.0 | 164.0 |
| 16 | [redacted] | 24 | Indian | [redacted] | Right | 76.0 | 178.0 |
| 17 | [redacted] | 22 | Indian | [redacted] | Right | 71.0 | 175.0 |
| 18 | [redacted] | 24 | Indian | [redacted] | Right | 74.0 | 174.0 |
| 19 | [redacted] | 21 | Indian | [redacted] | Right | 65.0 | 171.0 |
| 20 | [redacted] | 23 | Chinese | [redacted] | Right | 103.0 | 171.0 |
| 21 | [redacted] | 23 | Chinese | [redacted] | Right | 66.0 | 169.0 |
| 22 | [redacted] | 23 | Chinese | [redacted] | Right | 50.0 | 170.0 |
| 23 | [redacted] | 22 | Chinese | [redacted] | Left | 65.0 | 171.0 |
| 24 | [redacted] | 20 | Chinese | [redacted] | Right | 56.0 | 164.0 |
| 25 | [redacted] | 23 | Chinese | [redacted] | Right | 61.0 | 176.0 |
| 26 | [redacted] | 24 | Chinese | [redacted] | Left | 71.0 | 175.0 |
| 27 | [redacted] | 25 | Malay | [redacted] | Right | 60.0 | 170.0 |
| 28 | [redacted] | 23 | Chinese | [redacted] | Right | 74.0 | 174.5 |
| 29 | [redacted] | 22 | Malay | [redacted] | Right | 53.0 | 170.0 |
| 30 | [redacted] | 24 | Indian | [redacted] | Right | 73.0 | 176.0 |
| 31 | [redacted] | 24 | Indian | [redacted] | Right | 68.0 | 174.2 |
| 32 | [redacted] | 22 | Indian | [redacted] | Right | 69.0 | 175.0 |
| 33 | [redacted] | 21 | Chinese | [redacted] | Right | 70.0 | 174.0 |
| 34 | [redacted] | 23 | Chinese | [redacted] | Right | 76.0 | 178.0 |
| 35 | [redacted] | 25 | Malay | [redacted] | Right | 77.0 | 173.0 |
| 36 | [redacted] | 22 | Malay | [redacted] | Right | 45.0 | 150.0 |
| 37 | [redacted] | 22 | Malay | [redacted] | Right | 55.0 | 170.0 |
| 38 | [redacted] | 23 | Indian | [redacted] | Right | 77.0 | 180.0 |
| 39 | [redacted] | 22 | Indian | [redacted] | Left | 68.0 | 172.0 |
| 40 | [redacted] | 24 | Others | [redacted] | Right | 55.0 | 157.0 |
| 41 | [redacted] | 23 | Chinese | [redacted] | Left | 73.0 | 175.0 |
| 42 | [redacted] | 23 | Chinese | [redacted] | Right | 66.0 | 169.0 |
| 43 | [redacted] | 23 | Chinese | [redacted] | Left | 70.0 | 172.0 |
| 44 | [redacted] | 21 | Chinese | [redacted] | Right | 72.0 | 165.0 |
| 45 | [redacted] | 24 | Chinese | [redacted] | Right | 63.0 | 166.0 |
| 46 | [redacted] | 22 | Chinese | [redacted] | Left | 68.0 | 172.0 |
| 47 | [redacted] | 24 | Chinese | [redacted] | Right | 66.0 | 169.0 |
| 48 | [redacted] | 24 | Malay | [redacted] | Left | 77.4 | 174.0 |
| 49 | [redacted] | 24 | Malay | [redacted] | Right | 70.0 | 173.0 |
| 50 | [redacted] | 24 | Malay | [redacted] | Right | 65.0 | 176.0 |
| 51 | [redacted] | 24 | Malay | [redacted] | Right | 66.0 | 169.0 |
| 52 | [redacted] | 22 | Malay | [redacted] | Right | 70.0 | 178.0 |
| 53 | [redacted] | 22 | Malay | [redacted] | Right | 65.0 | 172.0 |
| 54 | [redacted] | 24 | Malay | [redacted] | Right | 65.0 | 169.0 |
| 55 | [redacted] | 24 | Malay | [redacted] | Right | 71.0 | 175.0 |
| 56 | [redacted] | 21 | Malay | [redacted] | Right | 69.0 | 176.0 |
| 57 | [redacted] | 23 | Malay | [redacted] | Right | 77.0 | 180.0 |
| 58 | [redacted] | 24 | Malay | [redacted] | Right | 63.0 | 166.0 |
| 59 | [redacted] | 22 | Malay | [redacted] | Right | 71.0 | 175.0 |
| 60 | [redacted] | 24 | Malay | [redacted] | Right | 70.0 | 173.0 |
| 61 | [redacted] | 22 | Malay | [redacted] | Right | 60.0 | 168.0 |
| 62 | [redacted] | 24 | Malay | [redacted] | Right | 69.0 | 173.0 |
| 63 | [redacted] | 24 | Malay | [redacted] | Right | 65.0 | 171.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 64 | [redacted] | 23 | Malay | [redacted] | Right | 65.0 | 170.0 |
| 65 | [redacted] | 22 | Malay | [redacted] | Right | 68.0 | 172.0 |
| 66 | [redacted] | 21 | Malay | [redacted] | Right | 70.0 | 173.0 |
| 67 | [redacted] | 23 | Malay | [redacted] | Right | 73.0 | 176.0 |
| 68 | [redacted] | 23 | Malay | [redacted] | Right | 71.0 | 175.0 |
| 69 | [redacted] | 22 | Malay | [redacted] | Left | 70.0 | 170.0 |
| 70 | [redacted] | 22 | Malay | [redacted] | Right | 72.0 | 165.0 |
| 71 | [redacted] | 24 | Malay | [redacted] | Right | 70.0 | 174.0 |
| 72 | [redacted] | 24 | Malay | [redacted] | Left | 77.0 | 180.0 |
| 73 | [redacted] | 24 | Malay | [redacted] | Right | 68.0 | 172.0 |
| 74 | [redacted] | 22 | Malay | [redacted] | Right | 65.0 | 171.0 |
| 75 | [redacted] | 24 | Malay | [redacted] | Right | 67.0 | 170.0 |
| 76 | [redacted] | 21 | Malay | [redacted] | Right | 74.0 | 174.0 |
| 77 | [redacted] | 21 | Malay | [redacted] | Right | 70.0 | 173.0 |
| 78 | [redacted] | 23 | Malay | [redacted] | Left | 65.0 | 170.0 |
| 79 | [redacted] | 25 | Malay | [redacted] | Right | 54.0 | 172.0 |
| 80 | [redacted] | 23 | Malay | [redacted] | Left | 70.0 | 173.0 |
| 81 | [redacted] | 23 | Malay | [redacted] | Left | 73.0 | 176.0 |
| 82 | [redacted] | 23 | Malay | [redacted] | Right | 74.0 | 174.0 |
| 83 | [redacted] | 23 | Malay | [redacted] | Right | 68.0 | 172.0 |
| 84 | [redacted] | 22 | Malay | [redacted] | Right | 72.0 | 172.0 |
| 85 | [redacted] | 21 | Malay | [redacted] | Right | 62.0 | 173.0 |
| 86 | [redacted] | 22 | Malay | [redacted] | Right | 69.0 | 168.0 |
| 87 | [redacted] | 23 | Malay | [redacted] | Right | 66.0 | 169.0 |
| 88 | [redacted] | 21 | Malay | [redacted] | Right | 66.0 | 170.0 |
| 89 | [redacted] | 24 | Malay | [redacted] | Right | 67.0 | 170.0 |
| 90 | [redacted] | 24 | Malay | [redacted] | Right | 74.0 | 174.0 |
| 91 | [redacted] | 21 | Malay | [redacted] | Left | 74.0 | 164.0 |
| 92 | [redacted] | 22 | Malay | [redacted] | Left | 56.5 | 164.0 |
| 93 | [redacted] | 22 | Malay | [redacted] | Right | 66.0 | 175.0 |
| 94 | [redacted] | 21 | Malay | [redacted] | Right | 65.0 | 171.0 |
| 95 | [redacted] | 21 | Malay | [redacted] | Right | 71.0 | 175.0 |
| 96 | [redacted] | 24 | Malay | [redacted] | Right | 69.0 | 176.0 |
| 97 | [redacted] | 22 | Malay | [redacted] | Right | 45.0 | 154.0 |
| 98 | [redacted] | 24 | Malay | [redacted] | Right | 55.5 | 175.0 |
| 99 | [redacted] | 24 | Malay | [redacted] | Right | 73.0 | 178.0 |
| 100 | [redacted] | 21 | Malay | [redacted] | Left | 67.0 | 170.0 |
| 101 | [redacted] | 24 | Malay | [redacted] | Right | 60.0 | 167.0 |
| 102 | [redacted] | 22 | Malay | [redacted] | Right | 92.5 | 174.0 |
| 103 | [redacted] | 25 | Malay | [redacted] | Right | 130.0 | 170.0 |
| 104 | [redacted] | 22 | Malay | [redacted] | Right | 78.0 | 164.0 |
| 105 | [redacted] | 24 | Malay | [redacted] | Right | 58.0 | 172.0 |
| 106 | [redacted] | 24 | Malay | [redacted] | Left | 67.0 | 170.0 |
| 107 | [redacted] | 23 | Malay | [redacted] | Right | 57.0 | 165.0 |
| 108 | [redacted] | 23 | Indian | [redacted] | Right | 67.0 | 170.0 |
| 109 | [redacted] | 23 | Chinese | [redacted] | Left | 73.0 | 176.0 |
| 110 | [redacted] | 22 | Chinese | [redacted] | Left | 75.0 | 176.0 |
| 111 | [redacted] | 22 | Chinese | [redacted] | Right | 75.0 | 179.0 |
| 112 | [redacted] | 23 | Indian | [redacted] | Right | 76.0 | 173.0 |
| 113 | [redacted] | 24 | Indian | [redacted] | Left | 55.0 | 165.0 |
| 114 | [redacted] | 23 | Indian | [redacted] | Right | 68.0 | 172.0 |
| 115 | [redacted] | 23 | Indian | [redacted] | Left | 67.0 | 170.0 |
| 116 | [redacted] | 21 | Indian | [redacted] | Right | 70.0 | 173.0 |
| 117 | [redacted] | 21 | Indian | [redacted] | Left | 63.0 | 174.0 |
| 118 | [redacted] | 22 | Indian | [redacted] | Right | 65.0 | 171.0 |
| 119 | [redacted] | 24 | Indian | [redacted] | Right | 70.0 | 165.0 |
| 120 | [redacted] | 23 | Chinese | [redacted] | Right | 69.0 | 169.0 |
| 121 | [redacted] | 24 | Indian | [redacted] | Right | 67.0 | 170.0 |
| 122 | [redacted] | 24 | Indian | [redacted] | Right | 65.0 | 171.0 |
| 123 | [redacted] | 24 | Indian | [redacted] | Right | 87.0 | 175.0 |
| 124 | [redacted] | 22 | Indian | [redacted] | Right | 72.0 | 165.0 |
| 125 | [redacted] | 21 | Indian | [redacted] | Right | 78.0 | 168.0 |
| 126 | [redacted] | 25 | Indian | [redacted] | Left | 70.8 | 176.5 |
| 127 | [redacted] | 23 | Indian | [redacted] | Right | 61.0 | 185.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 128 | [redacted] | 24 | Indian | [redacted] | Right | 72.0 | 165.0 |
| 129 | [redacted] | 25 | Malay | [redacted] | Left | 50.0 | 168.0 |
| 130 | [redacted] | 24 | Chinese | [redacted] | Left | 69.0 | 175.0 |
| 131 | [redacted] | 23 | Chinese | [redacted] | Right | 70.0 | 169.0 |
| 132 | [redacted] | 23 | Chinese | [redacted] | Right | 72.0 | 174.0 |
| 133 | [redacted] | 24 | Chinese | [redacted] | Left | 76.0 | 178.0 |
| 134 | [redacted] | 22 | Chinese | [redacted] | Right | 70.0 | 173.0 |
| 135 | [redacted] | 23 | Chinese | [redacted] | Right | 69.0 | 169.0 |
| 136 | [redacted] | 22 | Chinese | [redacted] | Right | 71.0 | 175.0 |
| 137 | [redacted] | 24 | Chinese | [redacted] | Right | 69.0 | 172.0 |
| 138 | [redacted] | 21 | Indian | [redacted] | Right | 66.0 | 169.0 |
| 139 | [redacted] | 24 | Indian | [redacted] | Right | 67.0 | 170.0 |
| 140 | [redacted] | 23 | Indian | [redacted] | Right | 60.0 | 164.0 |
| 141 | [redacted] | 25 | Malay | [redacted] | Right | 94.0 | 165.0 |
| 142 | [redacted] | 20 | Malay | [redacted] | Right | 50.0 | 161.0 |
| 143 | [redacted] | 23 | Chinese | [redacted] | Left | 65.0 | 170.0 |
| 144 | [redacted] | 28 | Chinese | [redacted] | Left | 79.8 | 180.2 |
| 145 | [redacted] | 28 | Chinese | [redacted] | Right | 58.0 | 172.0 |
| 146 | [redacted] | 23 | Chinese | [redacted] | Right | 82.0 | 176.5 |
| 147 | [redacted] | 23 | Chinese | [redacted] | Right | 77.0 | 180.0 |
| 148 | [redacted] | 20 | Chinese | [redacted] | Right | 65.0 | 165.0 |
| 149 | [redacted] | 24 | Chinese | [redacted] | Right | 76.0 | 173.0 |
| 150 | [redacted] | 24 | Chinese | [redacted] | Right | 74.0 | 164.0 |
| 151 | [redacted] | 23 | Indian | [redacted] | Right | 77.0 | 175.0 |
| 152 | [redacted] | 24 | Malay | [redacted] | Right | 50.0 | 169.0 |

| Participant | Forearm Length, in cm | Forearm Circumference, in cm | Palm Circumference, in cm | Palm-Wrist, in cm |
|---|---|---|---|---|
| 1 | 27.4 | 24.8 | 17.5 | 19.2 |
| 2 | 25.3 | 25.0 | 17.3 | 18.2 |
| 3 | 26.1 | 25.3 | 18.0 | 19.0 |
| 4 | 26.4 | 24.8 | 17.6 | 19.0 |
| 5 | 27.9 | 22.9 | 16.7 | 18.3 |
| 6 | 28.1 | 25.3 | 18.0 | 19.0 |
| 7 | 28.0 | 29.5 | 21.8 | 19.0 |
| 8 | 27.5 | 28.5 | 21.0 | 18.5 |
| 9 | 27.7 | 28.8 | 22.2 | 19.1 |
| 10 | 27.8 | 27.8 | 21.5 | 18.8 |
| 11 | 27.0 | 26.0 | 20.0 | 18.8 |
| 12 | 24.0 | 24.7 | 18.5 | 17.5 |
| 13 | 27.6 | 25.2 | 21.5 | 19.1 |
| 14 | 26.4 | 25.8 | 21.3 | 18.6 |
| 15 | 26.4 | 24.3 | 20.4 | 19.0 |
| 16 | 27.1 | 24.9 | 21.0 | 19.0 |
| 17 | 26.8 | 25.6 | 20.7 | 19.0 |
| 18 | 26.3 | 25.9 | 20.3 | 19.1 |
| 19 | 27.5 | 26.0 | 21.4 | 19.1 |
| 20 | 23.5 | 24.7 | 24.5 | 19.0 |
| 21 | 27.0 | 26.0 | 21.3 | 19.1 |
| 22 | 26.5 | 22.4 | 19.5 | 18.9 |
| 23 | 27.8 | 26.9 | 21.8 | 19.3 |
| 24 | 26.5 | 25.7 | 20.5 | 19.0 |
| 25 | 26.0 | 26.5 | 20.3 | 19.0 |
| 26 | 27.1 | 27.5 | 21.4 | 19.1 |
| 27 | 27.0 | 29.5 | 21.2 | 19.5 |
| 28 | 27.0 | 29.0 | 22.2 | 19.1 |
| 29 | 25.5 | 28.2 | 21.0 | 19.0 |
| 30 | 27.3 | 28.0 | 21.2 | 19.0 |
| 31 | 28.0 | 29.2 | 20.7 | 19.0 |
| 32 | 26.8 | 26.0 | 20.7 | 19.1 |
| 33 | 26.6 | 25.8 | 21.0 | 18.7 |
| 34 | 27.5 | 27.7 | 21.6 | 19.2 |
| 35 | 25.5 | 27.5 | 22.3 | 19.0 |
| 36 | 23.2 | 22.5 | 16.5 | 16.5 |
| 37 | 24.5 | 27.0 | 19.5 | 19.5 |
| 38 | 27.0 | 29.3 | 22.0 | 19.0 |
| 39 | 27.7 | 28.9 | 21.5 | 19.1 |
| 40 | 25.5 | 23.0 | 17.5 | 17.0 |
| 41 | 27.9 | 28.8 | 21.9 | 18.7 |
| 42 | 26.0 | 26.2 | 20.3 | 18.7 |
| 43 | 27.2 | 27.4 | 21.5 | 18.7 |
| 44 | 27.0 | 30.0 | 21.0 | 18.7 |
| 45 | 27.3 | 27.0 | 21.5 | 19.1 |
| 46 | 26.8 | 25.9 | 20.8 | 19.1 |
| 47 | 27.2 | 29.4 | 22.2 | 19.5 |
| 48 | 27.0 | 29.0 | 22.3 | 18.7 |
| 49 | 27.7 | 27.9 | 21.5 | 18.8 |
| 50 | 27.5 | 27.1 | 20.8 | 19.0 |
| 51 | 26.9 | 27.1 | 21.7 | 18.4 |
| 52 | 27.0 | 30.6 | 22.3 | 20.5 |
| 53 | 26.7 | 27.5 | 21.3 | 18.7 |
| 54 | 25.0 | 26.3 | 20.0 | 18.5 |
| 55 | 27.4 | 26.6 | 21.4 | 18.4 |
| 56 | 27.4 | 28.3 | 21.3 | 18.4 |
| 57 | 27.3 | 26.5 | 21.2 | 19.0 |
| 58 | 25.3 | 25.5 | 20.3 | 18.5 |
| 59 | 27.5 | 30.3 | 22.3 | 19.0 |
| 60 | 27.0 | 28.2 | 20.0 | 19.0 |
| 61 | 26.8 | 26.6 | 18.4 | 19.0 |
| 62 | 26.9 | 25.5 | 18.3 | 19.6 |
| 63 | 27.4 | 27.6 | 19.0 | 19.0 |

| | | | | |
|---|---|---|---|---|
| 64 | 27.5 | 26.7 | 20.4 | 18.7 |
| 65 | 27.6 | 29.3 | 21.7 | 19.0 |
| 66 | 27.5 | 27.7 | 21.4 | 19.1 |
| 67 | 28.0 | 28.7 | 21.4 | 18.6 |
| 68 | 26.9 | 28.1 | 20.8 | 19.0 |
| 69 | 27.4 | 27.4 | 21.5 | 18.6 |
| 70 | 27.9 | 27.5 | 21.7 | 19.0 |
| 71 | 27.5 | 25.5 | 21.4 | 18.7 |
| 72 | 27.0 | 29.2 | 21.8 | 19.0 |
| 73 | 27.1 | 26.3 | 21.0 | 19.0 |
| 74 | 27.1 | 25.3 | 21.0 | 18.2 |
| 75 | 27.3 | 28.8 | 21.5 | 19.1 |
| 76 | 27.3 | 28.0 | 21.2 | 19.0 |
| 77 | 26.4 | 26.6 | 19.2 | 19.0 |
| 78 | 26.5 | 24.2 | 18.0 | 18.2 |
| 79 | 28.0 | 29.3 | 21.3 | 19.0 |
| 80 | 27.0 | 27.0 | 19.2 | 19.0 |
| 81 | 27.6 | 28.8 | 21.5 | 19.1 |
| 82 | 26.0 | 26.5 | 21.0 | 21.0 |
| 83 | 26.9 | 26.2 | 21.5 | 18.6 |
| 84 | 26.6 | 29.0 | 21.9 | 19.5 |
| 85 | 26.5 | 25.0 | 20.0 | 20.5 |
| 86 | 26.8 | 27.4 | 21.5 | 18.7 |
| 87 | 28.1 | 29.3 | 22.0 | 19.2 |
| 88 | 27.4 | 28.0 | 21.4 | 19.0 |
| 89 | 26.8 | 28.0 | 20.7 | 19.0 |
| 90 | 27.3 | 27.5 | 21.6 | 18.6 |
| 91 | 26.3 | 26.4 | 19.6 | 19.1 |
| 92 | 24.5 | 26.0 | 19.3 | 17.8 |
| 93 | 26.5 | 26.9 | 21.0 | 18.5 |
| 94 | 26.4 | 26.6 | 20.4 | 19.0 |
| 95 | 27.9 | 27.1 | 21.7 | 19.0 |
| 96 | 27.5 | 28.7 | 21.4 | 19.1 |
| 97 | 23.0 | 21.3 | 17.0 | 19.0 |
| 98 | 27.5 | 28.5 | 22.0 | 20.0 |
| 99 | 24.5 | 27.0 | 23.0 | 20.5 |
| 100 | 27.2 | 29.0 | 22.0 | 18.8 |
| 101 | 24.0 | 28.7 | 19.8 | 18.0 |
| 102 | 25.5 | 29.8 | 22.3 | 19.5 |
| 103 | 24.0 | 34.5 | 22.8 | 19.5 |
| 104 | 26.8 | 27.0 | 19.7 | 18.4 |
| 105 | 28.2 | 28.4 | 21.6 | 19.0 |
| 106 | 26.8 | 26.2 | 18.7 | 18.4 |
| 107 | 26.9 | 28.1 | 19.8 | 18.3 |
| 108 | 27.3 | 27.5 | 21.2 | 19.0 |
| 109 | 28.0 | 30.0 | 22.0 | 19.2 |
| 110 | 27.3 | 27.6 | 19.7 | 19.2 |
| 111 | 26.2 | 27.0 | 19.2 | 18.8 |
| 112 | 24.5 | 26.5 | 21.0 | 20.0 |
| 113 | 27.0 | 28.6 | 18.5 | 18.5 |
| 114 | 26.8 | 26.3 | 20.7 | 19.0 |
| 115 | 26.9 | 27.1 | 21.4 | 18.4 |
| 116 | 27.5 | 27.4 | 21.4 | 19.1 |
| 117 | 25.0 | 25.2 | 19.0 | 18.5 |
| 118 | 26.8 | 27.4 | 21.6 | 18.6 |
| 119 | 27.3 | 28.0 | 21.6 | 18.6 |
| 120 | 28.2 | 29.2 | 21.8 | 18.7 |
| 121 | 27.4 | 26.3 | 21.3 | 18.9 |
| 122 | 27.4 | 26.6 | 21.3 | 17.5 |
| 123 | 26.0 | 29.0 | 19.5 | 19.0 |
| 124 | 27.9 | 29.1 | 21.7 | 19.0 |
| 125 | 28.1 | 27.3 | 18.5 | 19.0 |
| 126 | 27.5 | 28.8 | 22.2 | 18.6 |
| 127 | 27.0 | 22.5 | 17.8 | 19.5 |

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|---|---|---|---|---|
| 128 | 27.1 | 27.2 | 21.0 | 18.6 |
| 129 | 26.0 | 28.3 | 21.9 | 18.9 |
| 130 | 26.7 | 26.8 | 20.7 | 19.0 |
| 131 | 26.9 | 27.0 | 20.9 | 19.1 |
| 132 | 27.7 | 28.5 | 21.8 | 19.3 |
| 133 | 27.2 | 26.9 | 21.5 | 19.3 |
| 134 | 25.9 | 25.8 | 19.8 | 18.5 |
| 135 | 24.6 | 27.8 | 20.3 | 17.6 |
| 136 | 24.3 | 26.8 | 18.3 | 17.7 |
| 137 | 27.6 | 29.6 | 22.1 | 19.3 |
| 138 | 25.4 | 26.5 | 17.3 | 18.3 |
| 139 | 26.7 | 27.9 | 21.5 | 19.1 |
| 140 | 24.2 | 26.4 | 18.2 | 18.2 |
| 141 | 28.0 | 31.0 | 22.5 | 18.5 |
| 142 | 27.5 | 28.8 | 18.5 | 17.5 |
| 143 | 25.8 | 26.3 | 21.8 | 18.7 |
| 144 | 28.0 | 28.3 | 21.8 | 19.0 |
| 145 | 26.1 | 24.0 | 20.1 | 18.3 |
| 146 | 28.2 | 30.5 | 22.0 | 19.1 |
| 147 | 27.8 | 29.0 | 21.8 | 19.3 |
| 148 | 25.5 | 26.0 | 19.0 | 18.4 |
| 149 | 27.6 | 26.7 | 21.5 | 19.2 |
| 150 | 26.5 | 27.0 | 22.0 | 19.0 |
| 151 | 28.5 | 31.0 | 22.0 | 19.0 |
| 152 | 27.3 | 27.9 | 21.0 | 18.3 |



| Participant | Sit-N-1 | Sit-N-2 | Sit-P-1 | Sit-P-2 | Sit-S-1 | Sit-S-2 | Stand-N-1 | Stand-N-2 | Stand-P-1 | Stand-P-2 | Stand-S-1 | Stand-S-2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 31.0 | 30.5 | 24.0 | 24.5 | 28.0 | 26.5 | 33.0 | 31.5 | 25.5 | 24.0 | 28.5 | 29.0 |
| 2 | 27.0 | 28.5 | 25.5 | 26.0 | 28.0 | 27.5 | 28.0 | 29.0 | 25.0 | 25.0 | 29.0 | 29.0 |
| 3 | 30.0 | 30.0 | 27.0 | 27.0 | 32.0 | 31.0 | 30.0 | 31.0 | 26.0 | 25.0 | 30.5 | 29.0 |
| 4 | 31.0 | 31.0 | 27.0 | 26.0 | 29.0 | 30.0 | 32.5 | 33.5 | 27.0 | 28.0 | 30.0 | 30.5 |
| 5 | 26.0 | 26.5 | 22.0 | 23.5 | 26.0 | 25.0 | 26.0 | 27.0 | 23.0 | 23.0 | 26.0 | 26.0 |
| 6 | 30.0 | 30.0 | 24.0 | 25.5 | 27.0 | 26.0 | 32.0 | 31.5 | 25.0 | 24.5 | 28.5 | 27.0 |
| 7 | 48.0 | 49.0 | 38.0 | 39.0 | 43.0 | 42.0 | 47.0 | 48.0 | 42.0 | 43.0 | 42.0 | 43.0 |
| 8 | 36.0 | 37.0 | 35.0 | 35.0 | 37.0 | 38.0 | 36.5 | 37.0 | 35.0 | 34.5 | 37.5 | 38.0 |
| 9 | 43.0 | 43.0 | 35.0 | 36.0 | 39.0 | 37.5 | 43.0 | 41.5 | 34.0 | 33.5 | 38.0 | 36.5 |
| 10 | 38.0 | 39.0 | 35.0 | 36.0 | 39.0 | 39.0 | 39.5 | 40.5 | 36.0 | 36.0 | 40.0 | 39.0 |
| 11 | 30.0 | 31.5 | 25.0 | 25.0 | 28.0 | 27.0 | 30.0 | 31.0 | 26.0 | 26.0 | 29.0 | 29.0 |
| 12 | 25.0 | 26.0 | 25.0 | 24.0 | 27.0 | 28.0 | 24.0 | 23.0 | 22.0 | 23.0 | 26.0 | 27.0 |
| 13 | 31.0 | 32.5 | 24.0 | 23.0 | 28.0 | 27.5 | 31.5 | 30.0 | 23.0 | 22.0 | 29.0 | 27.5 |
| 14 | 29.0 | 29.0 | 27.0 | 26.0 | 31.0 | 31.0 | 30.0 | 31.0 | 28.0 | 28.5 | 31.0 | 32.0 |
| 15 | 27.0 | 28.0 | 22.0 | 21.0 | 27.0 | 26.0 | 25.5 | 25.0 | 21.0 | 21.0 | 26.0 | 27.5 |
| 16 | 30.0 | 31.0 | 23.0 | 21.5 | 27.0 | 26.0 | 30.0 | 30.0 | 24.0 | 25.0 | 28.0 | 27.5 |
| 17 | 34.0 | 35.0 | 27.0 | 27.5 | 31.0 | 32.0 | 35.0 | 34.0 | 27.0 | 28.0 | 32.5 | 33.0 |
| 18 | 27.5 | 27.5 | 24.0 | 24.0 | 28.0 | 26.5 | 28.0 | 27.5 | 23.5 | 22.0 | 29.0 | 28.0 |
| 19 | 31.0 | 32.5 | 28.0 | 28.0 | 33.0 | 31.5 | 30.5 | 32.0 | 28.0 | 28.0 | 32.0 | 33.0 |
| 20 | 24.0 | 26.0 | 28.0 | 27.0 | 28.0 | 28.0 | 35.0 | 36.0 | 22.0 | 23.0 | 36.0 | 36.0 |
| 21 | 35.0 | 35.0 | 28.0 | 29.5 | 32.0 | 30.0 | 30.5 | 29.0 | 27.0 | 26.5 | 33.0 | 33.0 |
| 22 | 25.0 | 26.0 | 19.0 | 18.0 | 23.0 | 24.0 | 26.0 | 26.0 | 20.0 | 21.0 | 25.0 | 26.0 |
| 23 | 37.0 | 37.0 | 33.0 | 34.5 | 36.0 | 34.0 | 39.0 | 38.5 | 34.5 | 36.5 | 37.5 | 36.0 |
| 24 | 28.0 | 26.5 | 23.0 | 23.0 | 26.0 | 25.0 | 29.0 | 29.0 | 22.0 | 23.5 | 27.0 | 26.0 |
| 25 | 32.0 | 33.0 | 28.0 | 28.0 | 32.0 | 33.0 | 30.0 | 31.0 | 28.0 | 27.0 | 30.0 | 31.0 |
| 26 | 31.0 | 32.0 | 24.0 | 23.5 | 28.0 | 28.0 | 32.5 | 31.5 | 24.5 | 26.0 | 29.0 | 28.0 |
| 27 | 37.0 | 40.0 | 34.0 | 35.0 | 40.0 | 42.0 | 39.0 | 40.0 | 35.0 | 37.0 | 39.0 | 40.0 |
| 28 | 48.0 | 49.0 | 40.0 | 41.0 | 46.0 | 47.0 | 51.0 | 50.0 | 43.0 | 41.0 | 48.0 | 48.0 |
| 29 | 35.0 | 36.0 | 34.0 | 32.0 | 34.0 | 33.0 | 36.0 | 37.0 | 32.0 | 34.0 | 32.0 | 32.0 |
| 30 | 32.0 | 31.5 | 28.0 | 28.5 | 31.0 | 29.5 | 30.0 | 28.5 | 26.5 | 27.0 | 29.5 | 29.0 |
| 31 | 39.0 | 40.0 | 33.0 | 34.0 | 36.0 | 35.0 | 41.0 | 41.0 | 35.0 | 35.0 | 38.0 | 37.0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | 29.0 | 30.5 | 28.0 | 28.0 | 31.0 | 32.0 | 30.5 | 31.5 | 27.0 | 28.0 | 32.0 | 32.0 |
| 33 | 28.5 | 30.0 | 26.0 | 27.0 | 30.0 | 31.0 | 29.0 | 30.0 | 26.0 | 27.0 | 30.0 | 30.0 |
| 34 | 37.0 | 38.0 | 34.0 | 33.0 | 39.0 | 39.0 | 37.5 | 38.5 | 35.5 | 34.5 | 39.0 | 37.0 |
| 35 | 32.0 | 36.9 | 28.0 | 30.0 | 36.0 | 36.0 | 28.0 | 34.0 | 28.0 | 30.0 | 36.0 | 34.0 |
| 36 | 22.0 | 23.0 | 16.0 | 18.0 | 21.0 | 22.0 | 22.0 | 23.0 | 19.0 | 20.0 | 21.0 | 22.0 |
| 37 | 36.0 | 37.0 | 30.0 | 30.0 | 40.0 | 41.0 | 34.0 | 34.0 | 32.0 | 33.0 | 38.0 | 38.0 |
| 38 | 44.0 | 45.0 | 37.0 | 35.5 | 42.0 | 43.0 | 45.5 | 46.5 | 37.0 | 38.0 | 43.0 | 43.5 |
| 39 | 38.0 | 37.0 | 32.0 | 30.0 | 34.0 | 35.0 | 39.0 | 40.0 | 31.0 | 31.0 | 36.0 | 36.0 |
| 40 | 26.0 | 27.0 | 26.0 | 27.0 | 29.0 | 30.0 | 25.0 | 26.0 | 24.0 | 25.0 | 24.0 | 25.0 |
| 41 | 36.0 | 37.0 | 31.0 | 32.0 | 36.0 | 35.0 | 36.0 | 37.5 | 32.0 | 32.0 | 35.0 | 36.0 |
| 42 | 25.0 | 26.5 | 21.0 | 22.0 | 23.0 | 22.0 | 25.0 | 26.0 | 20.0 | 22.0 | 23.0 | 24.5 |
| 43 | 31.0 | 32.0 | 27.0 | 25.5 | 31.0 | 30.0 | 31.0 | 31.0 | 28.0 | 29.5 | 32.0 | 31.0 |
| 44 | 26.0 | 26.0 | 22.5 | 21.0 | 27.0 | 25.0 | 24.0 | 24.5 | 21.0 | 23.0 | 26.0 | 24.5 |
| 45 | 32.0 | 32.0 | 25.0 | 26.5 | 29.0 | 30.0 | 33.5 | 33.5 | 25.5 | 24.0 | 30.5 | 30.5 |
| 46 | 27.0 | 28.0 | 22.0 | 23.0 | 25.0 | 25.0 | 27.5 | 28.5 | 23.0 | 23.0 | 24.0 | 26.0 |
| 47 | 45.0 | 45.5 | 38.0 | 37.5 | 43.0 | 43.5 | 45.0 | 45.5 | 39.5 | 39.0 | 44.5 | 43.0 |
| 48 | 50.0 | 49.0 | 44.0 | 44.0 | 48.0 | 49.0 | 53.0 | 54.0 | 46.0 | 45.0 | 50.0 | 50.0 |
| 49 | 34.0 | 33.0 | 29.0 | 27.0 | 35.0 | 36.0 | 33.0 | 34.0 | 27.5 | 28.0 | 34.0 | 34.0 |
| 50 | 29.0 | 30.0 | 24.0 | 23.5 | 27.0 | 25.0 | 28.0 | 29.0 | 22.5 | 24.0 | 26.0 | 25.5 |
| 51 | 33.0 | 33.0 | 26.0 | 27.0 | 31.0 | 30.5 | 34.5 | 34.0 | 27.0 | 27.0 | 32.0 | 33.0 |
| 52 | 52.0 | 52.0 | 42.0 | 43.0 | 46.0 | 47.0 | 48.0 | 48.0 | 40.0 | 42.0 | 44.0 | 43.0 |
| 53 | 36.0 | 35.0 | 33.0 | 33.0 | 37.0 | 38.0 | 38.0 | 39.0 | 34.0 | 33.0 | 38.0 | 38.0 |
| 54 | 36.0 | 33.0 | 27.0 | 28.0 | 32.0 | 31.0 | 29.0 | 30.0 | 27.0 | 26.0 | 30.0 | 31.0 |
| 55 | 27.0 | 28.0 | 23.0 | 24.0 | 28.0 | 27.0 | 27.0 | 25.5 | 24.0 | 24.0 | 29.0 | 30.0 |
| 56 | 31.0 | 31.0 | 24.0 | 25.0 | 28.0 | 28.0 | 30.0 | 31.5 | 23.0 | 23.0 | 27.0 | 29.5 |
| 57 | 28.0 | 28.0 | 23.0 | 21.5 | 27.0 | 25.0 | 26.0 | 25.5 | 21.5 | 19.5 | 26.0 | 24.5 |
| 58 | 27.0 | 28.0 | 23.0 | 24.0 | 27.0 | 28.0 | 28.5 | 28.5 | 23.0 | 24.0 | 28.0 | 29.0 |
| 59 | 54.0 | 52.5 | 47.0 | 46.5 | 52.0 | 51.0 | 55.0 | 55.0 | 47.0 | 48.0 | 53.0 | 51.5 |
| 60 | 28.0 | 29.5 | 23.0 | 22.0 | 27.0 | 26.0 | 28.0 | 28.0 | 22.0 | 23.0 | 25.5 | 26.0 |
| 61 | 26.0 | 26.0 | 22.0 | 23.5 | 26.0 | 25.0 | 27.5 | 28.0 | 24.0 | 26.0 | 27.5 | 26.0 |
| 62 | 27.0 | 27.0 | 23.0 | 24.0 | 28.0 | 28.0 | 28.5 | 29.5 | 23.0 | 24.0 | 29.0 | 28.0 |
| 63 | 28.0 | 29.0 | 24.0 | 23.5 | 27.0 | 26.5 | 29.5 | 28.5 | 25.5 | 25.0 | 28.0 | 27.0 |
| 64 | 28.0 | 30.0 | 23.0 | 23.5 | 28.5 | 29.0 | 27.0 | 27.5 | 23.0 | 22.0 | 28.0 | 29.0 |
| 65 | 44.0 | 45.5 | 38.0 | 39.5 | 42.0 | 41.0 | 43.5 | 45.0 | 37.0 | 37.0 | 41.0 | 40.0 |
| 66 | 36.0 | 35.0 | 29.0 | 28.5 | 33.0 | 34.0 | 35.0 | 34.0 | 34.0 | 34.0 | 31.0 | 32.0 |
| 67 | 35.0 | 36.0 | 29.0 | 30.0 | 36.0 | 36.0 | 36.5 | 37.5 | 30.0 | 30.5 | 37.5 | 36.5 |
| 68 | 29.0 | 30.0 | 26.0 | 26.0 | 31.0 | 32.5 | 28.0 | 28.0 | 26.0 | 27.5 | 31.0 | 30.0 |
| 69 | 31.0 | 31.0 | 26.0 | 27.0 | 28.0 | 29.0 | 32.0 | 32.0 | 27.5 | 27.0 | 30.0 | 31.0 |
| 70 | 33.0 | 33.0 | 26.0 | 27.5 | 31.0 | 31.0 | 31.5 | 31.5 | 26.0 | 27.5 | 32.5 | 32.5 |
| 71 | 31.0 | 32.0 | 26.0 | 27.0 | 29.0 | 28.0 | 32.5 | 33.5 | 27.0 | 27.0 | 30.0 | 31.0 |
| 72 | 41.0 | 41.0 | 36.0 | 37.0 | 42.0 | 42.0 | 42.5 | 43.5 | 36.0 | 37.5 | 43.0 | 44.0 |
| 73 | 30.0 | 31.5 | 27.0 | 28.5 | 31.0 | 30.0 | 31.0 | 32.5 | 27.0 | 27.0 | 30.0 | 31.0 |
| 74 | 30.0 | 30.0 | 27.0 | 26.0 | 30.0 | 29.0 | 31.0 | 32.0 | 28.5 | 26.0 | 30.0 | 31.0 |
| 75 | 41.0 | 40.0 | 35.0 | 33.5 | 38.0 | 37.5 | 39.5 | 38.0 | 32.0 | 32.5 | 37.5 | 36.0 |
| 76 | 30.0 | 31.5 | 28.0 | 29.0 | 31.0 | 30.0 | 29.5 | 30.5 | 26.5 | 26.5 | 30.0 | 30.0 |
| 77 | 29.0 | 30.5 | 27.0 | 26.0 | 29.0 | 28.0 | 30.0 | 31.0 | 28.5 | 28.5 | 30.0 | 28.0 |
| 78 | 26.0 | 27.5 | 23.0 | 23.0 | 27.0 | 26.0 | 27.0 | 28.0 | 24.5 | 25.5 | 28.0 | 29.0 |
| 79 | 42.0 | 41.9 | 37.0 | 36.0 | 41.0 | 40.0 | 39.0 | 40.0 | 35.0 | 35.0 | 43.0 | 44.0 |
| 80 | 27.0 | 27.5 | 23.0 | 22.0 | 27.0 | 28.5 | 27.0 | 28.0 | 24.0 | 23.5 | 28.0 | 27.0 |
| 81 | 38.0 | 39.5 | 34.0 | 35.5 | 37.0 | 36.0 | 39.0 | 40.5 | 34.0 | 34.0 | 36.0 | 37.0 |
| 82 | 29.0 | 30.0 | 29.0 | 28.0 | 30.0 | 29.0 | 29.0 | 30.0 | 31.0 | 30.0 | 31.0 | 30.0 |
| 83 | 32.0 | 32.5 | 28.0 | 29.0 | 31.0 | 31.0 | 32.0 | 33.0 | 29.0 | 30.0 | 32.0 | 32.0 |
| 84 | 44.0 | 44.0 | 36.0 | 37.0 | 42.0 | 43.0 | 40.0 | 41.0 | 38.0 | 37.0 | 41.0 | 41.0 |
| 85 | 29.0 | 30.0 | 28.0 | 28.0 | 29.0 | 30.0 | 27.0 | 26.0 | 22.0 | 23.0 | 26.0 | 25.0 |
| 86 | 30.0 | 31.0 | 25.0 | 25.0 | 29.0 | 28.0 | 29.0 | 30.0 | 24.0 | 24.5 | 29.0 | 28.0 |
| 87 | 39.0 | 40.5 | 36.0 | 37.0 | 40.0 | 39.0 | 40.0 | 41.0 | 37.5 | 38.0 | 41.0 | 41.0 |
| 88 | 42.0 | 42.0 | 36.0 | 36.0 | 40.0 | 40.0 | 44.0 | 44.0 | 30.0 | 30.0 | 38.0 | 38.0 |
| 89 | 29.0 | 29.0 | 26.0 | 27.0 | 28.0 | 26.5 | 30.5 | 30.5 | 26.0 | 25.0 | 27.0 | 27.0 |
| 90 | 35.0 | 34.0 | 29.0 | 27.5 | 34.0 | 34.0 | 35.0 | 36.0 | 30.0 | 31.5 | 34.0 | 33.0 |
| 91 | 27.0 | 27.0 | 25.0 | 24.0 | 29.0 | 27.0 | 28.0 | 27.0 | 26.5 | 26.5 | 30.5 | 29.5 |
| 92 | 32.0 | 30.0 | 30.0 | 28.0 | 34.0 | 33.0 | 33.0 | 32.0 | 31.0 | 30.0 | 33.0 | 31.0 |
| 93 | 28.0 | 29.5 | 26.0 | 26.0 | 29.0 | 30.5 | 28.0 | 29.0 | 25.0 | 26.0 | 28.0 | 27.0 |
| 94 | 32.0 | 31.0 | 25.0 | 23.5 | 29.0 | 28.0 | 31.0 | 30.0 | 23.0 | 24.0 | 30.0 | 31.0 |
| 95 | 28.0 | 28.0 | 24.0 | 25.5 | 26.0 | 24.0 | 30.0 | 30.5 | 26.0 | 28.0 | 27.5 | 26.0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | 35.0 | 35.0 | 28.0 | 29.5 | 32.0 | 31.0 | 36.0 | 36.0 | 28.5 | 27.5 | 33.0 | 31.5 |
| 97 | 25.0 | 26.0 | 22.0 | 23.0 | 28.0 | 28.0 | 26.0 | 26.0 | 25.0 | 24.0 | 26.0 | 26.0 |
| 98 | 41.0 | 40.0 | 39.5 | 41.0 | 40.0 | 40.5 | 40.0 | 39.5 | 40.0 | 40.0 | 41.0 | 41.5 |
| 99 | 27.0 | 29.0 | 27.0 | 28.0 | 29.0 | 28.0 | 27.0 | 26.0 | 28.0 | 27.0 | 29.0 | 28.0 |
| 100 | 36.0 | 37.0 | 33.0 | 34.5 | 37.0 | 36.0 | 37.5 | 38.5 | 34.0 | 34.0 | 38.0 | 37.0 |
| 101 | 35.0 | 37.0 | 32.0 | 34.0 | 37.0 | 36.0 | 36.0 | 37.0 | 27.0 | 29.0 | 35.0 | 37.0 |
| 102 | 44.0 | 42.0 | 40.0 | 38.0 | 43.0 | 42.0 | 38.0 | 37.0 | 36.0 | 35.0 | 36.0 | 35.0 |
| 103 | 42.0 | 43.0 | 30.0 | 31.0 | 30.0 | 31.0 | 37.0 | 38.0 | 35.0 | 36.0 | 35.0 | 35.0 |
| 104 | 28.0 | 29.5 | 25.0 | 26.0 | 28.0 | 30.0 | 27.0 | 27.0 | 25.0 | 26.0 | 28.0 | 29.0 |
| 105 | 42.0 | 40.8 | 36.0 | 35.0 | 36.0 | 40.0 | 38.5 | 40.0 | 36.0 | 42.0 | 44.0 | 40.0 |
| 106 | 27.0 | 27.5 | 25.0 | 26.0 | 29.0 | 30.5 | 28.0 | 29.0 | 26.0 | 26.0 | 28.0 | 27.0 |
| 107 | 29.0 | 28.0 | 26.0 | 26.0 | 28.0 | 29.0 | 30.0 | 30.5 | 26.0 | 27.0 | 29.5 | 29.5 |
| 108 | 33.0 | 34.5 | 29.0 | 29.0 | 32.0 | 30.5 | 33.0 | 34.0 | 30.0 | 30.0 | 33.0 | 32.0 |
| 109 | 42.0 | 42.0 | 35.0 | 36.0 | 39.0 | 40.0 | 44.0 | 42.0 | 35.0 | 33.5 | 41.0 | 41.0 |
| 110 | 29.0 | 30.0 | 24.0 | 24.0 | 30.0 | 29.0 | 27.5 | 28.5 | 23.0 | 24.0 | 30.0 | 31.0 |
| 111 | 26.0 | 26.0 | 22.0 | 23.5 | 25.0 | 24.0 | 27.5 | 28.0 | 24.0 | 25.0 | 26.5 | 28.5 |
| 112 | 34.0 | 34.0 | 33.0 | 33.0 | 32.0 | 32.0 | 36.0 | 36.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 113 | 39.0 | 40.0 | 36.0 | 34.0 | 36.0 | 37.0 | 34.0 | 36.0 | 36.0 | 37.0 | 34.0 | 35.0 |
| 114 | 29.0 | 28.0 | 26.0 | 26.5 | 29.0 | 28.0 | 30.5 | 30.0 | 28.0 | 26.5 | 30.5 | 31.0 |
| 115 | 29.5 | 30.5 | 26.0 | 26.0 | 30.0 | 29.0 | 29.0 | 30.0 | 27.0 | 28.0 | 30.0 | 30.5 |
| 116 | 33.0 | 33.0 | 26.0 | 27.5 | 30.0 | 28.0 | 35.0 | 34.5 | 28.0 | 29.0 | 31.5 | 31.0 |
| 117 | 28.0 | 29.0 | 24.0 | 24.0 | 26.5 | 27.0 | 27.5 | 27.0 | 25.0 | 24.0 | 27.0 | 28.0 |
| 118 | 33.0 | 33.0 | 26.0 | 27.5 | 31.0 | 29.5 | 33.5 | 34.5 | 27.0 | 27.0 | 31.0 | 30.0 |
| 119 | 31.0 | 32.0 | 24.0 | 24.0 | 28.0 | 26.5 | 31.0 | 31.0 | 25.0 | 25.5 | 28.5 | 29.5 |
| 120 | 43.0 | 42.0 | 36.0 | 35.0 | 40.0 | 40.0 | 45.0 | 47.0 | 38.0 | 39.0 | 42.0 | 41.0 |
| 121 | 33.0 | 33.0 | 29.0 | 30.0 | 34.0 | 33.0 | 34.0 | 35.5 | 30.0 | 31.0 | 34.0 | 34.0 |
| 122 | 33.0 | 33.0 | 29.0 | 30.5 | 32.0 | 31.0 | 34.0 | 34.0 | 29.0 | 27.5 | 33.0 | 32.0 |
| 123 | 38.0 | 39.0 | 32.0 | 35.0 | 30.0 | 34.0 | 40.0 | 42.0 | 32.0 | 33.0 | 34.0 | 33.0 |
| 124 | 43.0 | 44.0 | 36.0 | 35.0 | 41.0 | 39.0 | 44.5 | 45.0 | 38.0 | 38.0 | 40.0 | 38.5 |
| 125 | 30.0 | 30.5 | 26.0 | 28.0 | 30.0 | 28.5 | 31.5 | 30.0 | 28.0 | 26.0 | 30.5 | 29.0 |
| 126 | 44.0 | 43.0 | 38.0 | 38.0 | 42.0 | 41.0 | 46.0 | 48.0 | 39.0 | 40.0 | 44.0 | 43.0 |
| 127 | 26.0 | 27.0 | 31.0 | 30.0 | 35.0 | 33.0 | 39.0 | 38.0 | 32.0 | 31.0 | 40.0 | 40.0 |
| 128 | 30.0 | 31.0 | 28.0 | 28.0 | 31.0 | 31.0 | 31.0 | 32.5 | 28.0 | 28.5 | 32.5 | 31.5 |
| 129 | 40.0 | 39.0 | 34.0 | 34.0 | 39.0 | 40.0 | 39.0 | 39.0 | 34.0 | 35.0 | 35.0 | 35.0 |
| 130 | 33.0 | 34.5 | 25.0 | 26.0 | 32.0 | 30.5 | 33.5 | 32.0 | 24.0 | 25.0 | 31.0 | 30.0 |
| 131 | 30.0 | 31.0 | 24.0 | 23.0 | 32.0 | 33.5 | 28.5 | 29.0 | 23.0 | 23.0 | 32.0 | 32.0 |
| 132 | 40.0 | 40.0 | 36.0 | 35.0 | 39.0 | 40.0 | 39.0 | 40.0 | 36.0 | 36.0 | 38.0 | 36.5 |
| 133 | 35.0 | 35.5 | 28.0 | 27.0 | 33.0 | 32.5 | 36.0 | 36.0 | 28.0 | 27.0 | 33.0 | 33.0 |
| 134 | 30.0 | 31.0 | 26.0 | 25.0 | 31.0 | 30.5 | 29.0 | 30.0 | 26.0 | 24.0 | 30.0 | 32.0 |
| 135 | 25.0 | 25.0 | 21.0 | 20.5 | 26.0 | 26.0 | 24.0 | 24.0 | 19.5 | 20.0 | 25.0 | 23.5 |
| 136 | 26.0 | 26.0 | 22.0 | 21.0 | 27.0 | 28.0 | 27.0 | 28.0 | 22.5 | 22.5 | 28.0 | 26.5 |
| 137 | 44.0 | 44.0 | 37.0 | 38.0 | 42.0 | 41.0 | 44.0 | 45.5 | 38.0 | 39.0 | 41.0 | 40.0 |
| 138 | 27.0 | 28.5 | 23.0 | 22.5 | 28.0 | 28.0 | 27.0 | 28.0 | 22.0 | 22.0 | 27.0 | 26.0 |
| 139 | 34.5 | 34.0 | 27.0 | 26.0 | 31.0 | 31.0 | 34.0 | 35.0 | 27.0 | 26.0 | 31.0 | 30.5 |
| 140 | 26.0 | 27.0 | 22.0 | 23.0 | 25.0 | 26.0 | 25.0 | 26.0 | 21.0 | 22.0 | 24.0 | 26.0 |
| 141 | 50.0 | 47.0 | 43.0 | 42.0 | 43.0 | 41.0 | 45.0 | 46.0 | 39.0 | 42.0 | 45.0 | 46.0 |
| 142 | 38.0 | 38.0 | 36.0 | 36.0 | 40.0 | 40.0 | 37.0 | 37.0 | 36.0 | 36.0 | 37.0 | 37.0 |
| 143 | 30.0 | 31.5 | 28.0 | 29.0 | 30.0 | 29.0 | 30.5 | 29.5 | 29.0 | 29.0 | 31.0 | 32.0 |
| 144 | 42.0 | 42.0 | 34.0 | 33.0 | 40.0 | 38.0 | 45.0 | 46.0 | 36.0 | 36.0 | 42.0 | 41.0 |
| 145 | 33.0 | 33.0 | 28.0 | 27.0 | 31.0 | 32.0 | 35.0 | 34.0 | 29.0 | 29.0 | 34.0 | 33.0 |
| 146 | 48.0 | 48.0 | 40.0 | 41.0 | 48.0 | 47.0 | 50.0 | 52.0 | 42.0 | 41.0 | 49.0 | 49.0 |
| 147 | 42.0 | 42.0 | 35.0 | 35.0 | 39.0 | 37.5 | 43.0 | 43.0 | 36.0 | 37.0 | 40.0 | 40.0 |
| 148 | 28.0 | 28.0 | 26.0 | 27.0 | 29.0 | 29.5 | 29.5 | 31.0 | 27.0 | 26.0 | 30.0 | 31.0 |
| 149 | 32.0 | 32.0 | 25.0 | 26.0 | 29.0 | 30.0 | 32.5 | 31.0 | 26.5 | 27.0 | 30.0 | 28.5 |
| 150 | 35.0 | 35.0 | 29.0 | 30.0 | 33.0 | 33.5 | 36.5 | 37.5 | 29.0 | 29.0 | 34.0 | 33.0 |
| 151 | 48.0 | 48.0 | 51.0 | 51.0 | 46.0 | 46.0 | 52.0 | 52.0 | 49.0 | 49.0 | 48.0 | 48.0 |
| 152 | 39.0 | 40.0 | 39.0 | 39.0 | 44.0 | 43.0 | 43.0 | 42.0 | 40.0 | 38.0 | 40.0 | 39.0 |

## Appendix I: Bare Hand and Gloves Data - Wrist Torque, Grip Strength and Performance Rating

| Participant | Name | Hand Length | Hand Circumference | Hand Width | Wrist Circumference |
|---|---|---|---|---|---|
| 1 | [redacted] | 17 | 22.5 | 8.5 | 15 |
| 2 | [redacted] | 16.5 | 17.5 | 8 | 17.5 |
| 3 | [redacted] | 17 | 17.5 | 8 | 14 |
| 4 | [redacted] | 19.2 | 21.7 | 10.5 | 18 |
| 5 | [redacted] | 19 | 20.7 | 9 | 17 |
| 6 | [redacted] | 18.9 | 19.5 | 8.5 | 16 |

N = Neutral, P = Pronation, S = Supination, E = Extension, F = Flexion, WT = Wrist Torque, GS = Grip Strength

Bare Hand

| Participant | GS (N) | GS (P) | GS (S) | WT (N, F) | WT (N, E) | WT (P, F) | WT (P, E) | WT (S, F) | WT (S, E) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 20.5 | 18 | 21 | 321 | 343 | 261 | 275 | 222 | 254 |
| 2 | 27 | 25.5 | 27 | 339 | 395 | 318 | 323 | 337 | 315 |
| 3 | 24 | 23 | 24.5 | 379 | 452 | 293 | 345 | 443 | 311 |
| 4 | 45 | 42 | 44.5 | 743 | 795 | 675 | 689 | 713 | 740 |
| 5 | 39 | 33 | 36 | 543 | 586 | 482 | 492 | 516 | 537 |
| 6 | 25 | 18 | 24 | 498 | 532 | 459 | 512 | 509 | 432 |

Synthetic Leather Glove

| Participant | GS (N) | GS (P) | GS (S) | WT (N, F) | WT (N, E) | WT (P, F) | WT (P, E) | WT (S, F) | WT (S, E) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 17.5 | 16.5 | 16 | 273 | 292 | 223 | 234 | 189 | 216 |
| 2 | 24.5 | 23 | 24.5 | 305 | 349 | 285 | 292 | 308 | 284 |
| 3 | 21 | 20.5 | 22 | 345 | 398 | 267 | 303 | 387 | 281 |
| 4 | 40.5 | 38.5 | 40 | 680 | 720 | 611 | 629 | 641 | 677 |
| 5 | 37 | 32 | 34.5 | 523 | 565 | 486 | 498 | 506 | 521 |
| 6 | 22.5 | 16 | 21.5 | 415 | 452 | 386 | 433 | 427 | 358 |



Microfiber Glove

| Participant | GS (N) | GS (P) | GS (S) | WT (N, F) | WT (N, E) | WT (P, F) | WT (P, E) | WT (S, F) | WT (S, E) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 17.5 | 17 | 16.5 | 241 | 257 | 196 | 206 | 167 | 191 |
| 2 | 26.5 | 24 | 25.5 | 326 | 373 | 302 | 309 | 322 | 305 |
| 3 | 23 | 21 | 23 | 358 | 435 | 285 | 322 | 415 | 310 |
| 4 | 38 | 35.5 | 38 | 655 | 695 | 576 | 588 | 622 | 630 |
| 5 | 37 | 31 | 34 | 515 | 558 | 460 | 470 | 492 | 515 |
| 6 | 23.5 | 17 | 23 | 433 | 464 | 402 | 444 | 445 | 382 |

Long Leather Glove

| Participant | GS (N) | GS (P) | GS (S) | WT (N, F) | WT (N, E) | WT (P, F) | WT (P, E) | WT (S, F) | WT (S, E) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 16.5 | 15 | 14.5 | 177 | 182 | 166 | 175 | 155 | 159 |
| 2 | 23 | 21.5 | 23 | 288 | 338 | 274 | 277 | 290 | 272 |
| 3 | 20.5 | 19.5 | 21 | 330 | 375 | 245 | 287 | 365 | 270 |
| 4 | 43 | 40 | 42 | 705 | 760 | 635 | 658 | 684 | 710 |
| 5 | 33 | 28 | 31 | 455 | 496 | 411 | 423 | 439 | 449 |
| 6 | 21 | 15 | 20.4 | 387 | 415 | 363 | 412 | 402 | 342 |

Synthetic Leather Glove

| Force | Angle of motion | Comfort level | Size | Product quality |
|---|---|---|---|---|
| 8 | 9 | 7 | 7 | 3 |
| 8 | 8 | 7 | 9 | 3 |
| 6 | 7 | 8 | 9 | 5 |
| 8 | 9 | 9 | 9 | 4 |
| 9 | 9 | 8 | 9 | 4 |
| 8 | 9 | 7 | 9 | 4 |

Microfiber Glove

| Force | Angle of motion | Comfort level | Size | Product quality |
|---|---|---|---|---|
| 9 | 8 | 9 | 8 | 7 |
| 9 | 7 | 8 | 9 | 7 |
| 8 | 7 | 8 | 9 | 7 |
| 8 | 8 | 9 | 8 | 7 |
| 9 | 8 | 8 | 9 | 6 |
| 9 | 7 | 9 | 8 | 6 |

Long Leather Glove

| Force | Angle of motion | Comfort level | Size | Product quality |
|---|---|---|---|---|
| 7 | 6 | 3 | 2 | 9 |
| 6 | 5 | 4 | 3 | 7 |
| 6 | 7 | 4 | 2 | 7 |
| 9 | 7 | 6 | 7 | 8 |
| 6 | 7 | 5 | 5 | 8 |
| 7 | 5 | 4 | 2 | 6 |

# Appendix J: Anthropometry and Wrist Torque Data: 30 Male Participants

Male

| Participant/ Subject | Age (years) | Weight (kg) | Height (cm) | Anthropometry of participant | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Forearm Length (cm) | Forearm Circumference (cm) | Wrist circumference (cm) | Hand length (cm) | Hand circumference (cm) | Hand width (cm) |
| 1 | 25 | 76 | 173 | 27 | 29 | 18 | 21 | 22 | 11 |
| 2 | 24 | 61 | 172 | 24.5 | 27 | 17 | 20 | 21 | 10 |
| 3 | 25 | 66 | 178 | 25 | 24 | 18 | 20 | 22 | 9.5 |
| 4 | 26 | 95 | 179 | 28 | 28.5 | 18.5 | 21 | 22 | 10.5 |
| 5 | 24 | 60 | 183 | 28 | 26 | 17 | 21 | 21.5 | 9 |
| 6 | 24 | 90 | 172 | 26.5 | 28 | 17 | 19.5 | 22.5 | 10 |
| 7 | 26 | 89 | 179 | 26 | 29 | 19 | 21.5 | 21.5 | 10.5 |
| 8 | 25 | 90 | 165 | 29 | 31 | 18 | 19 | 22 | 10 |
| 9 | 23 | 54 | 174 | 28 | 25 | 12 | 19.5 | 20.5 | 9.5 |
| 10 | 23 | 65 | 173 | 27 | 25 | 16 | 19.5 | 20 | 9 |
| 11 | 23 | 75 | 180 | 28 | 28 | 18 | 21 | 22 | 10 |
| 12 | 23 | 50 | 167 | 26 | 24 | 15 | 19 | 19 | 9 |
| 13 | 25 | 110 | 173 | 26 | 32 | 21.5 | 20 | 24 | 10.5 |
| 14 | 22 | 92 | 173 | 29 | 29 | 18.5 | 20 | 21 | 10 |
| 15 | 22 | 57 | 176 | 26 | 26 | 16 | 18 | 19.5 | 9 |
| 16 | 24 | 93 | 169 | 25 | 33.5 | 19 | 18 | 23.5 | 10 |
| 17 | 22 | 66 | 170 | 25 | 27 | 16 | 20 | 20.5 | 8.5 |
| 18 | 22 | 44 | 154 | 23 | 23 | 14.5 | 17 | 18 | 8 |
| 19 | 24 | 55 | 165 | 16 | 24 | 15 | 19 | 19 | 8.5 |
| 20 | 24 | 66 | 175 | 27 | 28 | 18 | 20 | 21.5 | 9.5 |
| 21 | 25 | 72 | 174 | 26.5 | 26 | 17 | 21 | 20 | 10.5 |
| 22 | 26 | 75 | 170 | 25 | 30 | 19 | 19.5 | 22 | 9 |
| 23 | 24 | 82 | 168 | 28 | 25 | 16.5 | 18 | 19 | 10 |
| 24 | 24 | 64 | 174 | 24 | 28 | 19 | 20.5 | 21.5 | 9.5 |
| 25 | 26 | 70 | 166 | 27 | 23 | 17 | 20 | 20 | 8.5 |
| 26 | 25 | 68 | 177 | 29.5 | 27 | 20.5 | 21.5 | 18 | 9 |
| 27 | 25 | 60 | 171 | 24 | 25 | 18.5 | 17 | 19.5 | 10 |
| 28 | 26 | 58 | 169 | 25 | 29.5 | 19 | 18 | 21.5 | 8 |
| 29 | 25 | 71 | 170 | 26 | 25 | 18.5 | 19 | 20 | 9 |
| 30 | 25 | 56 | 172 | 28 | 31 | 20 | 21 | 22 | 10.5 |

Male

| | Wrist Position: Pronation | | Wrist Position: Supination | | Wrist Position: Neutral/ Vertical | |
|---|---|---|---|---|---|---|
| | Flexion | Extension | Flexion | Extension | Flexion | Extension |
| Participant/ Subject | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) |
| 1 | 700 | 704 | 687 | 770 | 719 | 687 |
| 2 | 676 | 694 | 663 | 712 | 773 | 756 |
| 3 | 631 | 557 | 563 | 766 | 627 | 703 |
| 4 | 576 | 547 | 594 | 598 | 634 | 613 |
| 5 | 463 | 334 | 300 | 385 | 479 | 462 |
| 6 | 580 | 520 | 454 | 503 | 632 | 713 |
| 7 | 523 | 459 | 431 | 531 | 548 | 400 |
| 8 | 496 | 487 | 532 | 675 | 672 | 841 |
| 9 | 480 | 468 | 600 | 570 | 673 | 714 |
| 10 | 448 | 369 | 536 | 424 | 509 | 673 |
| 11 | 346 | 443 | 530 | 586 | 579 | 635 |
| 12 | 357 | 411 | 438 | 465 | 511 | 546 |
| 13 | 641 | 462 | 610 | 733 | 551 | 666 |
| 14 | 401 | 438 | 567 | 468 | 597 | 613 |
| 15 | 225 | 202 | 340 | 307 | 553 | 622 |
| 16 | 492 | 518 | 552 | 635 | 628 | 661 |
| 17 | 471 | 456 | 594 | 606 | 602 | 652 |
| 18 | 339 | 301 | 243 | 396 | 486 | 524 |
| 19 | 502 | 588 | 340 | 441 | 690 | 592 |
| 20 | 634 | 684 | 570 | 644 | 506 | 668 |
| 21 | 588 | 692 | 602 | 598 | 766 | 772 |
| 22 | 641 | 588 | 620 | 688 | 644 | 779 |
| 23 | 592 | 408 | 488 | 472 | 524 | 482 |
| 24 | 498 | 447 | 520 | 516 | 532 | 547 |
| 25 | 524 | 501 | 476 | 506 | 673 | 447 |
| 26 | 568 | 410 | 513 | 523 | 609 | 737 |
| 27 | 581 | 493 | 477 | 482 | 633 | 591 |
| 28 | 630 | 518 | 481 | 486 | 615 | 516 |
| 29 | 574 | 476 | 511 | 577 | 475 | 566 |
| 30 | 664 | 552 | 557 | 634 | 694 | 709 |

# Appendix K: Anthropometry and Wrist Torque Data: 30 Female Participants

Female

| | | | | Anthropometry of participant | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Participant/ Subject | Age (years) | Weight (kg) | Height (cm) | Forearm Length (cm) | Forearm Circumference (cm) | Wrist circumference (cm) | Hand length (cm) | Hand circumference (cm) | Hand width (cm) |
| 1 | 24 | 53 | 158 | 27 | 24 | 13.5 | 16.5 | 17.5 | 8 |
| 2 | 24 | 58 | 160 | 27 | 24 | 14 | 17 | 17 | 8 |
| 3 | 23 | 50 | 157 | 25 | 24 | 14 | 16.5 | 18 | 8.5 |
| 4 | 24 | 72 | 153 | 25 | 28 | 16 | 18.5 | 20 | 9 |
| 5 | 24 | 36 | 158 | 28 | 19 | 13 | 18.5 | 17 | 7.5 |
| 6 | 23 | 46 | 152 | 23 | 23 | 14 | 17 | 17.5 | 8 |
| 7 | 25 | 47 | 153 | 24 | 23 | 13.5 | 15.5 | 17.5 | 8 |
| 8 | 26 | 83 | 157 | 24 | 28 | 15.5 | 17 | 18 | 8 |
| 9 | 25 | 47 | 154 | 24 | 22 | 14 | 17 | 18 | 8.5 |
| 10 | 24 | 65 | 169 | 25 | 25 | 15 | 18 | 18.5 | 9 |
| 11 | 23 | 72 | 156 | 25 | 29 | 17 | 17.5 | 21 | 10 |
| 12 | 26 | 43 | 156 | 25 | 23 | 17 | 16.5 | 17.5 | 8 |
| 13 | 26 | 65 | 156 | 25 | 25 | 15 | 17 | 18 | 8 |
| 14 | 21 | 52 | 158 | 26.5 | 23 | 14.5 | 16.5 | 18 | 8.5 |
| 15 | 21 | 48 | 168 | 29 | 21.5 | 14 | 17 | 18.5 | 8.5 |
| 16 | 23 | 80 | 158 | 27 | 33 | 17.5 | 18.5 | 20 | 9 |
| 17 | 21 | 63 | 160 | 27 | 23.5 | 14.5 | 18 | 19.5 | 9.5 |
| 18 | 23 | 63 | 160 | 28 | 25 | 14.5 | 18.5 | 17.5 | 8 |
| 19 | 23 | 47 | 153 | 24 | 20 | 13 | 16 | 17 | 8 |
| 20 | 23 | 49 | 156 | 25 | 21 | 13 | 16 | 18 | 8.5 |
| 21 | 24 | 56 | 159 | 27 | 22.5 | 15 | 17.5 | 18 | 8.5 |
| 22 | 23 | 67 | 162 | 25.5 | 24.5 | 14.5 | 17.5 | 17.5 | 8.5 |
| 23 | 23 | 50 | 154 | 25 | 20 | 13.5 | 16 | 17 | 8.5 |
| 24 | 24 | 61 | 165 | 26 | 22 | 15.5 | 18 | 19 | 9.5 |
| 25 | 24 | 56 | 170 | 30 | 21.5 | 14 | 18.5 | 17.5 | 9 |
| 26 | 24 | 64 | 155 | 25 | 25 | 15 | 16 | 18 | 8.5 |
| 27 | 21 | 55 | 158 | 28 | 24 | 14 | 15.5 | 16.5 | 8.5 |
| 28 | 21 | 51 | 168 | 28 | 22.5 | 17 | 17.5 | 18 | 9 |
| 29 | 21 | 71 | 155 | 26 | 25 | 15.5 | 17.5 | 19 | 9.5 |
| 30 | 21 | 56 | 153 | 24 | 21 | 14 | 15.5 | 17 | 8.5 |

Female

| | Wrist Position: Pronation | | Wrist Position: Supination | | Wrist Position: Neutral/ Vertical | |
|---|---|---|---|---|---|---|
| | Flexion | Extension | Flexion | Extension | Flexion | Extension |
| Participant/ Subject | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) | Max. Wrist Torque (Ncm) |
| 1 | 318 | 323 | 337 | 315 | 339 | 395 |
| 2 | 293 | 345 | 443 | 311 | 379 | 452 |
| 3 | 333 | 386 | 288 | 303 | 298 | 339 |
| 4 | 363 | 333 | 167 | 370 | 381 | 462 |
| 5 | 181 | 142 | 223 | 152 | 299 | 305 |
| 6 | 217 | 249 | 233 | 243 | 188 | 126 |
| 7 | 346 | 337 | 315 | 315 | 314 | 356 |
| 8 | 219 | 212 | 313 | 278 | 352 | 312 |
| 9 | 320 | 412 | 403 | 364 | 387 | 397 |
| 10 | 355 | 319 | 265 | 447 | 232 | 202 |
| 11 | 365 | 382 | 412 | 381 | 271 | 332 |
| 12 | 483 | 324 | 287 | 134 | 315 | 324 |
| 13 | 293 | 248 | 350 | 327 | 391 | 301 |
| 14 | 168 | 156 | 148 | 158 | 167 | 208 |
| 15 | 200 | 162 | 196 | 188 | 210 | 204 |
| 16 | 273 | 242 | 271 | 247 | 225 | 223 |
| 17 | 407 | 460 | 450 | 385 | 445 | 472 |
| 18 | 379 | 480 | 457 | 480 | 445 | 499 |
| 19 | 233 | 367 | 259 | 261 | 272 | 337 |
| 20 | 193 | 200 | 180 | 158 | 271 | 263 |
| 21 | 261 | 275 | 222 | 254 | 321 | 343 |
| 22 | 260 | 387 | 321 | 246 | 324 | 356 |
| 23 | 181 | 201 | 164 | 195 | 229 | 237 |
| 24 | 315 | 325 | 358 | 365 | 357 | 318 |
| 25 | 119 | 173 | 105 | 124 | 126 | 169 |
| 26 | 383 | 491 | 428 | 390 | 361 | 413 |
| 27 | 269 | 298 | 298 | 244 | 295 | 294 |
| 28 | 333 | 266 | 306 | 305 | 277 | 359 |
| 29 | 161 | 143 | 212 | 179 | 198 | 206 |
| 30 | 339 | 387 | 399 | 306 | 308 | 373 |

## Appendix L: Bare Hand and Gloves Wrist Torque Data

| Wrist Torque \ Participant | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Bare Hand | Neutral, Flexion | 321 | 339 | 379 | 743 | 543 | 498 |
| | Neutral, Extension | 343 | 395 | 452 | 795 | 586 | 532 |
| | Pronation, Flexion | 261 | 318 | 293 | 675 | 482 | 459 |
| | Pronation, Extension | 275 | 323 | 345 | 689 | 492 | 512 |
| | Supination, Flexion | 222 | 337 | 443 | 713 | 516 | 509 |
| | Supination, Extension | 254 | 315 | 311 | 740 | 537 | 432 |
| Synthetic Leather Glove | Neutral, Flexion | 273 | 305 | 345 | 680 | 523 | 415 |
| | Neutral, Extension | 292 | 349 | 398 | 720 | 565 | 452 |
| | Pronation, Flexion | 223 | 285 | 267 | 611 | 486 | 386 |
| | Pronation, Extension | 234 | 292 | 303 | 629 | 498 | 433 |
| | Supination, Flexion | 189 | 308 | 387 | 641 | 506 | 427 |
| | Supination, Extension | 216 | 284 | 281 | 677 | 521 | 358 |
| Microfiber Glove | Neutral, Flexion | 241 | 326 | 358 | 655 | 515 | 433 |
| | Neutral, Extension | 257 | 373 | 435 | 695 | 558 | 464 |
| | Pronation, Flexion | 196 | 302 | 285 | 576 | 460 | 402 |
| | Pronation, Extension | 206 | 309 | 322 | 588 | 470 | 444 |
| | Supination, Flexion | 167 | 322 | 415 | 622 | 492 | 445 |
| | Supination, Extension | 191 | 305 | 310 | 630 | 515 | 382 |
| Long Leather Glove | Neutral, Flexion | 177 | 288 | 330 | 705 | 455 | 387 |
| | Neutral, Extension | 182 | 338 | 375 | 760 | 496 | 415 |
| | Pronation, Flexion | 166 | 274 | 245 | 635 | 411 | 363 |
| | Pronation, Extension | 175 | 277 | 287 | 658 | 423 | 412 |
| | Supination, Flexion | 155 | 290 | 365 | 684 | 439 | 402 |
| | Supination, Extension | 159 | 272 | 270 | 710 | 449 | 342 |
| Modified Glove | Neutral, Flexion | 282 | 312 | 340 | 712 | 533 | 429 |
| | Neutral, Extension | 309 | 366 | 409 | 752 | 569 | 472 |
| | Pronation, Flexion | 232 | 282 | 271 | 639 | 492 | 394 |
| | Pronation, Extension | 242 | 310 | 320 | 641 | 502 | 452 |
| | Supination, Flexion | 198 | 316 | 389 | 669 | 515 | 438 |
| | Supination, Extension | 253 | 313 | 346 | 687 | 522 | 427 |

## Appendix M: Bare Hand and Gloves Grip Strength Data

| Grip Strength \ Participant | | 1 | 2 | 3 | 4 | 5 | 6 | Average (N+P+S)/3 |
|---|---|---|---|---|---|---|---|---|
| Bare Hand | Neutral | 20.5 | 27.0 | 24.0 | 45.0 | 39.0 | 25.0 | 28.72 |
| | Pronation | 18.0 | 25.5 | 23.0 | 42.0 | 33.0 | 18.0 | |
| | Supination | 21.0 | 27.0 | 24.5 | 44.5 | 36.0 | 24.0 | |
| Synthetic Leather Glove | Neutral | 17.5 | 24.5 | 21.0 | 40.5 | 37.0 | 22.5 | 26.00 |
| | Pronation | 16.5 | 23.0 | 20.5 | 38.5 | 32.0 | 16.0 | |
| | Supination | 16.0 | 24.5 | 22.0 | 40.0 | 34.5 | 21. 5 | |
| Microfiber Glove | Neutral | 17.5 | 26.5 | 23.0 | 38.0 | 37.0 | 23.5 | 26.17 |
| | Pronation | 17.0 | 24.0 | 21.0 | 35.5 | 31.0 | 17.0 | |
| | Supination | 16.5 | 25.5 | 23.0 | 38.0 | 34.0 | 23.0 | |
| Long Leather Glove | Neutral | 16.5 | 23.0 | 20.5 | 43.0 | 33.0 | 21.0 | 24.88 |
| | Pronation | 15.0 | 21.5 | 19.5 | 40.0 | 28.0 | 15.0 | |
| | Supination | 14.5 | 23.0 | 21.0 | 42.0 | 31.0 | 20.4 | |
| Modified Glove | Neutral | 18.0 | 26.5 | 23.5 | 39.0 | 37.0 | 24.0 | 26.50 |