THE RELATIONSHIP BETWEEN ANTHROPOMETRY AND HAND GRIP STRENGTH AMONG OLDER MALAYSIAN PEOPLE

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FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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Field of Study: Ergonomics

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ABSTRACT

Physiological changes and loss of hand grip strength are natural consequences of the ageing process. Previous studies have shown that physiological changes will affect the hand grip strength of elderly people. However, to date, there are no studies which have developed models that predicts the hand grip strength of elderly Malaysians as a function of anthropometric dimensions. Knowledge on the correlation between these variables is crucial in order to create a suitable living environment as well as designing and developing products that cater specifically to the needs of the elderly. Hence, the main objective of this study is to examine the correlation between anthropometric dimensions and hand grip strength in a representative sample of the elderly population in Malaysia and developing the regression models that predicts the hand grip strength of elderly Malaysian males and females.

In order to achieve the objectives, a total of ninety one (91) anthropometric dimensions along with hand grip strength data are collected from a sample of 112 subjects aged 60 years and above. The subjects comprises of 56 males and 56 females, recruited from a densely populated urban area in Selangor, namely, Petaling Jaya. The anthropometric parameters are measured using standard anthropometric set whereas hand grip strength is measured using Jamar hydraulic hand dynamometer. Statistical analysis was then carried out to identify the anthropometric dimensions that significantly influence hand grip strength, and the results indicate that only 37 anthropometric dimensions significantly influence the hand grip strength of elderly Malaysians.

In addition, the anthropometric dimensions and hand grip strength data were obtained and compared with the data for two age groups (20-30 years and 50-59 years) in order to determine if there is a significant difference in the measurements between these groups. In general, it can be observed that the ageing adult group exhibits lower values for the

majority of anthropometric parameters and hand grip strength compared to the young adult group. This finding indicates the importance for product designers to gain an understanding on the differences in the physiological dimensions of elderly people with those of other age groups in order to create ergonomic products that account for their special needs.

Two regression models have been developed in this study, which predicts the hand grip strength of elderly Malaysian males and females. In both of these models, the hand grip strength is predicted by a regression equation as a function of anthropometric dimensions. A case study has been carried out to validate the prediction models, in which the subjects are required to open bottles of different sizes. Five bottles are chosen for this purpose; the first one, a perfume vial, second, a vitamin supplement bottle, the third, a tall, narrow-mouthed jar of blueberry jam, the fourth, a short, wide-mouthed jar of orange marmalade and the fifth, a mini shower cream bottle. These bottles are typical objects which are available at home and are therefore representative of the actual scenario faced by the elderly. The results indicate that there is a relationship between hand anthropometric dimensions and hand grip strength for elderly Malaysians, whereby the size and surface texture of the lid affects their ability to open the bottles.

The significant contributions of this study are as follows. First, the findings of this study can be used to build a database of anthropometric and hand grip strength measurements for the elderly population in Malaysia. Second, the regression models developed in this study can be used as a means to predict the hand grip strength of the elderly populations in Malaysia, which will assist product designers in creating ergonomically designed products. Third, an improved methodology was being proposed in this study which will be useful for researchers who intend to deepen their understanding on the relationship between anthropometric parameters and hand grip strength of elderly Malaysians.

ABSTRAK

Perubahan fisiologi serta kehilangan kekuatan genggaman merupakan perkara semulajadi yang berlaku dalam proses penuaan. Kajian-kajian yang lepas telah menunjukkan bahawa perubahan fisiologi pada tangan akan mempengaruhi kekuatan genggaman warga tua. Walaubagaimanapun, sehingga kini belum ada kajian yang membangunkan model yang meramal kekuatan genggaman warga tua khususnya di Malaysia. Hubungan antara kekuatan genggaman dan dimensi antropometrik adalah penting untuk mewujudkan lingkungan kehidupan dan membangunkan produk yang memenuhi keperluan warga tua. Oleh yang demikian, objektif utama kajian ini adalah untuk mengkaji hubungan antara dimensi antropometrik dan kekuatan genggaman warga tua dan membangunkan model regresi yang meramal kekuatan genggaman warga tua lelaki dan perempuan di Malaysia.

Untuk mencapai objektif di atas, sejumlah 91 dimensi antropometrik beserta data kekuatan genggaman telah dikumpul dari suatu sampel yang terdiri daripada 112 subjek berumur 60 tahun ke atas. Subjek terdiri daripada 56 lelaki dan 56 perempuan dan telah direkrut daripada kawasan bandar yang mempunyai kepadatan penduduk yang tinggi di Selangor, iaitu Petaling Jaya. Dimensi antropometrik telah diukur dengan menggunakan set antropometrik piawai manakala kekuatan genggaman diukur dengan menggunakan dinamometer tangan hidraulik Jamar. Analisis statistik telah dilaksanakan untuk mengenalpasti dimensi antropometrik yang mempengaruhi kekuatan genggaman secara signifikan, dan hasil keputusan menunjukkan bahawa 37 dimensi antropometrik sahaja yang mempengaruhi kekuatan genggaman warga tua di Malaysia.

Satu perbandingan juga telah dibuat, di mana data dimensi antropometrik dan kekuatan genggaman telah dibandingkan dengan data dari dua kumpulan dengan lingkungan umur yang berlainan (20-30 tahun dan 50-59 tahun) untuk menentukan sama ada terdapat

perbezaan yang signifikan antara kumpulan. Secara umumnya, hasil keputusan menunjukkan bahawa kebanyakan dimensi antropometrik dan juga kekuatan genggaman bagi kumpulan dewasa berumur adalah rendah berbanding dengan kumpulan dewasa muda. Hasil penemuan ini menunjukkan betapa pentingnya bagi pereka produk untuk memahami perbezaan fisiologi warga tua dengan golongan lain demi menghasilkan produk ergonomik yang mengambil kira keperluan khusus golongan ini.

Dua model regresi telah dibangunkan dalam kajian ini dan bertujuan meramal kekuatan genggaman warga tua lelaki dan perempuan di Malaysia. Kedua-dua model ini terdiri daripada persamaan regresi yang menunjukkan hubungan antara kekuatan genggaman dengan dimensi antropometrik. Satu kajian kes telah dilaksanakan untuk mengesahkan kedua-dua model tersebut, di mana para subjek dikehendaki untuk membuka lima jenis botol dengan saiz berlainan. Lima jenis botol telah dipilih untuk tujuan ini; pertama, vial minyak wangi, kedua, botol vitamin, ketiga, balang jem beri biru yang tinggi dan bermulut kecil, keempat, balang marmalad oren yang pendek dan bermulut luas dan kelima, botol krim mandian yang kecil. Botol-botol tersebut merupakan objek yang biasa dijumpai di dalam rumah dan menunjukkan keadaan sebenar yang biasa dihadapi oleh warga tua. Hasil kajian menunjukkan bahawa terdapat hubungan antara dimensi antropometrik dan kekuatan genggaman untuk warga tua di Malaysia, di mana saiz dan tekstur permukaan penutup botol mempengaruhi kebolehan warga tua untuk membuka botol.

Sumbangan signifikan kajian ini adalah seperti berikut. Pertama, hasil penemuan kajian ini boleh digunakan untuk membina satu pangkalan data dimensi antropometrik dan kekuatan genggaman bagi warga tua khususnya di Malaysia. Kedua, kedua-dua model regresi yang dibangunkan dalam kajian ini boleh digunakan sebagai suatu alat untuk meramal kekuatan genggaman warga tua dan ini akan membantu pereka produk untuk merekacipta produk ergonomik. Ketiga, suatu kaedah diperbaiki telah dicadangkan dalam kajian ini, di mana ia akan memberi manfaat kepada para penyelidik yang ingin mendalami ilmu berkenaan hubungan antara dimensi antropometrik dan kekuatan genggaman warga tua di Malaysia.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADL	:	Activity of Daily Living
IADL	:	Instrumental of Activity of Daily Living
BMI	:	Body Mass Index
CV	:	Coefficient of Variation
SPSS	:	Statistical Package for Social Science
SD	:	Standard Deviation
SEE	:	Standard Error of Estimate

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CHAPTER 1: INTRODUCTION

1.1 Overview

The world is affected by a demographic revolution in the modern era, in which the number of elderly people are escalating all around the globe. In general, the elderly group has outnumbered the youngsters and the figure is forecasted to double within the next few decades. According to a report by the United Nations, it is expected that the number of people aged 60 years and above will increase more than 50% over the next four decades (United Nations, 2011). In the more developed regions, the population aged 60 or over is increasing at the fastest pace ever (growing at 2.4 per cent annually before 2050 and 0.7 per cent annually from 2050 to 2100) and is expected to increase by more than 50 per cent over the next four decades, rising from 274 million in 2011 to 418 million in 2050 and to 433 million in 2100. Compared with the more developed world, the population of the less developed regions is ageing rapidly. Over the next three decades, the population aged 60 or over in the developing world is projected to increase at rates far surpassing 3 per cent per year and its numbers are expected to rise from 510 million in 2011 to 1.6 billion in 2050 and to 2.4 billion in 2100.

It is expected that the elderly population will also being increased in Malaysia based on statistics. The number of elderly people in Malaysia is 2.25 million in year 2010 (which represents 7.9% of the total population) and the value is predicted to increase to 9.8% in year 2020 (Department of Statistics Malaysia, 2013). The number of elderly Malaysians is predicted to increase from 2.25 to 6.30 million within a span of 30 years (from 2010 – 2040), as shown in Table 1.1. In other words, the elderly group is expected to increase threefold compared to the younger population.

This demographic transition brings certain challenges and the main question lies as to whether the society is ready to fulfil the special needs of these older individuals. In general, most people have the misconceptions that the elderly group is a burden to the society since they perceive that those belonging to this group are unable to perform daily tasks. This stereotypical perception is not unfounded however, considering that elderly people are generally limited in some ways because of the ageing process (Yen, 2011). Hence, there is a critical need to explore the limitations commonly faced by elderly people in order to provide them with a means to live independently, and thus minimizing their reliance on their family members or caretakers.

Table 1.1: The Number of Citizens Aged 60 Years and Above from Year 2010 to 2040 Forecasted by the Department of Statistics Malaysia (2013)

Year	Total no. of citizens ('000)	Percentage of the total population (%)
2010	2248.6	7.9
2020	3440.9	10.6
2030	4842.1	13.5
2040	6295.3	16.3

Despite their physical limitations, a previous study had shown that elderly people are able to perform their daily activities independently by ergonomic reshaping of their living environment (Jarosz, 1999). In other words, they are able to carry on with their daily routine by developing products that will help them perform their tasks with ease. Knowledge on the capabilities and limitations of elderly people is essential to enable designers to design and develop products that will cater to their special needs and provide adequate support for their physical limitations. Such products will make their lives easier and reduce their dependence on the assistance of others. According to (Jarosz, 1999), it is necessary for one to obtain knowledge on the somatic characteristics of the elderly group in order to design and develop products which are ergonomic-friendly.

Anthropometric dimensions and hand grip strength are critical parameters that needs to be considered when designing ergonomic products for the elderly (Jarosz, 1999). One of the reasons is because the elderly group exhibits a noticeable decrease in their anthropometric dimensions and previous studies have shown that one's height tends to decrease as they age (Perissinotto et al., 2002; Dey et al., 1999). For instance, Perissinotto et al. (2002) discovered that Italians tend to become shorter as they grow older at a rate of 20 to 30 mm/decade.

Besides changes in their anthropometric dimensions, the elderly exhibit a noticeable decrease in their hand grip strength (Corish & Kennedy, 2003). According to (Carmeli et al., 2003) hand grip strength reflects the effectiveness of a person's hand when it comes to gripping tasks. Bellamy, Campbell, et al. (2002) explored the hand grip strength of older individuals as they interacted with products in their living environment and the results showed that most of them with limited hand grip strength faced difficulties when operating hand-held products such as opening a new bottle (92%), carrying a full pot (80%), fastening jewellery (78%), turning faucets on and off (76%) and doing up buttons (72%).

The decrease in hand grip strength and anthropometric dimensions is one of the factors why the elderly face difficulties when operating products in their living environment as these factors are closely related to one another (Merkies et al., 2000; MacDermid et al., 2002; Aghazadeh et al., 1993). To date, there are many studies pertaining to anthropometry in Malaysia, while studies on hand grip strength are mostly carried out in the medical field. Even though anthropometric dimensions and hand grip strength have been investigated extensively in Malaysia, there is a lack of studies which focus on the relationship between these parameters specifically among elderly Malaysians. Hence, there is a critical need to examine the relationship between anthropometric dimensions and hand grip strength in elderly Malaysians in order to enable designers to design and develop products which addresses the special needs of this group.

1.2 Significance of the Study

A comprehensive anthropometric and hand grip strength database is required to design and develop products which are ergonomic-friendly. However, such comprehensive database is currently lacking particularly for elderly Malaysians, which forms the main motivation of this study. The primary aim of this study is to establish a comprehensive database of anthropometric dimensions and hand grip strength of the elderly population in Malaysia, which serves as a basis for ergonomic design as well as evaluation criteria to improve the living environment of this group. It is believed that the database is relevant and sufficient since the data are collected from the most densely populated area in Selangor. Thus, the data are representative of the average elderly Malaysians. In addition, it is deemed crucial to develop models which predict the hand grip strength of elderly Malaysian males and females as a function of anthropometric dimensions. The models will be greatly beneficial for designers to design and develop ergonomic hand-held products for the elderly.

1.3 Objectives of the Study

The objectives of this study are listed as follows:

1. To identify the anthropometric dimensions that significantly influences the hand grip strength of elderly Malaysians.
2. To determine the correlations between anthropometric dimensions and hand grip strength of elderly Malaysians.
3. To develop regression models which predicts the hand grip strength of elderly Malaysian males and females as a function of anthropometric dimensions.
4. To validate the regression models using a case study.

1.4 Outline of the Thesis

This thesis consists of six chapters. A brief overview of this study, its significance and objectives are presented in Chapter 1. The key issues, trends and theories relevant to this study are presented in Chapter 2. The methodology used in this study described in detailed in Chapter 3, consisting of the research design, data collections and statistical analysis techniques. The key findings of this study are highlighted in Chapter 4, and the results are discussed in detail in Chapter 5. Finally, the general conclusions of this study, as well as limitations and recommendations for future work are presented in Chapter 6.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

A comprehensive review of literature relevant to this study is presented in this chapter. The definition of elderly people and projected future growth of the elderly population are presented in Section 2.2, whereas a brief historical background on anthropometry, the applications of anthropometric data and the key anthropometric studies in Malaysia are presented in Section 2.3. A discussion on hand grip strength and is significance among the elderly is presented in Section 2.4. The models were developed to predict the hand grip strength of elderly as a function of anthropometric variables is presented in Section 2.5. A summary of this chapter is presented in Section 2.6.

2.2 Elderly Population

A general overview on the elderly population is presented in this section, consisting of its definition and projected future growth in Malaysia as well as on the global scale.

2.2.1 Definition of Elderly People

The definition of old age is arbitrary. Most of the developed countries defined old people as people who are eligible for statutory and occupational retirement pensions. However, this definition is inapplicable for those in developing countries such as sub-Saharan Africa, whereby the majority of old people working outside the formal sector are ineligible for retirement pensions. The lack of a standard definition of old people leads to the use of pensionable age as the default definition. Nonetheless, the definition of old age differs across countries. For example, the normal retirement age for most developed countries is 65, whereas the retirement age is 56 in Malaysia. Hence, the difference in the definition of retirement age across nations introduces problems when it comes to data comparisons.

The definition of old people is somewhat vague in the literature and there is a lack of consensus among researchers on the true definition of elderly people. Glascock and Feinman (1980) classified old age into three main categories, namely (1) chronological age, (2) societal age (change in work patterns) and (3) change in capabilities (i.e. change in physical functions). They proposed that chronological age is a predominant definition of old age. However, this definition contradicts the definition proposed by Togonu-Bickersteth (1988), in which societal age is a more convincing definition of old people. It is perceived that there may be a population bias in both of these studies since the experiments were carried out in Africa, and thus, the results could not be compared directly with those of other nations.

The various definitions of elderly people used in previous studies are summarized in Table 2.1. It shall be noted however, that these definitions were obtained from literature dated from the past few decades due to a lack of recent definitions. In general, it can be seen that there is a difference with regards to the definition of the elderly. According to studies from the 1950s to 1970s, old age is closely related to health status (Erikson, 1959; Brubaker & Powers, 1976). However, according to studies published from the 1970s to 1980, old age is associated with economic status. Roebuck (1979) and Thane (1978) defined old age as someone who have begun to benefit from retirement pensions. In contrast, according to recent studies from 2000 onwards, old age is associated with societal function, which is evidenced from the numerous programs and studies on active elderly people and their contribution to the society.

Table 2.1: Definitions of Elderly People from Past Studies

Author	Definition
United Nations (2001)	No numerical criterion, but generally 60 years and above
Gorman (1999)	Old age in many developing countries is seen to begin at the point when an active contribution is no longer possible
Atchley (1991)	Decline in everyday competence and independent living routine
Glascock and Feinman (1980)	Societal age is the predominant means of old age
Roebuck (1979)	The age at which a person becomes eligible for statutory and occupational retirement pensions
Thane (1978)	Retirement age occurs between the 45 and 55 years for women and between 55 and 75 years for men
Brubaker (1976); Johnson (1976); Freund and Smith (1997)	Old age is related to health status
Erikson (1959)	Old age is characterized by a tension between integrity and despair and this tension manifests itself by reflections on the past and thoughts about death

In this study, the term 'elderly people' is defined as those aged 60 years and above due to the following reasons:

1. This is a widely used definition by trusted organizations such as the United Nations and World Health Organization. Thus, the data can be easily compared with the work of others.
2. This definition is used by the Department of Statistics Malaysia (2013) in their Monograph Series No. 1: Population Ageing Trends in Malaysia which is produced every 10 years.

2.2.2 Statistical Perspective on Ageing

According to the 'World Population Prospects: The 2012 Revision, Highlights and Advance Table' report published by the United Nations, the population is ageing (United Nations, 2011) whereby the number of people aged 60 years and above is increasing at a rapid rate. The UN predicts that this group will increase from 2.4% annually prior to 2050 to 0.7% annually from 2050 to 2100. The ageing population is also expected to increase by more than 50% over the next four decades, which means that the number of ageing people will rise from 274 million in 2011 to 418 million in 2050 and increases further to 433 million in 2100.

However, the growth of the ageing population is different between over-developed and under-developed regions. The data of both regions are shown in Table 2.2, which indicate that the population almost quadruples in under-developed regions compared to over-developed ones. However, the least developed countries experience a more rapid population growth. It can be seen that the data show a slow increase in the number of ageing population in developing countries, with a value of just 9%. However, it is expected that this proportion will double and triple by 2050 and 2100, reaching 20 and 30%, respectively. Based on these data, it can be deduced that the ageing population will increase in the future.

The average annual rates of change of the total population and the population in broad age groups (0-14 years, 15-59 years, 60+ years and 80+ years) from 2011 to 2050 are shown in Table 2.3. It can be seen that the number of elderly people aged 80 years and above is increasing. There are 109 million of elderly people aged 80 years and above in the world in 2011, which corresponds to 1.6% of the world population. This group is forecasted to reach 402 million of the world population and it will ascend to 792 million in year 2100. This group is the fastest growing population of the world compared with those aged 60 years and above. In Asia, this group is forecasted to increase to 3.07% from 2011 to 2050. However, the percentage of growth of this elderly group will decline to 1.23% from 2050 to 2100. This is also expected to occur for elderly people aged 60 years and above. The number is expected to be high between 2011 and 2050, as much as 2.74%. The figure then declines to 0.32% from 2050 to 2100.

Table 2.2: Average Annual Rates of Change of the Population in Various Regions of the World (1950-1980, 1980-2011, 2011-2050 and 2050-2100) for Different Variants (United Nations, 2011)

Region	1950-2011	1950-1980	1980-2011	2011-2050				2050-2100			
				Low	Medium	High	Constant	Low	Medium	High	Constant
World……………………………….	1.66	1.88	1.45	0.38	0.72	1.05	1.12	-0.54	0.17	0.80	1.79
More developed regions……………	0.70	0.96	0.44	-0.17	0.14	0.44	0.02	-0.67	0.03	0.64	-0.28
Less developed regions……………..	1.97	2.24	1.71	0.49	0.83	1.16	1.31	-0.53	0.19	0.82	1.95
Least developed countries………….	2.41	2.32	2.49	1.45	1.77	2.07	2.62	0.31	0.89	1.41	3.26
Africa……………………………….	2.48	2.47	2.49	1.54	1.85	2.15	2.63	0.42	0.98	1.49	3.22
Asia………………………………....	1.80	2.10	1.51	0.15	0.50	0.84	0.85	-1.06	-0.22	0.49	0.96
Europe………………………………	0.49	0.79	0.21	-0.39	-0.70	0.24	-0.24	-0.89	-0.13	0.52	-0.66
Latin America and the Caribbean…..	2.08	2.57	1.61	0.20	0.58	0.94	0.92	-1.03	-0.18	0.57	0.75
Northern America…………………...	1.16	1.31	1.01	0.33	0.63	0.91	0.61	-0.29	0.33	0.88	0.28

Table 2.3: Average Annual Rates of Change of the Total Population and Population in Broad Age Groups, by Major Areas (2011-2050 and 2050-2100) (Medium Variant) (United Nations, 2011)

Region	2011-2050					2050-2100				
	0-14	15-59	60+	80+	Total population	0-14	15-59	60+	80+	Total population
World……………………………….	0.08	0.55	2.44	3.35	0.74	-0.10	0.04	0.66	1.35	0.17
More developed regions……………	0.16	-0.31	1.08	2.07	0.14	0.07	0.00	0.07	0.51	0.03
Less developed regions……………..	0.07	0.70	2.95	4.20	0.85	-0.12	0.05	0.79	1.63	0.19
Least developed countries………….	1.02	2.05	3.57	4.20	1.81	0.23	0.81	2.26	3.55	0.89
Africa……………………………….	1.20	2.13	3.37	4.08	1.90	0.26	0.95	2.40	3.60	0.98
Asia………………………………....	-0.46	0.26	2.74	3.97	0.51	-0.42	-0.44	0.32	1.23	-0.22
Europe………………………………	-0.01	-0.61	1.00	1.92	-0.07	-0.02	-0.12	-0.19	0.33	-0.13
Latin America and the Caribbean…..	-0.61	0.40	2.89	3.94	0.59	-0.38	-0.46	0.46	1.36	-0.18
Northern America…………………...	0.49	0.34	1.56	2.54	0.64	0.20	0.20	0.63	0.97	0.33

It is expected that Malaysia is also not exempted from demographic transition that is occurring globally. According to the ‘Population Projection’ report published by the Department of Statistics Malaysia (2010), the population in Malaysia is 28.6 million in 2010 and is projected to increase by 10 million (35%) to 38.6 million in 2040. It is expected that those aged 65 years and above will increase more than threefold of the population in 2010. This significant increase shows an increase in the ageing population in year 2021, in which elderly people aged 65 years and above reaches 7.1%. The pyramid of the population in Malaysia from 2010 to 2040 is shown in Figure 2.1, and it can be seen that the pyramid has a smaller base, which indicates a low birth rate. The convex slopes indicate that the adult population mortality is low. The data in year 2040 shows a flat boarder apex, which indicates a rise in the elderly population beginning from an age of 60 years and above.

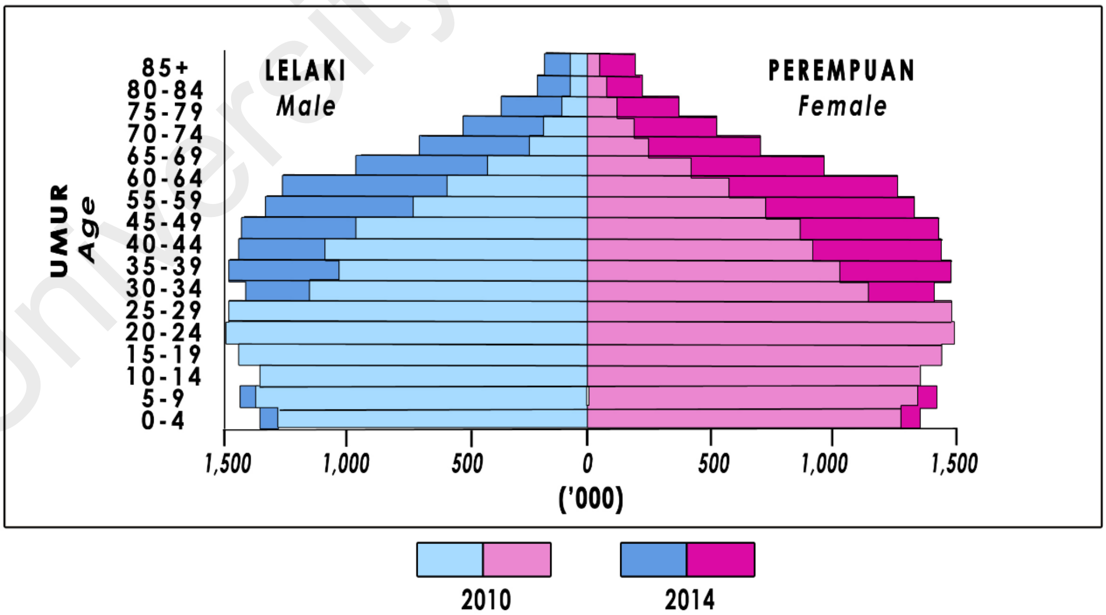

Figure 2.1: Malaysian Population Pyramid in Year 2010 and 2040 (Department of Statistics Malaysia, 2010)

The growth of senior citizens is higher in the rural area compared to the urban area in Malaysia. The most recent statistics show that the states that have a higher incidence of ageing population include Kelantan, Pahang, Terengganu, Perlis and Kedah (Department of Statistics Malaysia, 2010). This is due to the emigration of the younger population from the rural to the urban areas in search of employment and education opportunities, leaving the elderly group behind. The data show that the younger population migrate to more populous states such as Selangor, Federal Territory of Kuala Lumpur, Sabah and Federal Territory of Labuan.

In addition, the increase in the number of elderly people is different between three major ethnics in Malaysia (Department of Statistics Malaysia, 2010). It is expected that there will be an increase in the total population for each ethnic group in Malaysia, whereby the number of Malays shows the most significant increase, followed by Chinese and Indians. The variation between ethnics is due to differences in the levels of fertility, mortality and migration rates of these ethnic groups.

It is believed that the increase in the ageing population is mainly attributed to a decline in fertility (United Nations, 2011). In addition, the longer life of elderly people may be attributed to improvements in social security (Cowgill & Holmes, 1994). Cowgill and Holmes (1994) highlighted that with modernization, the provision of economic security for dependent elderly tends to shift from the family to the government. This can be directly measured based on the pensions received by the elderly group, which reduces their dependence on family members. This is likely to improve the quality of life of elderly people.

Improved healthcare is also a major reason for the growing ageing population (Kart & Ford, 2002). The definition of health measures is rather ambiguous, and thus Kart and Ford (2002)) categorized health measurements in three sub-categories of physical health, i.e. (1) general physical health, (2) the ability to perform basic Activity of Daily Living (ADL) and (3) Instrumental Activity of Daily Living (IADL). Mental health is an additional aspect of health. Zainal (2010) quoted The Ministry of Health Malaysia defined health as the capacity of the individual, group as well as environment interacting with one another to promote subjective well-being and optimal functioning, along with the use of cognitive, affective and rational abilities towards the achievement of individual and collective goals. Programs have been developed throughout the Asian region in response to the healthcare needs of elderly people. Developing countries such as Malaysia has made recent initiatives in the development of health services for older people which include community nursing, occupational therapy, pharmaceutical and dental services.

In general, the ageing population is increasing not only on the global scale, but also in Malaysia. Statistics have shown that it can be expected that there will be a significant increase in the elderly group within the next few decades. However, previous studies have shown that elderly people are physically limited due to the ageing process, which affect their performance when carrying out daily activities (Jarosz, 1999). Jarosz (1999) also highlighted that the elderly group can perform their daily activities independently by ergonomic reshaping of their living environment. This involves designing and developing products and facilities which will facilitate the elderly group in performing their tasks. Indeed, ergonomic products and facilities will make their lives easier and reduce their dependence on others. Hence, it is necessary to obtain a comprehensive database on the somatic characteristics of the elderly. The somatic characteristics that are important when designing and developing products and facilities for elderly people are anthropometric and hand grip strength data (Jarosz, 1999).

2.3 Anthropometry

Anthropometry refers to the measurements of the human body dimensions, which can either be taken in static or dynamic states. Anthropometric data are essential since they provide designers with knowledge on the users' physical dimensions which will enable designers to propose design solutions that fulfil their special needs. It has been shown that consumers experience discomfort and in worse cases, accidents and injuries, due to the use of unsuitable products and workspace dimensions. Hence, knowledge on anthropometric data will be beneficial to tailor products which will fulfil consumers' physical needs and limitations.

In general, anthropometry is typically confined to the measurements of a person's body size and shape. However, anthropometry may also include postural data and a person's reach capabilities. The user's abilities such as strength or psychological data are sometimes measured for specific applications and are also referred to as anthropometric data. This is due to the fact that the term 'ergonomics' and 'anthropometry' overlap one another. However, in this thesis, the definition of anthropometric data is limited to the physical measurements of the human body. The historical background of anthropometry, reliability and applications of anthropometric data, as well as anthropometric studies of elderly people and an overview of anthropometric studies in Malaysia are presented in the following sub-sections.

2.3.1 Historical Background

Anthropometry has a long history, dating back to the work of Leonardo da Vinci such as his proportional drawings in portraitures. However, from a technical and engineering perspective, the first anthropometric study is traced back to the early 1860s. The major anthropometric methods developed in 1870 were 'Broca' and 'French' which were invented by two French scholars, namely Broca and Quetelet. They used binomial distributions (average in human stature) and determined the relationship between the number of individuals of average size in proportion to ‘nains’ (dwarfs) and ‘giants’ (giants). Their findings emphasized on population statistics in order to understand populations, body proportions and generate summaries concerning the human form. The historical timeline of anthropometric works from 1860 to 1950 is presented in Figure 2.4.

A sampling of anthropometric history is given by (After the Franco-Prussian War in 1870, a German scholar, Ihering, made proposals to call German anatomists and anthropologists to re-investigate craniometric and anthropometric measurement methods. In 1892, a French scholar, Collignon, made an effort to unify anthropometric measurements with nomenclature. However, his work was only influential on French scholars rather than the international audience. The beginning of a true international movement on anthropometry began in Moscow in 1892, in the Twelfth International Congress of Prehistoric Anthropology and Archaeology.

A number of congresses followed thereafter. However, it was in 1912 that the anthropometric framework on both skeletal and living human subjects was standardized. Numerous anthropometric works have been carried out since then to increase people’s awareness on anthropometry and its uses, as well as focusing on the scientific rigor of anthropometry. Traditional anthropometry has a long history with regards to its methods of measurement and standardization, which enables ergonomists to evaluate and assess the physical interactions between people and their environment (Feathers, 2005).

Current works on anthropometry have been discussed by Parsons (1995) in his seminal paper titled ‘Ergonomics and international standers’. The USA was initially the secretariat of ISO TC 159 SC3 (Human Factors Society); however, the responsibility was entrusted to Japan due to a lack of progress. There are four working groups (WG) in ISO TC 159 SC3, namely WG1 (Anthropometry), WG2 (Evaluation of working postures), WG3 (Human physical strength) and WG4 (Manual handling and heavy weights). There are two work items in the first working group (WG1), namely ‘Basic list of anthropometric measurements’ and ‘Ergonomics-Hand reach envelopes’.

The introduction of the standard emphasizes the importance of designing and developing products and facilities based on the size and shape of people. The scope is covers a basic list of anthropometric measurements for use in establishing common, comparative definitions of population groups. The content is presented in three sections, i.e. (i) definitions, (ii) measuring conditions and (iii) basic list of anthropometric measurements. A standard diagram is used for each measurement along with a description, method of measurement and measuring instrument for the whole body while standing and sitting, as well as measurements of body segments including the hands, head and feet.

Other standards (PrEN 547-1 and PrEN 547-2) are concerned with the safety of machinery, human body dimensions and the design of access openings. The anthropometric data for these standards are obtained from static measurements on nude individuals and are representative of European men and women. These data form the basis to design access openings, whereby the PrEN 547-1 and PrEN 547-2 standard provides information and method of measurement for the whole body and certain parts of the body, respectively.

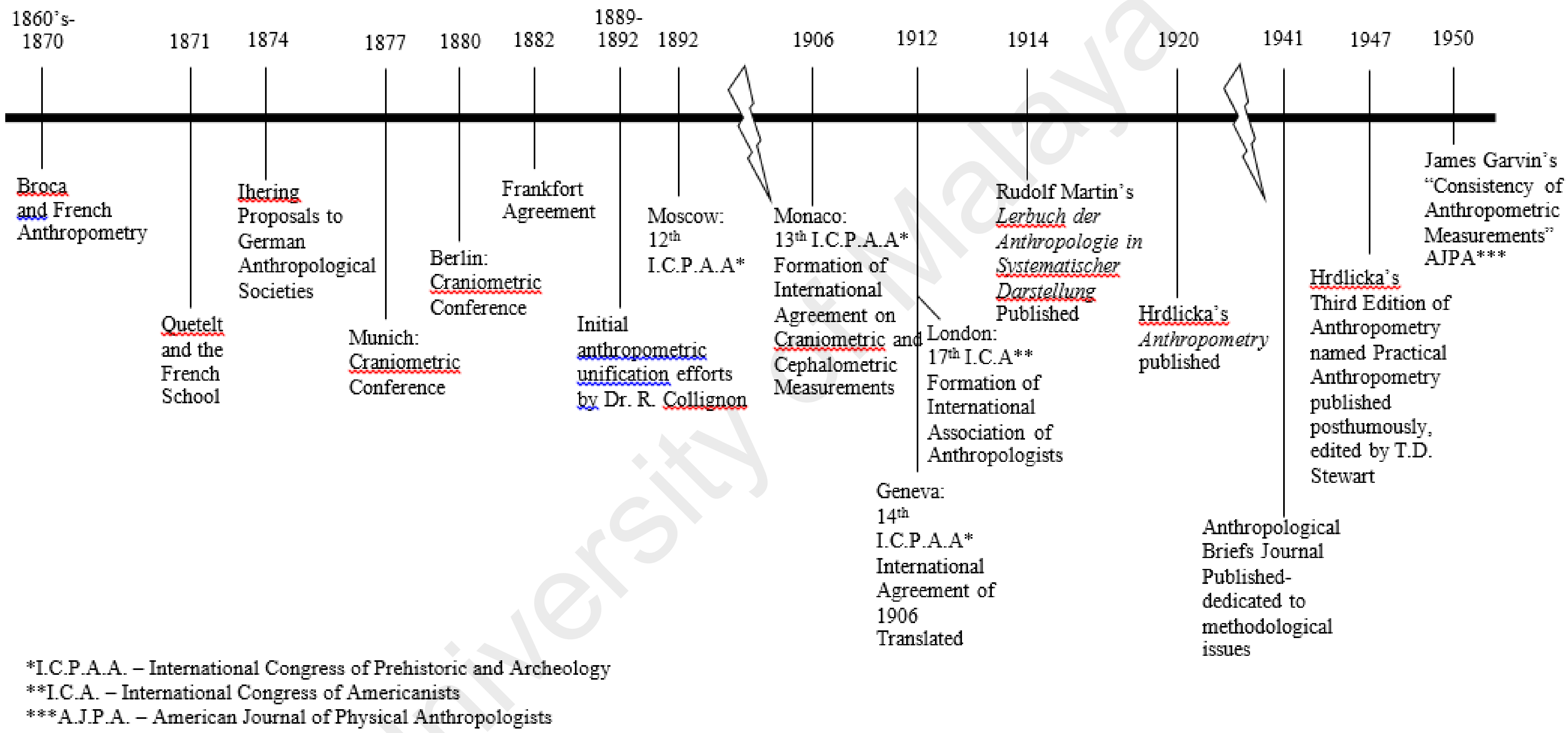

Figure 2.2: Sampling of Anthropometric Works from 1860 to 1950 (Feathers, 2005)

2.3.2 Anthropometric Measurement Techniques

In general, there are two types of anthropometric measurement techniques, namely traditional anthropometry and 3D body scanning, and are summarized in Table 2.4.

Table 2.4: Summary of Traditional Anthropometry and 3D Body Scanning

Measurement technique	Traditional anthropometry	3D body scanning
Description	Provides data on static dimensions of the human body in standard postures (Kroemer et al., 1986). Most measurements are taken while standing, except for a few measures. Subjects should be completely bare or dressed in minimal clothing.	A system that uses a horizontal sheet of light to completely surround and measure the body introduced by Magnant in 1985 (Simmons & Istook, 2003). The framework of the system involves the use of projectors and cameras to scan the body from head to toe.
Tool	The same anthropometric instruments are used since Richer first used callipers in 1890 (Simmons & Istook, 2003). These simple, quick, non-invasive tools include a weighing scale, camera, measuring tape, anthropometer, spreading callipers, sliding compass and a head spanner.	Recent instrumentation for 3D body scanning utilizes lasers. A list of current major scanning systems is listed in Table 2.10.
Landmarks	Uniformity must be achieved for all common points on the body in order to obtain consistent body measurements in an anthropometric-based study (Simmons & Istook, 2003). These points are known as landmarks.	The primary way to locate anthropometric landmarks involves placing markers on the human body prior to scanning (Azouz et al., 2006). However, these methods are tedious and time-consuming. Therefore, the method is improved by eliminating pre-marking or using pre-marking only on a few subjects. Most of the recent works are limited to locating the branching points such as armpits and crotch.
Strength	Traditional anthropometric data are represented in the form of statistical summary (means, percentiles etc.) and are easy to use. They are particularly useful to compare samples from different populations in order to determine differences in size and variation (Ball et al., 2010).	1. Improved modelling accuracy which aids complex design solutions. This helps to visualize cases involving the equipment or apparel used (Robinette & Hudson, 2006).

Table 2.4 continued

Measurement technique	Traditional anthropometry	3D body scanning
Strength		2. Gives better approximation to real life than 3D models built from traditional anthropometric data which lead to better outcomes, such as improved accommodation envelope (fit more people in the same space or product) and greater safety (Simmons & Istook, 2003).
Weakness	Time-consuming and inaccurate (Gordon & Bradtmiller, 1992)	1. 3D anthropometric data are relatively new and their use requires knowledge and skills. The data must be accessible. Furthermore, the method requires users to learn specialized software. 2. The errors in landmark locations have significant effects on body dimensions as well as the results of shape analysis (Kouchi et al., 2012).

2.3.3 Reliability of Anthropometric Data

Several studies have discussed the reliability of anthropometric data measured using the traditional approach and 3D body scanning method. (Kouchi et al., 2011) discussed the reliability of anthropometric data, as shown in Figure 2.3. It is found that the factors that significantly influence the reliability of anthropometric data are landmarking and benchmarking errors. The landmarking errors need to be reduced in order to obtain data with high reliability.

<table>
<tr><th colspan="2" rowspan="2">Data / Factor</th><th rowspan="2">Traditional body dimension</th><th colspan="3">Scan-derived measurement</th></tr>
<tr><th>Body dimension</th><th>Landmark coordinate</th><th>Surface shape</th></tr>
<tr><td rowspan="4">Tool</td><td rowspan="2">Hardware accuracy</td><td>Accuracy of instrument</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Accuracy of scanner system hardware</td></tr>
<tr><td rowspan="2">Software performance</td><td rowspan="2"></td><td colspan="2">Landmarking software</td><td rowspan="2"></td></tr>
<tr><td>Measurement calculation software</td><td></td></tr>
<tr><td rowspan="6">Human</td><td rowspan="2">Measurer skill</td><td colspan="3">Skill of landmarking</td><td rowspan="2"></td></tr>
<tr><td>Skill of measurement</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Operator skill</td><td rowspan="2"></td><td colspan="2">Landmarking software</td><td rowspan="2"></td></tr>
<tr><td>Measurement calculation software</td><td></td></tr>
<tr><td rowspan="2">Subject</td><td colspan="4">Repeatability of posture</td></tr>
<tr><td></td><td colspan="3">Body sway during scan</td></tr>
</table>

Figure 2.3: Possible Factors which Introduce Errors in Anthropometry (Source: Kouchi et al., 2012)

According to the Australian Safety and Compensation Council (2009), the difficulties encountered during data interpretation lies in determining the point of reference. Even though raw data can be obtained from measuring tapes, anthropometers and callipers and are typically presented in the form of spreadsheets, these data are hard to find and may be difficult to use. Knowledge and skills are still required to decipher and separate the numbers from one another and determine the actual measurements using a computerized statistical analysis package. Furthermore, it shall be noted that knowledge on anthropometric data are still insufficient to create a good product design if the relationship between these elements is not known (Robinette & Hudson, 2006). According to the report, there are numerous standards used in studies which will affect the reliability of the data, comprising a variety of anthropometric measurement techniques and terminologies. A lack of a unified, internationally accepted standardized measurement and naming system has hampered the use of anthropometric data for many years. The reliability of anthropometric data is questionable and it is likely that a designer who is neither an expert in anthropometry nor a skilled ergonomist will end up making errors.

The main reliability issue concerning anthropometry is inter-observer errors, as highlighted by Kouchi et al. (2012). Measurement error consists of two aspects, namely (1) the closeness of the measured value to the true value (accuracy) and (2) the closeness of the two repeated measurements (precision). They investigated 32 measurement items and the variance was overestimated by more than 10% for five items because of random errors or inter-observer errors or both.

Even though anthropometric measurement errors are unavoidable, they should be minimized by examining each aspect carefully in order to increase the reliability of anthropometric data. A few suggestions have been made in previous studies as follows:

1. Perform equipment calibration and train research personnel (Routen, 2010).
2. Use a standardized data collection methodology, and conduct rigorous training and monitoring of data collection personnel, frequent and effective equipment calibration and maintenance, and perform periodic assessment of anthropometric measurement reliability (De Onis et al., 2004).
3. Test and re-test an experiment using technical error of measurement (TEM) and determine the standard deviations of differences between repeated measurements (Cameron, 2013).
4. Standardize the measurement technique when it comes to giving instructions to the subjects, locating landmarks and handling instruments in order to minimize both inter-observer and random measurement errors (Kouchi et al., 2012).

Thus, this study has practiced a few provisions to get the most accurate data as possible, which are:

1. By avoiding inter-observer errors to get the accuracy of value (the closeness of the measured value to the true value. This has been done by appointing two researchers for the task of measuring the anthropometry. One researcher measured the subjects, while the other one documented the data. This practice would minimize the risk of inter-observer errors.
2. The average of three measurements was taken into the analysis. This practice would enrich the precision of data.

2.3.4 Applications of Anthropometric Data

Anthropometric data can be applied in various ways. Some may use them to compare the body dimensions of the population between countries or races, while others may use them as a predictor of diseases. The applications of anthropometric data are summarized in Table 2.5.

Table 2.5: Applications of Anthropometric Data

Application	Researcher(s)	Description	Significance of the study
Products and facilities	Liu (2008)	200 subjects aged from 20-59 years are selected to measure their outer ear dimensions.	Anthropometric dimensions are presented, and it is concluded that the current ear-related products need to be re-designed. The shapes of ear hole and pinna are not circular.
	Ball et al. (2010)	Geometric morphometric are used to dense surface data in order to quantify and characterize shape differences using 600 random datasets from two recent 3D anthropometric surveys (one in North America and Europe, and one in China).	Chinese heads are rounder than Caucasian counterparts, with a flatter back and forehead. The quantitative measurements and analyses of these shape differences may be applied in many fields, including anthropometrics, product design, cranial surgery and cranial therapy.
	Dewangan et al. (2008)	An anthropometric survey is carried out for female agricultural workers of two northeastern hill states of India. A total of 400 subjects participated in the study aged from 18-60 years, and 76 body dimensions are measured.	The anthropometric data taken shall be used in the design and/or design modification of agricultural tools, machinery and equipment which will be operated by female workers in the hilly region of the country.
	Dewangan et al. (2010)	A set of 76 body dimensions including age and body weight is measured from a sample of 801 male agricultural workers from four major and 14 minor tribes of northeastern region of India.	The anthropometric data taken shall be used in the design and/or design modification of agricultural tools, machinery and equipment which will be operated by female workers in the hilly region of the country.
	Ramadan and Al-Shayea (2013)	The suitability of a modified backpack that distributes the carrying loads on the school children's chest and back is investigated, involving 238 subjects aged 4-18 years. The height, weight, heart rate and subjective measurements are measured.	The data can be used to provide the community with a new backpack that increases comfort as well as decreases pain and occupational illness.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
	Oyewole et al. (2010)	The anthropometric measures of 20 first-graders are used to develop regression equations for furniture dimensions.	This anthropometric analysis can be used to design ergonomic-oriented classroom furniture which will not only incorporate adjustability, but also improve the level of comfort for the intended users.
Spaces	Zhuang et al.(2013)	Head-and-face shape variations of US civilian workers are quantified using modern methods of shape analysis.	The results can be used to improve respirator designs in order to develop a more efficient and safer product.
	Kumar et al. (2009)	A tractor control layout assessment is examined with respect to the Indian population. The location of controls and workspace envelopes is compared with the IS12343 standard for commonly used tractors on Indian farms.	The controls of the tractors are not within the workspace envelopes of the Indian population. The data obtained can be used as a guideline to improve Indian tractors.
	Pennathur et al. (2003)	The effects of age on the functional outer fingertip and grip reaches of men and women are investigated.	The differences in the functional reach are more pronounced among Mexican American women than Mexican American men.
	Toomingas and Gavhed (2008)	A survey of workstation layout and work postures among 156 computer operators in Sweden is carried out. The data are examined to determine the operators' comfort, symptoms and existing ISO-standards, EU-directives and National Work Environment Law.	The quality of the furniture and equipment is generally good and fulfils the demands of the law, directives and standards. The data can be utilized to improve comfort, health and productivity.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
	Yang and Malek (2009)	A general analytical method is presented to determine the upper extremity workspace for any percentile in Santos^{TM}, which is a digital human modelling system.	The workspace of virtual humans can be easily visualized using Santos^{TM}. The general method presented in this study is important in human factor analysis and can be widely used for product design, manufacturing and ergonomics evaluations.
	Bae and Armstrong (2011)	A model is developed to describe finger motion during reach and grasp.	The proposed model shows a good fit with the observations. The model can be used to design hand-held tools, controls and handles.
Secular trend	Dangour et al. (2003)	The changes in body size of 4.0-4.9-year-old children are investigated over an 8-year study period. The data are collected from samples in 1992, 1994 and 2000.	The results show that there is no statistically significant change in body size of 4.0-4.9-year-old boys between 1992 and 2000, but the girls become significantly smaller. This may be due to the prolonged period of economic instability in Kazakhstan. There is a possibility that the different trends between Kazakh boys and girls may be due to gender discrimination in food allocation over the study period.
	Helmuth (1983)	The anthropometry and secular trend in growth of three principal Canadian populations (native Indians, Inuits and Europeans) are investigated from 1901 to 1977 (76-year period).	It seems unlikely that nutrition can account for the secular trend in growth for Canadian native Indians and Inuits. The protein hypothesis needs to be examined critically.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
	Cole (2003)	The aim of this review paper is to study the secular trend in biological aspects rather than social history.	The secular trend in human physical growth is a natural experiment which highlights the complex interplay between genes, physiology and environment in determining the size and shape of individuals from one generation to the next.
	Bartali et al. (2003)	A cross-sectional survey of a population-based sample of older people is carried out over a wide range living in the Chianti area, Italy between 1998 and 2000.	Height and weight decline with age, regardless of the differences in body size which are attributable to secular trend. The findings may be relevant to interpret the changes in waist-to-hip ratio among older people. However, the findings are obtained from a cross-sectional study and should be verified based on a longitudinal perspective.
	Cardoso and Canina (2010)	The secular trends in social class differences of height, weight and BMI of boys investigated. The study is focused on two schools in Lisbon, Portugal from 1910-2000 (90-year period).	Both samples show a considerable increase in height, weight and BMI. However, the class differences in height, weight and BMI decrease slightly throughout the 90-year period. The data suggest that socioeconomic disparities are persistent, having diminished only slightly since the early 20^{th} century.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
	Kinnunen et al. (2003)	The secular trends in the average pregnancy weight gain are studied between the 1960s and 2000 in Finland. The focus of the study is to determine whether the changes are related to BMI, age or parity.	The mean pregnancy weight gain has increased since the 1960s, which may be of importance with regards to the pregnancy weight gain over time.
	de Onis et al. (2004)	The results of national and international studies concerning the assessment of childhood growth are reviewed. The weight of each child is evaluated using the 1077 National Center for Health Statistics and the growth charts from the Centers for Disease Control and Prevention 2000.	The findings can be used as an early recognition of excessive weight gain relative to linear growth and can be used for standard clinical practice.
Gender differences	Nicolay and Walker (2005)	The relationship between anthropometric variation and grip performance among 51 male and female individuals aged 18-33 years old is investigated.	The findings can be used by ergonomists as important factors for design and research.
	Mohammad (2005)	The hand dimensions of right- and left-handed individuals are measured. The study is carried out on 400 Jordanian subjects (200 males and 200 females).	The results indicate that there are significant differences in the hand measurements between right and left-handed individuals between male and female subjects. The findings can be used to design hand tools for the Middle East market.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
	da Silva Coqueiro et al. (2009)	A cross-sectional, population-based household survey is conducted on 1905 subjects between 1999 and 2000. The data are presented in the form of the mean and percentiles for body mass, height or stature, waist, arm and calf circumference, triceps skinfold thickness, as well as arm muscle circumference.	All anthropometric variables show a decrease with increasing age in men and women. This study provides information that can be used for anthropometric evaluation of elderly people in Havana and other urban areas in Cuba.
Ethnic differences	Chuan et al. (2010)	The anthropometric data of Singaporean and Indonesian populations are collected mainly from university students. The data are collected from 245 male and 132 female subjects (Indonesia) and 206 male and 109 female subjects (Singapore).	The data are used to update the anthropometric database of Singaporeans and Indonesians populations.
	Ball et al. (2010)	The shape differences are quantified and characterized using a large dataset from two recent 3D anthropometric surveys; one in North America and Europe, and one in China.	The data are applied in many fields, including anthropometrics, product design, cranial surgery and cranial therapy.
	Lin et al. (2004)	The means of 33 body dimensions and 31 bodily proportions are compared between Chinese, Japanese, Korean and Taiwanese in East Asia.	The ethnic diversity in bodily proportions should be considered as well as the mean dimensions.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
Social class and occupation	Pigeyre et al. (2012)	The relationship between BMI and socioeconomic position according to gender is investigated and the weight-related behaviours are explored. A total of 1646 French adults are weighed and they complete questionnaires regarding their eating behaviour, ideal weight perception, physical activity and smoking.	Gender differences in the relationship between BMI and socioeconomic position are mainly due to the subjects' perception of weight appropriateness and their weight-related behaviours.
	Oliveira et al. (2000)	The anthropometric profiles of 132 female adolescents are investigated, aged from 11 to 18 years old from different social and economic levels in Rio de Janeiro. The anthropometric evaluation consists of measuring the weight, stature, mid-arm circumference and seven skinfolds of the adolescents.	The privileged social and economic level adolescents exhibit a larger percentile of body fat and they are significantly taller than the socially and economically underprivileged adolescents.
	Schoch et al. (2012)	The height of Swiss conscripts from 1875 to 1950 is analysed.	Height is affected by economic status and social-class affiliation.
Functional abilities	de Castro et al. (2010)	The anthropometric characteristics of the feet of elderly women with and without arthritis are determined. The right and left feet of 227 older women aged between 60 and 90 years old are measured.	The width of the right foot is significantly greater among women with arthritis. These preliminary findings may help direct future studies in investigating the foot characteristics of older adults with arthritis.

Table 2.5 continued

Application	Researcher(s)	Description	Significance of the study
	Paquet and Feathers (2004)	The structural anthropometric dimensions of adult wheelchair users are studied in order to develop a database of the structural characteristics and functional abilities of wheelchair users. The measurements are made on 121 adults using manual and powered wheelchairs with an electromechanical probe that registers 3D locations of 36 body and wheelchair landmarks.	The results can be applied to create a universal design of occupational environments and products that afford greater usability for mobile wheelchair users.
	Xu et al. (2008)	The effects of body weight on lifting performance are explored. The lifting kinematics and ground reaction forces of a group of 12 subjects are investigated; 6 with a BMI of less than 25 kg/m^2 (normal) and 6 with a BMI greater than 30 kg/m^2 (obese).	BMI has a significant effect on trunk kinematics. This study provides quantitative data which describes the difference in lifting task performance between people of different weights.

2.3.5 Anthropometric Studies in Malaysia

A review of anthropometric studies in Malaysia is presented in this section. The key anthropometric studies and their findings are summarized in Table 2.6. Anthropometry is an area that has received much attention from researchers in Malaysia over the years, and it can be seen that numerous studies have been carried out on anthropometric measurements, the differences in anthropometric dimensions between ethnic groups, the application of anthropometry to improve product design (particularly school furniture and household products), the application of anthropometry for medical purposes, the estimation of stature from mathematical equations and comparison of anthropometric data with other populations from various countries.

Studies pertaining to anthropometric measurements of Malaysians were carried out by Nasir et al. (2011), Mohamad et al. (2010) and Ngoh et al. (2011). These studies have successfully produced a comprehensive anthropometric database for the Malaysian population, encompassing different ethnic groups. It shall be highlighted that Malaysia is a multi-racial nation, in which the major ethnic groups are Malays, Chinese and Indians. Studies on the anthropometric differences between ethnics were conducted by Rosnah et al. (2009) and Karmegam et al. (2011). The results showed that there are differences in the anthropometric dimensions between ethnics in Malaysia. Hence, ethnicity should be considered when designing products and facilities for Malaysian citizens.

Studies related to the use of anthropometric measurements to improve product design have been carried out in the past few years. Nazif et al. (2011) and Afzan et al. (2012) studied the use of anthropometric measurements with regards to school furniture whereas Zakaria (2011) studied the sizing system for school uniforms. These studies showed there is a mismatch between school furniture and children’s anthropometric measurements. They recommended that school furniture should be designed to fit in with the children’s physiological measurements. Daruis (2011) and Deros et al. (2009) studied the improvement of chairs and seats for Malaysians and they found that the seating parameter dimensions are generally larger than other Asians' 95th percentile values, but smaller than those for Filipinos and Thais.

Other researchers have estimated stature from mathematical equations such as the works of Hisham et al. (2012) and Shahar and Pooy (2003). Other studies have focused on anthropometric dimensions for medical purposes. For example, Yap et al. (2001) investigated the difference in lung volume between ethnics whereas Hussain and Abdul Kadir (2010) conducted anthropometric measurements on the distal femur and proximal tibia of Malays.

Several researchers have carried out comparative studies on anthropometric measurements with other countries. Taha et al. (2009) compared the anthropometric characteristics of Malaysian and Saudi Arabian males from 20 to 30 years of age. The results showed that there is a significant difference in the number of body dimensions between these populations, with the exception of the eye height and elbow height and height while standing, as well as eye height, shoulder height and elbow height while sitting. Chong and Leong (2011) compared the anthropometric data of Malaysians with those for Dutch people and found that the largest difference between these samples is stature.

Table 2.6: Summary of Anthropometric Studies in Malaysia

Researcher(s)	Objective	No. of subjects	No. of body dimensions	Method	Key findings
Nasir et al. (2011)	To establish anthropometric data of male youth.	50 males Age range: 19-24 years;	24	Manual measurement	The respondents from the East Coast of Peninsular Malaysia are significantly taller than the respondents from other regions.
Rosnah et al. (2009)	To determine if there are differences in the anthropometric data between age, gender and ethnic groups of the elderly population in Malaysia.	129 males and 101 females	39	Manual measurement	Some anthropometric dimensions are influenced by age, gender and ethnicity.
Nazif et al. (2011)	To evaluate the percentage of mismatch between Malaysian secondary students' anthropometric measurements with existing school science laboratory furniture.	57 males and 63 males Age range: 16-19 years	7	Manual measurement	There is a substantial degree of mismatch between the students' body dimensions and laboratory furniture.
Karmegam et al. (2011)	To determine the differences in anthropometric data between three ethnic groups in Malaysia.	150 males and 150 females Age range: 18-24 years;	33	Manual measurement	There are differences in the body dimensions between ethnic groups in Malaysia and there is a need to consider ethnicity when designing products for Malaysians.
Deros et al. (2009)	To propose the appropriate chair and table dimensions based on the anthropometric data of Malaysians.	273 males and 365 females Age range: 18-80 years	12	Manual measurement	90% of the values for stature lie between 1473.42 and 1773.68 mm for Malaysian citizens.

Table 2.6 continued

Researcher(s)	**Objective**	**No. of subjects**	**No. of body dimensions**	**Method**	**Key findings**
Hisham et al. (2012)	To estimate stature from foot measurements of Malaysian Chinese.	107 males and 106 females Age range: 20-64 years;	3	Manual measurement	Foot measurements reveal important predictive information about an individual's stature.
Rashid et al. (2008)	To provide guidelines to design ergonomic living environments for older Malaysians.	230 old people Age range: 60 years and above	39	Manual measurement	The designs of 10 homes investigated in the study do not take into account the anthropometric measurements of elderly Malaysians, which in turn may cause discomfort.
Shahar and Pooy (2003)	To develop an equation using several anthropometric measurements in order to estimate stature of elderly Malaysians.	100 adults (aged 30-49 years) 100 elderly people (aged 60-86 years)	6	Manual measurement	Standing height is an ideal technique to estimate the stature of individuals.
Siti Zawiah et al. (2012)	To develop an anthropometric database for high school and university students from Kuala Lumpur, Malaysia.	21 males and 20 females (high school) CHAPTER 1 74 males and 69 females (university)	21	Manual measurement	The data is significantly different between male and female university students.

Table 2.6 continued

Researcher(s)	Objective	No. of subjects	No. of body dimensions	Method	Key findings
Mohamad et al. (2010)	To measure anthropometric dimensions of Malaysians.	516 males and 491 females	40	Manual measurement	A comprehensive anthropometric database is successfully established for the Malaysian population.
Zakaria (2011)	To propose a sizing system specifically for school-aged children in Malaysia.	1001 females Age range: 7-17 years;	93	Manual measurement	This study is the first detailed anthropometric survey to develop a sizing system in Malaysia for local school uniforms.
Yap et al. (2001)	To examine whether anthropometric measurements can explain the differences in the lung volume between ethnic groups.	1250 subjects Age range: 20-90 years;	3	Manual measurement	Ethnic differences in the length of the upper body segment may partially explain the differences in lung volume.
Lim and Ding (2000)	To describe the distribution of body weight, height and BMI of Malaysian adults according to age, sex and ethnicity.	28737 individuals Age range: 20 years and above;	3	Manual measurement	Indians have the highest BMI, followed by Malays, Chinese and other indigenous ethnic groups.
Taha et al. (2009)	To compare the anthropometric characteristics between Malaysians and Saudi Arabians.	241 Malaysians and 646 Saudi Arabians (all males) Age range: 20-30 years	26	Manual measurement	There is a significant difference in the number of body dimensions between these populations, except for eye height and elbow height and height while standing, as well as eye height, shoulder height and elbow height while sitting.

Table 2.6 continued

Researcher(s)	Objective	No. of subjects	No. of body dimensions	Method	Key findings
Chong and Leong (2011)	To determine whether there are differences in the anthropometric data between Malaysian adults and other populations.	50 males and 50 females Age range: 19-25 years;	27	Manual measurement	The largest difference between Malaysians and Dutch is stature.
Daruis (2011)	To present sitting anthropometric data for Malaysians, with focus on seat fitting parameters.	216 subjects	16	Manual measurement	The fit parameter dimensions are larger than other Asians' 95^{th} percentile values, but smaller than those for Filipinos and Thais.
Bari et al. (2010)	To examine the foot anthropometric data of preschool children in Malaysia.	129 males and 174 females	4	Manual measurement	There is a significant difference in the length and width between the right and left foot.
Zarith Afzan et al. (2012)	To determine the mismatch between school furniture and anthropometric measurements among primary school children in Mersing.	46 males and 45 females Age range: 8-10 years;	7	Manual measurement	There is a mismatch between school furniture and children's anthropometric measurements. Thus, school furniture should be re-designed to conform to children's physiological measurements.
Hussain and Abdul Kadir (2010)	To obtain anthropometric data of the distal femur and proximal tibia of Malays.	50 males and 50 females Age range: 19-38 years	2	3D body scanning	The results will be used to develop a high-flex knee implant for Malays throughout South-East Asia region.

Table 2.6 continued

Researcher(s)	Objective	No. of subjects	No. of body dimensions	Method	Key findings
Sulaiman, et al. (2013)	To identify the acceptable stove height and depth and to determine the working envelope of elderly Malaysians using anthropometric data.	25 males and 30 females Age range: 60-85 years;	5	Manual measurement	56.4% of the waist height of elderly is lower than the standard table-top height (which is 36 inches) and 36.4% of the stove height is higher than that of the standard.
Anne and Moy (2013)	To study the association between physical activity levels and metabolic risk factors of Malay adults in Malaysia.	272 males and 414 females Age range: 35-74 years	8	Manual measurement	Moderate and high activity levels are associated with reduced odds for metabolic syndrome, regardless of gender.
Singh (2010)	To study the secular trends in cardio-respiratory parameters and anthropometric data of Malaysian females in 1995, 2000 and 2005.	Age range: 13-60 years	4	Manual measurement	The weight of Malaysian females increases with a co-commitment decline in pulmonary capacity and fitness levels.
Ngoh et al. (2011)	To investigate the age differences of anthropometric characteristics among elderly men.	135 males Age range: 60 years	4	Manual measurement	There is a risk of malnutrition among institutionalized elderly men in Northern Peninsular Malaysia.

2.4 Hand Grip Strength

It is known that hand grip strength is correlated with age, weight, height, gender, occupation and hand dominance (Ahmad et al., 2010). The definition of hand grip strength, the tools used to measure hand grip strength and studies related to hand grip strength for elderly people are presented in this section.

2.4.1 Measurement of Hand Grip Strength

Hand grip strength can be measured quantitatively using a hand dynamometer. However, the methods used to characterize grip strength vary considerably, and it is dependent upon the dynamometer and the measurement protocol used. Jamar hand dynamometer (Lafayette Instrument Company, USA) is the most widely used hand dynanometer in previous studies and is accepted as the gold standard by which other dynamometers are evaluated (Mathiowetz et al., 1985; Massy-Westropp et al., 2011). This instrument features the most extensive normative data (Innes, 2002) even though such data are available for other instruments such as the BTE work simulator (Potter et al., 2007) and Martin vigorimeter (Ohn et al., 2013). The Jamar hand dynamometer has demonstrated excellent concurrent validity with known weights (r = 0.9998) (Mathiowetz, 2006). The main features of the different types of dynamometers are summarized in Table 2.7 based on a review by Roberts et al., 2011.

Table 2.7: Summary of the Main Features of Hand Dynamometers (Roberts et al., 2011)

Type of instrument	Hydraulic	Pneumatic	Mechanical	Strain
Measurement parameter	Grip strength	Grip pressure	Grip strength	Grip strength
Operating principle	A sealed hydraulic system that enables grip strength to be read from a dial gauge	Based on the compression of an air-filled compartment such as a bag or bulb	Based on the amount of tension produced in a spring	Based on the variation in electrical resistance of a length of wire due to the strain applied to it
Example of instrument	Jamar hand dynamometer	Martin vigorimeter	Harpenden dynamometer	Isometric strength tester
Measurement units	kilograms (kg) or pounds of force (lbf)	millimetres of mercury (mmHg) or pounds per square inch (psi or lb/in^2)	kilograms (kg) or pounds of force (lbf)	Newtons of force (N)
Advantages	Portable, economical, large amount of normative data available	Gentler on weak or painful joints	No evidence of superiority available in the literature	Not susceptible to leaks (oil, water or air) which will otherwise compromise measurement accuracy
Disadvantages	Can cause stress on weak joints	Measures grip pressure which is dependent on the surface area over which the force is applied. Hand size can therefore influence measurements.	Reproducibility of the grip force measurements is limited due to difficulties in replicating the grip position and calibrating the device	Can be expensive and heavy

The Jamar hand dynamometer is the focus of this study since this dynamometer is widely used among researchers. Even though the dynamometer is small and portable, it is relatively heavy with a weight of 1.5 lb. The unit of measurement for force is kilograms and pounds, with markings at intervals of 2 kg or 5 lb. This enables measurements to be made to the nearest 1 kg or 2.5 lb. The Jamar hand dynamometer requires 3-4 pounds of force in order to move the needle of the indicator, and therefore the instrument may be unsuitable to measure the hand grip strength of very weak patients (Imrhan et al., 2010). In addition, it has been reported that the measurement errors are greater at lower force loads. Hence, the calibration accuracy of the instrument should be checked regularly for new instruments (Massy-Westropp et al., 2011) and it is recommended that the instrument is calibrated annually or at frequent intervals if it is used on a daily basis. The studies that used Jamar hand dynamometer to measure hand grip strength are summarized in Table 2.8.

Table 2.8: Summary of Hand Grip Strength Measurement Protocols Employed in Previous Studies Using Jamar Hand Dynamometer

Studies	Population (*n*)	Instructions	Hands tested	Measure used
Bohannon and Schaubert (2005)	Community-dwelling elderly people, USA (21)	Not stated	Both	Reading from a single trial
Desrosiers et al. (1995)	Community-dwelling elderly people, Canada (360)	Standardized instructions based on the work of Mathiowetz et al. (1984)	Both	Highest reading out of three trials
Fried and Guralnik (1997)	Community-dwelling elderly people, Cardiovascular Health Study (419)	Not stated	Dominant	Mean reading of three trials
Sayer et al. (2004)	Community-dwelling elderly people, the Hertfordshire Cohort Study (2677)	Standardized encouragement given	Both	Highest reading of three trials
Werle et al. (2009)	Community-dwelling adults, Switzerland (1023)	Standard instructions at a constant volume	Both	Mean reading of three trials

Hand grip strength is the only measurement parameter recommended to assess muscle strength. Furthermore, it is the simplest method to assess muscle function (Roberts et al., 2011). Longitudinal studies have confirmed that hand grip strength declines after midlife, and the losses in hand grip strength increase with increasing age (Bohannon, 2008) and throughout old age (Sayer et al., 2004). Hand grip strength also differs between healthy elderly people (Wu et al., 2009; Tsang, 2005; Luna-Heredia, 2005; Schlüssel et al., 2008) as shown in Table 2.9. The relationship between hand grip strength and other variables that has been investigated in previous studies is discussed in the following section.

Table 2.9: Comparison of Hand Grip Strength between Healthy, Elderly People

No.	Researcher(s)	Country	Age range of subjects	Number of subjects	Mean hand grip strength (N)	
					Males	Females
1.	Wu et al. (2009)	Taiwan	60-80 years (males and females)	144	264.78	169.16
2.	Tsang (2005)	Hong Kong	60-69 years (males and females)	18	355	204.96
3.	Schlüssel et al. (2008)	Brazil	60+ years (males and females)	197	336.37	192.70
4.	Luna-Heredia et al. (2005)	Spain	60-79 years (males and females)	132 (males) 93 (females)	272.62	164.07

2.4.2 Relationship between Hand Grip Strength and Other Variables

Studies on hand grip strength have been carried out in a large number of countries, and in most cases, the data are divided into age and gender sub-groups (Angst et al., 2010; Bohannon and Schaubert, 2005; Mathiowetz et al., 1985). In general, it is found that hand grip strength is higher among males regardless of age group, whereas the hand grip strength is highest among those in their forties, followed by a gradual decline in strength for both males and females (Angst et al., 2010; Bohannon and Schaubert, 2005; Mathiowetz et al., 1985). The trend is similar, regardless whether the subjects are classified according to age, gender or hand dominance (Incel et al., 2002).

Hand grip strength can be used as an indicator of other health conditions (Angst et al., 2010; Bohannon and Schaubert, 2005). It has been shown that normal hand grip strength is positively related to normal bone mineral density in post-menopausal women (Karkkainen et al., 2010), whereas some researchers suggest that hand grip strength can be used as a screening tool for women who are at risk of osteoporosis (Di Monaco et al., 2000). There is a lack of consensus regarding the relationship between hand grip strength and BMI in the literature, whereby a large number of researchers claimed that there is a positive correlation between hand grip strength and BMI for both males and females of all ages, whereas others discovered that there is no relationship between these parameters (Koley et al., 2009; Apovian et al., 2002). The relationship between hand grip strength and age, gender and body composition found in previous studies is summarized in Table 2.10.

Table 2.10: Relationship between Hand Grip Strength and Age, Gender and Body Composition

Variable	Researcher(s)	Title of the article	Key findings
Age	Evans and Hurley (1995)	Age, gender, and muscular strength	Hand grip strength peaks at around 25-35 years of age. (Male: *n* = 35; female: *n* = 50)
	Metter et al. (2002)	Skeletal muscle strength as a predictor of all-cause mortality in healthy men	There is a significant decrease in hand grip strength at around 50 years of age, and the decrease is more pronounced after an age of 65 years. (Male: *n* = 993; female: *n* = 184)
	Evans and Hurley (1995)	Age, gender, and muscular strength	The average decrease in hand grip strength is 12-15% per decade and 30% after the seventh decade. (Subjects age range: 20-93 y; male: *n* = 346; female, *n* = 308)
	Evans and Hurley (1995)	Age, gender, and muscular strength	Losses in strength occur earlier in the lower extremities compared to the upper extremities (including hand grip strength). However, the total percentage of decrease in strength is equal for both the lower and upper extremities. (Subjects age range: 20-93 y; male: *n* = 346; female, *n* = 308)
	Metter et al. (2002)	Skeletal muscle strength as a predictor of all-cause mortality in healthy men	There is a loss of hand grip strength within a range of 40-50% for both males and females from 20 to 90 years of age. (Male: *n* = 993; female: *n* = 184)
Gender	Metter et al. (2002)	Skeletal muscle strength as a predictor of all-cause mortality in healthy men	Men are stronger and have greater muscle mass than women. (Male: *n* = 993; female: *n* = 184)
	Evans and Hurley (1995)	Age, gender, and muscular strength	Women experience a decrease in strength at a younger age but at a slower rate. (Subjects age range: 20-93 y; male: *n* = 346; female, *n* = 308)

Table 2.10 continued

Variable	Researcher(s)	Title of the article	Key findings
Gender	Edgren et al. (2004)	Grip force vectors for varying handle diameters and hand sizes	The hand grip strength of women is between 50 and 74% the strength of men. (Male: *n* = 29; female: *n* = 32)
	Watanabe et al. (2005a)	The short-term reliability of grip strength measurement and the effects of posture and grip span	Women have a muscle capacity which is approximately two-thirds the capacity of men. (Male: *n* = 50, mean age, 38.2; female: *n* = 50, age range, 22-58 y)
	Matsuoka et al. (2006)	An analysis of symmetry of torque strength of the forearm under resisted forearm rotation in normal subjects	Men have a strength that is twice the strength of women. (Subjects age range: 22-45 y; male: *n* = 51; female, *n* = 51)
Body composition	Frontera et al. (1991)	A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women	A 12-year study suggests that the loss of muscle cross-sectional area may account for 90% of the loss in strength among healthy sedentary men with increasing age. (Subjects age range: 45-78 y; male: *n* = 100; female, *n* = 100)
	Harris et al. (2000)	Waist circumference and sagittal diameter reflect total body fat better than visceral fat in older men and women:The health, aging and body composition study	Heavier subjects are generally stronger because they have more muscle mass, regardless of age. (Subjects age range: 70-79 y; male: *n* = 1391; female, *n* = 1439)
	Miyatake et al. (2012)	Relationship between muscle strength and anthropometric, body composition parameters in Japanese adolescents	Hand grip strength is greater among Japanese obese subjects (BMI > 26.4 kg/m^2) relative to the control groups for both genders under 60 years of age, but similar between groups for those above 60 years of age. (Subjects age range: 15-19 y; male: *n* = 48; female, *n* = 189)

2.4.3 Correlation between Hand Grip Strength and Anthropometric Dimensions

The studies that involve direct measurements of hand grip strength and anthropometric dimensions are reviewed and presented briefly in this section.

Schmidt and Toews (1970)

The relationship between hand grip strength and anthropometric dimensions was investigated in this study, in which the anthropometric dimensions are height and weight. They tested the grip strength of the dominant and non-dominant hands of 1128 males using Jamar hand dynamometer whereby the grip setting was fixed at 1½ inches. The distribution of the dominant and non-dominant grip strength was recorded as a function of height and weight.

The results showed that the mean grip strength is 51.3 and 49.7 kg for the dominant and non-dominant hand in male subjects, respectively. They also examined the individual scores of the right and left hand and discovered that 22.6% of the men are stronger in their non-dominant hand, whereas 5.4% possess equal strength bilaterally. Hence, 28% of the men have a non-dominant hand grip strength that is equal to or greater than the grip strength of their dominant hand.

In addition, there is a linear relationship between height and weight with hand grip strength. In general, subjects who are taller have higher hand grip strength. The same trend is observed for weight, whereby subjects who are heavier have higher hand grip strength. However, it shall be noted that these data are representative of healthy male individuals and therefore they may be inapplicable to females.

Figure 2.4: Major and Minor Grip Strength versus Height (Schmidt & Toews, 1970)

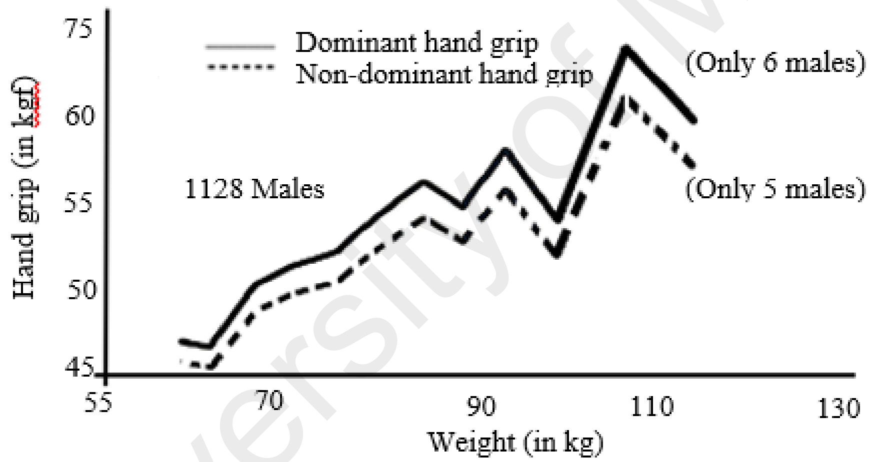

Figure 2.5: Major and Minor Grip Strength versus Height (Schmidt & Toews, 1970)

Hulens et al. (2001)

The main focus of this study was to investigate whether peripheral muscle strength is significantly different between lean and obese women, in which age and physical activity are the controlled factors. An allometric approach was adopted in this study. The isometric hand grip, isokinetic leg and trunk muscle strength were compared between lean and obese women. The anthropometric measures investigated in this study are weight and height. The isometric strength and isokinetic strength were measured using Jamar dynamometer and Cybex dynamometer, respectively, and the results revealed that the isokinetic output is larger among obese women compared to lean women, except for the knee-flexion and isometric hand grip, whereby the difference was insignificant ($p > 0.05$). It is found that the Pearson correlation coefficients between the strength measures and fat-free mass (kg) are low to moderate for lean women. In addition, there is no correlation between the strength measures and fat mass (kg) among lean women. In contrast, there is a weak positive correlation for most of the isokinetic data for obese women.

Roberts et al. (1959)

The effects of limb position and other variables on arm strength were explored in this study, and relative values were established for various conditions. Seven anthropometric dimensions were quantified, namely stature, weight, upper arm length, forearm length, hand length, upper-arm girth and forearm girth. The hand grip strength, elbow flexion strength and elbow extension strength were also measured.

In general, the results showed that anthropometric dimensions and hand grip strength are positively correlated with one another. This suggests that people who are large in one body dimension tend to have body measurements and limb strength that are above average. It is also found that the better the correlation between the longitudinal measurements, the better the correlation between the girth measurements.

A few conclusions can be drawn from these three seminal papers by Schmidt and Toews (1970), Hulens et al. (2001) and Roberts el al. (1959):

1. There is a linear relationship between anthropometry and hand grip strength.

2. People who have larger anthropometry dimension tends to have strength above the average value.

These studies have shown that both anthropometry and hand grip strength are strongly related to each other. Taking this idea into consideration, the current study will investigate both variables in Malaysian elderly population. First, the need is thus obvious for data gathering for Malaysian database and second, to use the data as a guideline in order to produce hand-held products which later can cater the older people's needs.

2.5 Summary

A comprehensive review on elderly people and studies pertaining to anthropometry and hand grip strength is presented in this chapter. The key findings of previous studies are also highlighted in this chapter.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Overview

The methodology adopted in this study is described in detail in this chapter, which is divided into two major sections. The method used for measuring anthropometric dimensions and hand grip strength among elderly Malaysians is described in Section 3.2, which includes the criteria for selection of subjects, sample size, equipment as well as data analysis. The development of the regression models is also discussed in detail in this section. The regression models are validated using a case study, which is described in Section 3.3, consisting of the dependent and independent variables. A summary is given at the end of this chapter.

3.2 Research Design

This study was designed to investigate the relationship between anthropometric dimensions and hand grip strength among elderly Malaysians. The criteria used in the selection of subjects, sample size, dependent and independent variables, as well as data analysis techniques are presented in this section.

3.2.1 Subject

The inclusion criteria used in the selection of subjects are listed as follows:

1. The subjects must be aged 60 years and above.
2. The subjects must be community-dwelling elderly.
3. The subjects must be able to understand and speak basic Malay and English.
4. The subjects must sign the written informed consent given by the University of Malaya Medical Centre Ethics Committee, which indicates that they fully agree to participate in this study.

5. The subjects were not reported or found to suffer from uncontrolled orthopaedic, cardiovascular, pulmonary neurological or cognitive diseases, which was determined from the oral interview and health screening questionnaire adapted from Nasarwanji (2012). The health screening questionnaire is shown in Appendix A.
6. The subjects did not suffer from other health problems which may interfere with their ability to perform the hand grip strength test such as skin ulcers on the skin.

3.2.2 Sample Size

The sample size was estimated based on a study by (Hu et al., 2007). The number of subjects was estimated according to the equation given in Annex A of ISO 15535:2003 'General requirements for establishing anthropometric databases' based on a 95% confidence interval and 5th and 95th percentiles:

$$n \geq \left(3.006 \times \frac{\mathrm{CV}}{\alpha}\right)^2 \tag{3.1}$$

where n is the sample size, CV is the coefficient of variation and α is the percentage of relative accuracy desired. In this study, a 10% relative accuracy was required for the 5th and 95th percentiles and an empirical value of CV = 25 was used to pre-determine the sample size. The number of subjects was roughly 56 for both males and females, and hence, the sample size was 112 subjects. The executed numbers were also approved by the expert opinion by the statisticans. Sampling was carried out at Petaling Jaya, Selangor as shown in Figure 3.1. This city was chosen as the sampling area because Petaling Jaya is the most densely populated area in Selangor, with a high number of elderly Malaysians compared to other areas within the state.

Figure 3.1: Map of All Districts in Selangor Darul Ehsan (Department of Statistics Malaysia, 2013)

3.2.3 Equipment

Anthropometric Measuring Instruments

The measuring instruments used to collect data consist of a standard anthropometer (TTM Martin's Human Body Measuring Kit, Mentone Educational Centre, Carnegie, Vic., Australia), a weighing scale and an adjustable chair. The measuring kit consisted of instruments which can measure distance in the form of straight lines, curves, circumferences and thicknesses. An adjustable chair was used to measure variations in the sitting position.

Figure 3.2: Human Body Measuring Kit

Hand Grip Strength Equipment

Jamar hand dynamometer (Sammons Preston Roylan, Bolingbrook, IL) was used to measure the hand grip strength of the subjects. The dial measures force in both kilograms and pounds, with markings at intervals of 2 kg or 5 lb, which enables measurements to the nearest 1 kg or 2.5 lb. The hand dynamometer requires 3-4 pounds of force to move the indicator needle (Roberts et al., 2011). However, the error is more pronounced at lower loadings.

Figure 3.3: Jamar Hand Dynamometer

3.2.4 Measurement Protocol

Anthropometric Measurements

The protocol used for anthropometric measurements was based on the procedure outlined by Pheasant and Haslegrave (2006). In addition, it was required that the subjects were measured with minimal clothing and bare feet. Each measurement is presented in detail in Appendix B.

Hand Grip Strength Measurements

The protocols used for hand grip strength measurements are summarized in Table 3.1. The protocols shown were based on the review by Roberts et al. (2011).

Table 3.1: Protocols for Hand Grip Strength Measurements

Protocol	Study	Findings	Settings used in this study
Hand dominance	Petersen et al. (1989)	The dominant hand has a grip which is 10% stronger than the non-dominant hand.	Previous studies have shown that there are significant results in the dominant hand. Thus, the hand grip strength of elderly Malaysians was focused on their dominant hand.
	Crosby et al. (1994)	Hand grip strength among Americans and Greeks is stronger for right-handed people, but the hand grip strength is equal in both hands for left-handed people.	
	Bohannon (2003)	A review on 10 studies reveals that right-handed subjects are stronger in their right hand compared with left-handed subjects, in which the results are equivocal.	
Wrist and forearm position	Bohannon (2003)	Varying the position of the forearm between neutral, supinated and pronated alters the hand grip strength. The supinated position produces the strongest force, whereas the force is weakest in the pronated position.	The forearm pronates to the neutral position and wrist is between 0 and 30° for dorsiflexion and between 0 and 15° for ulnar deviation. These settings were chosen in accordance to the manufacturer's manual for Jamar dynamometer.

Table 3.1 continued

Protocol	Study	Findings	Settings used in this study
Elbow	Mathiowetz et al. (1985)	Sitting with the elbow in 90° flexion rather than fully extended produces higher hand grip strength.	Sitting with the elbow in 90° flexion was chosen due to the higher hand grip strength shown in previous studies.
	Beaton et al. (1995)	There is a significant difference in the hand grip strength between 45 and 90° of elbow flexion.	
Shoulders	Su et al. (1994)	The highest mean hand grip strength is obtained when the shoulder is in 180° of flexion, whereas the lowest mean grip strength is found when the shoulder is in 0° flexion and the elbow is flexed to an angle of 90°.	The shoulder position was chosen based on the manufacturer's manual, in which the shoulders were adducted and neutrally rotated.
Posture	Shechtman et al. (2001)	There is an insignificant difference in the hand grip strength of the subjects between sitting and standing positions.	Hand grip strength measurements were carried out while the elderly was in sitting position.
	Balogun et al. (1991)	The hand grip strength of college students is higher in standing compared to the sitting position.	
Effort and encouragement	Jung and Hallbeck (1999)	Verbal encouragement influences the hand grip strength and introduce measurement errors.	No verbal encouragement was made.
Interval between measurements	Watanabe et al. (2005)	The mean of two readings is compared for each hand, which is measured repeatedly without rest or taken at 1-min intervals in 100 subjects. The hand grip strength decreases gradually during repeated measurements, whereas there is no difference in the hand grip strength during interval measurements, regardless of gender or the dominant hand.	The interval in between tests was chosen to be 1 min.
Number of assessments	Hamilton et al. (1994)	Similar test-retest reliability is obtained with a single trial, as well as the mean of two or three trials and the maximum of three trials.	The mean of the highest two trials from three measurements was used for analysis.

3.2.5 Procedure

The procedure implemented in this study was approved by the University of Malaya Medical Centre Ethics Committee. The subjects were informed on the purpose of the study prior to data collection, which is to explore the relationship between anthropometric dimensions and hand grip strength in elderly Malaysians. The subjects were required to sign an informed consent form (Appendix C) which indicates that they agree to participate in the study. The experimental procedure was described in detail and the subjects were allowed to rest for 5 minutes after each measurement, if necessary.

The experiment consisted of two phases, as shown in Figure 3.4. The first phase involved measuring the anthropometric dimensions of the subjects, and the subjects were required to wear light clothing and remove their shoes (bare feet). Measurements were made according to the definitions given by Pheasant and Haslegrave (2006) consists of 91 anthropometric dimensions, as shown in Table 3.2. The dimensions include most of the basic anthropometric measurements for facility design recommended by several sources (Molenbroek, 1987; Pheasant, 1986; Steenbekkers and Van Beijsterveldt, 1998; Stoudt, 1981). Each measurement was taken three times and the mean value was determined. The measurements were carried out in both standing and sitting positions. A description of each anthropometric dimension is given in Appendix B.

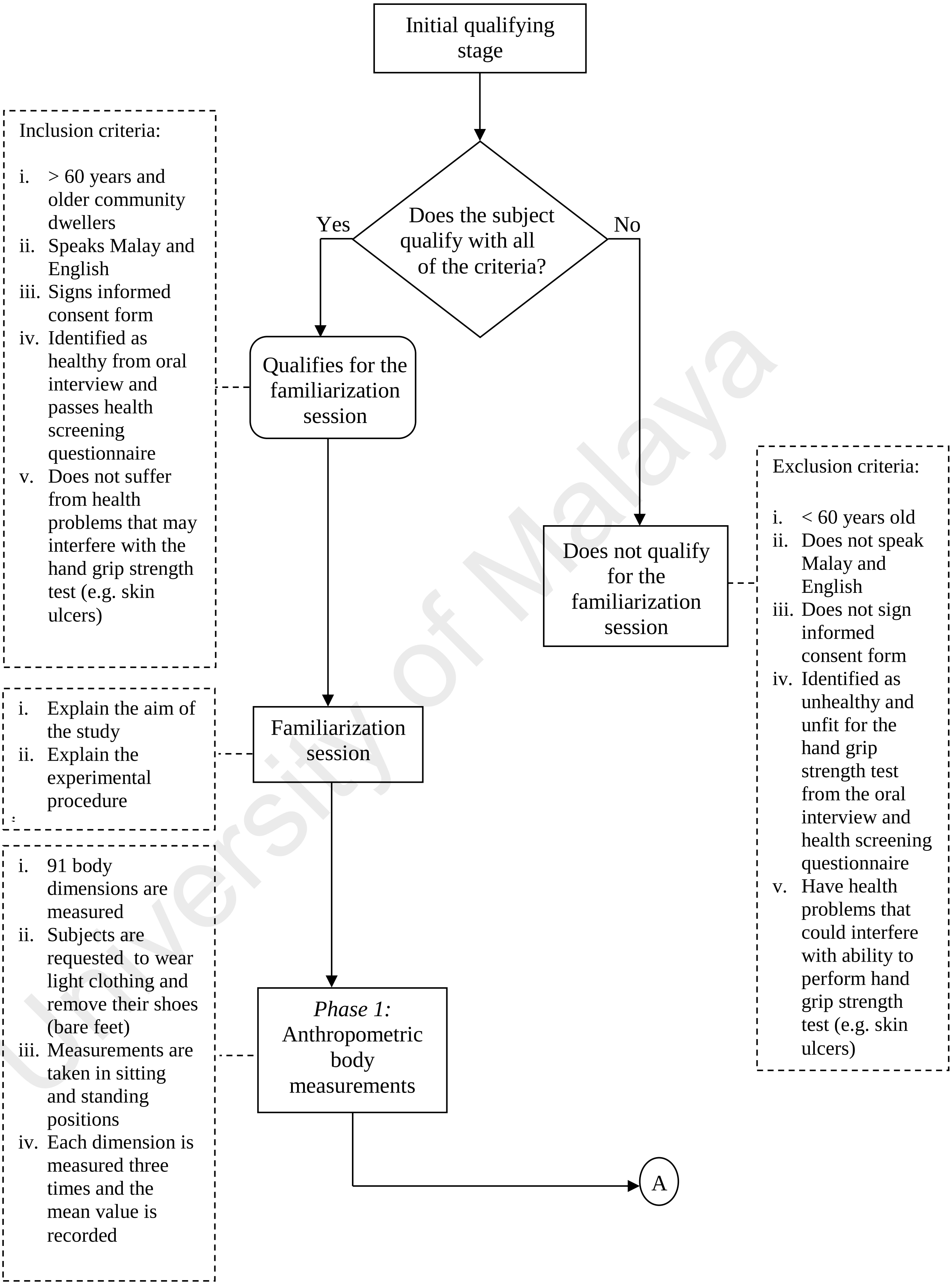

Figure 3.4: Flow Chart of Research Design

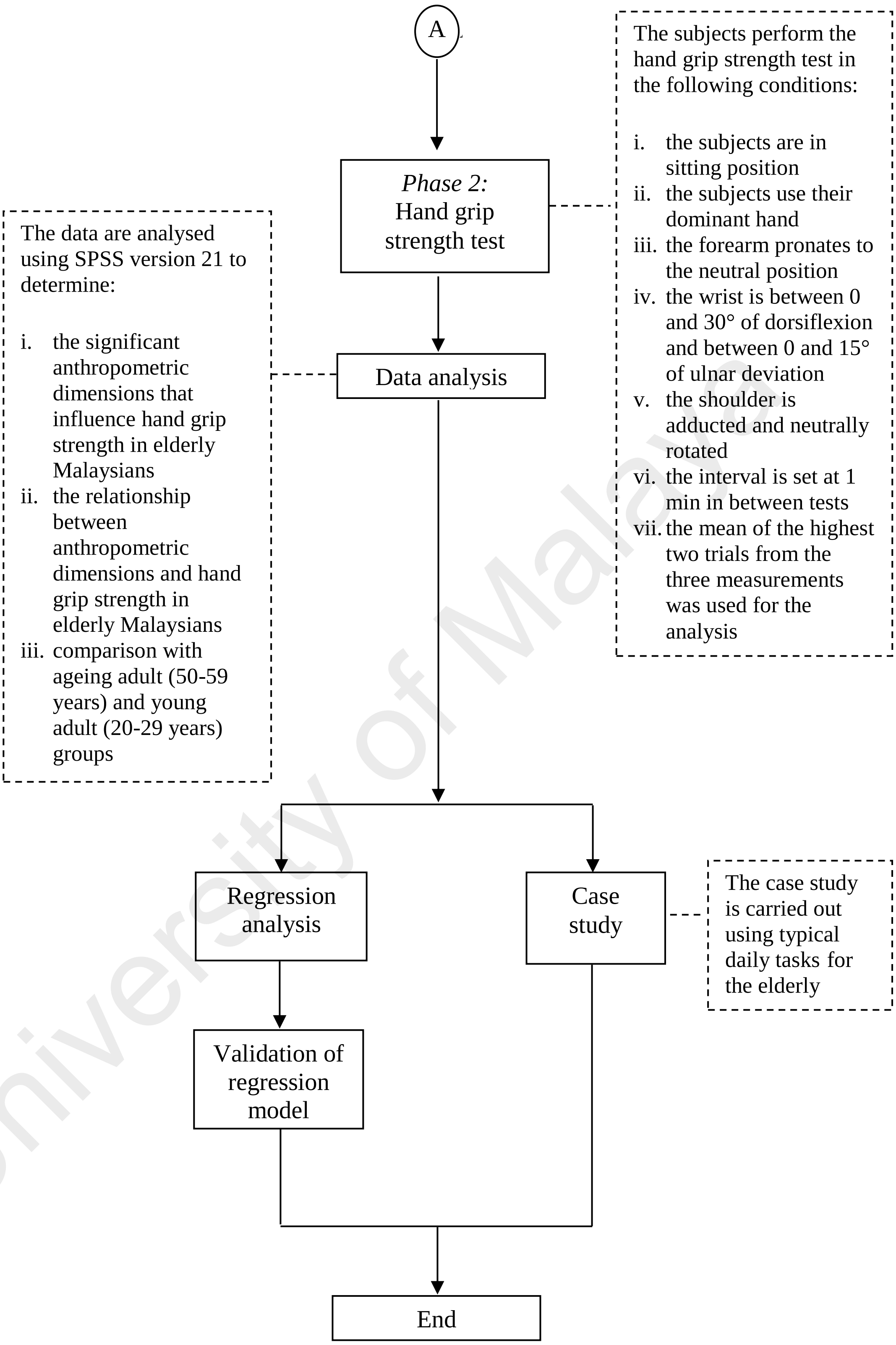

Figure 3.4 continued

Table 3.2: List of Selected Anthropometric Dimensions

No.	Dimension	No.	Dimension
1.	Weight	47.	Hand length
2.	Overhead reach	48.	Wrist-index finger length
3.	Stature	49.	Index finger length
4.	Eye height, standing	50.	Index finger breadth, proximal
5.	Shoulder height	51.	Index finger breadth, distal
6.	Elbow height	52.	Wrist-thumb tip length
7.	Chest height	53.	Hand breadth
8.	Waist height, omphalion	54.	Thumb breadth
9.	Buttock height	55.	Palm length
10.	Crotch height, standing	56.	Wrist centre of grip length
11.	Knee height, midpatella	57.	Foot length
12.	Calf height	58.	Ball of foot length
13.	Span	59.	Foot breadth, horizontal
14.	Elbow span	60.	Heel breadth
15.	Shoulder breadth, standing	61.	Foot height
16.	Thumb tip reach	62.	Head length
17.	Wrist-wall length, extended	63.	Head breadth
18.	Wrist-wall length	64.	Face breadth
19.	Sleeve inseam	65.	Interpupillary breadth
20.	Elbow to elbow breadth	66.	Menton to top of head
21.	Chest breadth	67.	Face length
22.	Waist breadth	68.	Head circumference
23.	Hip breadth	69.	Neck circumference
24.	Shoulder length	70.	Shoulder circumference
25.	Chest depth	71.	Chest circumference at scye
26.	Waist depth	72.	Chest circumference
27.	Buttock depth	73.	Waist circumference, omphalion
28.	Sitting height	74.	Buttock circumference
29.	Eye height, sitting	75.	Scye circumference
30.	Acromion height, sitting	76.	Axillary arm circumference
31.	Waist height, omphalion, sitting	77.	Elbow circumference, straight
32.	Thigh clearance	78.	Biceps circumference, flexed
33.	Sitting elbow height	79.	Forearm circumference, flexed 90°
34.	Arm reach upward	80.	Wrist circumference
35.	Knee height sitting	81.	Hand circumference
36.	Popliteal height (lower leg height)	82.	Thumb circumference
37.	Arm reach forward	83.	Index finger circumference
38.	Forearm-hand length	84.	Middle finger circumference
39.	Elbow fingertip length	85.	Crotch thigh circumference
40.	Shoulder width	86.	Lower thigh circumference
41.	Interscye breadth	87.	Knee circumference
42.	Shoulder-elbow length	88.	Calf circumference
43.	Buttock knee length	89.	Ankle circumference
44.	Buttock popliteal length	90.	Head ankle circumference
45.	Abdominal extension depth, sitting	91.	Ball of foot circumference
46.	Hip breadth, sitting		

The hand grip strength of the subjects were measured after measuring their body dimensions. The hand grip strength test was carried out when the subject was in a sitting position with the arm near the torso, the elbow flexed at 90°, the forearm pronated to a neutral position, the wrist between 0 and 30° of dorsiflexion and between 0 and 15° of ulnar deviation, and the shoulder was adducted and neutrally rotated. The readings of the three trials were recorded, and the mean of the two highest trials was used in subsequent analysis. The hand grip strength was chosen over other muscle strengths due to the following reasons:

1. There is a direct correlation between hand grip strength and the overall body strength among very old females (Smith et al., 2006).
2. There is a correlation between hand grip strength and performance, as shown among weightlifters in the American Men Junior Weightlifting (Fry et al., 2006).

The data was analysed using Statistical Package for Social Science software (IBM SPSS Statistics for Windows version 21.0, Armonk, NY: IBM Corp) in order to determine the anthropometric dimensions that significantly influence hand grip strength in elderly Malaysians. The results were then used to determine the relationship between anthropometric dimensions and hand grip strength among elderly Malaysians. Detail of statistical procedure is shown is Figure 3.5.

In conducting a correlation or a regression test, it is important to decide on the statistical significance which is given as p-value. There are three alternative hypotheses can be selected if the test statistic is symmetrically distributed. Two of these correspond to one-tailed tests and one corresponds to a two-tailed test. However, the p-value presented is (almost always) for a two-tailed test. Two-tailed test means that a significance level of 0.05 is used. A two-tailed test allots half of the alpha to test the statistical significance in one direction and half of the alpha to test statistical significance in the other direction. This means that 0.025 is in each tail of the distribution of the test statistic. The mean is considered significantly different if the test statistic is in the top 2.5 % or bottom 2.5 % of its probability distribution, resulting in a p-value less than 0.05.

Whereas, one-tailed test means that 0.05 is in one tail of the distribution of the test statistic. When using a one-tailed test, the possibility of the relationship in one direction and completely disregarding the possibility of a relationship in the other direction. Depending on the chose tail, the mean is significantly greater or less if the test statistic is in the top 5 % of its probability distribution or 5 % of its probability distribution, resulting on a p-value less than 0.05.

However, this study used mostly two-tailed distribution due to the reasons stated below:

1. The one-tailed test provides more power to detect an effect in one direction by not testing the effect in the other direction, however, it is appropriate to consider the consequences of missing an effect in the other direction.
2. The default in SPSS performing tests is to report two-tailed p-values. Because the most commonly used test statistic distributions are symmetric about zero, most one-tailed p-values can be derived from the two-tailed p-values.

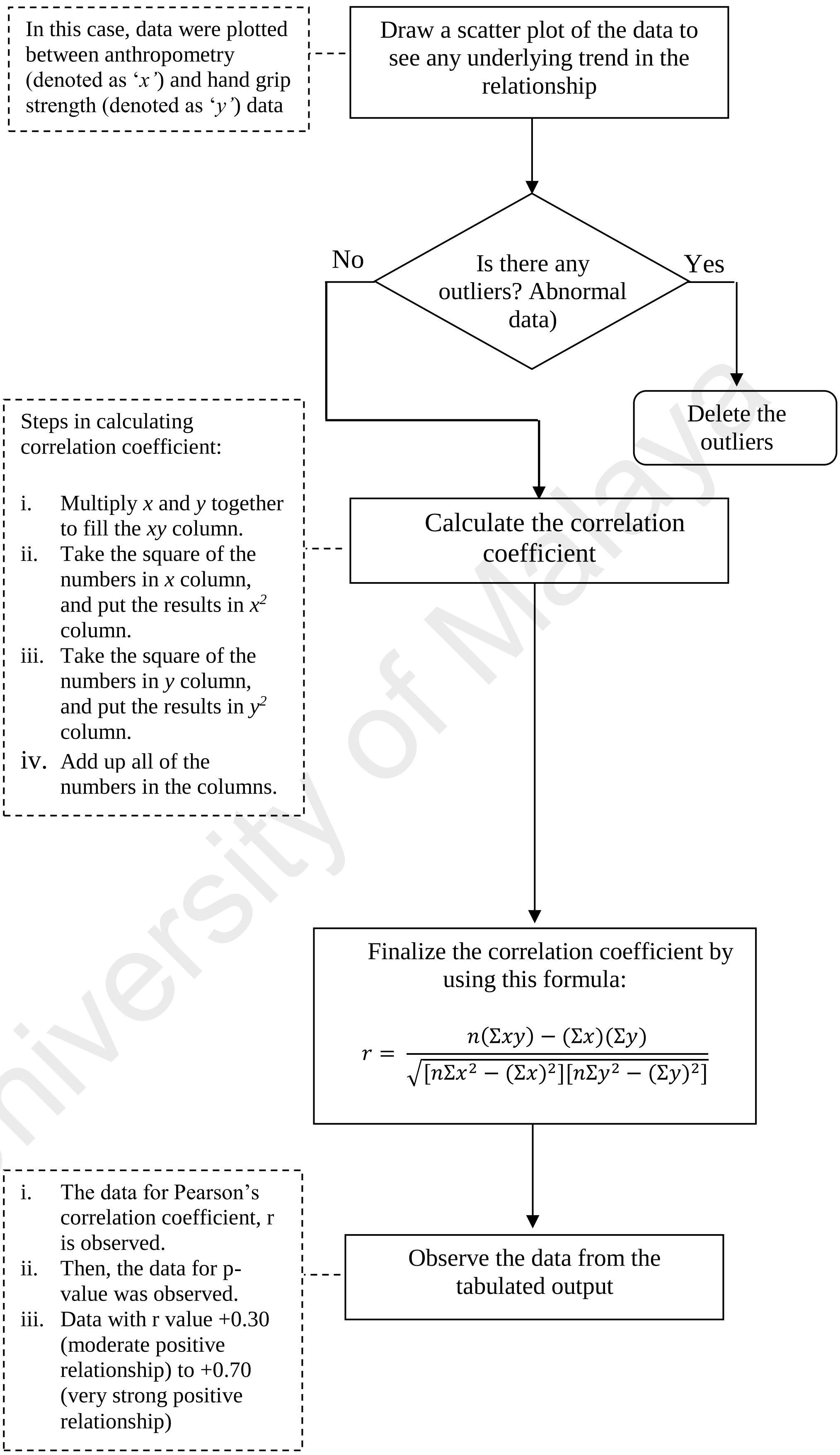

Figure 3.5: Detail Steps in Statistical Analysis

Then, a further analysis has been done on another two groups of population with the similar 37 anthropometry dimensions and hand grip strength analysis. First group is a group of people age between 20 to 30 years old, whereas the second group is a group of people age between 50 to 59 years old. Sample size for both groups are 30 subjects for the each group (15 males and 15 females) which accumulate of 60 subjects. The analysis was also carried out to determine if there is a significant difference in the anthropometric dimensions and hand grip strength among these three groups.

Then, a linear regression test was then carried out to establish a regression model which predicts the hand grip strength of elderly Malaysians as a function of significant anthropometric variables; one for males and females, respectively. The models were validated using sample from other elderly data. A case study was conducted to validate the methodology used in this study and is discussed in detail in the following sub-section.

3.3 Case Study

A case study was conducted to validate the methodology used in this study to correlate anthropometric dimensions with hand grip strength. The case study involved an experiment where the subjects were required to perform a task that is typically faced by the elderly, which is bottle-opening. This task was chosen since it has been proven in previous studies that bottle-opening is one of the most challenging tasks faced by the elderly in their daily activities (Voorbij and Steenbekkers, 2002; Yoxall et al., 2006).

3.3.1 Subjects

The inclusion criterion is such that the subjects must participate in the anthropometric dimension and hand grip strength measurements in order to be eligible for the case study. Thirty elderly subjects (15 males and 15 females) were included in case study.

3.3.2 Dependent Variables

The dependent variables were the hand anthropometric dimensions which have a significant correlation with hand grip strength, i.e. hand length, wrist-index finger length, thumb circumference, index finger circumference and middle finger circumference. The dimensions of the dominant hand were measured. The hand torque strength was another dependent variable and refers to the strength exerted when the subject twisted the lid in order to open the bottle and accessed its contents (Yoxall & Janson, 2008). The subjective measurements were measured based on the subjects' ratings of perceived discomfort.

The perceived discomfort ratings were reported verbally by the subjects in accordance to the Borg CR10 Scale (Borg, 1998). A rating of 0, 1-2, 3, 4-5, 6-7, 8, 9 and 10 indicates 'Extremely comfortable', 'Very comfortable', 'Comfortable', 'Somewhat uncomfortable', 'Uncomfortable', 'Very uncomfortable', 'Extremely uncomfortable' and 'Painful'. The subjects rated their level of perceived discomfort using this scale. The reader is referred to Appendix E.

3.3.3 Independent Variables

The independent variables investigated in this study pertain to the design of the bottle lid, (i.e. diameter, height and surface texture). Five bottles (as shown in Figure 3.6 and Table 3.3) were chosen for the case study, whereby each bottle has a different diameter, height and surface texture and labelled as A, B, C, D and E, respectively. The bottles were typical products sold in grocery stores and hypermarkets in Malaysia and therefore they were representative of products commonly found at home.

Figure 3.6: Photograph of the Bottles Used in the Case Study

Table 3.3: Characteristics of the Bottle Lids Used in the Case Study

Code	Shape of lid	Surface properties		Size (mm)	
		Texture	Material	Lid diameter	Bottle height
A	Circular	Smooth	Plastic	18	85
B	Circular	Serrate	Plastic	40	83
C	Circular	Smooth	Metal	55	148
D	Circular	Smooth	Metal	61	77
E	Ball	Smooth	Metal	23	85

The experiment consists of one independent variable and four dependent variables, as shown in Table 3.4.

Table 3.4: Variables Used in the Case Study

Variables		Description	Unit
Independent	Bottle lid design	- Five levels (A, B, C, D and E)	N/A
Dependent	Hand dimension	- Five dimensions	mm
	Hand torque strength	- Maximum strength	Nm
	Subjective rating	- Perceived discomfort ratings	Borg's CR-10 scale

3.3.4 Hand Anthropometric Measurements

The hand anthropometric dimensions were measured using a small metallic anthropometer. The anthropometer was used to measure the breadth, length and depth of the subject's hand, and it was equipped with curved sliding branches which provide direct readings to the nearest millimetre over a range of 30 cm. Circumference measurements were taken using a measuring tape with a scale in centimetres and millimetres and a measurement range of 1.5 m.

Hand Torque Strength Test

Mecmesin Orbis digital torque tester (Mecmesin Limited, West Sussex, UK) was used to measure the hand torque strength of the subjects when they open the bottle lids. The digital torque tester has a measurement range of 0-6 N.m (0-60 kgf.cm) and a display resolution of 0.002 N.m (0.02 kgf.cm). The instrument is capable of measuring the diameter of a container up to 190 mm while the sampling rate is 5000 Hz averaged to a peak capture of 80 Hz. The Mecmesin Orbis digital torque tester is shown in Figure 3.7.

Figure 3.7: Digital Torque Tester

3.3.5 Procedure

The subjects were briefed on the purpose of the case study prior to the test, which is to determine the relationship between anthropometric dimensions and hand torque strength of elderly Malaysians in bottle-opening task. The subjects were required to sign an informed consent form, which indicates that they agree to participate in the case study. The experimental procedure was described in detail and the subjects were encouraged to ask questions if they have any doubts regarding the procedure.

The hand dimensions were then measured three times and mean value of each dimension was recorded. The hand torque strength test was carried out when the subject opens the bottle lids. The test was conducted on the subjects' dominant hand while they were in sitting position. The subjects were requested to sit comfortably upright with their feet on the floor, shoulder adducted, elbow flexed at about 90°, forearm pronated and wrist in neutral position. The subjects were instructed to position each bottle in the digital torque tester by themselves, at a position which they feel is most comfortable to open the bottles.

The order of opening the five bottles was random. Even though the subjects were instructed to exert their maximum possible strength when opening each bottle, they were informed to stop the task immediately if they experienced pain or discomfort during the test. This was to ensure that the subjects gave their maximum effort for the test, which emulates real-life scenario where they intend to access the contents of each bottle. The subjects were instructed to hold the applied strength for 4 seconds and they were required to repeat the task three times. The hand grip strength of the individual was defined as the maximum reading out of three consecutive measurements. A 30-second break was given in between tests in order to minimize fatigue among the subjects. The subjects may prolong their break if they experience symptoms of fatigue during the course of the experiment. The subjects were required to rate the level of perceived discomfort while opening the bottles upon completion of the experiment. The perceived discomfort ratings are presented in Appendix D.

The data was analysed using SPSS software in order to compute the minimum, maximum and mean values, standard deviation (SD), as well as 5th and 95th percentiles of the hand anthropometric dimensions and hand torque strength. The correlation between the hand anthropometric dimensions and hand torque strength was then determined. The subjects' perceived discomfort ratings were also analysed. The flow chart of the case study is summarized in Figure 3.8.

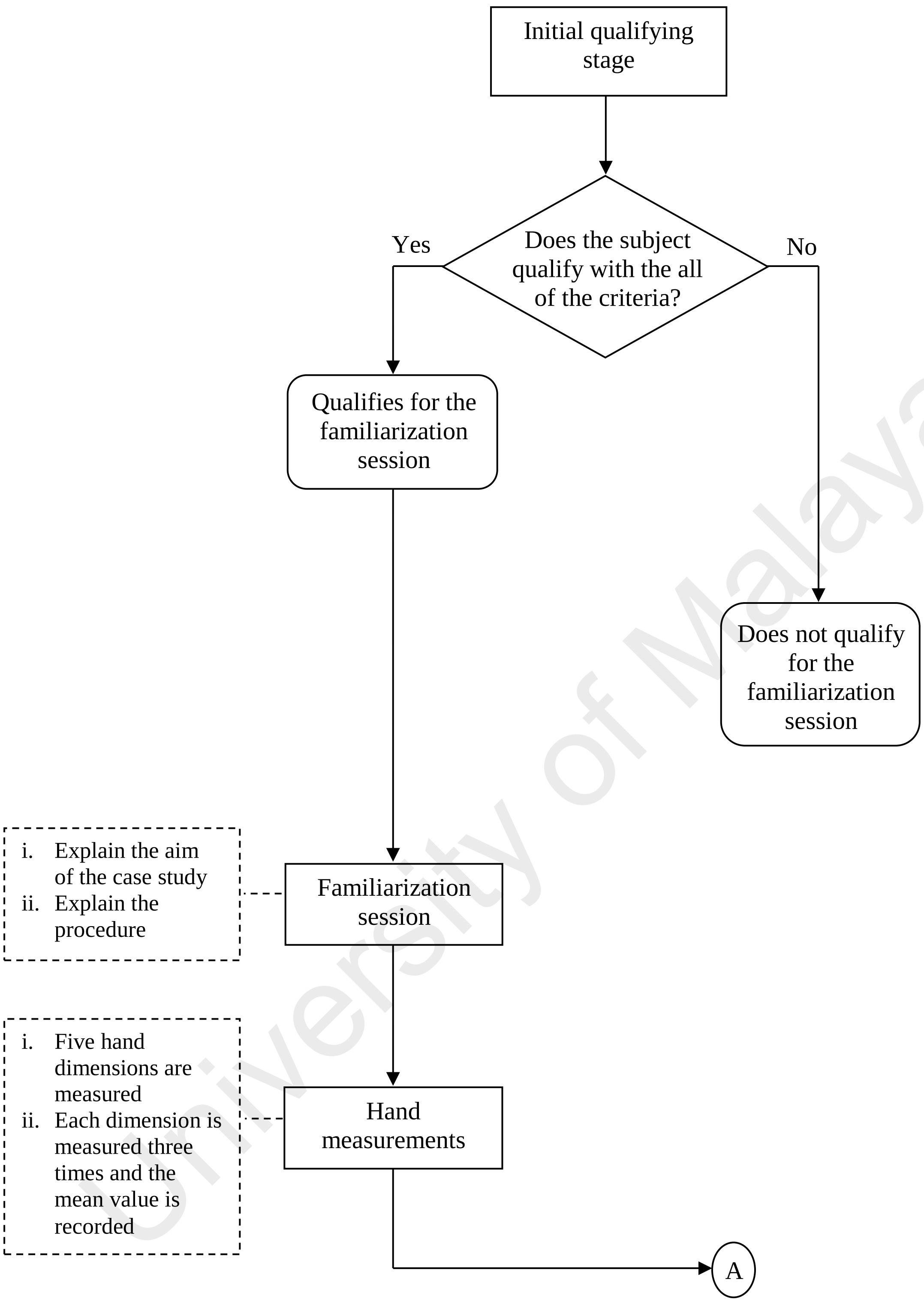

Figure 3.8: Flow Chart of the Case Study

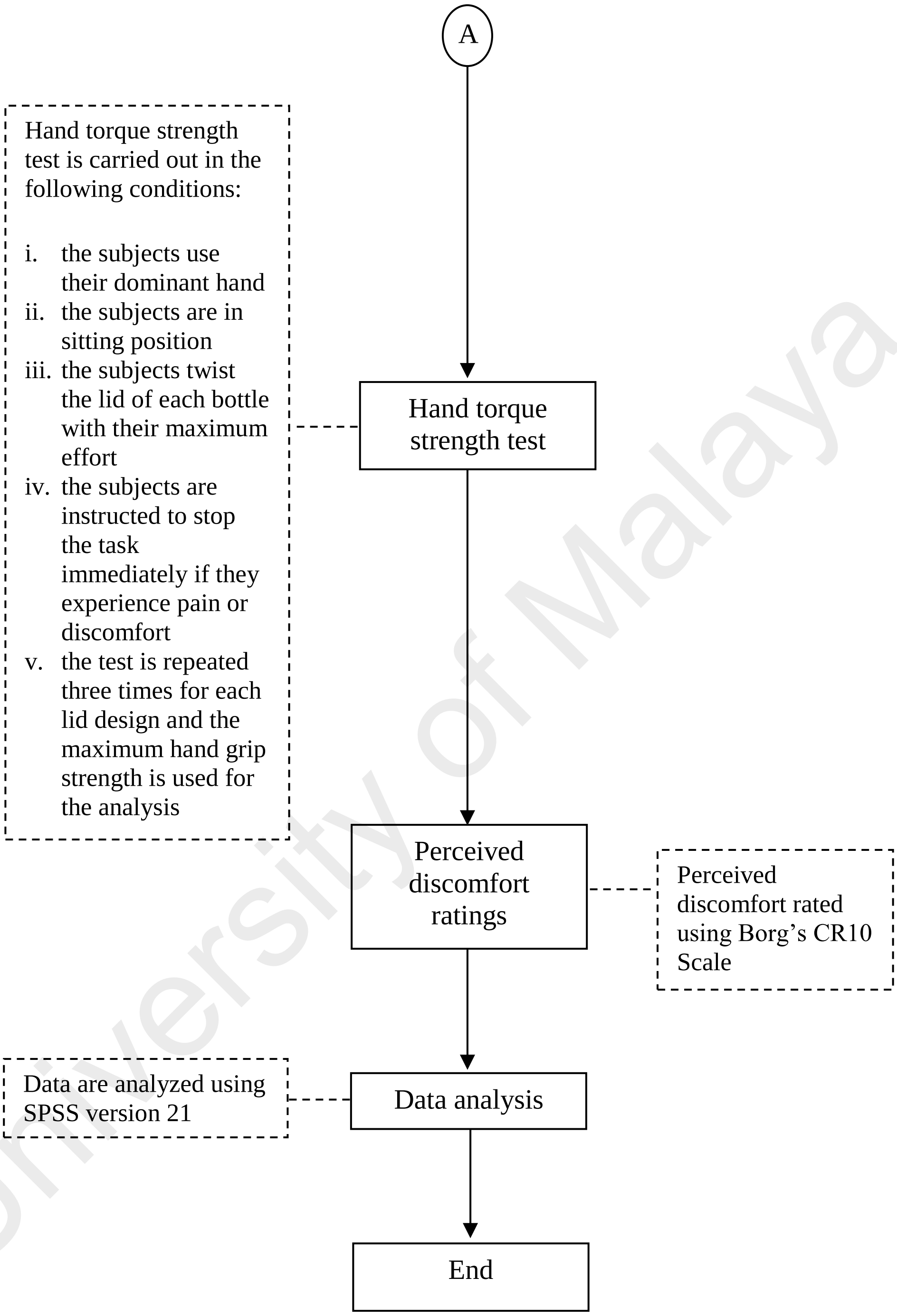

Figure 3.8 continued

3.4 Summary

The methodology used to determine the relationship between anthropometric dimensions and hand grip strength among elderly Malaysians has been described in detail in this chapter. Statistical analysis was used to identify the anthropometric dimensions that are significantly correlated with hand grip strength. The data were then compared with young adult and ageing adult groups (aged 20-30 years and 50-59 years, respectively). Regression analysis was used to develop regression models which predict the hand grip strength of elderly Malaysians as a function of anthropometric variables; one for males and females, respectively. The model was then validated with other sample of elderly data. A case study was also conducted to validate the methodology used in this study, in which the subjects were required to perform an experimental task that was typically carried out by elderly people, i.e. bottle-opening. The results of the case study were analysed using statistical techniques.

CHAPTER 4: RESULTS AND DATA ANALYSIS

4.1 Overview

The key findings of this study are presented in this chapter, which is divided into four major sections. The results and analysis of the data obtained from the preliminary test are presented in Section 4.2. The preliminary test is conducted to identify the anthropometric dimensions that significantly influence hand grip strength in elderly Malaysians. The hand grip strength test is then carried out and the results are presented in Section 4.3. The demographic data of the subjects, as well as their anthropometric and hand grip strength measurements are also presented in this section. Correlation analysis of these variables is also presented and the data are analysed using regression analysis, as presented in Section 4.4. Regression analysis is carried out to develop regression models which predict the hand grip strength of elderly Malaysian males and females as a function of anthropometric variables and the models are validated accordingly using standard error of the estimate (SEE). The data are compared with two samples of Malaysians different age groups (20-29 years and 50-59 years) and the results are presented in Section 4.5. Finally, the results of the case study are presented in Section 4.6. A summary is given at the end of this chapter.

4.2 Preliminary Test

The purpose of the preliminary test is to determine the anthropometric dimensions that significantly influence the hand grip strength of elderly Malaysians from a total of 91 anthropometric dimensions. The preliminary test was carried out on 32 subjects and the details of the preliminary test are summarized in Table 4.1.

Table 4.1: Details of the Preliminary Test

Item	Preliminary test (n = 32)
No. of anthropometric dimensions measured	91
Sample size	32
No. of subjects who have completed the survey	32
No. of subjects whose data are used in the analysis	32
Rate of usable response	100%

4.2.1 Demographic Data

The demographic data of the subjects were gathered using a health screening questionnaire which was adapted from Yen (2011). The questionnaire was used to determine the inclusion criteria of the subjects. The demographic data of the subjects are summarized in Table 4.2, in which 19 males (age range: 60-79 years, mean: 66.68, SD: 5.97) and 13 females (age range: 61-81 years, mean: 67.23, SD: 5.88) from Petaling Jaya were recruited in the preliminary test. It is found that more than 90% of the subjects live with their spouses, family members or caretakers, whereas only 6% live by themselves. Most of the subjects were right-handed rather than left-handed, and none were ambidextrous.

It is found that 38% of the subjects have hypertension, followed by heart problem and diabetes (each with a percentage of 9%). The results also revealed that only 6% have physical disabilities. Even though these subjects reported they suffer from severe knee problems, they were still able to walk and perform simple household chores independently. One person reported having a hearing problem in the right ear. None of them were found to suffer from vision problems, while some reported to have mild, blurred vision. However this did not affect their daily activities.

Table 4.2: Demographic Data of the Subjects

Characteristic	No. of subjects	Percentage (%)
Residency		
Living alone	2	6
Living with spouse/family members/ caretakers	30	94
Hand dominance		
Right-handed	29	91
Left-handed	3	9
Ambidextrous	0	0
Diagnosed disease		
Hypertension	12	38
Heart problem	3	9
Diabetes	3	9
Arthritis	0	0
Alzheimer	0	0
Physical impairment		
Physical disability	2	6
Hearing	1	3
Vision	0	0

4.2.2 Correlation between Anthropometric Dimensions and Hand Grip Strength

Correlation analysis was conducted to identify the anthropometric dimensions that significantly influence the hand grip strength of elderly Malaysians. Pearson product-moment correlation coefficient analysis was used to examine the relationship between these variables and the results are tabulated in Table 4.3. The results indicate that there was a significant correlation between 37 anthropometric dimensions (out of 91 body dimensions) and hand grip strength for both genders ($p < 0.01$ and $p < 0.05$, 2-tailed).

Correlation analysis was also carried out for each gender and it is found that seven anthropometric dimensions were correlated with hand grip strength for males, i.e. stature, eye height (standing), span, elbow span, hip breadth sitting, sitting height, eye height sitting, foot length and ankle circumference ($p < 0.01$ and $p < 0.05$, 2-tailed). However, it is found that only two anthropometric dimensions were correlated with hand grip strength for females, i.e. hip breadth sitting and thumb circumference. It shall be noted that only these 37 anthropometric dimensions will be investigated in the hand grip strength test and are summarized in Table 4.4.

Table 4.3: Correlation between Anthropometric Dimensions and Hand Grip Strength

No.	Anthropometric dimension	Hand grip strength (N)	
		r	***p***
1.	Weight	0.182	0.327
2.	Overhead reach	0.626	0.110
3.	Stature	0.724**	0.000
4.	Eye height, standing	0.673**	0.000
5.	Shoulder height	0.610**	0.000
6.	Elbow height	0.594**	0.000
7.	Chest height	0.670	0.000
8.	Waist height, omphalion	0.322	0.072
9.	Buttock height	0.288	0.110
10.	Crotch height, standing	-0.071	0.700
11.	Knee height, midpatella	0.459**	0.008
12.	Calf height	0.584**	0.000
13.	Span	0.683**	0.000
14.	Elbow span	0.726**	0.000
15.	Shoulder breadth, standing	0.501**	0.004
16.	Thumb-tip reach	0.459	0.008
17.	Wrist-wall length, extended	0.372*	0.036
18.	Wrist-wall length	0.154	0.410
19.	Sleeve inseam	0.446*	0.011
20.	Elbow to elbow breadth	0.438*	0.012
21.	Chest breadth	0.374	0.042
22.	Waist breadth	0.287	0.111
23.	Hip breadth	0.278	0.130
24.	Shoulder length	0.314	0.086
25.	Chest depth	-0.170	0.352
26.	Waist depth	0.195	0.284
27.	Buttock depth	-0.096	0.600
28.	Sitting height	0.740**	0.000
29.	Eye height, sitting	0.764**	0.000
30.	Acromion height, sitting	0.593**	0.000
31.	Waist height, sitting, omphalion	0.162	0.375
32.	Thigh clearance	0.313	0.081
33.	Sitting elbow height	0.199	0.275
34.	Arm reach upward	0.624**	0.000
35.	Knee height sitting	0.241	0.184
36.	Popliteal height (lower leg height)	-0.021	0.908
37.	Arm reach forward	0.444	0.012
38.	Forearm-hand length	0.481**	0.006
39.	Elbow fingertip length	0.211	0.246
40.	Shoulder width	0.524	0.002
41.	Intersyce breadth	0.194	0.288
42.	Shoulder-elbow length	0.385*	0.030
43.	Buttock knee length	0.227	0.212
44.	Buttock popliteal length	0.083	0651

Table 4.3 continued

No.	Anthropometric dimension	Hand grip strength (N)	
		r	***p***
45.	Abdominal extension depth, sitting	-0.216	0.235
46.	Hip breadth, sitting	0.406*	0.021
47.	Hand length	0.430*	0.014
48.	Wrist-index finger length	0.456**	0.009
49.	Index finger length	0.379	0.035
50.	Index finger breadth, proximal	0.494**	0.145
51.	Index finger breadth, distal	0.268	0.386
52.	Wrist-thumb tip length	0.430	0.014
53.	Hand breadth	0.311	0.083
54.	Thumb breadth	0.297	0.098
55.	Palm length	0.606	0.000
56.	Wrist centre of grip length	0.268	0.137
57.	Foot length	0.481**	0.005
58.	Ball of foot length	0.362	0.045
59.	Foot breadth, horizontal	0.431*	0.014
60.	Heel breadth	0.375*	0.034
61.	Foot height	0.088	0.632
62.	Head length	0.080	0.663
63.	Head breadth	0.479**	0.005
64.	Face breadth	0.347	0.052
65.	Interpupillary breadth	0.466**	0.007
66.	Menton to top of head	0.194	0.286
67.	Face length	0.495	0.005
68.	Head circumference	-0.061	0.741
69.	Neck circumference	0.073	0.690
70.	Shoulder circumference	0.325	0.069
71.	Chest circumference at scye	0.143	0.435
72.	Chest circumference	-0.182	0.335
73.	Waist circumference, omphalion	-0.025	0.891
74.	Buttock circumference	0.094	0.608
75.	Scye circumference	0.204	0.263
76.	Axillary arm circumference	0.152	0.405
77.	Elbow circumference, straight	0.440*	0.012
78.	Biceps circumference, flexed	0.096	0.602
79.	Forearm circumference, flexed 90°	0.558**	0.001
80.	Wrist circumference	0.424**	0.018
81.	Hand circumference	0.502**	0.003
82.	Thumb circumference	0.557**	0.001
83.	Index finger circumference	0.365**	0.040
84.	Middle finger circumference	0.420*	0.017
85.	Thigh circumference	0.325	0.070
86.	Lower thigh circumference	0.263	0.146
87.	Knee circumference	0.301	0.095
88.	Calf circumference	0.259	0.152
89.	Ankle circumference	0.535**	0.002
90.	Heel ankle circumference	0.432*	0.013
91.	Ball of foot circumference	0.515**	0.003

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)
'r' is Pearson correlation coefficient
'p' is statistical significant

Table 4.4: Anthropometric Dimensions that are Significantly Correlated with Hand Grip Strength

No.	Anthropometric dimension	No.	Anthropometric dimension
1.	Stature	20.	Hand length
2.	Eye height, standing	21.	Wrist-index finger length
3.	Shoulder height	22.	Index finger breadth, proximal
4.	Elbow height	23.	Foot length
5.	Knee height, midpatella	24.	Foot breadth, horizontal
6.	Calf height	25.	Heel breadth
7.	Span	26.	Head breadth
8.	Elbow span	27.	Interpupillary breadth
9.	Shoulder breadth, standing	28.	Elbow circumference, straight
10.	Wrist-wall length, extended	29.	Forearm circumference, flexed 90°
11.	Sleeve inseam	30.	Wrist circumference
12.	Elbow to elbow breadth	31.	Hand circumference
13.	Sitting height	32.	Thumb circumference
14.	Eye height, sitting	33.	Index finger circumference
15.	Acromion height, sitting	34.	Middle finger circumference
16.	Arm reach upward	35.	Ankle circumference
17.	Forearm-hand length	36.	Heel ankle circumference
18.	Shoulder-elbow length	37.	Ball of foot circumference
19.	Hip breadth, sitting		

Legend :

Correlation is significant at the 0.05 level (2-tailed)

Correlation is significant at the 0.01 level (2-tailed)

4.3 Anthropometric and Hand Grip Strength Test of Elderly Malaysians

A total of 37 anthropometric dimensions are identified to be significantly correlated with hand grip strength, based on results of the preliminary test.

4.3.1 Demographic Data

A total of 112 elderly subjects (aged 60 years and above) were recruited from Petaling Jaya for this investigation, comprising 56 males (age range: 60-79 years, mean: 66.88, SD: 5.35) and 56 females (age range: 60-82, mean: 66.98, SD: 5.16). The demographic data of the subjects are summarized in Table 4.5. It can be seen that the majority of the subjects (above 85%) live with their spouses, family members or caretakers, whereas only 11% live by themselves. In addition, 50% of the subjects completed their formal education whereas the remaining 50% do not have any formal education. It is found that

49% of the subjects were retired or unemployed, whereas the remaining 51% were employed. With regards to hand dominance, most of the subjects were right-handed rather than left-handed, and none of them were ambidextrous. It can be seen from the demographic data that 45% of the subjects suffered from hypertension, followed by diabetes (29%), heart problem (14%), and arthritis (6%). The remaining 41% did not suffer from any major diseases.

Seven subjects reported that they have vision problems. However, the subjects only suffered from mild blurred vision, which does not affect their ability to carry out daily activities. The results also showed that even though five subjects had hearing problems on one side, these subjects were able to hear using a hearing aid. In addition, it is found that only two subjects suffered from physical disabilities (severe knee problems). However, these subjects were still able to walk and perform simple household chores independently. Although 11% of the subjects suffered from physical impairment, the physical impairment did not inhibit them from carrying out daily activities. Based on the demographic data, the subjects fulfilled the inclusion criteria for the hand grip strength test since this study focused on the relationship between anthropometric dimensions and hand grip strength of elderly Malaysians.

Table 4.5: Demographic Data of the Subjects

Characteristic	No.	%
Gender		
Male	56	50
Female	56	50
Highest educational level completed		
Primary school	26	23
Secondary school	3	3
Tertiary institution	31	28
No formal education	52	46
Employment status		
Employed	23	21
Self-employed	12	11
Retired or unemployed	77	69

Table 4.5 continued

Characteristic	No.	%
Residency		
Alone	5	4
With spouse/ family members/ caretakers	107	96
Hand dominance		
Right-handed	96	86
Left-handed	16	14
Ambidextrous	0	0
Diagnosed diseases		
Hypertension	50	45
Heart problem	14	13
Diabetes	29	26
Arthritis	6	5
None	46	41
Physical impairment		
Physical disability	2	1
Hearing	5	4
Vision	7	6

4.3.2 Anthropometric Data

The mean, standard deviation as well as 5th and 95th percentiles of the 37 anthropometric dimensions for males and females are shown Table 4.6 and Table 4.7, respectively. It is found that elderly males are taller (+ 112 mm) with a greater span (+ 135 mm). In addition, elderly males have a better arm reach upward compared to females (+ 117 mm). It is evident that elderly males have larger anthropometric dimensions compared to females, i.e. sitting height (+ 65 mm), eye height (+ 58 mm), shoulder height (+ 54 mm) and hip breadth (+ 15 mm). The finger circumference dimensions of elderly males are also larger than those for females, i.e. thumb circumference (+ 9 mm), index finger circumference (+ 8 mm) and middle finger circumference (+ 8 mm). Male elderly have a larger palm size compared to females, with a difference of 23 mm.

Table 4.6: Descriptive Statistics of Anthropometric Dimensions for Elderly Male Subjects

No.	Anthropometric dimension (mm)	Male (n = 56)			
		Mean	SD	5th percentile	95th percentile
1.	Stature	1611	5.0	1529	1685
2.	Eye height, standing	1499	4.9	1425	1566
3.	Shoulder height	1336	4.7	1258	1401
4.	Elbow height	984	6.3	891	1060
5.	Knee height, midpatella	462	2.9	421	504
6.	Calf height	408	3.2	355	453
7.	Span	1644	7.0	1514	1738
8.	Elbow span	820	5.5	701	899
9.	Shoulder breadth, standing	393	3.6	342	453
10	Wrist-wall length, extended	707	9.7	565	867
11.	Sleeve inseam	420	3.1	366	478
12.	Elbow to elbow breadth	439	5.5	346	529
13.	Sitting height	821	3.9	746	865
14.	Eye height, sitting	708	4.0	648	761
15	Acromion height, sitting (shoulder height sitting)	550	3.3	494	599
16.	Arm reach upward	1216	6.7	1100	1321
17.	Forearm-hand length	449	2.0	416	480
18	Shoulder-elbow length	331	2.2	300	357
19	Hip breadth, sitting	345	3.7	288	405
20	Hand length	183	1.0	166	197
21.	Wrist-index finger length	169	1.0	156	185
22.	Index finger breadth, proximal	18	0.1	16	20
23.	Foot length	240	1.2	219	263
24.	Foot breadth, horizontal	98	0.7	87	109
25.	Heel breadth	62	0.6	54	73
26.	Head breadth	143	1.4	120	161
27.	Interpupillary breadth	65	0.6	55	75
28.	Elbow circumference, straight	258	1.9	229	289
29.	Forearm circumference, flexed 90°	260	3.1	200	303
30.	Wrist circumference	169	1.3	142	186
31	Hand circumference	201	1.4	181	221
32.	Thumb circumference	74	0.5	68	82
33.	Index finger circumference	66	0.5	58	73
34.	Middle finger circumference	67	0.6	56	76
35.	Ankle circumference	226	2.3	194	260
36.	Heel ankle circumference	326	2.1	292	356
37.	Ball of foot circumference	241	1.6	212	261

Table 4.7: Descriptive Statistics of Anthropometric Dimensions for Elderly Female Subjects

No.	Anthropometric dimension (mm)	Female (n = 56)			
		Mean	SD	5th percentile	95th percentile
1.	Stature	1499	5.3	1405	1593
2.	Eye height, standing	1387	5.1	1321	1449
3.	Shoulder height	1236	4.7	1175	1295
4.	Elbow height	918	4.6	835	979
5.	Knee height, midpatella	451	3.4	391	505
6.	Calf height	366	5.8	284	446
7.	Span	1509	7.2	1364	1630
8.	Elbow span	744	7.1	560	822
9.	Shoulder breadth, standing	366	2.4	322	400
10	Wrist-wall length, extended	695	14.7	513	875
11.	Sleeve inseam	377	3.2	322	420
12.	Elbow to elbow breadth	422	6.5	306	516
13.	Sitting height	756	3.5	706	818
14.	Eye height, sitting	650	4.2	594	734
15	Acromion height, sitting (shoulder height sitting)	496	3.7	450	559
16.	Arm reach upward	1099	6.4	977	1195
17.	Forearm-hand length	419	3.4	357	466
18	Shoulder-elbow length	313	2.6	275	346
19	Hip breadth, sitting	330	3.9	272	386
20	Hand length	170	0.8	157	186
21.	Wrist-index finger length	158	1.0	145	177
22.	Index finger breadth, proximal	16	0.3	14	18
23.	Foot length	223	1.3	208	246
24.	Foot breadth, horizontal	87	0.8	74	101
25.	Heel breadth	55	0.7	43	65
26.	Head breadth	128	1.5	107	148
27.	Interpupillary breadth	64	0.7	50	72
28.	Elbow circumference, straight	248	3.0	203	304
29.	Forearm circumference, flexed 90°	235	3.8	168	287
30.	Wrist circumference	156	1.3	138	179
31	Hand circumference	178	1.2	155	198
32.	Thumb circumference	65	0.5	58	72
33.	Index finger circumference	58	0.4	52	66
34.	Middle finger circumference	59	0.5	52	68
35.	Ankle circumference	209	2.0	178	245
36.	Heel ankle circumference	292	1.8	266	320
37.	Ball of foot circumference	214	1.6	194	243

4.3.3 Hand Grip Strength Data

It is found that 96 (86%) out of 112 subjects are right-handed, comprising 45 (40%) males and 51 (46%) females. In contrast, 16 (14%) subjects are left-handed, comprising 11 (10%) males and 5 (5%) females. None of the subjects are ambidextrous. In general, it is found that the hand grip strength is higher for males compared to females. The hand grip strength refers to the maximum value of two out of three highest measurements of the subjects' dominant hand (271.64 ± 69.01 N and 159.39 ± 58.03 N for males and females, respectively). The mean hand grip strength of males is higher compared to females, with a difference of 41%. The mean, standard deviation, as well as 5^{th} and 9^{5th} percentiles of the hand grip strength measurements for elderly male and female subjects are summarized in Table 4.8.

Table 4.8: Descriptive Statistics of Hand Grip Strength Measurements for Elderly Male and Female Subjects

	Male (n = 56)					Female (n = 56)			
	Mean	**SD**	**5^{th} pct**	**95^{th} pct**		**Mean**	**SD**	**5^{th} pct**	**95^{th} pct**
Hand grip strength (N)	271.6	69.0	166.7	366.5		159.4	58.0	78.5	269.7

'pct' is percentile

4.3.4 Correlation between Anthropometric Dimensions and Hand Grip Strength

The results show that there is a significant correlation between the anthropometric dimensions and hand grip strength for both elderly males and females ($p < 0.01$ and $p < 0.05$, 2-tailed). The Pearson's product moment correlation coefficient is used to determine the correlation between 37 anthropometric dimensions and hand grip strength for each gender. It is found that there is a significant correlation between seven anthropometric dimensions and hand grip strength for males, i.e. eye height (standing), span, elbow span, sitting height, eye height (sitting), arm reach upward and ankle circumference. However, it is observed that elderly females have a higher number of anthropometric dimensions (while sitting) that are significantly correlated with hand grip strength compared to males. These dimensions are sitting height, eye height (sitting), shoulder height (sitting) and hip breadth (sitting) ($r = 0.489$, $r = 0.462$, $r = 0.305$, $r = 0.303$, $p < 0.01$, 2-tailed). Nevertheless, there are six anthropometric dimensions that are correlated with hand grip strength for both elderly males and females, i.e. eye height (standing), span, elbow span, sitting height, eye height (sitting) and arm reach upward. The correlation results for males and females are shown in Table 4.9 and 4.10, respectively.

Table 4.9: Correlation between Anthropometric Dimensions and Hand Grip Strength in Elderly Male Subjects

No.	Anthropometric dimension	Hand grip strength	
		r	***p***
1.	Eye height, standing	.284*	0.034
2.	Span	.276*	0.039
3.	Elbow span	.331*	0.013
4.	Sitting height	.297*	0.026
5.	Eye height, sitting	.418**	0.001
6.	Arm reach upward	.419**	0.001
7.	Ankle circumference	.310*	0.020

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)
‘r’ is Pearson correlation coefficient
‘p’ is statistical significant

Table 4.10: Correlation between Anthropometric Dimensions and Hand Grip Strength in Elderly Female Subjects

No.	Anthropometric dimension	Hand grip strength	
		r	***p***
1.	Eye height, standing	.309*	0.021
2.	Span	.322*	0.066
3.	Elbow span	.272*	0.043
4.	Sleeve inseam	.266*	0.048
5.	Sitting height	.489**	0.000
6.	Eye height, sitting	.462**	0.000
7.	Shoulder height, sitting	.305*	0.022
8.	Arm reach upward	.281*	0.036
9.	Hip breadth, sitting	.303*	0.023
10.	Index finger breadth, proximal	.331*	0.013
11.	Head breadth	.372**	0.005
12.	Thumb circumference	.315*	0.018

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)
‘r’ is Pearson correlation coefficient
‘p’ is statistical significant

4.4 Development of Regression Models

Stepwise multiple regression is used to establish the relationship between anthropometric dimensions and hand grip strength of elderly Malaysians. The data obtained from anthropometric and hand grip strength measurements are used to develop regression models which predict the hand grip strength of elderly Malaysian males and females as a function of anthropometric dimensions.

The regression model summary for elderly Malaysian males is shown in Table 4.11. The correlation coefficient (R value) is found to be 0.508, which indicates a good level of prediction, and the adjusted coefficient of determination (adjusted R squared) is found to be 0.258. There is a significant correlation between the independent variables and dependent variable (F (2, 95) = 5.904, p < .0005), which indicates that the regression model is a good fit of the data. Furthermore, the regression values are below 0.005, which indicates that the correlation is reliable and the model can be used to make predictions. The complete details of the regression analysis are given in Appendix F.

Table 4.11: Regression Model Summary for Elderly Malaysian Males

Model	R	R squared	Adjusted R squared	Std. error of the estimate	Sig.
1	.508	.258	.239	58.25102	.000

The resulting prediction equation is given as follows:

$$PHGS_m = -468.281 + 3.859a + 3.329b$$

where $PHGS_m$ represents the predicted hand grip strength of elderly Malaysian males, while a and b represents the arm reach upward and elbow span, respectively.

The prediction model is validated using data of 10 elderly Malaysian males and the standard error of estimate (SEE) is used to measure the accuracy of the prediction. The SEE is an indicator of the average error of prediction for the regression equation. The better the fit of the regression line, the less variability of the data scattered around the regression line and thus, the smaller the SEE (Portney & Watkins, 2000). The SEE is given by:

$$SEE = \sqrt{\frac{\sum(Y-\bar{Y})^2}{(n-2)}} \tag{5.1}$$

where:

Y = observed value

$\bar{Y}$ = predicted value

n = number of pairs of scores

Calculation of the SEE is presented in detail in Appendix F. It is found that the SEE value is 2.43. Since the SEE value is small, this proves that the prediction model is valid.

Following this, stepwise multiple regression is used to develop a regression model that predicts the hand grip strength for elderly Malaysian females and the regression model summary is shown in Table 4.12. It is found that the adjusted R squared is 0.228, which indicates that there is a significant correlation between the independent variables and the dependent variable (F (11, 95) = 2.473, p < .0005). However, the regression values are all above 0.005, which indicates that the correlation is not statistically reliable. Thus, the relationship is discarded from further analysis.

Table 4.12: Regression Model Summary for Elderly Malaysian Females

Model	R	R squared	Adjusted R squared	Std. error of the estimate	Sig.
1	.618	.382	.228	51.00615	.017

4.5 Comparison of Anthropometric Dimensions and Hand Grip Strength between Elderly, Ageing Adult and Young Adult Groups

The anthropometric dimensions and hand grip strength data of the elderly subjects are compared with those for two different age groups (20-30 years and 50-59 years) in order to determine if there is a significant difference among these groups. Data for these two groups are randomly measured from University Malaya students and staff. The mean, standard deviation as well as 5th and 95th percentiles of these groups for males and females are presented in Table 4.13 and 4.14, respectively. The results show that 32 out of 37 anthropometric dimensions differ significantly among the three age groups, except for the extended wrist-wall length, elbow to elbow breadth, forearm-hand length, sitting hip breadth and interpupillary breadth. The complete details of this analysis are shown in Appendix F.

Table 4.13: Comparison of Anthropometric Dimensions and Hand Grip Strength among Elderly, Ageing Adult and Young Adult Male

No.	Anthropometric dimension (mm)	Elderly (n = 56)				Ageing adult (n = 15)				Young adult (n = 15)			
		Mean	SD	5th percentile	95th percentile	Mean	SD	5th percentile	95th percentile	Mean	SD	5th percentile	95th percentile
1.	Stature	1606	6.17	1529	1685	1636	4.70	1578	1709	1675	4.65	1617	1749
2.	Eye height, standing	1499	4.94	1425	1566	1525	5.41	1460	1615	1570	5.07	1517	1659
3.	Shoulder height	1336	4.72	1258	1401	1372	3.98	1322	1442	1385	4.66	1314	1453
4.	Elbow height	996	9.35	898	1094	1009	9.49	868	1097	1039	3.27	981	1085
5.	Knee height, midpatella	461	2.90	421	504	459	2.08	423	489	472	2.41	434	500
6.	Calf height	408	3.17	355	453	324	2.38	287	364	382	7.54	278	462
7.	Span	1623	13.17	1514	1738	1664	6.07	1592	1766	1697	6.00	1616	1778
8.	Elbow span	817	5.77	701	899	832	5.77	759	918	860	4.29	806	922
9.	Shoulder breadth, standing	400	6.18	342	457	430	3.81	385	489	390	3.41	346	434
10	Wrist-wall length, extended	707	9.73	565	867	680	3.66	623	736	671	6.19	570	761
11.	Sleeve inseam	420	3.09	366	478	458	7.22	367	559	503	9.44	409	671
12.	Elbow to elbow breadth	439	5.48	346	529	396	3.78	345	448	385	4.97	311	463
13.	Sitting height	821	3.93	746	865	828	7.65	723	888	849	3.04	807	895
14.	Eye height, sitting	708	4.05	648	761	731	2.97	692	778	741	2.82	700	789
15	Shoulder height, sitting	550	3.32	494	599	579	2.71	547	619	571	2.35	539	602
16.	Arm reach upward	1216	6.68	1099	1321	1257	6.54	1161	1345	1273	3.71	1234	1338
17.	Forearm-hand length	449	2.03	416	480	253	1.32	237	275	324	8.75	235	448
18	Shoulder-elbow length	331	2.23	300	357	346	1.49	323	368	338	2.09	303	365
19	Hip breadth, sitting	345	3.71	288	405	341	3.20	311	397	346	2.51	308	374
20	Hand length	183	0.95	166	197	179	2.13	149	197	181	1.13	162	194
21.	Wrist-index finger length	169	0.91	156	185	169	0.93	157	183	174	0.85	160	186
22.	Index finger breadth, proximal	18	0.13	16	20	17	0.13	16	19	17	0.19	15	21
23.	Foot length	240	1.24	219	263	247	1.07	232	262	242	1.33	228	262
24.	Foot breadth, horizontal	98	0.72	87	109	94	0.97	82	106	90	0.78	79	103
25.	Heel breadth	62	0.60	54	73	63	0.66	54	72	59	0.56	52	67
26.	Head breadth	143	1.39	120	161	148	0.80	133	156	155	0.95	141	169

Table 4.13 continued

No.	Anthropometric dimension (mm)	Elderly (n = 56)				Ageing adult (n = 15)				Young adult (n = 15)			
		Mean	**SD**	**5th percentile**	**95th percentile**	**Mean**	**SD**	**5th percentile**	**95th percentile**	**Mean**	**SD**	**5th percentile**	**95th percentile**
27.	Interpupillary breadth	65	0.64	55	75	62	0.66	55	72	61	0.40	55	66
28.	Elbow circumference, straight	258	1.95	229	289	266	0.86	255	279	250	1.80	224	274
29.	Forearm circumference, flexed 90°	260	3.06	200	303	254	1.68	233	282	255	2.01	226	282
30.	Wrist circumference	170	1.39	147	189	176	1.06	160	189	153	1.13	138	167
31	Hand circumference	201	1.35	181	221	213	0.73	203	224	209	2.76	176	254
32.	Thumb circumference	74	0.47	68	82	75	0.61	67	83	60	0.99	48	75
33.	Index finger circumference	66	0.47	58	73	71	0.77	60	80	54	1.23	39	69
34.	Middle finger circumference	67	0.64	56	76	71	0.88	59	81	55	1.15	40	70
35.	Ankle circumference	226	2.26	194	260	254	3.18	214	297	217	1.89	189	243
36.	Heel ankle circumference	328	2.07	292	356	326	2.87	280	355	310	1.81	280	334
37.	Ball of foot circumference	241	1.58	212	261	253	1.43	230	273	231	1.57	207	250
38.	Hand grip strength (N)	271.6	69.0	166.7	366.5	337.3	68.1	237.3	445.9	377.8	70.7	304.6	497.6

Table 4.14: Comparison of Anthropometric Dimensions and Hand Grip Strength among Elderly, Ageing Adult and Young Adult Female

No.	Anthropometric dimension (mm)	Elderly (*n* = 56)				Ageing adult (*n* = 15)				Young adult (*n* = 15)			
		Mean	**SD**	**5th percentile**	**95th percentile**	**Mean**	**SD**	**5th percentile**	**95th percentile**	**Mean**	**SD**	**5th percentile**	**95th percentile**
1.	Stature	1496	5.47	1405	159.3	1508	7.14	1408	1609	1542	5.61	1475	1644
2.	Eye height, standing	1387	5.07	1321	144.9	1401	7.26	1292	1505	1423	5.75	1354	1521
3.	Shoulder height	1236	4.70	1175	129.5	1247	6.00	1165	1329	1260	6.53	1161	1369
4.	Elbow height	918	4.55	835	97.9	928	4.66	859	992	957	4.76	903	1048
5.	Knee height, midpatella	451	3.44	391	50.5	432	2.57	395	471	415	3.57	353	443
6.	Calf height	366	5.76	284	44.6	282	2.16	255	326	312	2.66	267	342
7.	Span	1495	10.22	1364	163.0	1544	4.33	1493	1615	1538	5.44	1465	1620
8.	Elbow span	740	7.34	608	82.2	759	4.04	704	810	796	4.16	736	852
9.	Shoulder breadth, standing	364	2.73	322	40.0	394	3.13	354	440	383	6.63	340	477
10	Wrist-wall length, extended	674	10.08	513	84.3	638	1.87	619	675	628	4.14	589	699
11.	Sleeve inseam	375	3.52	322	42.0	421	4.34	375	491	405	2.65	369	450
12.	Elbow to elbow breadth	422	6.52	306	51.6	394	2.98	354	447	376	8.01	281	497
13.	Sitting height	756	3.52	706	81.8	768	3.74	709	821	803	3.70	759	871
14.	Eye height, sitting	650	4.21	594	73.4	696	8.62	650	815	691	4.10	646	764
15	Shoulder height, sitting	496	3.72	450	55.9	522	2.96	485	572	538	5.78	494	636
16.	Arm reach upward	1094	7.19	977	119.5	1162	2.66	1122	1197	1150	8.38	1030	1272
17.	Forearm-hand length	416	3.82	357	46.6	324	9.49	223	442	245	2.36	221	284
18	Shoulder-elbow length	313	2.61	275	34.6	315	1.28	296	334	310	1.09	299	327
19	Hip breadth, sitting	330	3.87	272	38.6	339	2.48	307	378	355	6.08	287	472
20	Hand length	170	0.84	157	18.6	162	1.91	135	175	169	0.87	160	185
21.	Wrist-index finger length	158	0.96	145	17.7	160	0.32	156	165	157	0.88	147	173
22.	Index finger breadth, proximal	16	0.33	14	1.8	17	0.12	16	19	15	0.11	14	17
23.	Foot length	223	1.28	208	24.6	224	1.18	205	236	226	1.26	212	251
24.	Foot breadth, horizontal	87	0.84	74	10.1	90	0.50	83	98	94	1.79	80	124
25.	Heel breadth	55	0.73	43	6.5	57	0.61	51	67	50	0.53	44	59
26.	Head breadth	128	1.50	107	14.8	144	0.65	136	154	145	1.15	136	166

Table 4.14 continued

No.	Anthropometric dimension (mm)	Elderly (*n* = 56)				Ageing adult (*n* = 15)				Young adult (*n* = 15)			
		Mean	**SD**	**5th percentile**	**95th percentile**	**Mean**	**SD**	**5th percentile**	**95th percentile**	**Mean**	**SD**	**5th percentile**	**95th percentile**
27.	Interpupillary breadth	64	0.74	50	72	59	0.58	51	67	56	0.47	52	64
28.	Elbow circumference, straight	248	3.01	203	304	249	1.63	227	277	241	3.46	207	299
29.	Forearm circumference, flexed 90°	235	3.81	168	287	216	2.09	196	252	210	4.62	159	286
30.	Wrist circumference	156	1.34	138	179	164	1.03	149	177	151	1.37	138	176
31	Hand circumference	178	1.25	155	198	188	1.24	169	205	174	1.80	157	210
32.	Thumb circumference	65	0.46	58	72	70	0.58	61	76	59	0.38	55	67
33.	Index finger circumference	58	0.45	52	66	66	0.62	57	74	57	0.42	52	64
34.	Middle finger circumference	59	0.50	52	68	67	0.62	57	73	57	0.46	53	66
35.	Ankle circumference	207	2.39	175	245	239	3.18	205	289	223	2.74	194	270
36.	Heel ankle circumference	310	1.79	266	320	302	2.17	278	340	294	3.16	259	350
37.	Ball of foot circumference	214	1.46	194	243	232	1.26	216	251	223	1.73	208	248
38.	Hand grip strength (N)	159.4	58.0	78.5	269.7	176.3	28.1	147.2	224.6	195.8	46.5	131.2	258.0

It can be seen from Table 4.13 that there is a significant decrease in height with increasing age for males ($p < 0.005$), in which elderly males are shorter than ageing adult males, with a difference of 1.9% (1606 SD 6.2 vs. 1636 SD 4.7 mm). The decrease in height is even more apparent from the young adult and ageing adult groups (1675 SD 4.7 vs. 1636 SD 6.2 mm), with a difference of 2.4%. A similar trend is also observed for females, whereby elderly females are shorter than ageing adult females, with a difference of 0.6% (1496 SD 0.7 vs. 1505 SD 1.8 mm) whereas the difference between the ageing adult and young adult groups is 2.6% (1505 SD 1.8 vs. 1544 SD 1.4 mm). The results also reveal that males are taller than females (1623 SD 6.2 vs. 1506 SD 5.9 mm) and the difference among the groups is statistically significant ($p < 0.005$). It is found that height decreases at a constant rate with increasing age among females, whereas there is a significant difference in height among the three age groups for males, as determined from the Tukey's test. The height of the subjects from the three age groups for both males and females is shown in Figure 4.1, and it can be seen that there is a decreasing trend in height with increasing age.

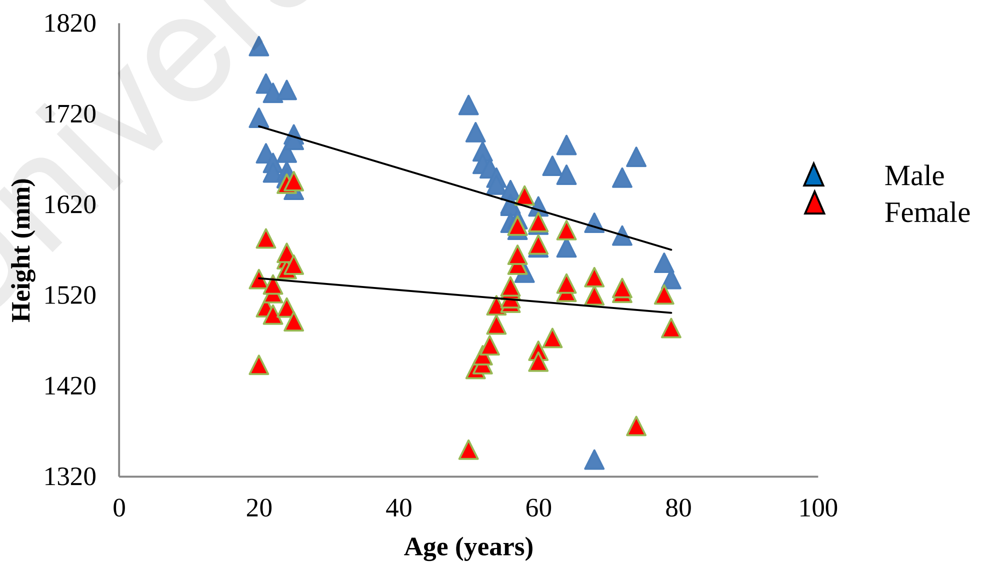

Figure 4.1: Height of Male and Female Subjects from Three Age Groups

The results show that there are three anthropometric dimensions that differ significantly among groups, i.e. sitting height, eye height (sitting) and arm reach upward (sitting). The results show that there is a significant difference in the sitting height among age groups in females, but not in males. In general, there is a decrease in sitting height from the young adult to ageing adult to elderly adult group in males (849 SD 3.0 vs. 828 SD 7.6 vs. 821 SD 3.9 mm) as well as in females (805 SD 3.6 vs. 769 SD 3.7 vs. 756 SD 3.5 mm). However, the sitting height is generally higher in males compared to females (827 SD 4.7 vs. 76 SD 4.0 mm) and elderly females are shorter than ageing adult females with a difference of 6.1% (1094 SD 7.1 vs. 1161 SD 2.6 mm). It is found that there is no difference in the sitting height between the ageing adult and young adult groups.

In addition, there is a decrease in the eye height (sitting) with increasing age for both males and females ($p < 0.005$). Elderly males are shorter than ageing adult males with a difference of 3.2% (708 SD 4.0 vs. 731 SD 3.0 mm). There is also a decrease in the eye height (sitting) from the young adult and ageing adult groups with a difference of 1.3% (741 SD 2.8 vs. 731 SD 3.0 mm). A similar trend is also observed for females, in which there is a decrease in the eye height (sitting) between young adult and ageing adult groups by 5.6% (694 SD 4.1 vs. 693 SD 8.4 mm), and between ageing adult and elderly groups by 6.6% (693 SD 8.4 vs. 650 SD 4.2 mm). It is evident that the eye height (sitting) is significantly higher in males compared to females (718 SD 3.9 vs. 665 SD 5.5 mm) and there is a significant difference in this dimension among the three age groups ($p < 0.005$).

Furthermore, the results show that there is a significant difference in the arm reach upward (sitting) among the three age groups for both genders ($p < 0.005$), from young adult to ageing adult to the elderly group (male: 1273 SD 3.7 vs. 1257 SD 6.5 vs. 1216 SD 6.7 mm; female: 1152 SD 8.1 vs. 1161 SD 2.6 vs. 1094 SD 7.1 mm). The decrease in the arm reach upward (sitting) is more pronounced between the ageing adult and elderly groups for both genders. There is a significant difference in this dimension between males and females (male: 1233 SD 6.6 vs. 1116 SD 7.4 mm).

In addition, it is found that there is a significant difference in two hand anthropometric dimensions, i.e. hand length and hand circumference. There is a significant difference in the hand length between males and females ($p < 0.005$). However, there is a rather odd trend in the hand length among the three age groups, whereby the hand length decreases from the young adult to ageing adult group, and the hand length increases thereafter. The mean hand length of males for the young adult, ageing adult and elderly group is 181, 179 and 183 mm, respectively. A similar result is obtained for females, whereby the mean hand length for the young adult, ageing adult and elderly group is 169, 162 and 170 mm, respectively. It is clear that the hand length of the elderly group is longer than the ageing adult group for both genders.

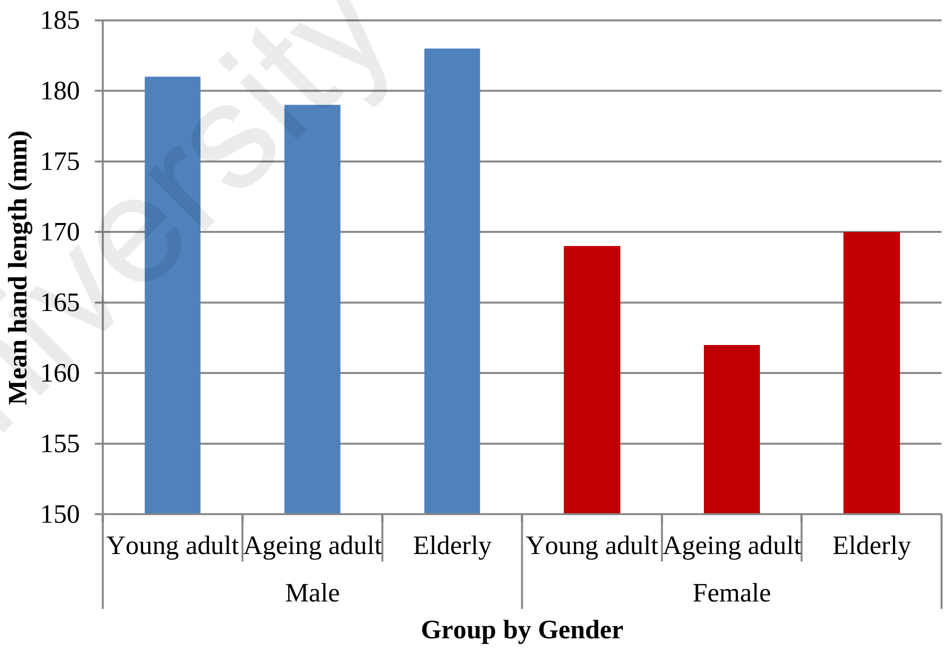

Figure 4.2: Mean Hand Length of Male and Female Elderly Subjects According to Age Group

Similarly, the results reveal that the hand circumference decreases from the young adult to the ageing adult group, but increases from the ageing adult to the elderly group. The mean hand circumference of males for the young adult, ageing adult and elderly group is 209, 213 and 201 mm, respectively. The same trend is also observed for females, in which the mean hand circumference for the young adult, ageing adult and elderly is 175, 187 and 178 mm, respectively.

Furthermore, there are interesting observations with regards to the foot anthropometric variables, and it is found that there is a significant difference in the foot length and heel ankle circumference. There is a significant difference in the foot length between male and females for all age groups (242 SD 1.2 vs. 224 SD 1.2 mm). It is also found that the foot length decreases with increasing age for both males and females. However, the decrease in foot length is minimum from the young adult to the elderly group, with a difference of 7 and 3 mm for males and females, respectively.

The heel ankle circumference is found to differ significantly between both genders ($p < 0.005$), whereby males have a larger heel ankle circumference compared to females (323 SD 2.2 vs. 295 SD 2.1 mm). The heel ankle circumference appears to enlarge with increasing age whereas other anthropometric variables decrease with increasing age. In general, young adults have smaller heel ankle circumference compared to the elderly. The heel ankle circumference of males for the young adult, ageing adult and elderly group is 310, 326 and 328 mm, respectively. Similarly, the heel ankle circumference of females for young adult, ageing adult and elderly group is 294, 302 and 310 mm, respectively.

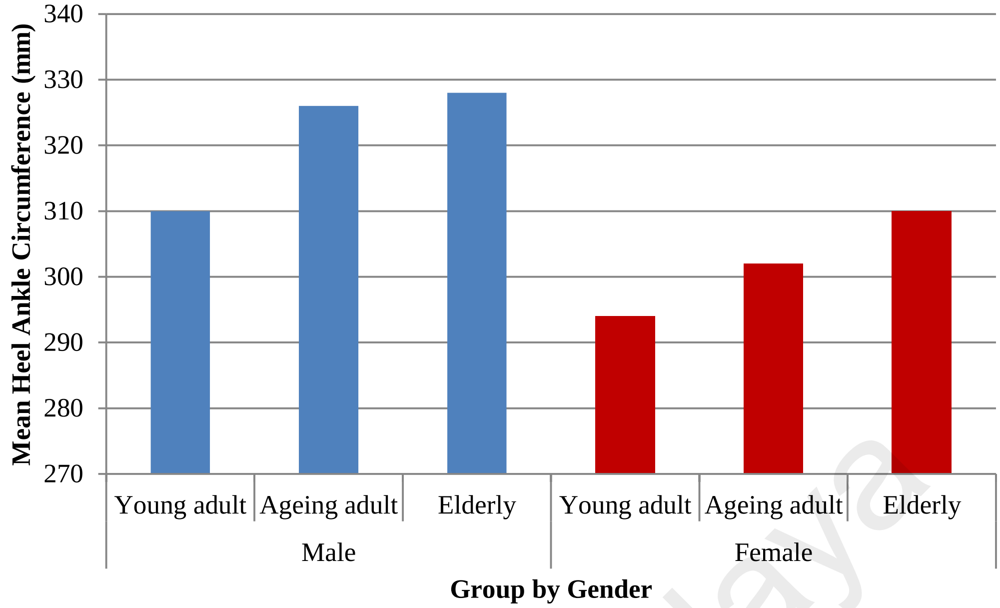

Figure 4.3: Mean Heel Ankle Circumference of Male and Female Elderly Subjects According to Age Group

The hand grip strength of male and female elderly Malaysians according to age group is shown in Figure 4.4. It can be observed that there is a significant decrease in the hand grip strength with increasing age for both males and females ($p < 0.005$). It is found that young adult males have higher hand grip strength compared to ageing adults, with a difference of 12% (377.8 SD 70.7 vs. 337.2 SD 68.1 N). The decrease in the hand grip strength is more pronounced from the ageing adult to elderly group (337.2 SD 68.1 vs. 271.6 SD 69.0 N), with a difference of 24%. A similar trend is also observed for females, in which there is a decrease in hand grip strength with increasing age. However, the difference is not as marked as males. Young adult females have higher hand grip strength than ageing adult females, with a difference of 11% (195.8 SD 46.5 vs. 176.3 SD 28.1 N). In addition, the hand grip strength of females decreases with progressing age from the ageing adult to elderly group, with a difference of 10% (176.3 SD 28.1 vs. 159.4 SD 58.0 N). The results also reveal that males have higher hand grip strength compared to females with a difference of 44% (301.6 SD 80.7 vs. 168.7 SD 53.5 N). It shall be noted that the difference in the hand grip strength among the three age groups as well as within each group is statistically significant ($p < 0.005$).

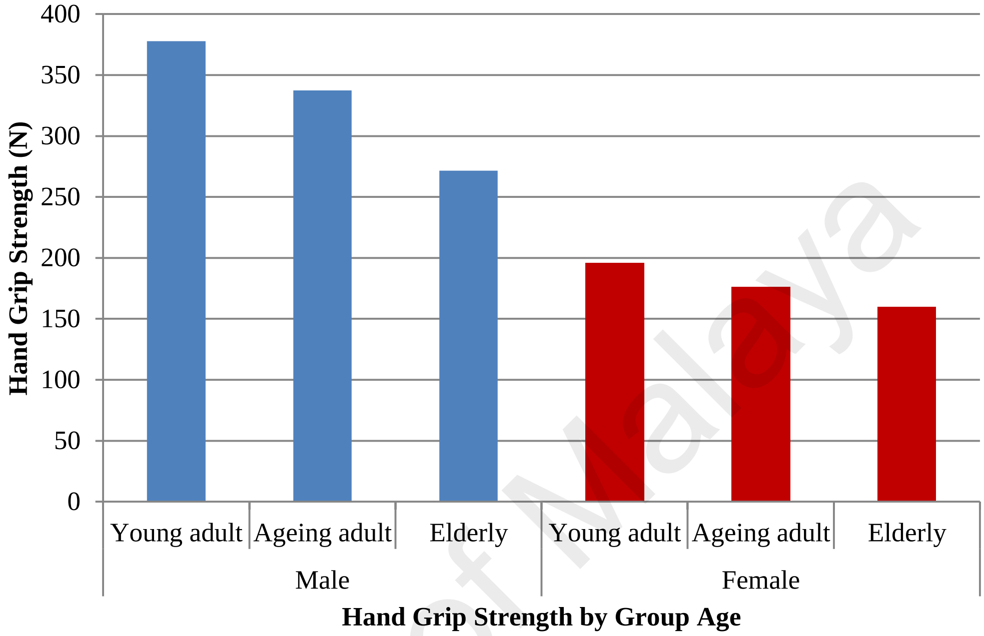

Figure 4.4: Hand Grip Strength of Male and Female Elderly Subjects According to Age Group

Correlation analysis is conducted to determine the correlation between anthropometric dimensions and hand grip strength for each age group and the results are summarized in Table 4.15. It is interesting to note that the results vary depending on the age group, i.e. elderly, ageing adults and young adults.

Table 4.15: Correlation between Anthropometric Dimensions and Hand Grip Strength for All Age Groups

No.	Anthropometric dimension	Elderly (*n* = 56)	Ageing adults (*n* = 15)	Young adults (*n* = 15)
		r	*r*	*r*
1.	Stature	.601**	.743**	.842**
2.	Eye height, standing	.655**	.735**	.852**
3.	Shoulder height	.551**	.750**	.820**
4.	Elbow height	.413**	.305	.744**
5.	Knee height, midpatella	.183	.543**	.693**
6.	Calf height	.319**	.669**	.657**
7.	Span	.522**	.742**	.853**
8.	Elbow span	.529**	.637**	.655**
9.	Shoulder breadth, standing	.285**	.386*	.240
10.	Wrist-wall length, extended	.032	.503**	.412*
11.	Sleeve inseam	.451**	.266	.444*
12.	Elbow to elbow breadth	.192*	.050	.277
13.	Sitting height	.657**	.272	.693**
14.	Eye height, sitting	.656**	.360	.680**
15.	Acromion height, sitting	.534**	.649*	.507**
16.	Arm reach upward	.640**	.731**	.754**
17.	Forearm-hand length	.447**	-.489**	.624**
18.	Shoulder-elbow length	.305**	.269	.724**
19.	Hip breadth, sitting	.293**	.109	.185
20.	Hand length	.430**	.448*	.619**
21.	Wrist-index finger length	.360**	.669**	.711**
22.	Index finger breadth, proximal	.288**	-.117	.651**
23.	Foot length	.477**	.686**	.511**
24.	Foot breadth, horizontal	.363**	.396*	-0.083
25.	Heel breadth	.431**	.569**	.690**
26.	Head breadth	.402**	.099	.406*
27.	Interpupillary breadth	.009	.029	.543
28.	Elbow circumference, straight	.303**	.579**	.354
29.	Forearm circumference, flexed 90°	.214*	.570**	.626**
30.	Wrist circumference	.403**	.567**	.164
31.	Hand circumference	.460**	.750**	.723
32.	Thumb circumference	.466**	.585**	.013
33.	Index finger circumference	.400**	.331	-0.189
34.	Middle finger circumference	.347**	.294	-0.157
35.	Ankle circumference	.411**	.438*	.057
36.	Heel ankle circumference	.523**	.435*	.380*
37.	Ball of foot circumference	.492**	.682**	.338

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)
'r' is Pearson correlation coefficient

4.6 Case Study

A case study is carried out in order to validate the correlation results shown in Section 4.3.4. The subjects are required to perform an experimental task, which is bottle-opening. This task is chosen because it has been shown in previous studies that bottle-opening is one of the most challenging tasks faced by the elderly in their daily routine. The subjects are required to open five different bottles and rate their perceived discomfort when opening the bottles.

4.6.1 Demographic Data of Subjects

Thirty elderly Malaysians are involved in this study, comprising 15 males (age range: 60-79 years, mean: 66.68, SD: 5.97) and 15 females (age range: 61-81, mean: 67.23, SD: 5.88). The subjects are all recruited from Petaling Jaya. The subjects are required to participate in the anthropometric and hand grip strength measurements in order to be eligible for the case study.

4.6.2 Correlation between Hand Anthropometric Dimensions and Hand Torque Strength in Bottle-Opening

The correlation between hand anthropometric dimensions and hand torque strength when the elderly subjects perform the bottle-opening task is presented in this section. The mean, standard deviation, as well as 5^{th} and 95^{th} percentiles of five hand anthropometric dimensions are presented in Table 4.16. The correlation between hand anthropometric dimensions and hand torque strength is presented in Table 4.17.

Table 4.16: Hand Anthropometric Data for Case Study (mm)

No.	Anthropometric dimension (mm)	Male (n = 15)				Female (n = 15)			
		Mean	SD	5th percentile	95th percentile	Mean	SD	5th percentile	95th percentile
1.	Hand length	184	1.1	164	197	168	0.8	157	181
2.	Wrist-index finger length	72	0.4	66	79	66	0.6	58	74
3.	Thumb circumference	67	0.4	61	74	63	0.6	56	72
4.	Index finger circumference	171	1.1	153	186	161	0.7	148	169
5.	Middle finger circumference	67	0.5	63	77	64	0.5	56	71

Pearson's product moment coefficient correlation is used to determine the correlation between five hand anthropometric dimensions and hand torque strength. It is found that there is a significant correlation between hand anthropometric dimensions and hand torque strength for both genders (p < 0.01, 2-tailed). It is found that the correlation between two dimensions (hand length and thumb circumference) and hand grip strength is statistically significant, particularly when the elderly subjects open bottles B, C and D (r = 0.382, r = 0.401, r = 0.372, p < 0.01, 2-tailed). The other hand anthropometric dimensions (wrist-index finger length, index finger circumference and middle finger circumference) are significantly correlated with hand grip strength.

Table 4.17: Correlation between Hand Anthropometric Dimensions and Hand Torque Strength in Bottle-Opening

No.	Anthropometric dimension	Hand torque strength (N.m)									
		Bottle A		Bottle B		Bottle C		Bottle D		Bottle E	
		r	p	r	p	r	p	r	p	r	p
1.	Hand length	.359	.051	.382*	.037	.037	.847	.003	.988	.080	.674
2.	Wrist-index finger length	-.036	.852	.089	.640	.346	.061	.136	.472	.329	.076
3.	Thumb circumference	.290	.121	.283	.129	.401*	.028	.372*	.043	.203	.281
4.	Index finger circumference	.327	.078	.256	.172	.294	.115	.287	.125	.262	.162
5.	Middle finger circumference	-.010	.957	.121	.523	.203	.282	-.098	.606	.158	.405

*Correlation is significant at the 0.01 level (2-tailed)

4.6.3 Subjective Ratings

Five bottles are used in the case study in order to investigate the effect of various bottle lid designs on the elderly's ability in opening the bottles. The subjects' levels of perceived discomfort are measured using Borg's CR10 Scale. The mean and standard deviation of the hand torque strength for males and females when performing the bottle-opening task are shown in Table 4.18 and 4.19, respectively. It can be seen that the hand grip strength of both male and female elderly Malaysians increases with an increase in the bottle lid diameter. The mean hand torque strength of elderly males increases from 0.99 to 1.41 to 2.17 N.m with an increase in bottle lid diameter, i.e. bottle B (40 mm), C (55 mm) and D (61 mm). Similarly, the mean hand torque strength of elderly females increases from 1.07 to 1.46 to 1.86 N.m with an increase in bottle lid diameter. The results indicate that the subjects need to increase their hand torque strength to open bottles with larger lid diameters. However, it can be observed that the mean hand torque strength to open bottles with small diameters such as bottles A (18 mm) and E (23 mm) appear to be small. In addition, both male and female subjects have equal mean hand torque strength for bottles A and E, with a value of 0.50 and 0.43 N.m, respectively.

Table 4.18: Hand Torque Strength of Males Obtained from the Case Study (N.m)

	Bottle A		Bottle B		Bottle C		Bottle D		Bottle E	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Hand torque strength	0.50	0.12	0.99	0.18	1.41	0.27	2.17	0.62	0.43	0.05

Table 4.19: Hand Torque Strength of Females Obtained from the Case Study (N.m)

	Bottle A		Bottle B		Bottle C		Bottle D		Bottle E	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Hand torque strength	0.50	0.17	1.07	0.20	1.46	0.20	1.86	0.60	0.43	0.09

It is apparent that bottle lid design influences the ability of elderly people to open the bottles. The numbers of male and female subjects who are able or unable to open the bottles are shown in Figure 4.5. In general, both males and females do not face problems when opening bottles B, C and D. However, both genders seem to face problems when opening bottles A and E. It is found that 53% of male subjects are able to open bottle A, whereas the remaining 47% are unable to open it. In contrast, 47% of female subjects are able to open bottle A, whereas the remaining 53% are unable to open it. It can be observed from the results that the number of male and female subjects who are able to open bottle E is the same, with a value of with 87%, while the remaining 13% are unable to open the bottle. It shall be noted that bottles B, C and D have a larger diameter compared to bottles A and E. It is also found that the surface texture of the lid influences the subjects' ability to open the bottles. The lids of bottles A and E are made from plastic, with a smooth texture. In contrast, even though bottle B is made of plastic, the lid is of a rough surface texture, which makes it easier for the subjects to open the bottle. Bottles C and D are made from metals, each having a smooth texture.

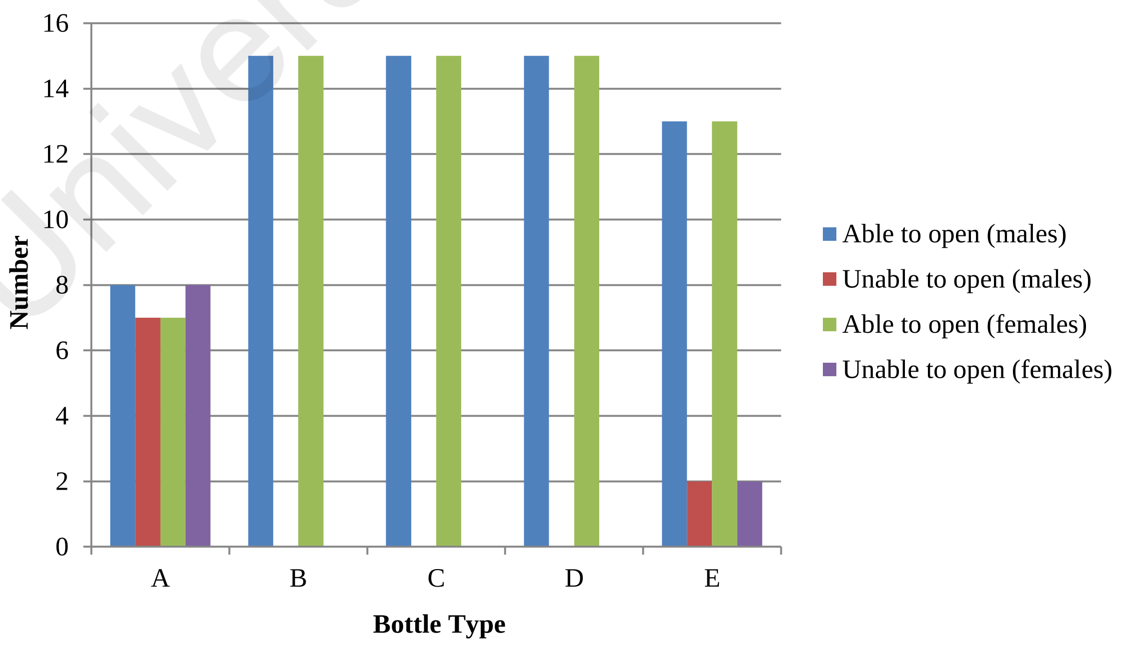

Figure 4.5: The Number of Male and Female Subjects Who are Able or Unable to Open the Bottles

The subjects' perceived discomfort while opening the bottles is also measured and the results are shown in Figure 4.6. It can be observed that both males and females feel very comfortable when opening bottles B, C and D. However, the perceived discomfort ratings are rather varied for bottles A and E. It is found that 53% of the male subjects feel comfortable when opening bottle A whereas the remaining 47% feel very uncomfortable. However, 33% of the female subjects feel extremely uncomfortable, 27% feel very uncomfortable, 20% feel uncomfortable and 20% feel somewhat uncomfortable. It is evident that most of the subjects (males and females) feel uncomfortable when opening bottle A. However, most of the male subjects feel comfortable when opening bottle E, comprising 80%, whereas the remaining 20% feel very uncomfortable. In contrast, 20% of the female subjects feel very uncomfortable, 33% feel uncomfortable and 33% feel somewhat uncomfortable. Only 13% of female subjects feel comfortable when opening bottle E. It can be seen that the perceived discomfort ratings conform to the results shown in Figure 4.5.

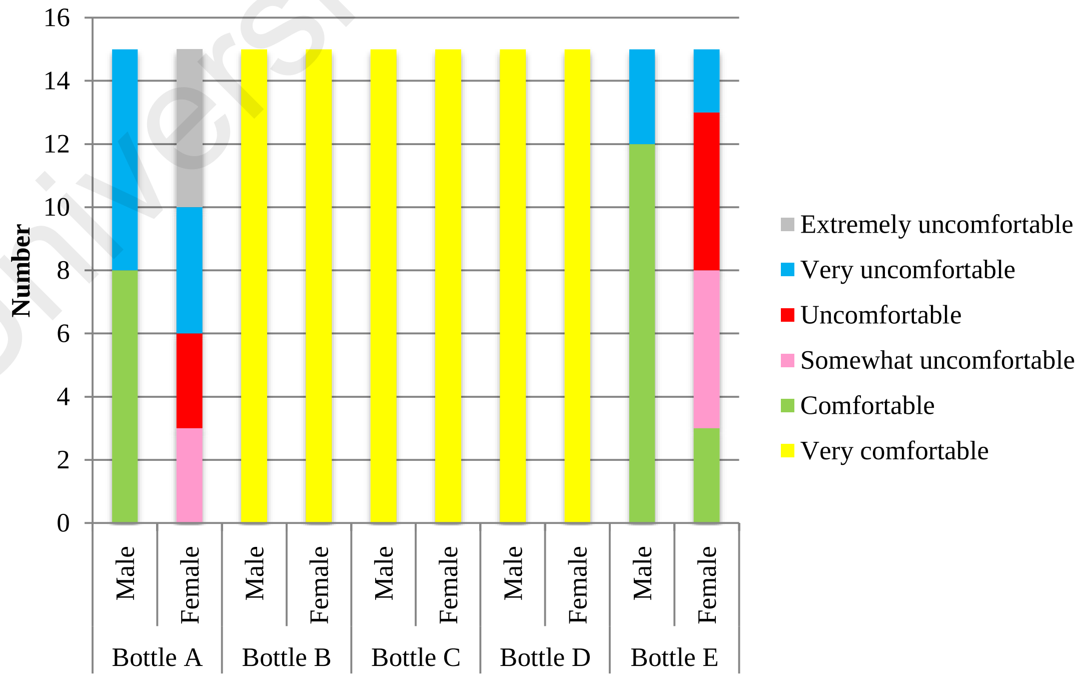

Figure 4.6: Perceived Discomfort Ratings of Male and Female Elderly Malaysians When Opening the Bottles

4.7 Summary

The results obtained from the preliminary test, hand grip strength test, regression models and case study have been described in detail in this chapter. It is found from the preliminary test that only 37 out of 91 anthropometric dimensions are significantly correlated with hand grip strength. These anthropometric dimensions are then used to explore the relationship between anthropometric dimensions and hand grip strength in elderly Malaysians. In general, it is found that males have fewer anthropometric dimensions that are correlated with hand grip strength compared to females. The data are compared with those for young adult and ageing adult age groups (20-30 years and 50-59 years, respectively), and the results reveal that there is a decrease in most of the anthropometric dimensions with increasing age. Regression analysis is carried out to establish models which predict the hand grip strength of elderly Malaysian males and females as a function of anthropometric dimensions. A case study is conducted to explore the relationship between anthropometric dimensions and hand torque strength among elderly Malaysians when they perform bottle-opening task. Five bottles, each having different lid diameter and surface texture, are used for this purpose and the results show that the lid diameter and surface texture influences the hand torque strength of elderly Malaysians. The results presented in this chapter will be discussed in detail in the following chapter.

CHAPTER 5: DISCUSSION

5.1 Overview

The results obtained in this study are discussed in detail in this chapter, which is divided into six major sections. The anthropometric dimensions of elderly Malaysians are discussed in Section 5.2, whereas the results of their hand grip strength are discussed and compared in Section 5.3. The correlation between anthropometric dimensions and hand grip strength is discussed in Section 5.4, followed by a discussion on the decrease in anthropometric dimensions and hand grip strength with increasing age in Section 5.5. The regression models developed in this study are compared with those of previous studies, and are discussed in Section 5.6. Finally, the results of the case study are discussed in Section 5.7.

5.2 Comparison of Anthropometric Dimensions of Elderly Malaysians with Those of Previous Studies

The anthropometric data of elderly Malaysians (aged 60 years and above) are compiled into a database and it is found from statistical analysis that more than half of the anthropometric dimensions are different, depending on gender. Most of the anthropometric dimensions are larger for males including stature, sitting height, hip breadth (sitting), straight elbow circumference, wrist circumference and heel ankle circumference. This indicates that gender influences the variation of anthropometric dimensions. This observation is supported by the findings of other studies (Rosnah et al., 2009; Hu et al., 2007; Kirvesoja et al., 2000; Pennathur and Dowling, 2003; Suriah et al., 1998; da Silva et al., 2009) in which elderly males tend to have larger anthropometric dimensions compared to females, within a range of 10-15%.

It is unsurprising that many anthropometric dimensions of elderly Malaysians are different the present anthropometric data are compared with those of previous studies.

According to Suriah et al. (1998) the anthropometric dimensions of elderly Malaysians (both males and females) are larger than those in the 1990s. Some significant dimensions include stature, weight, flexed bicep circumference and flexed forearm circumference. The average stature has increased by 24 and 22 mm for Malaysian males and females, respectively, in the last 16 years. (Perissinotto et al., 2002) studied the height of elderly Italians and found that their height increases from 20 to 30 mm per decade. This observation was also confirmed by reports of the World Health Organization (WHO, 1995). The decrease in height among elderly occurs due to losses in muscle tone, alterations in intervertebral discs as well as postural alterations as a result of osteoporosis (WHO, 1995). The average weight also increases by 10.3 kg for males and 7.3 kg for females. It is believed that the increase in weight is due to a reduction in total body water content (WHO, 1995), muscle mass (Nair, 2005) as well as sampling bias. Sampling bias is attributed to institutionalization or earlier death of overweight and obese individuals which may contribute to the lower values of such measurement among the elderly.

In general, it is found that there is a similar trend between the findings of this study and the works of others from other countries. Elderly males appear to have larger anthropometric dimensions while standing compared to females such as stature, standing knee height and span (Bermúdez et al. 1999; Payette et al., 2000; Pini et al., 2001; Mendoza-Núñez et al., 2002; Palloni et al., 2005). The results of these studies reveal that elderly males have larger stature and knee height (standing) compared to elderly males by 5-10%, which is similar to the findings of this study. Other studies have also found that the anthropometric dimensions of elderly males in sitting positions are larger compared to elderly females, such as sitting height, eye height, shoulder height and hip breadth. (Hu et al., 2007) discovered that elderly males have a higher sitting height compared to females with a difference of 9%. The results obtained in this study are similar, whereby elderly males have higher sitting height compared to males with a difference of 7%.

In general, there is a difference in the anthropometric data between elderly males and females. Hence, these differences should be taken into consideration. The methods implemented in this study are useful and practical to design and develop products for the elderly. It is crucial to design and develop products which cater to the special needs of elderly and this can be achieved by designing products that incorporate ergonomic principles and anthropometric data. A product can only be considered a success if people are able to use it well. This is the fundamental principle of ergonomics, which states that products should be designed to fit a particular task for the people intending to use it (Kroemer & Grandjean, 1997). Thus, anthropometric data are of critical importance in product design and development. This is one of the contributions of this study, whereby a comprehensive anthropometric database is provided to design and develop products specifically for elderly Malaysians.

5.3 Comparison of Hand Grip Strength between Elderly Malaysians with Those of Previous Studies

The hand grip strength data of elderly Malaysians aged 60 years and above are collected in this study based on the subjects' dominant hand. It is found that the mean hand grip strength of elderly males and females is 271.64 and 159.30 N, respectively, which are close to those for elderly Asians. For instance, the hand grip strength for of elderly Singaporean males and females is 258.8 and 178.5 N, respectively (Leng et al., 2014). A similar result is also obtained by Wu et al. (2009), whereby the hand grip strength of elderly Taiwanese males and females is 264.8 and 169.2 N, respectively (Wu et al., 2009). Hence, it can be deduced that the hand grip strength of elderly Asians is within 250 ± 30 N and 150 ± 30 N for males and females, respectively.

Nevertheless, the hand grip strength values of elderly Asians are significantly lower compared to those in other geographical regions. The mean hand grip strength of elderly Brazilians aged between 60 and 75 years is 336.4 and 205 N for males and females, respectively (Schlussel et al., 2008). In addition, the hand grip strength of elderly Swedish is higher, with a value of 431.5 and 378.5 N for males and females, respectively (Mosallanezhademail et al., 2012). The results obtained in this study agree well with those of previous study which revealed that the people in developed, industrialised countries have higher hand grip strength (Lloyd-Sherlock, 2000).

Hand grip strength is a useful parameter in assessing muscle function because it is non-invasive, simple, rapid and inexpensive. Numerous studies have used hand grip strength test as an indicator of the overall muscular strength (Foo, 2007) since it is the most appropriate measure to evaluate strength. Hand grip strength tests do not require great physical effort and are thus suitable for the elderly. Furthermore, hand grip strength is often used as a functional index of nutritional status (Jurimae et al., 2009; Kaur, 2009; Tsunawake et al., 2003) and physical performance (Samson et al., 2000).

Hand grip strength data are crucial to design products for the elderly. The weakness of the hands may result in difficulties in carrying out a number of daily activities such as turning a door knob, turning faucets on and off, dressing up and operating hand-held products (Yen, 2011). Increasing weakness of the hand may result in fatigue that can make self-care and household tasks more challenging. Thus, it is vital to design and develop products based on the hand grip strength of the elderly group.

5.4 Correlation between Anthropometric Dimensions and Hand Grip Strength

The results reveal that most of the anthropometric dimensions are correlated with hand grip strength ($p < 0.05$, 2-tailed). However, anthropometric dimensions that are significantly correlated with hand grip strength are found in the upper body extremity such as stature, standing eye height and shoulder height ($r = 0.526$, $r = 0.559$, $r = 0.546$, respectively, $p < 0.05$, 2-tailed). The findings agree with the results of (Koley et al., 2009) who sampled over 200 elderly people aged 60 years and above in the USA. They found that stature is strongly correlated with the right hand grip strength (males: $r = 0.925$ and females: $r = 0.800$). According to (Luna-Heredia et al., 2005) stature is highly correlated with hand grip strength due to lean body mass.

It is also found that several hand circumference dimensions are correlated with hand grip strength such as straight elbow circumference, wrist circumference, hand circumference, and thumb circumference ($r = 0.754$, $r = 0.772$, $r = 0.573$, $r = 0.532$, respectively, $p < 0.05$). This finding is in agreement with the results of Koley and Kumaar (2012) who estimated the grip strength of the dominant hand and its associations with selected hand anthropometric dimensions among randomly selected female labourers in India aged 50 years. They discovered that there is a strong correlation in the hand grip strength and hand size of females aged 50 years the hand grip strength is higher for larger hands. According to Pieterse et al. (2002) stronger hands have more muscle area and hence, larger hands. Likewise, smaller hands have smaller muscle area, which results in lower values of hand grip strength.

Based on the results, it is found that there is no significant correlation between hand grip strength and the weight of the subjects, which agrees with the findings of Bhoomiah and Jennifer (2009). They recruited 30 volunteers, measured their hand grip strength and calculated their weight. The results revealed that there is no significant correlation between these parameters and they highlighted the need for further research using larger, mixed sample sizes in the future. In this study, it is also found that there is no correlation between hand grip strength and three anthropometric dimensions, i.e. knee height midpatella, extended wrist-wall length and interpupillary breadth (r = 0.183, r = 0.032, r = 0.009, respectively, $p < 0.05$, 2-tailed).

However, anthropometric dimensions are not merely the determinants of hand grip strength. According to Li et al. (2010), other genotype and phenotype parameters, as well as psychological and methodological variables may influence physical performance. Indeed, regular measurements of hand grip strength should be performed preferably at home using a convenient set-up in order to obtain a robust way of measuring changes of hand grip strength over time (Kerr et al., 2006; Bohannon, 2008) suggested that grip strength should be measured routinely along with the measurement of other variables.

Several studies have proven that hand grip strength can be used to predict the functional limitations and disabilities of the elderly. (Rantanen et al., 2000) proved that subjects with higher grip strength during midlife remained stronger than others in the old age. Furthermore, hand grip strength is correlated with the strength of other muscle groups, and is thus a good indicator of the overall strength (Rantanen et al., 2000). Hence, grip strength measurements can be used as an early screening of samples to identify those at a higher risk of physical disability due to low muscle strength.

The results of this study also shows that hand grip strength can be predicted using anthropometric dimensions. The regression models are developed in this study using a randomly selected sample of elderly, with several inclusion criteria. Subjects with physical injuries or diseases which will interfere with the measurements of hand grip strength are excluded from this study. In general, prediction models of hand grip strength as a function of anthropometric dimensions have not been widely explored among the elderly group, and only a few researchers have developed regression models of hand grip strength. Nybo et al. (2001) developed a prediction model of hand grip strength through neuromuscular functioning. Deriving statistical models to predict one variable from one or more other variables, or predictive modeling, is an important activity in many fields, such as product designs, hospital-stays and to get to know the level of elderly's activity of daily living.

5.5 Trend of Anthropometric Dimensions and Hand Grip Strength with Increasing Age

The anthropometric dimensions and hand grip strength data of elderly Malaysians are compared with those for two control groups (20-30 years and 50-59 years). It is found that 32 out of 37 anthropometric dimensions differ significantly among age groups with the exception of the extended wrist-wall length, elbow to elbow breadth, forearm-hand length, hip breadth (sitting) and interpupillary breadth.

In addition, both genders exhibit a decrease in height over the years, which is comparable with the results of other studies (Perissinotto et al., 2002; Baumgartner et al., 1998; Dey et al., 1999). These studies have shown that height decreases from young to old age within a range of 20-40 mm per decade. According to Perissinotto et al. (2002) spinal deformity and thinning of the intervertebral discs results in a decrease in height.

Even though other anthropometric dimensions exhibit a declining trend with increasing age, the hand anthropometric dimensions exhibit a rather a peculiar trend. The results however, are comparable with those obtained by Carmeli et al. (2003). They discovered that the hand becomes progressively smaller once people have reached their 50s. This occurs because of the remarkable changes in the intrinsic bones and joints due to the ageing process. According to Burkholder (2000) and Estes, et al. (2000) ageing hands and fingers are especially prone to osteoarthritis and rheumatoid. They found that the bone density of the hand decreases by approximately 0.72% per year after the age of 50, which explains the smaller hand anthropometric dimensions. However, there is no explanation on the slight increase in hand anthropometric dimensions from the ageing adult to elderly group observed in this study.

It is also found that the foot length decreases with increasing age for both males and females. However, the decrease is minimal between the young adult and ageing adult groups, with a value of 7 and 3 mm in males and females, respectively. The results are similar with those obtained by Scott et al. (2007). They measured the foot length of 50 young adults (mean age 20.9 ± 2.6 years) and 50 elderly (mean age 80.2 ± 5.7 years) in La Trobe University in Australia. They found that the young adults have more pronated feet, indicating that they have a longer foot length compared to the elderly. There is also a significant difference in the foot length between male and female subjects. Scott et al. (2007) believed that the ageing process changes the anatomy of the foot in addition to extrinsic factors such as physical activity and walking style.

Even though most of the anthropometric dimensions appear to shrink with increasing age, the heel ankle circumference shows an opposite trend. In general, young adults appear to have smaller heel ankle circumference compared to the elderly, which is consistent with the observations of previous studies. Staheli et al. (1987) reported that the foot circumference increases after an age of approximately 30 years. This is likely due to the foot's tendons and ligaments which lose some of their elasticity and do not hold the bones and joints together as tidily as they used to be at a young age. The looser the tendons and ligaments, the larger the foot circumference.

In addition, it is found that there is a significant difference in the hand grip strength among young adult, ageing adult and elderly groups, in which there is a significant decrease in the hand grip strength with increasing age for both genders ($p < 0.005$). It is found that young adult males are stronger than ageing adult males by 12%, and the reduction in hand grip strength is even more apparent between the ageing adult and elderly groups, with a difference 24%. There is also a reduction in hand grip strength from the young adult to ageing adult to elderly groups for females. However, the reduction in hand grip strength is not as marked as those in males. In general, young adult females have higher hand grip strength compared to ageing adult females with a difference of 11%. The hand grip strength in females decreases from the ageing adult to the elderly group with a difference of 10%. It can be observed that the hand grip strength of males is nearly twice the value of females, with a difference of 44%. These results agree well with the findings of Luna-Heredia et al. (2005) in which the hand grip strength decreases with increasing age. This is likely due to various factors such as the ageing process, as well as nutritional and physical activities.

5.6 Regression Models of Hand Grip Strength

Stepwise multiple linear regression analysis is used to develop regression models which predict hand grip strength of elderly Malaysian males and females as a function of anthropometric dimensions. This is due to the fact that linear fit yields the best results in showing the relationship between anthropometric dimensions and hand grip strength for elderly males and females. It is found that the adjusted coefficient of determination (adjusted R squared) for elderly males and females is 0.239 and 0.228, respectively. The regression models are validated using data of other sample of elderly Malaysians. The results reveal that the standard error of estimate (SEE) value is relatively small for the regression model of elderly males, indicating that the model is valid. However, it is found that the regression model of elderly females is not statistically significant, whereby the regression values exceed 0.005.

In general, the results show that the hand grip strength of elderly Malaysians can be predicted using anthropometric dimensions. A number of models which predict hand grip strength as function of various variables have been developed in previous studies. Some studies investigated factors such as gender, age, weight and/or height either in children, adults or elderly (Balogun et al., 1991; Crosby et al., 1994; Niempoog et al., 2007; Günther et al., 2008). It has been shown in previous studies that measurements of the forearm and hand are better predictors of grip strength compared to height and weight (Nicolay & Walker, 2005). Furthermore, the prediction models developed in previous studies tend to be either too generic (i.e. based on age or gender only) or complicated, requiring variables that are difficult to assess and measure. In contrast, the regression models developed in this study are simple and straightforward, consisting of only a fewanthropometric dimensions. Deriving regression models to predict one variable from one or more other variables, or predictive modeling, is an important activity in many fields, such as product designs, hospital-stays and to get to know the level of elderly's activity of daily living. In addition, both models are reliable and valid, and they are the first of their kind in ergonomic studies in Malaysia.

5.7 Relationship between Hand Torque Strength and Anthropometric Dimensions of Elderly Malaysians in Bottle-Opening

A case study is carried out to validate the methodology used in this study, whereby the subjects are required to open five bottles of various sizes. Bottle-opening is chosen because it has been proven in previous studies that it is one of the most challenging tasks for the elderly (Bellamy et al., 2002; Voorbij and Steenbekkers, 2002; Yoxall et al., 2006). The correlation results reveal that there are significant correlations between anthropometric dimensions and hand torque strength for both male and female elderly ($p < 0.01$, 2-tailed). It is found that hand length and thumb circumference are significantly correlated with hand torque strength in the bottle-opening task. This finding is similar to the observation of (Yoxall, Rodriguez-Falcon, & Luxmoore, 2013) whereby hand size influences one's ability to open bottles commonly sold in stores. They also found that hand length and thumb length significantly influence one's ability to open bottles.

Crawford et al. (2010) discovered that there is a correlation between hand length and hand breadth for elderly subjects while carrying out bottle-opening task.

The results also show that the hand torque strength of both elderly males and females increases with an increase in bottle lid diameter. Based on the results, it can be seen that higher hand torque strength is required to open bottles with larger diameter. However, it is found that the mean hand torque strength is low for bottles with small lid diameters, which agrees with the results of Crawford et al. (2010). They discovered that the hand torque strength increases with an increase in diameter and height of bottles. The diameter of the bottles used in their tests is from 20 to 50 mm. The subjects create a larger torque by enclosing the test piece within their hands, which increases the surface area that is in contact with the hand, and not just the rim of the lid.

5.8 Summary

The key findings on anthropometric dimensions and hand grip strength of elderly Malaysians aged 60 and above have been discussed in this chapter. Based on the anthropometric data obtained in this study, it is found that elderly Malaysian males are heavier and taller, with greater sitting height compared to females. In addition, elderly males exhibit higher values for length, breadth and hand grip strength compared to females. Furthermore, even though there is a significant correlation between anthropometric dimensions and hand grip strength in elderly Malaysians such as stature, there is no correlation between anthropometric dimensions and weight. Comparison between elderly, ageing adult and young adult groups reveals that most of the anthropometric dimensions and hand grip strength decrease with increasing age, which is primarily due to the ageing process. In addition, regression models have been developed successfully in this study and it is found the SEE value is small for elderly males. A small SEE value is also obtained for elderly females, which indicates that both models can be used to predict the hand grip strength of elderly Malaysians as a function of anthropometric dimensions. A case study has also been carried out involving a typical daily task commonly faced by elderly Malaysians, which is bottle-opening. It is found that there is a significant correlation between anthropometric dimensions (hand size) and hand torque strength, which influences the elderly's ability to open bottles. This information can be used for to design and develop ergonomic products for elderly Malaysians which will account for their physical limitations. The anthropometric database established in this study is particularly useful to design and develop ergonomic products for elderly Malaysians.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 General Conclusions

The relationship between anthropometric variables and hand grip strength among the elderly population in Malaysia has been determined in this study. An improved methodology is proposed, which comprises a series of data collection methods as well as a case study.

The first objective of this study is to determine the anthropometric dimensions that significantly influence hand grip strength among elderly Malaysians. A total of 91 anthropometric measurements are selected based on a comprehensive review of related literature. The results obtained addresses the first objective of this study. In general, it is found that 37 out of 91 anthropometric dimensions were significantly influence the hand grip strength of elderly Malaysians. The improved methodology reduces 91 anthropometric measurements to 37 dimensions that are correlated with the hand grip strength. This finding is a significant contribution for future research.

The second objective is to determine the correlation between anthropometric dimensions and hand grip strength in elderly Malaysians. The results reveals that there is a strong correlation between anthropometric variables and hand grip strength. It is found that 34 anthropometric dimensions out of 37 are significantly correlated, namely, knee height midpatella, extended wrist-wall length and interpupillary breadth (r = 0.183, r = 0.032, r = 0.009, respectively, at $p < 0.05$, 2-tailed). Correlation analysis for each gender is also carried out and the results shows that there the results vary depending on gender. Elderly males appear to have fewer anthropometric dimensions that are significantly correlated with hand grip strength compared to females. However, there are six anthropometric dimensions that are correlated with hand grip strength for both elderly males and females, i.e. eye height (standing), span, elbow span, sitting height, eye height (sitting) and arm reach upwards.

The third objective is to develop regression models that predict the hand grip strength of elderly Malaysians as a function of anthropometric dimensions. Regression analysis is used for this purpose, and it is found that both models are valid and can be used as tools for designers to predict the hand grip strength of elderly Malaysians during product design and development.

6.2 Major Contributions of this Study

The major contributions of this study are listed as follows:

1. A comprehensive anthropometric and hand grip strength database is established in this study, which caters specifically for elderly Malaysians. The methods used for data collection, statistical analysis and model validation have also been described in detail.
2. Regression models which predict the hand grip strength of elderly Malaysian males and females as a function of anthropometric dimensions have been established in this study. It is believed that these models will be beneficial for designers to design and develop ergonomic products which cater to the special needs of elderly Malaysians.
3. The methodology implemented in this study can be used as a general guideline to determine the correlation between anthropometric dimensions and hand grip strength among elderly Malaysians.

6.3 Recommendation for Future Works

The relationship between anthropometric dimensions and hand grip strength among elderly Malaysians has been explored in this study. Knowledge on the correlation between body dimensions and hand grip strength is indeed beneficial for designers to design and develop products which cater specifically to the needs of the elderly group. It is recommended that future studies should be carried out for disabled elderly or older people with specific physical disabilities such as sarcopenia, osteoporosis or paralysed older persons. There is a global market for products and services designed with older and less able people. In order to make this to realistic levels, accurate and up-to-date data of impairment in the population needs to be surveyed. It is also necessary to collect a statistically accurate anthropometry data of this population, ultimately at a national and international level. Other than that, the data for major ethnics in Malaysia, such as Malays, Chinese and Indians should also be collected, as the domestic studies have found out that there is a significant difference between these ethnics groups. Hence, the results would be more useful and reliable with encompassed ethnic groups.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

Proceeding

1. Mohd Shalahim, N.S., Home-Related Injuries in Older Persons in Developing Countries: A Systematic Review, Proceeding National Conference for Postgraduate Research (NCON-PGR 2012), Pahang, Malaysia, 2012.
2. Mohd Shalahim, N.S., Md Dawal, S.Z., Keith, C., Relationship between Anthropometry Dimensions and Muscle Strength in Older Malaysian People, Proceeding International Research Conference on Engineering and Technology (IRCET 2014), Bali, Indonesia, 2014.
3. Mohd Shalahim, N.S., Md Dawal, S.Z., Keith, C., Anthropometry Dimensions and Muscle Strength in Older Malaysian People: A Correlation Study, Proceeding International Journal of Emerging Technology and Advanced Engineering (IJETAE 2014), New Delhi, India, 2014.
4. Mohd Shalahim, N.S., Md Dawal, S.Z., Keith, C., Anthropometry Dimensions and Muscle Strength in Older Malaysian People: An Ergonomic View, Proceeding International Journal Conference on Materials, Mechatronics, Manufacturing and Mechanical Engineering (ICMMMM 2014), Kuching, Malaysia, 2014.

Journal (Peer-reviewed)

1. Mohd Shalahim, N.S., Md Dawal, S.Z., Keith, C., Relationship of anthropometric and hand grip strength between older Malaysian people, Asian Journal of Engineering and Technology, 2014 (under review)

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1. Dawal, S. Z. M., Ismail, Z., Yusuf, K., Abdul-Rashid, S. H., Shalahim, N. S. M., Abdullah, N. S., & Kamil, N. S. M. (2015). Determination of the significant anthropometry dimensions for user-friendly designs of domestic furniture and appliances–Experience from a study in Malaysia. *Measurement*, *59*, 205-215. (Published)
2. Nurul Shahida, M.S., Siti Zawiah, M.D., Case, K. (2015). The relationship between anthropometry and hand grip strength among elderly Malaysians. *International Journal of Industrial Ergonomics,* 50, 17-25. (Published)
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5. Mohd Shalahim, N.S., Md Dawal, S.Z., A Correlation Study on Anthropometric and Muscle Strengh among Older People in Malaysia, Journal of Applied Ergonomics, 2014 (submitted, SCI-ISI index)