PROPOSED TOILET DESIGN BASED ON THE ELDERLY PERFORMANCE FOR FALL RISK PREVENTION

RATIH DIANINGTYAS KURNIA

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Industrial Systems and Environmental Engineering

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PROPOSED TOILET DESIGN BASED ON THE ELDERLY PERFORMANCE FOR FALL RISK PREVENTION

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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ราติ เดียนิงเตียซ คูร์เนีย: การออกแบบโถสุขภัณฑ์โดยป้องกันความเสี่ยงต่อการลื่นล้มตามความสามารถของผู้สูงอายุ. อาจารย์ที่ปรึกษา: รองศาสตราจารย์ พรศิริ จงกล, 131 หน้า.

คำสำคัญ: ผู้สูงอายุ เครื่องมือวัดสัดส่วนร่างกาย ความแข็งแรงของกล้ามเนื้อ การออกแบบห้องน้ำ

หลักการด้านการยศาสตร์มีบทบาทที่สำคัญในการปรับปรุงคุณภาพชีวิตของผู้สูงอายุ เนื่องจากการยศาสตร์ให้ความสำคัญแก่ความปลอดภัย ความสบาย การเข้าถึงได้ การเคลื่อนย้าย ความสามารถในการใช้งาน และการรับรู้ในความเป็นอยู่ของผู้สูงอายุ การประยุกต์ใช้หลักการยศาสตร์ในการออกแบบผลิตภัณฑ์ สิ่งแวดล้อม และระบบ ทำให้พัฒนาแนวทางการตอบสนองต่อความต้องการเฉพาะบุคคลของผู้สูงอายุได้อย่างเหมาะสม อีกทั้งส่งเสริมความเป็นอยู่ที่ดี ลดการพึ่งพิง และมีชีวิตอยู่อย่างปลอดภัยในสังคม การออกแบบโถส้วมโดยพิจารณาปัจจัยด้านอายุและความแข็งแรงของกล้ามเนื้อขาของผู้สูงอายุเป็นเรื่องที่สำคัญอย่างยิ่ง งานวิจัยนี้มีวัตถุประสงค์เพื่อวัดขนาดร่างกายของผู้สูงอายุไทยที่มีสุขภาพดีในเขตพื้นที่ชนบท ศึกษาความสัมพันธ์ระหว่างสัดส่วนของร่างกาย วัดเวลาที่ผู้สูงอายุใช้ในการนั่งลงที่โถส้วมและเวลาที่ใช้ในการลุกขึ้นยืนตรงโดยใช้ราวจับแนวนอน และวิเคราะห์ความสัมพันธ์ระหว่างค่าเวลาในการนั่งลงและลุกขึ้นยืนกับความแข็งแรงของขาส่วนล่างของผู้สูงอายุ การศึกษาครั้งนี้นำเสนอการออกแบบโถส้วมโดยพิจารณาจากขนาดร่างกายและความสามารถของผู้สูงอายุในการนั่งลงและลุกขึ้นยืน งานวิจัยนี้ศึกษาในผู้สูงอายุเพศชาย 23 คนและเพศหญิง 88 คนที่อาศัยอยู่ในพื้นที่ชนบทในภาคตะวันออกเฉียงเหนือของประเทศไทย โดยร้อยละ 49.5 อยู่ในช่วงอายุ 60-69 ปี ร้อยละ 32.4 อยู่ในช่วงอายุ 70-79 ปี ร้อยละ 17.2 อยู่ในช่วงอายุ 80-89 ปี และร้อยละ 0.9 อยู่ในวัย 90 ปีขึ้นไป ผลการวิเคราะห์ข้อมูลสัดส่วนของร่างกายพบว่าความสัมพันธ์ระหว่างสัดส่วนของร่างกายบางรายการเป็นความสัมพันธ์เชิงบวก ผลการวิเคราะห์ความสัมพันธ์ระหว่างค่าเวลาในการนั่งลงและลุกขึ้นยืนเมื่อใช้ราวจับที่มีความสูงแตกต่างกัน 5 ระดับกับความแข็งแรงของขาส่วนล่างของผู้สูงอายุพบว่าเป็นความสัมพันธ์เชิงลบ ซึ่งบ่งชี้ว่าเวลาที่ใช้ในการนั่งลงและลุกขึ้นยืนลดลงเมื่อความแข็งแรงของขาส่วนล่างเพิ่มขึ้น การศึกษาครั้งนี้เสนอแนะให้ราวจับมีความสูงเท่ากับ 85 เซนติเมตรเนื่องจากความสัมพันธ์ระหว่างค่าเวลาในการนั่งลงและลุกขึ้นยืนกับความแข็งแรงของขาส่วนล่างของผู้สูงอายุมีค่าสูงสุดเมื่อใช้ราวจับที่มีความสูงเท่ากับ 85 เซนติเมตร

สาขาวิชาวิศวกรรมอุตสาหการ ลายมือชื่อนักศึกษา...

ปีการศึกษา 2565 ลายมือชื่ออาจารย์ที่ปรึกษา.................................

RATIH DIANINGTYAS KURNIA: PROPOSED TOILET DESIGN BASED ON THE ELDERLY PERFORMANCE FOR FALL RISK PREVENTION. THESIS ADVISOR: ASSOC. PROF. DR. PORNSIRI JONGKOL, 131 PAGES.

Keyword: Elderly Anthropometry Muscle Strength Toilet Design

Ergonomics has a crucial role in improving the quality of life for older adults as it prioritizes safety, comfort, accessibility, mobility, functionality, and cognitive well-being. Through the application of ergonomic principles in product, environment, and system design, we can develop solutions that cater to the specific requirements of elderly individuals, fostering their well-being, independence, and a greater sense of age-friendly living. Toilet design with age and muscular strength parameters is crucial. The objective of this study was to measure the body dimension of healthy Thai elderly living in rural areas, investigate the relationship among body dimensions, measuring the time needed by the elderly in performing stand-to-sit and sit-to-stand movements in the toilet with the help of horizontal handrail, and analyze its correlation with the elderly's lower limb strength. This study proposes a toilet design for the elderly by considering the anthropometry aspect and its correlation with the elderly performance. The measurements were taken on a total of 23 male elderly and 88 female elderly people from rural areas in Northeastern Thailand. Most respondents (49.5%) of the total elderly are in their 60s, 32.4% in their 70s, 17.2% in their 80s, and 0.9% in their 90s. According to the anthropometry's correlation calculation data, positive correlations were found between some of the body dimensions. The results from time and muscle strength measurement on five different handrail heights showed that there was a moderate negative correlation between the time consumed in stand-to-sit and sit-to-stand movement with the elderly's lower limb extension and flexion strength in all five different experimental setups. The negative relationship indicates that the time needed in the act of stand-to-sit and sit-to-stand movement decreases as the lower limb strength increases. From this study, the recommended handrail

height is 85 cm since it showed strong correlation between the time required to sitting and standing up and the lower limb strength.

School of Industrial Engineering

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Student's Signature ....

Advisor's Signature ....

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LIST OF ABBREVIATIONS

ADA	= American with Disabilities Act
BMI	= Body Mass Index
cm	= centimeters
FIM™	= Functional Independence Measure
GRF	= Ground Reaction Force
Ho	= Hypothesis 0
H1	= Hypothesis 1
kg	= kilogram
N	= Sample size
Nm	= Newton-meter
p	= probability value
PA	= Physical Activity
PH	= Popliteal Height
QoL	= Quality of Life
s	= seconds
SD	= standard deviation
SH	= Seat Height
Sig	= Significance
SPSS	= Statistical Package for the Social Sciences
Std. Dev.	= Standard Deviation
STS	= Sit-to-Stand
UNFPA	= The United Nations Population Fund
WHO	= World Health Organization
WHOQOL	= World Health Organization Quality of Life

CHAPTER I

INTRODUCTION

1.1 Background of Study

The term “elderly” refers to people aged 65 and over, "early elderly" refers to people aged 65 to 74 years old, and "late-stage elderly" refers to people aged 75 and over (Orimo et al., 2006). The aging process that occurs naturally has a variety of effects of the emergence of physical, mental, and social problems, such that an elderly will experience the limitations as a result of aging process (Diana, 2007). The aging process is a progressive change in organisms that has reached inherent maturity and is irreversible, resulting in a decrease over time. The natural process, which is accompanied by a decline in physical, psychological, and social conditions will interact with one another (Palestin et al., 2006). Based on the survey results conducted by Palestine et al. (2006), it was reported that with increasing age, the incidence of functional disabilities in the elderly experienced a significant increase (Grundy & Glaser, 2000; Hillerås et al., 1999; Laukkanen et al., 1997). Elderly people can be categorized in different ways, including physical appearance, important life experiences, and social roles. Aging is an expected process and is usually measured in chronological order. According to Kowal & Peachey (2001), most developing countries agree that old age begins at age 60 or 65. According to data from World Population Prospects: the 2017 version (United Nations, 2017), the number of people aged 60 and above is estimated to more than double by 2050 and treble by 2100, rising from 962 million in 2017 to 2.1 billion in 2050 and 3.1 billion in 2100. In one of his research, Henry et al. (2001) noted that the number of old people in developing nations has rapidly grown as a result of improved access to health and public services. They also claimed that Thailand's economic growth is vital in improving the quality of life of Thai elderly.

An aging society is defined as a country with a population of more than 10% aged people (Swanson & Siegel, 2004). In Thailand, the proportion of adults over the age of 60 accounts for around 13% of the total population (UNFPA Thailand, 2006). According to the United Nations (2017), the elderly population in Thailand will increase significantly over the next 15 years, with the number of elderly people estimated to double by 2050. The proportion of the population aged 60 and above is expected to exceed 30% by 2035 (United nations, 2017). The elderly in rural locations have the same healthcare access issues as those in metropolitan areas. However, they may confront issues in their communities about housing quality, the availability of home-based services, and long-term care. According to Srithamrongsawat et al. (2009), Thailand's elderly requires long-term care due to the country's growing aging population.

WHOQOL (1994) in tandem with the nation's transition to an aging population stated that the quality of life of the elderly must be assessed and improved to a greater extent (Syafinas et al., 2018). The WHOQOL working group published quality of life criteria for those aged 60 and higher in 2004, which were tested in several countries (Power et al., 2005). Tiraphat et al. (2017) validated the importance of age-friendly environments in terms of physical and social environments for elderly's quality of life. As a consequence, it is necessary for elderly in Thailand to examine and enhance their quality of life status as it can be one of the indications of healthy life where elderly should be part of the society's social development resources. The difficulty with activities of daily living (ADL) is an early predictor of daily activity reliance in the elderly, and one of the criteria is mobility problems (Hirvensalo et al., 2000; in Kutsuna et al., 2019). According to a study conducted by (Ćwirlej-Sozańska et al., 2019), a worldwide report by the Department of Economic and Social Affairs of United Nations (2017) revealed in their study that over 45 percent of individuals aged 60 and older had difficulties performing daily tasks. Southeast Asia is home to some of the world's fastest aging countries, with Thailand ranking second. A study conducted by (Kumsuchat, 2017) showed that Thai elderly population consists of 56.5 percent early elderly (60-69 years), 29.9 percent of middle elderly (70-79 years), and 13.6 percent of late elderly (80 years and above). From the entire population, 79.5 percent are active aging, 19.0 percent are home bound elders, and the rest of them are bed bound elders (Kumsuchat, 2017). According to the United Nations (2017), the population of people aged 60 and over is expected to quadruple between 2015 and 2050. A rise in the number of elderly people has an impact on health status, which is related to biological and age risk factors and reflects age-related changes. Such alterations may result in bodily system disruption and degenerative illnesses, both of which give negative impacts functionally (Miller, 2004). Physiological and psychological changes occur in the elderly and changes in the elderly can have negative impacts on productivity, independence, and quality of life (Miller, 2004).

The neurological, sensory, and musculoskeletal systems are among the physiological alterations that occur. Changes in the neurological system cause cognitive changes, slower response times, balance and kinetic issues, and sleep difficulties (Mauk, 2010). The loss of touch sensitivity leads to a lack of detecting ability, position recognition, and pressure on the skin (Mauk, 2010). The changes and decreasing physiological function that the aged undergo will result in diminished muscular strength, nerve control, and sensory ability (Manuaba, 1998; Rabbitt & Carmichael, 1994). Changes in the aged might have an impact on the body's ability to balance. Balance ability declines with age as a result of changes in the central or neurological nerve system, sensory systems such as the visual system, and the muscular system (Miller, 2004).

As people age, their ability to use their senses deteriorates. The setbacks mentioned here solely involve physical impairment, particularly those impacting the safety of the elderly when doing activities in the bathroom, which is one of the common causes of fatal accidents in the elderly (Chisholm & Harruff, 2010; Copeland, 1985; DeVito et al., 1988). The State University of New York at Buffalo has conducted study and redesign of bathrooms for the elderly with the goal of lowering mortality as well as bathroom injuries. According to the National Safety Council (NSC), one person dies in the United States every day as a result of using a bathtub or shower in the bathroom. The NSC further reported that 345 people of all ages died in bathrooms in 1989, 364 people died in 1988, and 348 people died in 1987 (Mullick, 1993). According to data from the Brazilian Health System, individuals aged 60 and above account for one-third of traumatic lesions in hospitals. From that portion, 75 percent of them are the result of house accidents, with 34 percent of falls being followed by some sort of feature. Falls caused by visual and postural instability, which are common at this age, are major causes of death in the elderly. One-third of people who live at home and half of those who reside in institutions suffer fall at least once a year (Câmara et al., 2010). According to the preliminary study by Af'idah et al. (2012) based on interviews with nursing home officers in Surabaya, Indonesia, it was discovered that around 60 percent of elderly people from 39 nursing home residents had experienced fall accident in 2011. According to the officer's knowledge, it was caused by aging problems that allow them to fall easily, as well as the slippery bathroom environment. In Thailand, Jitapunkul et al. (1998) in Kuhirunyaratn et al., (2013) found the prevalence of one or more falls is 18.7% and elderly females fell more often (21.5%) than their male counterparts (14.4%). Most falls occurred outside (65%) and during the day time (85%) (Jitapunkul et al., 1998). According to Kuhirunyaratn (2013), in urban areas, Assantachai et al. (2003) found that the falling incidence happened to Thai elderly was about 19.8% within a period of 6 months. Falling is one of the major causes of injury among the elderly which can lead to death. Previous studies have suggested that more than half of the falling incidents caused minor injuries, and one quarter caused serious injury with 10% caused fractures (Bergland & Wyller, 2004).

Zein (2014) stated in her study that this type of accident is more common in residential environments due to factors such as slippery and uneven flooring, stumbling due to insufficient circulation, and unclear vision due to low lighting, and so on. Although accidents in the elderly are often caused by intrinsic factors or disease-related causes, extrinsic or environmental variables also play a significant role. Therefore, the bathroom must be built in a way that is "friendly" to the elderly. Aside from safe use, the elderly can also be independent in the bathroom, without the assistance of others. According to Hjalmarson (2014), one of the reasons old individuals moved from their houses to nursing facilities is because they have diminished ability and increasing reliance on others, particularly in the bathroom. House attendants described a narrow and constrained work environment in the bathroom and "poor posture" that appears around 50% of the time when they assist someone from and to the toilet (Brulin et al., 2000). House attendants frequently feel overburdened when doing their duties (Engels et al., 1994; Hasson & Arnetz, 2008), therefore this might be another concern occurred from this matter.

Leading a full social life can be achieved by experiencing a proper work and life environment to its fullest, with particular references to the themes of neighbourhood and daily activities. It can stimulate people to lead a healthy life from both a physical and mental point of view (Pericu, 2017). Good living conditions should be provided at home in order to help elderly independently carry out basic daily activities safely (Putthinoi et al., 2016). Toilet is one of the most essential things to have for good sanitation and provide healthy living environment. Elderly people have different physical condition compared to children and adults, the risk of every corner in their workplace and living environment should be paid attention to. Managing the risk will be very important to create a safe living environment. Elderly might need help getting on or off the toilet so they don't fall. Preventive action is one of the best solutions to this matter. A proper toilet design with hand railing as helper tool could also help elderly and nursing homes caregivers to avoid injury while helping with elderly toilet use.

Bathrooms require special ergonomic consideration since they are central to the notion of healthy living (Kroemer, 2017). The basic principle of the proposed study is to create a toilet design suitable for elderly that helps them do toilet use independently and safely. The main idea is to design a toilet fit to their body dimension with additional helper tool which is a handrail. In this study, we also consider elderly grip strength and knee muscle strength. The overall design and exact dimension of the handrail design will be adjusted to the proper dimension following the basic design guidelines and the overall measurement results.

1.2 Rationale and Problem Definition

There are a number of rationales as to why proposing toilet design by considering age and muscle strength factors are important. Several studies concerning on improving elderly quality of life have been conducted all across the country and the world. A development of each innovation is needed in order for it to be better and useful. The present study examined men and women aged 60 or more, because muscle mass and strength begin to decrease from the age of 50 (Lynch et al., 1999). As stated by Kumsuchat (2017), 79.5 percent of Thai elderly are active aging, which means they are in a state where they can do their activities independently. This also means that they are still actively using their muscle, however aging has their effect on their limitation because of the decreasing of strength, productivity, and independence (Miller, 2004). To increase the productivity, the tools the elderly are using must be integrated into the daily life activities and workflow of the elderly. Considering muscle strength of the elderly can help simplifying and humanizing the tools.

According to a statistic data by Prachuabmoh (2019), the percentage of age 60 having difficulties with daily life activities has reach 6.3 percent in 2016. This shows an increase of 2.6 percent from 3.7 percent in 2001. From a different perspective, such as health and home care worker, the design thinking can help improving the help care. However, this study was conducted with an orientation to provide a helpful toilet design with the right innovations to improve the quality of life of the elderly, especially those who wish to live on their own. The proper toilet design will accommodate elderly well with ageing in place, or in this case growing older in one’s own home or community with the ability to live safely, independently, regardless of age or ability level.

The body dimensions of the elderly in rural areas are useful for the design of appropriate facilities such as a handrail in the restroom and a toilet seat. Additionally, this helps improving the safety in the everyday activities of the elderly in rural areas. The anthropometric data developed here was intended to address the lack of information related to the dimensions of the elderly body and to help the products' development and other supporting equipment to be anthropometrically suitable for elderly residents of rural areas in the future, such as the manufacture of elderly public facilities and nursing home supporting tools. Based on the existing problems, it is necessary to evaluate the effect of the living environment in the bathroom on the comfort and safety of its use for the elderly. Elderly as the subjects of this research did the experiment as how we set it up for them with resting time in between the experiment. The results of these evaluations were further analyzed and given the proposed design work system to support the ease of the elderly in their activities, especially the activity in the bathroom for toilet use. This study considered elderly ability to perform independently as an additional criterion to improve overall system performance of the proposed toilet. In this study, the application of anthropometry for ergonomic requirements was explored and samples of utilizing anthropometric research in designing proposed toilet for the elderly were provided. The proposed toilet has handrail included. The concept is to help elderly in sitting down and getting up from the toilet easier with the additional helpful tool.

1.3 Research Objectives

Taking into account the background, rationale, and problem definition as discussed in previous section, this research aims to help finding a more user-friendly toilet designed for elderly. The objectives of this research are as follows:

1. To measure elderly body dimension related to toilet and handrail design.
2. To measure the hand grip and knee muscle strengths of the elderly.
3. To investigate the effect of handrail height, toilet type, and muscle strength on time required to stand up in simulated toilet environment.
4. To recommend toilet design that fit the needs of the elderly for achieving an improvement in the activity's performance of elderly.

1.4 Research Scopes and Equipment

The scope of this research is as follows:

1. This study was conducted on elderly who still have the ability to live independently.
2. This study was focused on the ability of elderly muscles in doing toilet activity.
3. The respondents of this study were elderly living in Pak Thong Chai district of Nakhon Ratchasima province.
4. The muscle strength of the elderly was measured by torque and hand grip dynamometer.
5. Data obtained from the measurements was evaluated and calculated by using SPSS statistical program.
6. The workplace setting was designed as close as possible to approach the realistic toilet bathroom situation.
7. The measurement of sitting down and rising up from toilet was set on two different settings, namely conventional toilet and modern toilet.
8. The time measurement was done manually and was recorded on digital camera.

The equipment used in this research is as follows:

1. Anthropometer and measured tape
2. Torque dynamometer
3. Hand grip dynamometer (JAMAR)
4. Digital camera
5. Stopwatch

1.5 Research Contribution

The research in this study offers valuable contribution on research novelty in the following areas:

1. This research will add an insight and knowledge about the relationship between the elderly with the environment especially the toilet, to get a true picture of the theory obtained with facts in the field.
2. The study result is expected to help the government to improve facilities for the elderly for the security in doing their activities, such as with the improvement of work system design.
3. The simple approach used in this study is expected to bring the research outcomes applicable in the real-life workplace environment.

1.6 Research Benefit

The research in this study offers benefits as follows:

1. The study result can be used to improve the quality of elderly life by improving their ability to perform independently.
2. The toilet design will be an important finding to guide people in designing the proper toilet for the elderly.

CHAPTER II

LITERATURE REVIEWS

This chapter describes a review of relevant literature to the present study. It is divided into three main topics which are anthropometry, muscle strength in elderly, and toilet environment for elderly. The first topic begins with definitions of ergonomics and its relation to anthropometry, the anthropometry of elderly, and how its measurement. The second topic describes the muscle strength of elderly and how it affects elderly's daily activities. The third topic describes the work environment for human daily activities and the importance of redesigning toilet environment for elderly. The previous research studies relevant to these topics are reviewed at the end of each section.

2.1 Ergonomics

Tayyari & Smith (1997) defined ergonomics as the science that focuses on the relationships between laborers and their work place. Ergonomics is the study of work involved: the people who do it and how they do it, the instruments and equipment they use, the environments in which they work, and the psychosocial elements of the working environment (Pheasant & Haslegrave, 2018). Ergonomics or (human factors) also defined as the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (Vink et al., 2006). The objectives of ergonomics design are to provide comfort, to improve occupation safety and health, and to increase work efficiency (Oborne, 1982; and Pulat, 1992). The ergonomic method, as a work science or a design science, attempts to achieve the most optimal fit between the product (object, system, or environment) being designed and the people who use it. In terms of definition, ergonomics is the science of fitting an assignment with the people and a product with the user (Pheasant & Haslegrave, 2018).

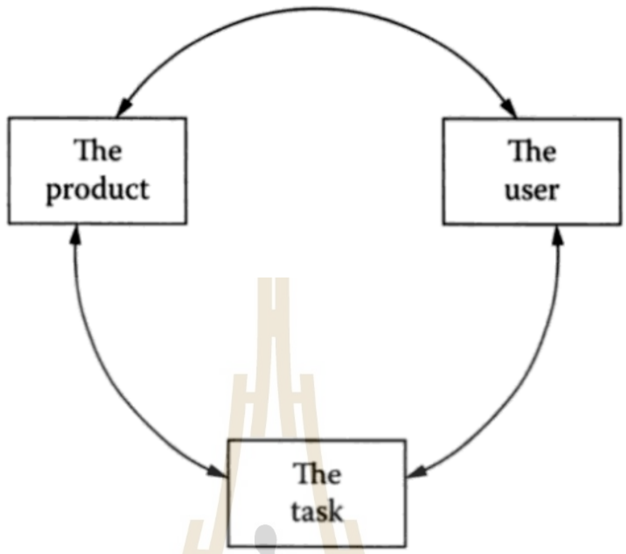

Figure 2.1 User-centred design: the product, the user, and the task (Pheasant & Haslegrave, 2018).

Humans have a variety of changes with age, culture, behavior, physical, psychology, health, and cognitive changes. In the work area, the first concentration will focus on changes that arise based on the physical, psychological, and psychosocial capacities of users who are beginning to enter the elderly stage (Perry, 2010). Accommodation for the elderly is essential in a definite workplace change. Workers should be aware of the changes that occur in older workers and how to accommodate them. Perry (2010) suggests that it is advisable to design suitable working environments for the elderly to improve the safety and productivity of all workers.

2.2 Anthropometry

Anthropometry is an important aspect of ergonomics study due to how it addresses the issue of fitting tasks/products to user characteristics (Dianat et al., 2018). Anthropometry is the science of measuring the dimensions of the human body, anthropometric data are used as a guideline for the design height, the space, the grip and the space of the workplace and equipment in the work area (Wickens et al., 2004). The usage of anthropometry is to help determining the user population, body dimensions, and percentile value of the selected anthropometric dimensions, where all of those will be used in designing the products with proper size of body dimensions (Wickens et al., 2004).

Anthropometry data will be useful especially in designing products. Product design is a scheme in which the functional elements and the products are arranged into a set of components that form the physical. Product design is determined during the phase of the development of the concept and design of system level (Ulrich & Eppinger, 2000). Anthropometry and ergonomics can be used to improve the physical environment in developing facilities for the elderly. Anthropometry has been widely recommended to assist in the management and treatment of physical human requirements (Hartono, 2018). Anthropometry plays an important role in the design of facilities and equipment because it must include proper measurements into product characteristics and designs. An appropriate design will utilize anthropometric data to increase productivity and reduce work-related musculoskeletal problems (Chuan et al., 2010; Klamklay et al., 2008). Human measurements and proportions diverse and this must be recognized and applied well in designing a product or facility (Pheasant & Haslegrave, 2005).

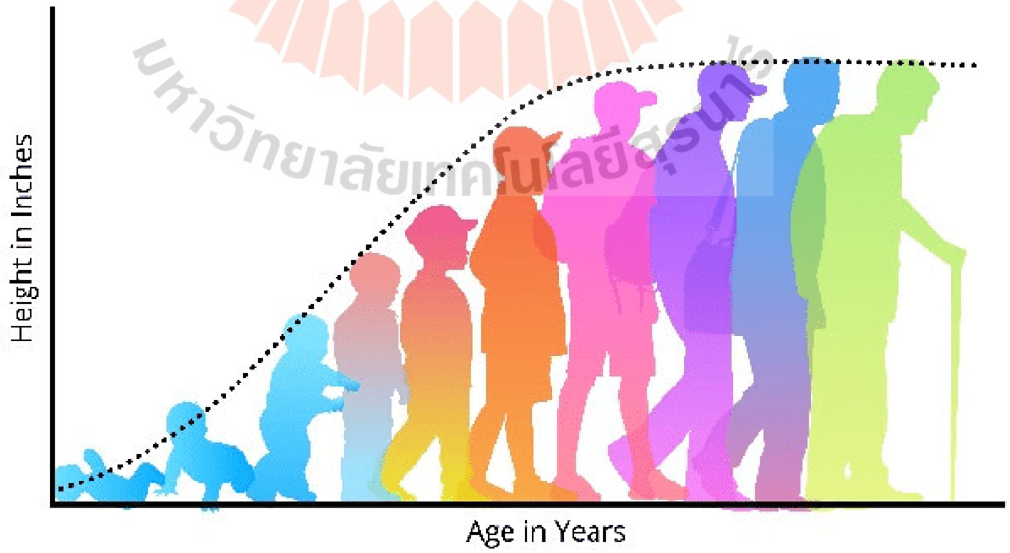

Figure 2.2 The differences of the dimensions of human body based on their age group (See et al., 2022).

Children and the elderly are considered as special populations who may have different anthropometric dimensions than adults, depending on size and the ratio of measurements (Hartono, 2018). Variation in human characteristics is also correlated to ethnicity, gender, and age (Jürgens & Pieper, 1990; in Abd Rahman et al., 2018). Figure 2.2 showed the differences of the dimensions of the human body which grow with age as it grows from the beginning of its birth and shrinks when they reach certain age. Ethnic diversity is an essential component that impacts anthropometric data since it is more prevalent among races than nations (Abd Rahman et al., 2018). As a result, the body dimensions of a person from one population, country, and ethnicity might range greatly from those of others. The use of an appropriate anthropometric database is critical for assisting in the adaptation of facilities and equipment to a certain population (Wickens et al., 2004).

2.2.1 Anthropometry of Elderly

In modern environment, user-centric design for the specific users while taking anthropometric and range of motion variability into account is quite preferred (Sutalaksana & Widyanti, 2016). Many researchers agreed that anthropometric measurements for the targeted user population play a vital role in designing ergonomic solutions (Brabec, 2005; Nowak, 1996; Vaidya et al., 2009; Wibneh et al., 2020).

Because aging is unavoidable, it is critical to address the physical limits of the elderly population. When designing and creating goods for the elderly, it is critical that product designers are using relevant and up-to-date anthropometric data (Nurul Shahida et al., 2015). Anthropometric measurements also represent physical limits that must be taken into account in the elderly. Perissinotto et al. (2002) revealed that males and women experience distinct changes in body composition, which impacts anthropometric measures. Anthropometry offers data that may be used to create elderly people's work and life environments (Nowak, 1996). According to Al-Ansari & Mokdad (2015), design should be developed particularly for the elderly because what is designed for younger individuals does not always fit the old. The elderly requires a suitable living environment and amenities to support their limits and ability to operate normally. Elderly people frequently have difficulty utilizing everyday products since the design of many regularly used products does not take their limits into consideration (Al-Ansari & Mokdad, 2015). Redesigning goods, workplaces, and facilities ergonomically for the aged by applying anthropometric data into design considerations might help lessen the risk of accident to occur (Lee et al., 2019).

2.2.2 Previous Studies Concerning on Anthropometry of Elderly

There were many studies conducted which considered anthropometry of elderly as an essential part of it. Some of the studies focused only on anthropometry and presented the anthropometric data in a form of percentiles which are generally needed for clinical practice and specifically designed products or living facilities for elderly.

Kothiyal and Tettey (2001) presented anthropometric data of 33 male and 138 female elderly people in Australia and assessed the relationship between different body dimensions by calculating the correlation coefficients. Active elderly people with normal physical health were randomly chosen from the population located in the metropolitan Sydney area in New South Wales, Australia. According to Kothiyal and Tettey (2001), one of the most important anthropometric characteristics that changes with age is stature. The anthropometry measurements were taken in standing and sitting positions and confined to certain body dimensions that were deemed relevant and useful for the design of facilities or workplaces for elderly (Steenbekkers & Beijsterveldt, 1998). A comparison of age and stature height of Australian, British, Dutch, and American elderly population were also presented in this study. The result showed that American males and females are the tallest compared to the rest of the populations. On the other hand, Australian, British, and Dutch elderly population have nearly similar stature height. In this study, there were also some examples of how the data are used in a design. For examples, office chairs and table, storage shelves, and public transport bus seat, which are specifically designed for elderly.

A study by Barbosa et al. (2005) presented gender and age-specific selected anthropometric data for elderly population in the city of São Paulo, Brazil. Anthropometry data were provided by examining a total of 1894 Brazilian elderly people consisted of 1124 female and 770 male elderly. This study aimed to present distribution values for Brazilian elderly people's anthropometric characteristics and to identify the variations in elderly's anthropometric characteristics. Participants were selected through a questionnaire screening and verification procedure. A total of 6 body dimensions and body mass were measured and taken in triplicate. Body mass was higher in the youngest in both female and male elderly people. According to Tukey's test, mean body weight in female elderly were less than male elderly at each age group. This study also indicated that male and female aged 60 years or older has significant age-related anthropometric differences. The data pointed to the occurrence of gender-specific changes in body dimensions. The oldest had thinner body compared to the youngest (in both genders). The study also suggested that there is reduction of fat mass and muscle mass in the elderly.

Dekker et al. (2007) analyzed the hand supports to help the elderly use the toilet. This study aimed to enhance the toilet environment in order to improve the quality of life for elderly and disabled persons. The study explored at elderly's preference and use of supports in the toilet during the entire toilet activity. A toilet and three different types of supports were used to construct and adjustable test frame. In general, preferred positions were determined more by elderly preferences than by body dimensions. It was determined that vertical supports are preferred for sitting and standing. The side supports were also equally appreciated when using the toilet.

Chen et al. (2010) examined the seat heights during sitting and standing activities in their research. This study has accumulated data regarding the subjective ratings of the perceived difficulty and safety of twenty elderly and younger subjects (10 each respectively) concerning rising and sitting transfers conducted under eight testing conditions, including 4 seat heights (SH) (80%, 90%, 100%, and 110% popliteal heights (PH)), and 2 preparatory situations (instant and non-instant). Results evidence that elderly subjects felt that it was more difficult and less safe to rise and sit at lower (80% and 90% popliteal height) and higher (110% popliteal height) seat height. Younger subjects felt that it was only a little difficult and less safe in lower seat height (80% popliteal height). The results also demonstrate that rising was faster than sitting and that the elderly were slower than their younger counterparts. Non-linear regression analysis shows that the best seat height ranges from 40.72 cm to 41.10 cm for elderly subjects, and 45.23 cm to 48.93 cm for younger ones whilst using subjective rating scores as dependent variables.

Hartono and Indah's research (2012) is a study of anthropomorphic-scale studies in the elderly as the basis for designing nursing homes. This study aims to determine the standard size of furniture for the elderly to be used as the basis for designing the nursing home. The data collected were anthropometric measurements on 5 elderly men and 5 elderly women from three different nursing homes. The results of this study are anthropometric data for dimensions in standing position, sitting position, and squatting position which can be used as a basis to determine the standard of furniture size in the nursing homes. In addition, the results of the research provided are the results of interviews on toilet, railing, bathroom floor, and bathroom door handle which is the preference for elderly. It was obtained in order to set the standardization by paying attention to user convenience.

Rahmawati et al. (2020) in their study of anthropometry proposed a bedroom design for Indonesian elderly. A total of 103 elderly from 5 nursing homes in Bandung, Indonesia, consisted of 21 male and 82 female aged between 50 to 94 years old were involved in this study. An interview was carried out to determine the differences in daily life of elderly between live-in residents and those who live in nursing facility. Anthropometric measurements were conducted on 15 body dimensions which are considered important in the design of an elderly bedroom. The anthropometry data were used in the proposed bedroom design. The proposed bedroom design was a pilot project to standardized the facilities needed by Indonesian elderly. The proposed design was expected to increase the well-being of elderly people, allowing it to be implemented in other sectors, particularly in other developing countries.

Kaewdok et al. (2020) designed products and living facilities by applying anthropometric data of 240 elderly people consisted of 138 female and 102 male elderly people resided at Prom Buri district, Sing Buri province, Thailand. The study suggested that anthropometric dimensions are recommended as a guideline for designing ergonomics products, equipment, and household facilities. A total of 32 body dimensions were measured and the data was analyzed which involved descriptive statistics, independent t-test, and percentile values calculation. The result indicated that male elderly tends to have larger anthropometry dimensions than female elderly and that between male and female elderly, it was found that there was no significant difference in chest depth and hip breadth body dimensions. The application of 9 standing body dimensions and 11 sitting body dimensions were selected and considered important in designing home and facility in order to achieve optimal functional efficiency, comfort, health and safety, and quality of working life. The anthropometry data were presented in mean value, standard deviation, 5th percentile, and 95th percentile of each body dimensions measured in the study. This study also presented how anthropometry data are used in elderly-friendly home and facility design. The percentile values of specified anthropometric characteristics were listed for clearance and reach dimensions. It is recommended to use 95th percentile of male standing stature to satisfy minimal clearance standards for door design or gateway heights which should not be less than 172 cm. The optimum reach zone should range from 86 cm to 115 cm and 61 cm to 81 cm in standing and sitting positions, respectively. This study also suggested that a well-designed living and working environment should improve the comfort, health, and safety of Thailand’s elderly.

2.3 Muscle Strength of Elderly

Muscle strength was shown to be related to many measures of functional status and young individuals have considerably more muscle area, mass, and strength

(Hyatt et al., 1990). The muscle area, mass, and strength of male elderly were significantly larger than those of female elderly (Hyatt et al., 1990). It is acknowledged that muscle strength declines as individuals get older (Lindle et al., 1997). Muscle strength and power loss is a characteristic of the aging process (Hartmann et al., 2009) and correlates with poor functional ability in elderly people (Chodzko-Zajko et al., 2009). According to Frischknecht (1998), muscular power declines by up to 50% between the ages of 30 and 80, with the most significant losses occurring in the lower limbs. In recent years, age-related muscular strength loss has been generally considered as one of the primary causes of impairment in the elderly (Rantanen et al., 1999) and the decrease of muscle strength in the elderly has appeared as one of the most frequent issues in elderly people (Clark & Manini, 2012; Mitchell et al., 2012). Several cross-sectional studies have been conducted for over the years and the results showed that muscle strength differs substantially between male and female. This was also shown on a study by Matsuoka et al. (2006) which observed that male in general had greater muscle strength than female.

Muscle strength and functional activity have been proven to decrease as people age (Akbari & Mousavikhatir, 2012). Muscle strength deterioration with age is caused by an overall decrease in muscle mass (Thompson, 1994). According to Stamford (1988) in a study conducted by Metter et al. (2002), the aging process affects the decrease in muscle strength for about 30-40%. Metter et al. (2002) also reported that beyond the age of 50, there is a notable reduction in muscle strength, which increases after the age of 65. It has also been proposed that frailty and impairment in the elderly are related to how their muscles are utilized (Shahida et al., 2015). Aging affects changes in the quantity and quality of skeletal muscles in the elderly (Seene et al., 2012). One of the most prevalent and serious health conditions in the elderly is falling. According to a study by Moreland et al. (2004), lower limb muscular weakness is a statistically significant and clinically important risk factor for falls. Lower extremity muscle strength is more impaired by aging than upper extremity muscle strength because the elderly utilizes their lower limbs less than their upper limbs in daily activities (Candow & Chilibeck, 2005). Data from the Health, Welfare, and Aging research, which involving 1413 elderly living in São Paulo's metropolitan area, revealed that 50.9% of the elderly had muscular weakness and 40.1% had poor levels of physical activity (Alexandre et al., 2014). Elderly population is likely to be one of the most vulnerable groups of individuals when it comes to the decrease of postural stability and general mobility. This is due to combination of a less active lifestyle and biological processes. The latter also includes muscle mass loss (i.e., sarcopenia) (Watson, 1995) and a reduced ability for voluntary neuromuscular activation (Morse et al., 2004), both of which leads to a decline in muscle strength and power (Macaluso & De Vito, 2004; Sayers, 2007). According to Nejc et al. (2013), the link between balance and strength has been established, however studies on the subject are rather contradictory, and the cause-effect relationship cannot be easily characterized.

2.3.1 Knee Strength of Elderly and Sit-to-Stand Movement

Skeletal muscle mass and strength decline with age, particularly in the knee extensor muscles (Overend et al., 1992; Kubo et al., 2003; Candow & Chilibeck, 2005; Kubo et al., 2007; on Takai et al., 2009). Takai et al. (2009) explained that in the elderly, decreased force-generation of knee extensors is related with a decline in the capacity to execute daily activities such as walking (Kim et al., 2000) and standing up from a chair (Hughes et al., 1996). According to Takai et al. (2009), the capacity to stand up from a sitting posture on surfaces of varying heights affects individual's independence (Corrigan & Bohannon, 2001), and the measure of such ability has been viewed as an indication of thigh muscle strength (Bohannon, 1998; Csuka & McCarty, 1985), according to Takai et al. (2009).

Stand-to-sit and sit-to-stand movements are few of the most common and essential movements performed in daily activities (Janssen et al., 2002). It involves the ability to manage one's body balance in the process of moving from sitting to standing position (Roebroeck et al., 1994). Because sitting and standing up movements involve postural control, the elderly people are likely to have more difficulties than younger persons (Mourey et al., 1998). Leg muscle function is defined as the level of function of the legs required for independent life. Leg muscle ability declines substantially with age which causing the elderly people to have trouble performing sit to stand motions (Alexander et al., 1991; Gross et al., 1998). The decline in the elderly's skeletal muscles has an impact on their performance, such as difficulties sitting and rising from a chair (Kuh et al., 2006) and a higher risk of falling (Orr et al., 2006). The loss of muscular strength and the ability to control body balance has long been recognized as a risk factor for falls and related injuries (Benichou & Lord, 2016). Reduced extensor strength may also induce an imbalance between the hamstring and quadriceps muscles, resulting in insufficient co-contraction of these muscles during the process of standing up (Brech et al., 2013). As a result, knee extensor strength is an important aspect in the proper biomechanical implementation of standing up (Rutherford & Jones, 1992, and Hurley et al., 1998). Sit-to-stand and stand-to-sit movements are repeated several times throughout the day, particularly during bathing and toileting activities, thus the sit-to-stand and stand-to-sit motions are crucial for independently completing activities of daily living (Kato et al., 2020). A few studies have also shown that the loss of lower limb strength that happens with aging has an impact on STS motions (Buzink et al., 2005; Zijlstra et al., 2010).

2.3.2 Hand Grip Strength of Elderly

Hand grip strength is a reliable measure if the user uses standardized procedures and calibrated tools (Massy-Westropp et al., 2011), and is a solid indication of muscle strength that can be easily measured in the laboratory with hand dynamometers (Syddall et al., 2003). Hand grip strength can also be utilized to detect and forecast other health problems in the elderly (Shahida et al., 2015). Hand strength has been recognized as an essential component in predicting impairment in musculoskeletal disorders (Öken et al., 2008), falling tendencies, and osteoporosis fractures (Ensrud et al., 2008; Sirola et al., 2008). It can also predict problems and general morbidity following surgical procedures (Mahalakshmi et al., 2004), as well as overall impairment and future outcome in older age (Bohannon, 2008; Rantanen et al., 1999; Snih et al., 2004).

According to Sallinen et al. (2010), hand-grip strength is an easy, reliable, and low-cost surrogate for overall muscle strength, as well as a valid predictor of physical impairment and mobility constraint (Rantanen et al., 1999; Shinkai et al., 2000). The hand-grip strength test is a helpful tool for identifying those who are at a higher risk of mobility limitations (Sallinen et al., 2010). According to Lenardt et al. (2016), as a component of physical frailty, reduced muscular strength as measured by handgrip strength is becoming an essential tool for health practitioners and researchers. Furthermore, handgrip strength is utilized as a predictor of overall strength and is related to mortality and disability (Fried et al., 2001; Gale et al., 2007; Bohannon, 2008). The results of a study done by Lenardt et al. (2016) revealed that handgrip strength was reduced in 64.3% of the elderly. In terms of physical activity (PA), 58.4% of the elderly had poor levels of physical activity, with 37% pre-frail and 21.4% frail.

The amount of static force that can be measured by squeezing a dynamometer can be used to determine the strength of a handgrip (Massy-Westropp et al., 2011). The Jamar Dynamometer has been proven to properly measure the handgrip strength (Mathiowetz et al., 1984).

2.3.3 Previous Study Concerning on Knee Strength and Hand Grip Strength of Elderly

Some studies have already found that sit-to-stand performance, defined as the time required to complete a given number of repetitions or the number of repetitions done in a given period of time, is strongly connected to the strength or power of the knee extensor muscles (Schenkman et al., 1996; Ferrucci et al., 1997; Lord et al., 2002). Many researchers have done a study about hand grip strength and knee strength of the elderly, especially in sit-to-stand movement. Some of the studies were also combined with anthropometry measurements in order to achieve the goal to establish better treatments and facilities for elderly.

Yamada & Demura (2010) examined the reliability of ground reaction force (GRF) characteristics during sit-to-stand movements, as well as the correlation between the GRF parameters, lower limb muscles mass, and knee extension muscle strength. The GRF, lower limb muscle mass, and isometric knee extension muscle strength of fifty female elderly people were measured by performing an STS movement twice from a chair adjusted to their knee height. The result showed high reliability from GRF parameters with intra-class correlation coefficient on 0.70-0.95. On the other hand, the parameters on force output during trunk flexion phase have small effect sizes (0.15-0.23). GRF parameters during hip-lift off and knee-hip joint extension phases were shown to be significantly correlated with knee extension strength (| r | = 0.29-0.64) but not with lower limb muscle mass. According to this study, the reliability of GRF during STS movement in elderly is good in hip-lift off and knee-hip joint extension phases. These phases have a strong relationship with lower limb muscle activity. Thus, these two phases are helpful for evaluation of elderly's leg muscle function.

Hanawa et al. (2017) examined the impact of aging on the muscle synergies that underlying sit-to-stand activities in elderly people and their correlation with kinetic characteristics. The purpose of this study was to offer basic knowledge on muscle coordination underlying sit-to-stand task by evaluating the correlation between biomechanics and muscle synergy. The research was done on four adults and three elderly people by performing sit-to-stand task at two speeds. The muscle synergies needed to complete these tasks were then extracted. These synergies were classified using hierarchical cluster analysis, to compare the groups, kinetic variables were also calculated. In general, each subject had three separate muscle synergies. These synergies had a similar spatial structure across age groups. Only the temporal structure of these synergies was altered by the change in motion speed. There were, however, subject-specific muscle synergies and kinetic variables existed.

Shahida et al. (2015) determined the relationship between anthropometry and hand grip strength in elderly Malaysians population. This study filled part of the gap by providing anthropometric and muscle strength data of the Malaysian elderly people. The purpose of this study was to develop a complete database of anthropometric dimensions and hand grip strength data of Malaysian elderly. Hand grip strength and 38 anthropometric dimensions were measured from 56 male and 56 female elderly people residing in Petaling Jaya, Selangor, Malaysia. The result showed that hand grip strength and anthropometry dimensions (stature, sitting hip breadth, wrist circumference, hand circumference, and heel ankle circumference) were significantly correlated. This study suggested that the findings were valuable for designing ergonomic hand-held products for elderly Malaysians.

Amaral et al. (2019) in their study about hand grip strength for adults and elderly in Brazil aimed to determine the correlations between hand grip strength and anthropometric characteristics as well as to create hand grip strength reference values for adults and the elderly. The data was taken from 1609 adults and elderly people residing in Rio Branco, Acre, Brazil. The result showed that male in general has a 57% higher maximum hand grip strength compared to female (43.4 kg vs 27.6 kg), and also higher level of hand grip strength in different age groups. Hand grip strength in both male and female adults and elderly presented a negative correlation with age and a weak to moderate positive correlation with anthropometric characteristics. Amaral et al. (2019) suggested that these findings can be used in rehabilitation programs and possible future studies in the relevant topic of evaluation of the health condition of adults and elderly people.

Shechtman et al. (2004) examined the relationship between impairment categories and grip strength in the frail elderly who live at home. This study involved 832 elderly who had activity restrictions as evaluated by the FIM™ instrument. The subjects were separated into three age groups and four impairment groups. The groups are 60-69, 70-79, and 80+ years old for age groups, and minimally impaired, visually impaired, motor impaired, and cognitively impaired for the impairment groups. Hand grip strength were measured by using Jamar dynamometer. The result indicated that grip strength reduced with age. The grip strength scores of the minimally impaired and visually impaired groups were substantially higher than those of the motor impaired and cognitively impaired groups. This study suggested that grip strength in the frail elderly is not only determined by age and gender. Grip strength is also affected by the type of impairment. As a result, age-based standards may not be the primary basis for unraveling evaluation data in order to establish treatment goals for elderly population.

2.4 Working and Living Environment for Elderly

People's attitudes regarding housing and their living surroundings vary throughout their life and housing becomes increasingly essential as one gets older (Kerbler et al., 2017). And the elderly's health is affected by their living environment, and one of their main worries is the safety of their home (Mahmoodabad et al., 2018). According to Kerbler et al. (2017), research showed that the elderly people prefer to stay in their homes for as long as possible since they are emotionally tied to them. When the physical and psychological capabilities of users are disregarded, difficult-to-use products or environment are a frequent cause of accidents. It is important to remember that as the population of elderly grows, so should the planning and design of their goods, which should take into account their physical, cognitive, and anthropometric characteristics (Rosnah et al., 2009; in Al-Ansari & Mokdad, 2015). In a working environment, Kimuli (2021) stated that in the ever-changing and increasingly demanding elderly care job environments, an improved workplace environment is critical. Because of the many changes in job demands, it is important to support worker retention by building working teams that are not only happy and healthy, but also driven to work in order to reach their full potential and productivity.

The elderly population is quickly increasing, resulting in large increases in demand for public housing. To preserve their quality of life (QoL), the elderly people often rely largely on the facilities provided in their living environment (Leung et al., 2016). According to Sophonratanapokin et al. (2012), the majority of the elderly in Thai society live at home. Living circumstances that allow the elderly to age safely at home are generally respected (WHO, 2007b). Given that the elderly people spend a significant amount of time at home, more than half of all elderly falls occur at home. As a result, paying attention to the living environment is a crucial aspect of caring for these people (Dionyssiotis, 2012). Because of the difference of settings in various houses, it is important to examine the design of each component and item in houses in accordance with ergonomic science (McCullagh, 2006), based on the elderly living environment (Haastregt et al., 2000).

CHAPTER III

RESEARCH METHODOLOGY

3.1 Respondents

3.1.1 Population and Sampling Data

The data collection was conducted in the Paktongchai sub-district, Thailand, over a period of 2 months. The population in this study consisted of all elderly individuals in the rural areas of northeastern Thailand. The target population for this research included the elderly residing in three rural locations within the Paktongchai sub-district, Thailand. To compute the sample size, pilot study was carried out.

The respondents were carefully chosen to match the intended main criteria of elderly people from Northeastern Thailand aged 60-90 years old. Based on the response data of the time required by the elderly in rising up from the sitting position in the preliminary observation, it was concluded that 20 replicates were considered as the minimum requirements of the amount of data for the desired sensitivity. This study included 111 elderly people as participants, 23 of whom were male and 88 of whom were female. The detail of sample size calculation is shown in Appendix A.1.

3.1.2 Research Design

The study was carried out in stages according to the research design. The accompanying flowchart as seen on Figure 3.1 provides a comprehensive overview of the entire research process, outlining the sequential steps involved in data collection, analysis, interpretation, and the ultimate presentation of findings.

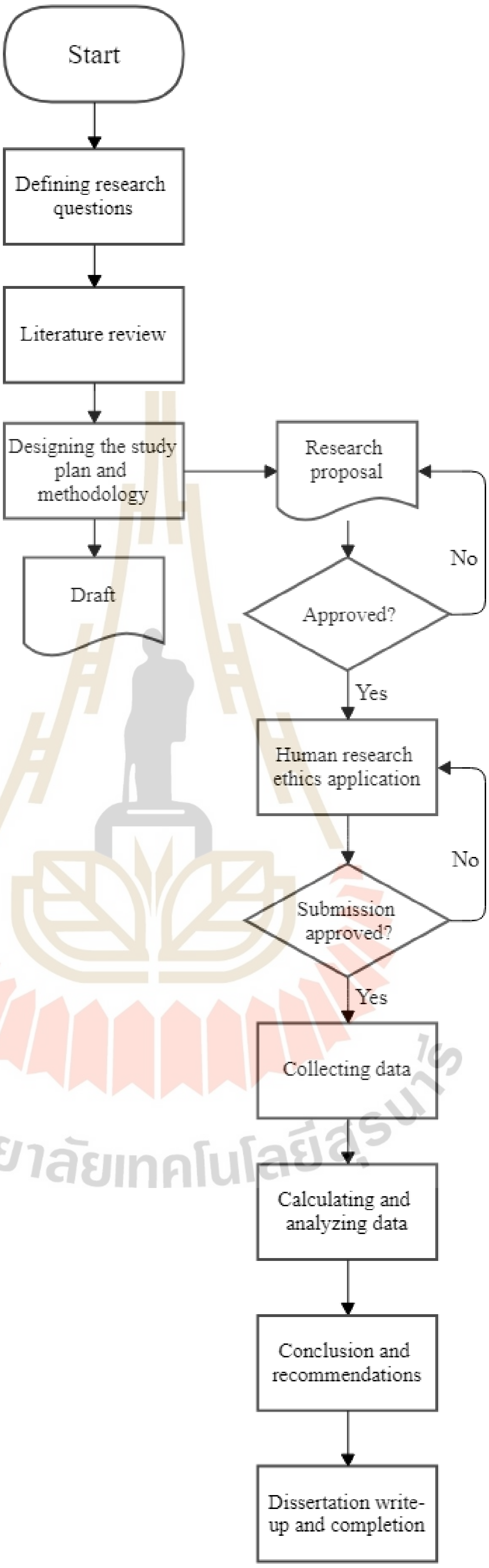

Figure 3.1 Flowchart of the comprehensive and sequential process of dissertation completion.

3.1.3 Data Collection Method

The data collected in this study was divided into primary and secondary data (Purwanto, 2004), which are described as follows:

1. Primary data, which was collected through direct observation and measurement of the research object in the field. The primary data related to this study included body dimensions, where the obtained measurements were derived from manual measurements of the required dimensions, namely anthropometry measurement, stand-to-sit and sit-to-stand time measurement, and knee strength measurement.
2. Secondary data, which was collected by other individuals or institutions. Secondary data consisted of articles, books, national and international journals, as well as utilizing internet sources as references to address research problems. The secondary data in this study included national and international journals, and books used as references to address research problems.

There were several methods that can be employed in collecting and processing data in a study. Data collection in this study was conducted through the following methods:

1. Literature review

A literature review was conducted to ensure that the relevant theories and basic concepts were related to the research problem. It was performed to enhance the quality and validity of the research by ensuring that it was built upon a solid foundation of existing knowledge and research findings.

2. Interviews and questionnaires

Interviews were conducted by asking general questions to the caregivers and the elderly individuals who directly use the elderly care facility's bathroom. Data collection using questionnaires was also conducted to obtain detailed information regarding the demographic data of the elderly and to gather information about the preferences and habits of the elderly in their daily activities.

3. Field study

A field study was conducted through direct observation, obtaining anthropometric data of the elderly, including standing dimensions, sitting dimensions, hand and foot dimensions, data on the time taken to transition from sitting to standing and from standing to sitting on the toilet, as well as data on the muscle strength of the elderly.

3.2 Anthropometric Measurement

3.2.1 Measurement Tools

The anthropometry measurement process involved utilizing various measurement tools to accurately assess different body dimensions and proportions. These tools included Martin anthropometer (Figure 3.2), calipers, scales, and measuring tapes. By employing these measurement tools, quantitative data essential for analyzing human body characteristics and variations were collected.

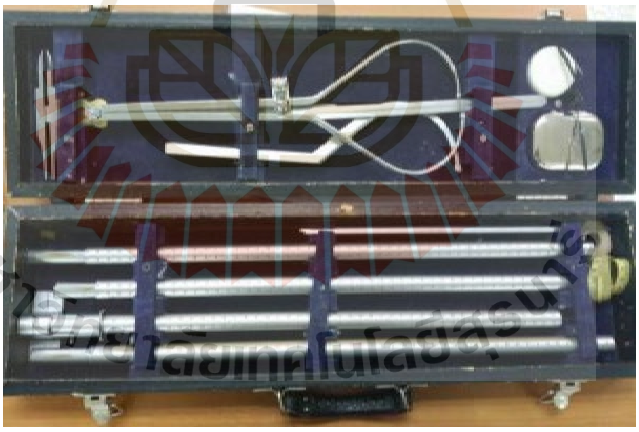

Figure 3.2 Martin anthropometer to measure the standing and sitting body dimensions

3.2.2 Experimental Procedure

Figure 3.3 illustrates the flowchart of the process for obtaining anthropometric data of the elderly through three repetitions of measurements.

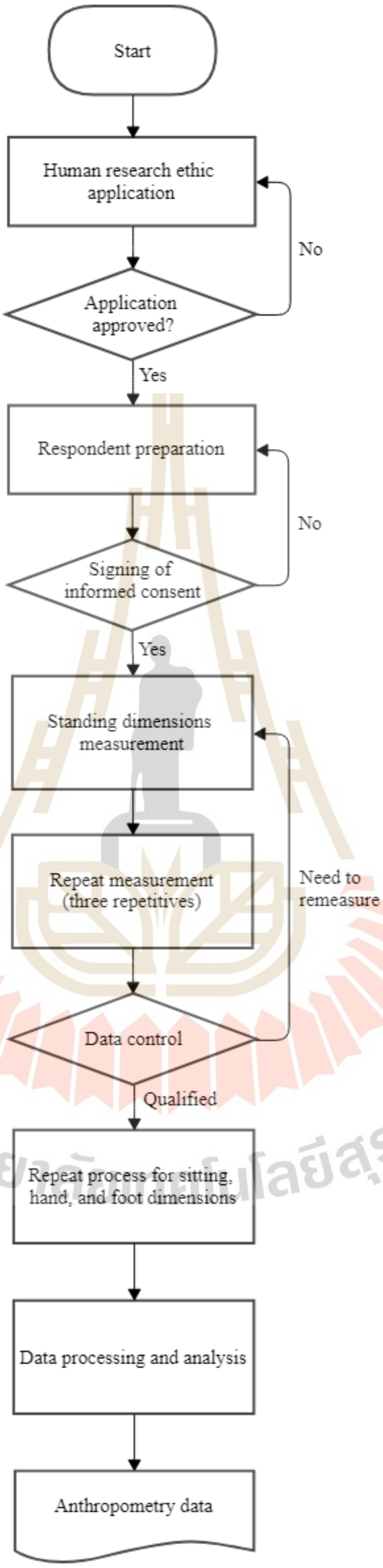

Figure 3.3 Flowchart of the process for elderly's anthropometry measurement data collection.

The first step of this measurement was to determine the population and sample criteria that could be used as research objects, and to identify the human body dimensions required in the design of the elderly bathroom. Every elderly respondent received informed consent which ensuring transparency, voluntary participation, and ethical conduct in scientific research. It provided respondents with essential information about the study, research methodology, protocol, compensation, and safeguards their rights and well-being as research subjects. The provided information was written in easily comprehensible language. The elderly individuals, acting as research subjects, were granted complete autonomy in deciding whether or not to volunteer for this study. This decision was made after carefully examining all aspects of the research and experiment. The procedure of measurements was explained in detail to the respondents. Recapitulation of measurement result data was then conducted, and the data results were calculated and transformed into a list of percentiles of body dimensions. These data were implemented as the results of recapitulation and calculation into the form of design.

Anthropometry measurement was manually carried out. The anthropometric data were measured from 111 respondents where the body dimensions measured consisted of 20 standing dimensions, 17 sitting dimensions, and 14 foot and hand dimensions. The details of body dimension and measurement of each dimension is shown in Appendix A.3. Anthropometer was used to measure the standing and sitting dimensions, with caliper used for measuring the foot and hand dimensions. Measuring tape was used to measure some of body part’s circumferences and diameters. Respondent’s weight was measured by using digital weighing scale. The respondents measured were instructed to wear thin clothes and without shoes. The procedure of measurements was explained in detail to the elderly. The respondents were required to keep proper natural posture throughout the measurement in order to get reliable measurement result. The process of anthropometric measurements started by measuring the standing dimensions. The measurements were repeated three times in order to minimize the error value. Subsequently, measurement was continued for the sitting dimensions, hand dimensions, and foot dimensions, maintaining an equal number of repetitions for each measurement. During the height measurement, the respondents were instructed to stand with their heels aligned parallelly, side by side, and in line with their shoulder blades and buttocks. Recapitulation of the measurement results was performed before calculating and converting them into a list of body dimension percentiles. These measurements were then elaborated into the design in a detailed manner.

3.2.3 Statistical Analysis

The findings of the experiments were subjected to a thorough statistical analysis, which resulted in a generalization of the cases analyzed. Statistical analysis of the anthropometry data was conducted by performing a calculation by using SPSS statistical software, including the data normality test and percentiles calculation. The hypotheses that were used to conduct the Kolmogorov-Smirnov normality test:

a. Ho: The questionnaire data for each item in the concept group were normally distributed.
b. H1: The questionnaire data for each item in the concept group were not normally distributed.

Percentile calculations for anthropometry measurements were performed to analyze and interpret the distribution of measurements within the sample, providing valuable insights into the variation and characteristics of the anthropometric data.

3.3 Stand-to-Sit and Sit-to-Stand Time Measurement

3.3.1 Measurement Tools

The measurement tools required for stand-to-sit and sit-to-stand time measurements in this study included a stopwatch or timer to accurately measure the time taken for the movement and two types of seated toilets equipped with railings to provide support for the respondents to perform the stand-so-sit and sit-to-stand movement. These tools were essential in capturing data and assessing the stand-to-sit performance of individuals.

3.3.2 Experimental Procedures

The stand-to-sit and sit-to-stand time measurements were carried out on toilet seat with a handrail attached as the experimental setup.

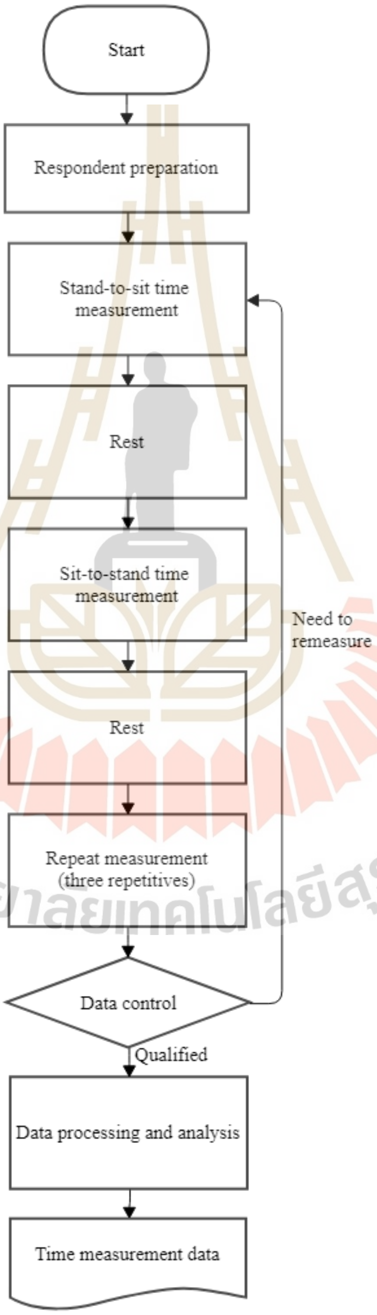

Figure 3.4 Flowchart of the process for stand-to-sit and sit-to-stand time measurement data collection.

Figure 3.4 illustrates the flowchart of the process for obtaining stand-to-sit and sit-to-stand time measurements with three repetitions of measurements. As part of the study protocols, all respondents had their stopwatches measurement done. The experiment was conducted on two types of toilets: conventional toilets and modern toilets, with handrails as an assisting instrument, as seen on Figure 3.5. The toilets had difference in dimension such as on its height. The height of conventional toilet seat was 38cm from the floor meanwhile the height of modern toilet seat was 45 cm height. The handrail was installed at five different heights: 75 cm, 80 cm, 85 cm, 90 cm, and 95 cm. The recommended height for a grab bar or handrail, according to American with Disabilities Act (ADA) requirements (ADA Guidelines, 2010), is between 33 inches and 36 inches (84 cm to 92 cm). In this study, the set heights were altered to be a few centimeters below and above the ADA suggested height to see how the difference affected the time required to sit down and stand up from the toilet. Another condition was the presence of handrails as supporting tool for the respondents during the sitting and standing activities. The distance between handrails was set at 92 cm, with each handrail installed 46 cm from the center of the toilet, following the recommendations of ADA Guidelines (2010). The measurements were carried out with three repetitions, with a minimum of 5-minute rest between each trial and a minimum of 15-minute interval between each setup.

The respondents were directed to perform the sitting activity on the toilet in a natural manner, maintaining the seated position for one minute before being instructed to stand up, utilizing the handrail. Specifically, they were instructed to start from a standing posture, sit on the toilet seat with their feet flat on the floor. The stopwatch timer was started as the respondent begins to sit down from the standing position and stop the stopwatch as soon as the respondent's buttocks touch the toilet with their hands were in comfortable position. After recording the time taken for the stand-to-sit movement, stopwatch was reset to zero. After sitting for one minute, the stopwatch timer started as the respondent begins to stand up from the seated position and stopped as soon as the respondent is fully upright, with their knees and hips fully extended. The time taken for the sit-to-stand movement was then recorded. The respondents were instructed to take a rest for 15 minutes before repeating the stand-to-sit and sit-to-stand measurements two more times for a total of three repetitions. A practice session was allowed for respondents to familiarize to the experiment. Measurements were done for three times repetition to ensure accuracy and reliability. After completing all five different experimental setups, the elderly people were asked which handrail height was most comfortable for them. It was important to maintain consistent measurement techniques and ensured respondents' safety throughout the process.

Figure 3.5 Stand-to-sit and sit-to-stand time measurement experimental set up with adjustable handrail height: (a) conventional toilet and (b) modern toilet.

3.3.3 Statistical Analysis

The experiment's results were based on a statistical analysis that provided a generalization of the cases studied. SPSS statistical software was used to generate and evaluate the results. The mean and standard deviation of descriptive data were calculated and presented. To evaluate the relationship between measurement variables, Pearson's coefficient of correlation (r) analysis was performed. In this study, a probability level of 0.05 was considered significant.

3.4 Muscle Strength Measurement

3.4.1 Measurement Tools

The GUNT WP500 Torque Dynamometer as seen on Figure 3.6 was used as a measurement tool to measure lower limb muscle strength in this study. It allowed for the quantification of torque exerted by the knee muscles during specific movements, such as flexion and extension, providing objective data on muscular performance. The dynamometer's design and functionality enabled precise and reliable measurements of muscle strength, contributing to a comprehensive analysis of participants' physical capabilities.

Figure 3.6 GUNT WP500 Torque Dynamometer as one of the tools used for lower limb strength measurement.

Figure 3.7 presented JAMAR hand dynamometer as the measuring tool for the hand grip strength of the elderly which helped evaluating the highest isometric force generated by elderly's hand muscles during a grip. Measuring grip strength involved firmly squeezing the handle for a brief period while the dynamometer captures and records the applied force. It was equipped with a scale readout that allows for the measurement of isometric grip force within a range of 0-90 kg. To facilitate accurate readings, the dynamometer includes a peak hold needle that automatically retains the highest recorded reading until the device is reset. Additionally, the handle of the dynamometer is adjustable, providing five grip positions ranging from 35-87 mm (1½ - 3¼") in increments of 13 mm (½").

Figure 3.7 JAMAR hand dynamometer as a measuring tool for grip strength measurement.

3.4.2 Experimental Procedures

The respondents were instructed to perform the extension and flexion motions with their lower limb for the measurement of knee strength. For the setup, their leg was attached to a leg attachment connected to a torque dynamometer. They were instructed to begin in a seated position with their back straight, keeping their knees at 90° angle, and feet flat on the floor. The experimental set up can be seen on Figure 3.8. The respondent was instructed to perform extension motion on their leg with maximum effort until the dynamometer displayed and recorded the torque number. After the dynamometer was reset to zero, the respondent was then instructed to perform the flexion motion, and the torque value was recorded. Following the data recording, the respondent was given instructions to rest before proceeding to the next measurement, ensuring a 15-minute interval between each measurement. Each movement was repeated three times for measurement purposes.

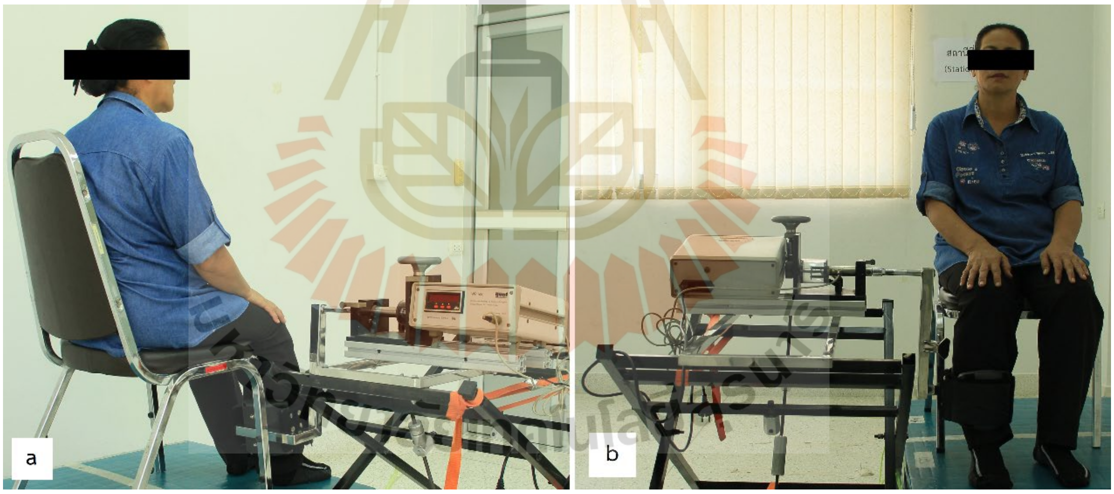

Figure 3.8 Experimental set up for measurement of lower limb strength: (a) side view and (b) front view.

Another muscle strength measurement that was conducted was the assessment of hand grip strength measurement. Figure 3.9 illustrated the measurement of hand grip strength using JAMAR dynamometer. The hand grip strength measurement involved assessing five different grip positions, specifically at spans of 3.4 cm, 4.7 cm, 6 cm, 7.3 cm, and 8.5 cm. Each span was utilized to evaluate grip strength across a range of hand sizes. The respondent was positioned comfortably in an upright posture with appropriate back support. They were instructed to hold the dynamometer in their hand, placing their arm on a flat surface such as arm rest, with their elbow flexed at approximately a 90° angle. The dynamometer's grip span was positioned between the base of the fingers and the palm. Following the instructions, the respondent was directed to squeeze the dynamometer with maximum force for a brief period while the tool recorded the data. The process involved three consecutive measurements for each grip span, with a minimum one-minute rest period between repetitions to minimize fatigue. This measurement sequence was then repeated for the other hand and for each different grip spans, with a minimum interval of 15 minutes maintained between measurements to allow sufficient muscle recovery time.

Figure 3.9 Hand grip strength measurement using JAMAR dynamometer (Vermeulen et al., 2015).

3.4.3 Statistical Analysis

The experiment's findings were obtained through a statistical analysis, enabling broader conclusions to be drawn about the studied cases. The results were generated and assessed using the SPSS statistical software. Descriptive statistics, including measures such as the mean and standard deviation, were calculated and presented to describe the data. Pearson's coefficient of correlation (r) analysis was performed to evaluate the relationships between the measured variables. For this study, a significance level of 0.05 was applied to determine statistical significance.

CHAPTER IV
RESULTS

This chapter shows the outcomes obtained from this study including demographic information, anthropometry data, stand to sit and sit to stand time, knee and hand grip strength data, and a proposed design for an enhanced toilet.

4.1 Demographic Data Result

In this study, a total of 23 elderly males and 88 elderly females participated as respondents. Among the elderly population, 49.5% were in their 60s, 32.4% were in their 70s, 17.2% were in their 80s, and 0.9% were in their 90s. Table 4.1 shows that 97.3% of the elderly were right-handed while the rest were left-handed. It was also observed that 0.9% of the elderly required assistance from handrails for certain activities, such as standing up from a sitting position, while 4.5% occasionally needed walking support, such as a walking stick as seen on Table 4.2.

Table 4.1 Percentage indicating dominant hand or leg of the respondents.

	Dominant Hand/Leg	
	Frequency	Percent (%)
Left	3	2.7
Right	108	97.3
Total	111	100.0

Table 4.2 Percentage indicating the dependency on handrails and walk support.

	Handrails Help		Walk Support	
	Frequency	Percent (%)	Frequency	Percent (%)
No	110	99.1	106	95.5
Yes	1	0.9	5	4.5
Total	111	100.0	111	100.0

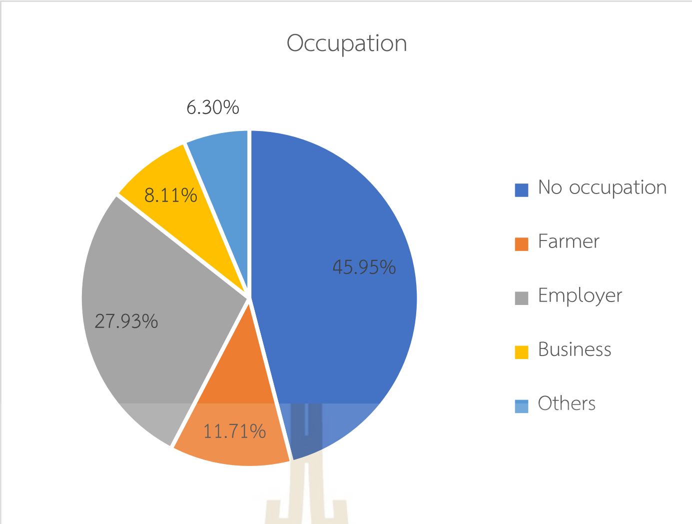

Figure 4.1 The percentage distribution of each occupation among the participating elderly respondents.

Approximately half of the respondents were engaged in active employment. As depicted in Figure 4.1, 45.9% of the elderly participants were not employed, while the remaining respondents were involved in various occupations. Specifically, 11.7% of the total elderly were employed as farmers, 27.9% worked as employers, 8.1% were involved in business ventures, and 6.3% pursued other occupations.

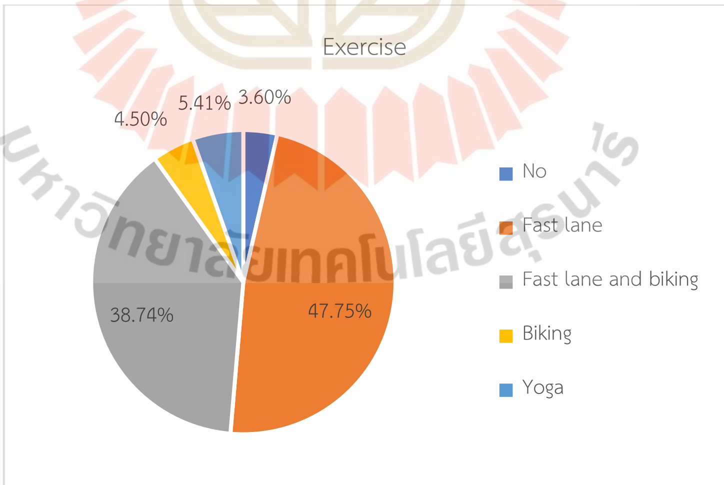

Figure 4.2 The percentage distribution of routine exercise among the participating elderly respondents.

According to Figure 4.2, the majority of the participants engaged in regular exercise to maintain physical fitness, enabling them to perform daily activities and work independently. As depicted in Figure 4.2, a total of 96.4% of the respondents included regular exercise into their routine. Among them, 38.7% did both fast lane and biking exercises on a regular basis, 47.7% exclusively focused on fast lane exercises, 4.5% solely participated in biking exercises, 5.4% regularly practiced yoga, and 3.6% did not engage in regular exercise.

4.2 Anthropometry Measurement

4.2.1 Anthropometry Data

The anthropometric data were measured from 111 respondents where the body dimensions measured consisted of 20 standing dimensions, 17 sitting dimensions, and 14 foot and hand dimensions. Descriptive statistical analysis, including measures such as mean, standard deviation (SD), and percentiles (5th, 50th, and 95th), was applied to analyze the anthropometric data. The collected data played a crucial role in the design of various environments, including workplaces, social care institutions, and interior design. The outcomes of the Kolmogorov-Smirnov normality test revealed that the majority of the body dimension data had p-values above 0.05, indicating a normal distribution of the data. Tables 4.3, 4.4, and 4.5 present descriptive statistics of anthropometric measurements, including body dimensions, mean values, standard deviations, 5th percentiles, 50th percentiles, and 95th percentiles. The overall percentile calculation result is shown in Appendix A.3.

Table 4.3 Descriptive statistics for measured standing dimensions

Male Elderly					
Body Dimension	Mean (cm)	Std. Dev.	Percentiles (cm)		
			5	50	95
Stature height	162.16	6.12	158.20	162.00	164.00
Chest circumference	88.35	8.19	76.20	87.00	109.60
Thigh circumference	43.78	6.13	33.00	44.00	56.00
Chest breadth	27.77	2.35	26.37	27.80	29.70
Abdominal breadth	28.53	3.40	26.70	28.70	30.43
Shoulder height	133.80	6.05	124.04	133.00	143.36

Table 4.3 Descriptive statistics for measured standing dimensions (continued)

Female Elderly					
Body Dimension	Mean (cm)	Std. Dev.	Percentiles (cm)		
			5	50	95
Stature height	151.46	5.68	147.28	151.00	156.23
Chest circumference	93.16	8.85	80.00	92.50	104.58
Thigh circumference	44.09	5.58	34.00	44.00	53.42
Chest breadth	26.80	2.57	24.93	27.00	28.88
Abdominal breadth	30.17	2.73	28.00	30.15	32.00
Shoulder height	123.71	5.03	115.78	123.25	132.15

In Table 4.3, elderly males had a height of 162.1 ± 6.12 cm, while elderly females had 151.5 ± 5.68 cm. The 5th and 95th percentiles for male and female heights were 158.2 cm, 164 cm, 147.28 cm, and 156.23 cm, respectively.

Table 4.4 Descriptive statistics for measured sitting dimensions

Male Elderly					
Body Dimension	Mean (cm)	Std. Dev.	Percentiles (cm)		
			5	50	95
Sitting body height	83.35	5.30	79.50	84.00	86.40
Popliteal height	44.19	2.31	42.30	43.80	45.43
Hip breadth	34.19	3.76	31.40	33.40	37.00
Buttocks to popliteal length	44.22	2.49	42.10	43.80	46.00
Female Elderly					
Body Dimension	Mean	Std. Dev.	Percentiles		
			5	50	95
Sitting body height	77.67	4.33	75.08	78.00	80.50
Popliteal height	42.78	3.24	40.75	42.60	44.20
Hip breadth	35.22	3.35	33.00	34.90	37.48
Buttocks to popliteal length	43.02	3.26	40.83	42.75	45.23

In terms of sitting body height, the male elderly had an average of 83.35±5.30 cm, whereas the female elderly had an average of 77.67±4.33 cm. For popliteal height, the male elderly measured at 54.18±2.31 cm, while the female elderly measured at 52.78±3.24 cm. In terms of hip breadth, male elderly had an average of 34.19±3.76 cm, whereas female elderly had an average of 35.22±3.35 cm. It is important to note that there are variations in body size, form, and structure between males and females. With a few exceptions, such as chest circumference, thigh circumference, abdominal width, and hip breadth, most body dimensions of male elderly were greater than those of female elderly. Specifically, the male elderly had an average chest circumference of 88.35±8.19 cm, while the female elderly had an average of 93.16±8.85 cm. The thigh circumference, abdominal breadth, and hip breadth of male elderly were recorded as 43.78±6.13 cm, 28.53±3.4 cm, and 34.19±3.76 cm, respectively. On the other hand, female elderly had a thigh circumference of 44.09±5.58 cm, abdominal breadth of 30.17±2.73 cm, and hip breadth of 35.22±3.35 cm. For a comprehensive overview of the measurements, please refer to Table 4.3 for standing dimensions, Table 4.4 for sitting dimensions, and Table 4.5 for foot and hand dimensions. For a detailed examination of the anthropometric measurements taken for the body dimensions of the elderly in this study, the overall data can be found in the Appendix A.3.

Table 4.5 Descriptive statistics for measured foot and hand dimensions

Male Elderly					
Body Dimension	Mean (cm)	Std. Dev.	Percentiles (cm)		
			5	50	95
Max. foot length	24.99	1.64	24.00	25.00	25.80
Front foot width	11.08	1.29	10.00	10.90	12.00
Palm length	10.84	1.53	10.20	10.50	11.00
Palm width	8.47	0.45	8.00	8.50	8.80
Largest grip diameter	6.61	1.01	5.90	7.00	7.30

Table 4.5 Descriptive statistics for measured foot and hand dimensions (continued)

Female Elderly					
Body Dimension	Mean (cm)	Std. Dev.	Percentiles (cm)		
			5	50	95
Max. foot length	23.01	1.46	22.00	23.00	24.00
Front foot width	10.02	1.06	9.31	10.00	10.55
Palm length	9.98	1.05	9.50	10.00	10.39
Palm width	7.71	0.75	7.31	7.58	7.82
Largest grip diameter	6.14	0.82	5.71	6.13	6.70

4.2.2 Comparison with Data from Other Countries

This research represented data specifically from the rural area of Northeastern Thailand. In order to examine the differences and variations in body dimensions among the elderly population, a comparison of data findings from this study were done with data obtained from various studies conducted in multiple countries. This comparison was carried out to explore the differences and variations in body dimensions among elderly individuals in the rural region of Northeastern Thailand in comparison to other geographical and cultural contexts. The findings from the statistical analysis of anthropometric measurements revealed both variations and similarities in body dimensions among the elderly populations, particularly in the Southeast Asian region. Table 4.4 presents the mean values and standard deviations for the current study, as well as data from previous studies conducted in Australia (Kothiyal & Tettey, 2001), Indonesia (Rahmawati et al., 2020), Singapore (Lee et al., 2019), Malaysia (Rosnah et al., 2009), and Thailand (Jarutat et al., 2005). Additionally, a comparison between the results of this study and the previous study by Jarutat et al. (2005) is performed to examine the disparities in body dimensions among Thai elderly residing in urban and rural areas. Due to certain discrepancies in the data, it became necessary to exclude certain body dimensions from the analysis. These exclusions were made in order to maintain data integrity.

Table 4.6 Comparison of elderly body dimensions in different populations

Body dimensions	Mean (SD) in cm					
	Present study	Australian[a] (2001)	Indonesian[b] (2020)	Singaporean[c] (2019)	Malaysian[d] (2009)	Thai[e] (2005)
Stature	162.1(6.12)	165.8(7.9)	156.08(7.3)	163.5(4.9)	162.3(7.5)	161.4
Eye height	149.9(5.55)	153.2(7.0)	143.31(7.02)	152.4(4.9)	149.9(6.1)	149.9
Elbow height	96.5(7.32)	104.3(5.0)	98.46(4.65)	106.0(4.8)	97.1(5.8)	98.9
Bideltoid breadth	41.36(2.7)	-	39.43(2.42)	42.1(1.9)		43.4
Hand length	21.9(1.49)	18.4(1.0)	-	18.1(0.7)	17.8(1.2)	-
Sitting body height	83.3(5.3)	84.3(5.6)	-	83.2(2.0)	83.1(4.3)	82.9
Sitting eye height	72.1(4.46)	72.9(4.6)	107.52(8.11)	72.1(2.4)	71.6(5.6)	73.4
Popliteal height	44.2(2.31)	41.6(2.5)	42.90(3.08)	39.4(1.7)	39.6(2.4)	40.1
Knee height	51.8(3.36)	51.5(3.1)	-	47.5(1.7)	49.8(2.9)	47.8
Buttock – knee length	54.53(3.47)	54.9(3.8)	-	57.1(1.5)	53.7(3.6)	-
Buttock – popliteal length	44.2(2.49)	45.2(3.8)	42.33(4.73)	46.2(1.3)	45.5(2.7)	-
Sitting hip breadth	34.2(3.76)	33.6(2.8)	34.71(3.61)	30.0(1.6)	35.0(3.5)	35.4
Foot length	24.99(1.64)	-	-	26.1(1.0)	24.6(1.1)	-
Foot breadth	11.1(1.29)	-	-	10.0(0.6)	10.2(0.7)	-

[a] Kothiyal and Tettey (2001), [b] Rahmawati *et al*. (2020), [c] Lee at al. (2019), [d] Rosnah *et al*. (2009), [e] Jarutat *et al*. (2005)

A comprehensive comparison between the present study and other research involved summarizing a total of 14 body dimensions. Table 4.6 illustrates that Australians exhibited the greatest stature, eye height, knee height, and sitting eye height when compared to individuals from other countries. These findings also indicate the presence of diverse body dimension variations among elderly individuals across Asian countries. The data from the present study specifically highlights that Thai elderly participant had greater popliteal height, hand length, and foot breadth, measuring approximately 44.2±2.31 cm, 21.9±1.49 cm, and 11.1±1.29 cm, respectively. On the other hand, the buttock-knee length and buttock-popliteal length were smaller in comparison to other countries' elderly populations. The buttock-to-knee length for Thai elderly participants in the present study was 54.53±3.47 cm, which was similar to the measurements observed among Australian elderly (54.9±3.8 cm) and Malaysian elderly (53.7±3.6 cm). However, it was smaller than the measurements recorded among Singaporean elderly (57.1±1.5 cm). Notably, significant differences between the body dimensions of Thai elderly individuals residing in rural areas, as observed in this study, and those residing in urban areas in a previous study are evident in knee height and popliteal height. The present study demonstrated that knee height and popliteal height among rural Thai elderly individuals (51.8±3.36 cm and 44.2±2.31 cm, respectively) were greater than those among Thai elderly individuals in urban areas, which were 47.8 cm and 40.1 cm for knee height and popliteal height, respectively.

4.2.3 Correlation Between Body Dimensions

The correlation coefficients were computed, and the results were summarized in appendices section. Among the body dimensions, the strongest correlation was observed between shoulder height and body height, with a coefficient of 0.933. Most correlation coefficients greater than 0.194 indicated a positive correlation between certain body dimensions, and these correlations were found to be statistically significant at the 0.05 level. The positive coefficients suggested that as one body dimension increased, the value of the correlated dimension also tended to increase. The strength of the correlation between body dimensions increased with larger correlation coefficient values. The correlation coefficient values were classified as very weak, weak, moderate, strong, or very strong, corresponding to ranges of 0.00-0.19, 0.20-0.29, 0.40-0.59, 0.60-0.79, and 0.80-1.00, respectively (Evans, 1996). Based on the correlation analysis, the body height and shoulder height of the elderly participants exhibited significant correlations with nearly all measured body dimensions, except for chest circumference and abdominal breadth.

4.3 Stand-to-Sit and Sit-to-Stand Measurement

4.3.1 Descriptive Statistics

Tabel 4.7 and 4.8 presents the descriptive statistics of the measured data used in this study for stand-to-sit and sit-to-stand time measurement on conventional toilet and modern toilet, respectively. The data was displayed using the mean and standard deviation values for each measurement. The data showed that both genders took longer to perform stand to sit activity compared to the sit to stand activity. This result was consistent across two different experimental setups, namely the conventional toilet and the modern toilet. In other words, individuals required more time to transition from a standing position to a sitting position than vice versa, regardless of the type of toilet being used.

Table 4.7 Descriptive statistics of stand-to-sit and sit-to-stand time measurement for conventional toilet

Handrail height	Activities	Mean (s)	Std. Deviation
75 cm	Stand to sit	6.0499	1.59741
	Sit to stand	3.2581	1.09680
80 cm	Stand to sit	6.1404	1.73755
	Sit to stand	3.4385	1.15530
85 cm	Stand to sit	6.2630	1.77838
	Sit to stand	3.3515	1.23880
90 cm	Stand to sit	6.1775	1.64863
	Sit to stand	3.2878	1.00400

Table 4.7 Descriptive statistics of stand-to-sit and sit-to-stand time measurement for conventional toilet (continued)

Handrail height	Activities	Mean (s)	Std. Deviation
95 cm	Stand to sit	6.3369	1.62100
	Sit to stand	3.4284	1.13634

Table 4.8 Descriptive statistics of stand-to-sit and sit-to-stand time measurement for modern toilet

Handrail height	Activities	Mean (s)	Std. Deviation
75 cm	Stand to sit	5.9894	1.62365
	Sit to stand	3.3196	1.03991
80 cm	Stand to sit	5.8824	1.56854
	Sit to stand	3.3259	1.02893
85 cm	Stand to sit	5.9239	1.50871
	Sit to stand	3.4037	1.18503
90 cm	Stand to sit	6.0717	1.63534
	Sit to stand	3.3906	1.04865
95 cm	Stand to sit	6.0120	1.49295
	Sit to stand	3.3553	1.04781

4.3.2 Time Comparison for Gender and Age Groups

The time for stand-to-sit and sit-to-stand movements varies based on factors like gender and age due to physiological differences. Table 4.9 displays elderly males' and females' times for these movements on both conventional and modern toilets. No significant time differences were observed for either handrail height. In a conventional toilet with a 75 cm high handrail, male elderly completed both activities faster, taking 6.24 seconds ± 1.95 and 3.21 seconds ± 1.09 for stand-to-sit and sit-to-stand, respectively. Female elderly performed stand-to-sit more swiftly with a 75 cm high handrail in a modern toilet, while a 90 cm handrail on a conventional toilet enabled faster sit-to-stand execution, around 3.24 seconds ± 0.98.

Table 4.9 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on gender group

Conventional Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
Male	Mean (s)	6.24	3.21	6.29	3.49	6.47	3.45	6.39	3.49	6.64	3.46
	SD	1.95	1.09	1.73	1.27	2.09	1.40	1.88	1.09	1.73	1.27
Female	Mean (s)	6.00	3.27	6.10	3.43	6.21	3.33	6.12	3.24	6.26	3.42
	SD	1.50	1.10	1.75	1.13	1.70	1.20	1.59	0.98	1.59	1.11
Modern Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
Male	Mean (s)	6.33	3.76	6.19	3.59	6.29	3.63	6.23	3.48	6.37	7.72
	SD	1.99	2.15	2.16	1.49	2.17	1.63	1.90	1.67	2.65	1.31
Female	Mean (s)	5.82	3.26	5.82	3.37	5.95	3.36	6.02	3.41	5.98	3.34
	SD	1.54	0.97	1.49	1.39	1.55	1.11	1.57	1.07	1.56	0.98

Table 4.10 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on age group

Conventional Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
60-69	Mean (s)	5.61	2.87	5.60	3.11	5.66	2.93	5.74	2.91	5.73	2.93
	SD	1.51	0.92	1.52	1.03	1.63	1.01	1.60	0.87	1.45	0.87
70-79	Mean (s)	6.11	3.38	6.13	3.47	6.29	3.40	6.16	3.43	6.44	3.56
	SD	1.22	1.01	1.34	0.96	1.50	1.03	1.13	0.84	1.34	0.90
80-90	Mean (s)	7.15	4.11	7.65	4.28	7.87	4.42	7.42	4.08	7.83	4.56
	SD	1.92	1.20	2.09	1.39	1.70	1.51	1.98	1.13	1.57	1.31
Modern Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
60-69	Mean (s)	5.42	2.94	5.40	3.09	5.49	2.95	5.57	3.06	5.55	3.06
	SD	1.42	0.77	1.36	1.50	1.40	0.83	1.56	0.93	1.43	0.82

Table 4.10 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on age group (continued)

Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
70-79	Mean (s)	5.92	3.38	5.79	3.52	6.10	3.52	6.24	3.55	6.04	3.37
	SD	1.26	0.86	1.12	0.79	1.33	0.92	1.33	0.99	1.33	0.92
80-90	Mean (s)	7.32	4.50	7.46	4.14	7.36	4.51	7.16	4.22	7.47	4.15
	SD	2.07	2.24	2.23	1.74	2.24	1.83	1.80	1.76	2.73	1.41

Based on the age categories shown in Table 4.10, the outcome differs from one to another. The 70 – 79 years old elderly people took 6.11 seconds ± 1.22 and the 80 – 90 years old elderly people took 7.15 seconds ± 1.92. On the other hand, elderly aged 60 – 69 years old spent the least amount of time on 80 cm handrail height on conventional toilet which was approximately 5.60 seconds ± 1.52. For sit-to-stand activity, the 60–69 and 70–79 age groups took the least amount of time on a 75 cm heighted-handrail on conventional toilet, taking 2.87 seconds ± 0.92 and 3.38 seconds ± 1.01, respectively. However, both age groups performed the sit-to-stand movement slightly quicker on an 80 cm heighted handrail on modern toilet. The elderly aged 80 to 90 showed similar outcome with the least amount of time spent doing the sit-to-stand movement taking 4.08 seconds ± 1.13 and 7.16 seconds ± 4.22 on a 90 cm heighted-handrail, both on conventional and modern toilet, respectively. In general, elderly people aged 60 to 69 performed the stand to sit and sit to stand activity with least amount of time on both conventional and modern toilet, followed by those aged 70 to 79 and 80 to 90.

Each age groups were showing different results could be attributed to several factors related to aging and individual differences, such as physical changes and lifestyle factors. According to Visser et. al. (2019), maintaining a healthy lifestyle in old age, which includes refraining from smoking, consuming alcohol in moderation, staying physically active, and maintaining a healthy body weight, is associated with slower deterioration of physical, psychological, cognitive, and social abilities as human ages, which contribute to an improved overall performance in general activities.

4.4 Muscle Strength Measurement

4.4.1 Descriptive Statistics

Tables 4.11 and 4.12 presents the descriptive statistics of the measured data used in this study for lower limb strength and hand grip strength measurement, respectively. The data showed that knee extension strength is greater than knee flexion strength and greatest hand grip strength was recorded in 6 cm grip position.

Table 4.11 Lower limb strength descriptive statistics

Activities	Mean (Nm)	Std. Deviation
Extension	9.31	3.04
Flexion	8.36	2.86

Table 4.12 Hand grip strength descriptive statistics

Grip position (cm)	Mean (kg)	Std. Deviation
Span 3.4	9.14	4.94
Span 4.7	14.58	7.11
Span 6	15.06	6.94
Span 7.3	13.62	6.39
Span 8.5	11.23	5.84

4.4.2 Correlation Between Variables

Correlation Between Lower Limb Strength and Time Measurement of Stand-to-Sit and Sit-to-Stand Activity

The Pearson correlation coefficient between flexion lower limb strength with the time measured for sitting down the toilet, and extension lower limb strength with the time measured for standing up from the toilet seat were calculated using SPSS statistical software. Table 4.13 and 4.14 represented the correlation between variables on conventional toilet. The Pearson correlation coefficient value of flexion strength and stand-to-sit time for all five different handrail heights indicated that there appeared to be a negative correlation between the variables, as shown in Table 4.13. The Pearson correlation between flexion strength and stand-to-sit time for 75cm, 80 cm, 85 cm, 90 cm, and 95 cm handrail height were -0.437, -0.369, -0.434, -0.369, and -0.360, respectively. The p-value was given as $p < 0.001$, indicating that there was conclusive evidence about the significance of the correlation between the variables.

Table 4.13 Pearson correlation between flexion strength and stand-to-sit time on conventional toilet

Handrail height		Stand-to-Sit Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Flexion Strength	Pearson Correlation	-0.437	-0.369	-0.434	-0.369	-0.360

Table 4.14 Pearson correlation between extension strength and sit-to-stand time on conventional toilet

Handrail Height		Sit-to-Stand Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Extension Strength	Pearson Correlation	-0.595	-0.614	-0.601	-0.600	-0.573

To determine the correlation between the two variables, a Pearson correlation was performed on lower limb extension strength and sit-to-stand time. Table 4.14 indicated a statistically significant moderate negative correlation between extension strength and sit-to-stand time. The Pearson correlation coefficient (r) were -0.595, -0.614, -0.601, -0.600, and -0.573 which presented the relationship between extension strength and sit-to-stand time on 75 cm, 80 cm, 85 cm, 90 cm, and 95 cm handrail height, respectively. The negative relationship implies that the time needed to do the stand-to-sit and sit-to-stand movement decreases as the lower limb flexion and extension strength increases. The scattered plot graph of the moderate negative correlation was shown in Appendix C. 2.

Similar to the findings on the conventional toilet, the Pearson correlation coefficient value between lower limb strength and both stand-to-sit and sit-to-stand activities demonstrated a moderate negative correlation in each experimental setting. Specifically, Table 4.15 displayed the Pearson correlation between flexion strength and stand-to-sit time for handrail heights of 75 cm, 80 cm, 85 cm, 90 cm, and 95 cm, resulting in correlation coefficients of -0.376, -0.395, -0.466, -0.365, and -0.377, respectively. The p-value was reported as $p < 0.001$, providing conclusive evidence of the significant correlation between these variables.

Table 4.15 Pearson correlation between flexion strength and stand-to-sit time on modern toilet

Handrail height		Stand-to-Sit Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Flexion Strength	Pearson Correlation	-0.376	-0.395	-0.466	-0.365	-0.377

Table 4.16 Pearson correlation between extension strength and sit-to-stand time on modern toilet

Handrail Height		Sit-to-Stand Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Extension Strength	Pearson Correlation	-0.564	-0.439	-0.509	-0.554	-0.504

Table 4.16 revealed a statistically significant moderate negative correlation between extension strength and sit-to-stand time. The Pearson correlation coefficient (r) indicated the strength of this relationship, with values of -0.564, -0.439, -0.509, -0.554, and -0.504 for handrail heights of 75 cm, 80 cm, 85 cm, 90 cm, and 95 cm, respectively. The scatter plot graphs depicting this moderate negative correlation were presented in Appendix C. 2. These findings, along with the negative relationship observed between elderly muscle strength and the time spent on stand-to-sit and sit-to-stand movements in each experimental setting, signified a decline in the quantity and quality of skeletal muscles in the elderly (Seene et al., 2012). Furthermore, this confirms the impact of reduced muscle strength on the performance of the elderly (Kuh et al., 2006). On the other hand, it is important to consider body mass, as it impacts BMI, which in turn can affect muscle function, such as a large waist circumference could potentially result in poor muscle function (Hasan et. al., 2016). Body mass which affects body size is one of the factors influencing muscle strength, with a clear link observed between lower muscle strength and reduced body weight, and vice versa (Hasan et al., 2016; Rantanen et al., 1998; Era et al., 1994). Multiple studies have shown correlation between BMI and muscle strength (Pasdar et al., 2019; Hasan et al., 2016; Lad et al., 2013), however it is important to consider conducting more detailed measurements due to BMI methodological limitations, particularly in terms of its inability to account for variations in body composition (Nevill et al., 2006).

The recommended height for a grab bar, according to American with Disabilities Act (ADA) requirements (ADA Guidelines, 2010), is between 33 inches and 36 inches (84 cm to 92 cm). However, this study showed varying results for each experimental setup. On conventional toilet experimental setting, the 75 cm and 85 cm handrail heights have a stronger correlation between flexion strength and its stand to sit time, as presented in Table 4.13 results. On the other hand, Table 4.14 showed that the correlation between extension strength and sit to stand time on 80 cm handrail height has the strongest correlation, followed by 85 cm, 90 cm, 75 cm, and 95 cm handrail height. For the modern toilet experimental setting, the result is slightly different where the strongest correlation with flexion strength was found on stand to sit time on 85 cm handrail height, meanwhile the extension strength showed strongest correlation with sit to stand time on 75 cm handrail height. Many factors, such as population origin, can have an impact on this. Many studies have shown that body dimensions differ from one population to another, and ethnic diversity is a crucial factor influencing anthropometric data since it is more widespread among races than nations (Abd Rahman et al., 2018). This is one of the reasons why various handrail heights were evaluated and studied in this experiment. According to the interview questionnaire, a 95 cm high handrail is more difficult to reach from a sitting posture. However, it does make it simpler for certain older people to sit down from a standing posture. A 75 cm railing is preferable for short-height senior people since it is simpler to reach from a sitting or standing posture.

Correlation Between Age, Lower Limb Strength, and Hand Grip Strength

A correlation coefficient measured the strength and direction of the linear relationship between two variables. The correlation between age and muscle strength in the elderly provided valuable insights that can result in evidence-based interventions, better health outcomes, reduced falls, improved rehabilitation, and enhanced aging experiences for. Table 4.17 showed that the correlation coefficients between age and grip strength of the respondents were -0.214 for a 3.4 cm span, -0.253 for a 4.7 cm span, -0.216 for 6 cm span, -0.172 for 7.3 cm span, and -0.169 for 8.5 cm span. It indicated a weak, negative correlation between age and grip strength. The negative sign suggested that as age increased, grip strength tended to decrease. However, the magnitudes of the correlation coefficients indicated weak correlations, meaning that the relationship between age and grip strength was not very strong or consistent in all span settings. Comparing all of the correlation coefficients, it appeared that the correlation was slightly stronger in the 4.7 cm span (-0.253) compared to the rest of the correlation coefficients but all correlations remained relatively weak.

Table 4. 17 Pearson correlation between knee strength and hand grip strength

		Span Setting (cm)				
		3.4	4.7	6	7.3	8.5
Pearson Correlation	Flexion	-0.054	0.062	0.031	0.051	0.051
	Extension	0.024	0.125	0.103	0.107	0.112

The correlation coefficients provided described the relationship between knee strength and grip strength at different span lengths. In this case, as shown in Table 4.15, a negative correlation coefficient (-0.054) indicated a weak negative relationship between knee flexion strength and grip strength when the span length was 3.4 cm. This meant that as knee flexion strength increased, grip strength tended to decrease slightly, although the relationship is not very strong. A positive correlation coefficient (0.062) at a span length of 4.7 cm suggested a weak positive relationship between knee flexion strength and grip strength. As knee flexion strength increased, grip strength also tended to increase, however, the relationship is not very strong. Similarly, at span lengths of 6 cm, 7.3 cm, and 8.5 cm, the correlation coefficients were all positive but very small (0.031, 0.051, and 0.051, respectively). These values indicated weak positive relationships between knee flexion strength and grip strength at those span lengths. Overall, the correlation coefficients suggested that there was a very weak relationship between knee flexion strength and grip strength across different span lengths. The correlation coefficients were close to zero, indicating that the strength of the relationship was minimal, regardless of the span length.

From the result shown in Table 4.15, the correlation between knee extension strength and handgrip strength was also examined, resulting in correlation coefficients of 0.24, 0.125, 0.103, 0.107, and 0.112 for span settings of 3.4 cm, 4.7 cm, 6 cm, 7.3 cm, and 8.5 cm, respectively. These correlation coefficients indicated the strength and direction of the relationship between knee extension strength and handgrip strength for each span setting. The positive coefficients suggested a weak positive association between knee extension strength and handgrip strength. As the span setting widened, the coefficients gradually increased, suggesting that a larger grip span might contribute slightly to a stronger correlation between knee extension strength and handgrip strength. However, it is important to note that the correlations for all span settings remained relatively weak. This suggested that while there was some degree of association between knee extension strength and handgrip strength, other factors beyond grip span played a more significant role in influencing the relationship between these two measures.

This study had the same findings as the research conducted by Chan et al., (2014) where the correlation between hand grip strength and quadriceps strength was found to be weak. The data utilized in this study did not indicate a significant correlation between handgrip and knee muscle strength. Chan (2014) suggested that this difference in findings could be attributed to the study population. In this study, the respondents were older adults aged 60 and above, while a previous study showed a strong correlation between upper and lower limb muscle strength included participants ranging in age from 20 to 102 (Lauretani et al., 2003). As individuals age, they tend to experience progressive physical impairments, which can affect the correlation between upper and lower limb muscle strength. This statement is corresponding with the result of the Pearson correlation between elderly muscle strength and their age as seen on Table 4.18.

Table 4. 18 Pearson correlation between knee strength, hand grip strength, and elderly age

	Knee Muscle		Hand Grip - Span Setting (cm)				
	Flexion	Extension	3.4	4.7	6	7.3	8.5
Pearson Correlation	-0.131	-0.279	-0.214	-0.253	-0.216	-0.172	-0.169

The correlation coefficient between age and both knee muscle and hand grip strength were showing a negative weak relationship. The negative correlation indicated that as age increases, there was a slight tendency for knee muscle strength and hand grip strength to decrease. Furthermore, it also suggested that on muscle strength in the knee and hand grip tends to be slightly lower in older individuals compared to younger individuals.

4.5 Proposed Toilet Design

By incorporating ergonomic considerations, a design solution is formulated to mitigate accidents and establish a safe and comfortable environment. Architects and interior designers bear a social responsibility to modify and transform the surroundings, rendering them more accessible to the elderly (Kurnia, 2014). Ensuring that the elderly can maintain a certain level of normalcy in their functioning requires providing them with an appropriate living environment and facilities that cater to their specific limitations and abilities (Kaewdok et al., 2020).

Anthropometric data plays a crucial role in the design of products and facilities tailored specifically for the elderly. By incorporating this data, the aim is to enhance comfort and user-friendliness, thereby promoting increased productivity and reduced stress levels (Lee et al., 2019). In the case of toilet design, adjustments were made to the proportions of body dimensions based on the anthropometric measurements of the elderly. By designing products that align with appropriate body dimensions, elderly individuals can work and move comfortably and independently. The practical application of this approach is demonstrated as follows.

Designing tools or products for specific populations, such as the elderly or children, often involved considering a range of body dimensions to ensure usability, safety, and comfort. The use of extreme body dimensions (5th and 95th percentile) rather than the 50th percentile was based on the concept of design for extremes. The tool designs in this study were proposed by considering that it could accommodate a broader range of the population. A tool designed for the 5th percentile is more accessible to smaller individuals and a tool designed for the 95th percentile is more accessible to larger individuals. Designing tools that fit a wide range of body sizes and shapes, including extreme percentiles, was important for achieving improved ergonomics and user comfort. By considering the needs of diverse users, designers could create products that were safe, user-friendly, and enhanced the overall user experience and usability of the tool.

Toilet Seat

To ensure convenient use for the majority of the elderly population, the toilet seat height is determined based on the 5th percentile of the female popliteal height dimension. Setting seat heights that are excessively high (more than 120% of lower leg length) or too low (less than 80% of lower leg strength) can lead to instability during seating, hinder safe transfers, and increase the risk of falls (Capezuti et al., 2008).

In this study, the 95th percentile of female hip breadth in the sitting position is determined to be 37.48 cm, which is used as the basis for setting the toilet seat width. For the toilet seat depth, the 5th percentile of female buttocks-popliteal length, measured at 42.10 cm, is utilized. Additionally, the toilet seat height is determined based on the 5th percentile of female popliteal height, which measures 42.30 cm. However, for practicality in manufacturing, rounded values of 40.00 cm, 45.00 cm, and 45.00 cm can be used for the toilet seat width, depth, and height, respectively. Figure 4.3 illustrates the application of anthropometry in the design of a toilet seat tailored to the needs of the elderly population.

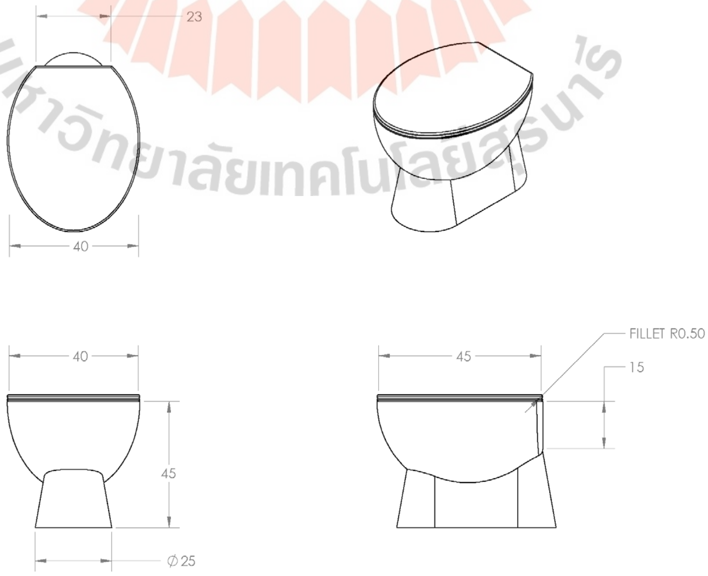

Figure 4.3 The proposed design of anthropometry applications for toilet seat specifically designed for elderly.

While conventional toilets tend to have a more traditional and standardized appearance, nowadays people are more familiar to modern toilet which feature different designs where it has water flush mechanism. The flush mechanism is located in the rear area of the toilet, which is in line with the location of the human back, allowing it to be used for leaning or support if needed. This specific part of the toilet will be mentioned as toilet tank in this study. The height of the toilet tank was set to 80 cm from the floor by following the recommendation of ADA guidelines (2010). Meanwhile for the width of the toilet tank, the proposed design used the 95th percentile of male shoulder bideltoid breadth, which measures at 47.76 cm. However, to ensure practicality in manufacturing, rounded values of 45 cm for the width are used in the design. The proposed design is illustrated on Figure 4.4.

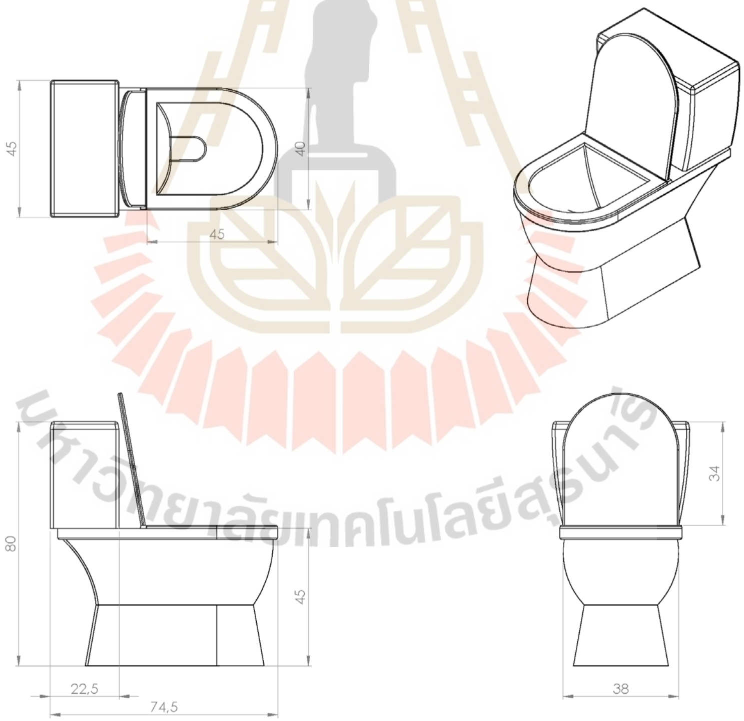

Figure 4.4 The proposed design of anthropometry applications for modern toilet specifically designed for elderly.

Handrail and Grab Bar

While some elderly individuals may still possess muscle strength, they commonly experience a decline in both independence and quality of life, including a reduction in their ability to walk unaided. Handrails and grab bars play a crucial role in providing support by bearing the weight of the elderly and assisting in maintaining their grip while walking, bending, or rising. Handrails prevent fall accidents for the elderly by providing essential support and stability during walking, enhancing confidence of fear of falling, and reducing the risk of slips or imbalance, especially in areas prone to potential falls. Grab bar has the same function as handrail, however the usage of these instruments depends on the purpose and where it will be installed. Grab bar is designed to be installed mounted to the wall while handrail is designed to be installed on the floor. To ensure optimal usability, the height of the handrail and grab bar should be comfortably reachable for the elderly from both sitting and standing positions. In the design of these tools, specific body dimensions are considered. According to the result of stand-to-sit and sit-to-stand time measurement, it was found that different age groups and gender gave different result for each handrail height. Notably, the shortest time needed in doing the stand-to-sit and sit-to-stand activity was found on 75 cm handrail height in conventional toilet settings. The modern toilet experimental setup revealed that quickest performance for stand-so-sit occurred on 75 cm handrail height, while the sit-to-stand activity was quickest on 80 cm handrail height, respectively. Remarkably, the strongest correlation coefficient between the knee muscle strength and handrail height was found on 75 cm, 80 cm, and 85 cm handrail height for both conventional and modern toilets. These results highlight the important role of these particular height in influencing support efficacy. Based on the findings from the measurements, the proposed toilet support handrail featured a two-stories design. This design incorporated a lower handrail height of 75 cm and a higher handrail height at 85 cm, thereby capitalizing on the outcomes consistently observed throughout the study. The recommended height for grab bar as walking support was determined on the 5th percentile of female elbow height, which measures 87.30 cm. Similarly, the handrail and grab bar diameter were based on the 5th percentile of female grip diameter, which measures 5.71 cm. Based on the hand grip strength measurement, the greatest strength was found on 6 cm grip span followed by 4.7 cm grip span. However, ADA guidelines (2010) recommended to use 5 cm diameter for handrail or grab bar. Therefore, in order to satisfy the requirements and to accommodate manufacturing feasibility, the value of 5.71 cm was adjusted to 5 cm for handrail diameter. Figure 4.5 and Figure 4.6 illustrate the practical application of anthropometric dimensions in the design of a handrail and grab bar for the elderly, ensuring optimal functionality and usability.

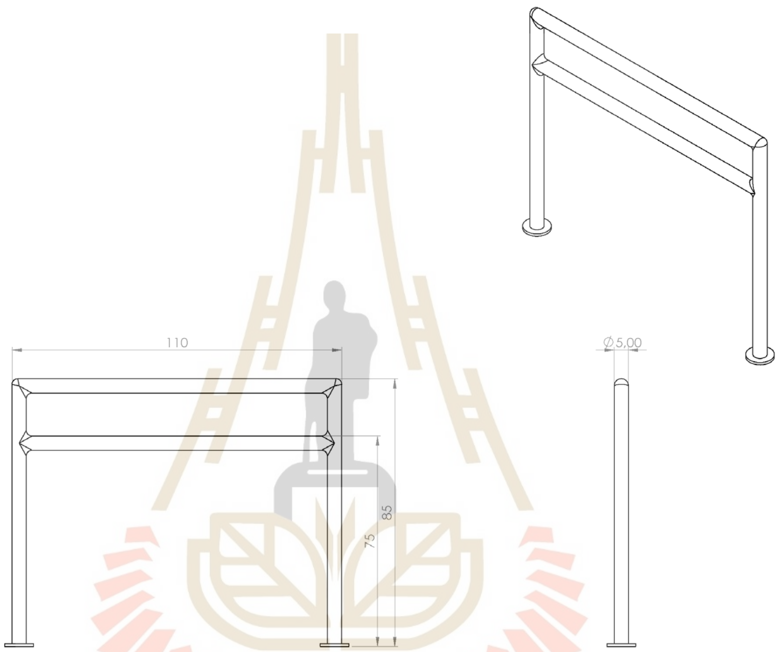

Figure 4.5 The proposed design of anthropometry applications for handrail specifically designed for elderly.

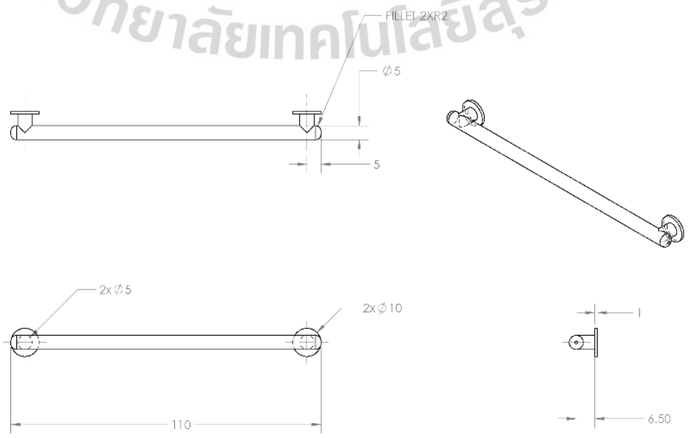

Figure 4.6 The proposed design of anthropometry applications for grab bar for walking support of the elderly.

By following the standard in ADA Guidelines (2010), it is recommended to set the distance between handrail and toilet on 46 cm. The consideration of the reach distance and the proposed tools design which incorporated anthropometric applications can be put into practice such as applying it in a bathroom as illustrated in Figure 4.7, showcasing how these dimensions contribute to enhanced functionality and usability. It is strongly recommended to use modern toilet for its cleanliness, comfort, and sustainability in personal hygiene practices compared to the conventional toilet. Toilet attachments such as bidets or water tanks can offer significant advantages, especially for individuals with limited mobility or specific health conditions. By providing readily available water for cleaning, these attachments eliminate the need for excessive reaching or twisting, making them more accessible and convenient for a diverse range of users, including the elderly or those facing mobility challenges.

Figure 4.7 The illustration of assembly view of the proposed toilet design in a bathroom.

CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The data analyzed in this study pertains to the elderly population residing in the rural area of Nakhon Ratchasima province in Thailand. It is important to note that the geographical location can have an impact on the measurement results. A total of 51 body dimensions were measured for Thai elderly individuals, encompassing 20 standing dimensions, 17 sitting dimensions, and 14 foot and hand dimensions. The correlation analysis revealed that body height and shoulder height of the elderly exhibited strong correlations with nearly all measured body dimensions, with the exception of chest circumference and abdomen breadth. These findings provide valuable insights into the interrelationships among various body measurements in the elderly population. On the other hand, a variety of musculoskeletal, movement control, and balance difficulties influence sit-to-stand movement (Brech et al., 2013). Reduced lower limb extension strength produces a reduction of concentric quadriceps contraction, which may result in balance instability throughout the standing up process (Brech et al., 2013). If unsteadiness occurs during the action of rising or sitting down, a handrail is required as one of the safety tools. The current study found that the elderly had greater knee extension strength compared to knee flexion strength, meanwhile greatest strength of hand grip was found on 6 cm grip span.

The time measurement on stand-to-sit and sit-to-stand activity did not show significant differences between conventional and modern toilet. However, it was observed that respondents completed these activities more quickly on the modern toilet in comparison to the conventional one. Similar outcomes were found when the time measurements were analyzed based on gender and age groups. The majority of the findings indicated that elderly performed these activities more quickly on the modern toilet compared to conventional toilet. This result could potentially be attributed to the differences in toilet size and dimensions. The modern toilet used in this study was designed closely adhere to the standards outlined by the ADA guidelines. A well-designed tool can contribute to better work efficiency, user safety, and comfort (MacLeod, 2000; Obi, 2016; Pheasant & Haslegrave, 2018). According to the Pearson correlation result between knee muscle strength and time measurement on the stand-to-sit and sit-to-stand motions, the time required to complete the exercise was related to the elderly's lower limb strength. The observation demonstrated that as lower limb flexion strength increased, stand-to-sit time decreased. The similar result was seen with the sit-to-stand time, which decreased as lower limb extension strength increased. The various heights of the handrail were utilized to evaluate the amount of time spent standing up and sitting down in the chair. The time taken to sit down and stand up on the toilet seat indicated no significant differences. On the contrary to the correlation between knee muscle strength and time measurements, the correlation between knee strength and hand grip strength was very weak, indicating that they were independently associated. This finding is consistent with a study conducted by Chan et al. (2014), which also observed a weak relationship between knee strength and handgrip strength. Despite the weak relationship indicated by the correlation coefficient between knee strength and handgrip strength, the utilization of both measurements in combination could be beneficial in identifying older adults in primary care who have the poorest health. Furthermore, this combination has the potential to contribute to predicting adverse health outcomes.

By considering the result of the measurements, this study proposed toilets, handrail, and grab bar designs. In general, grab bars should be installed at the height that is most comfortable for the users. Grab bars should be installed between 33 and 36 inches (84 cm – 91.5 cm) above the floor surface of the tub, shower, or bathroom, according to ADA guidelines. The most comfortable and preferable handrail height, on the other hand, was determined by human preferences. The ideal height for grab bars is always where the intended user will feel the most secure and comfortable. When compared to tall elderly, short-heighted elderly preferred grab bars that were designed lower in height. The opinions also differed depending on the height of the handrail. According to the majority of participants, the 95 cm handrail height is the least pleasant and desired since it is too high to reach for standing up from the toilet seat. This study designed the toilet support handrail with two tiers of height, aligning with the results from time measurements and knee strength evaluations. The lower handrail was set at 75 cm, while the higher one was set at 85 cm. This thoughtful design aims to enhance the performance of the elderly during stand-to-sit and sit-to-stand activities.

5.2 Recommendations

The differences observed between the anthropometric data in this study and those from other countries serve as a crucial reference point for the development of tools specifically designed for the elderly. It is essential for product features to align with the anthropometric body dimensions of the elderly population. Additionally, the utilization of percentiles can aid in the design of tools or facilities that accommodate the smallest and largest measurements within the elderly population. Given that human physiology can change over time, it is recommended to conduct anthropometric research periodically. The data collected in this study can be instrumental in the design of various public facilities and supportive tools, particularly those frequently used and needed in elderly nursing homes.

As of 2022, Thailand does not have a specific nationwide industrial standard or guidelines that are equivalent to the Americans with Disabilities Act (ADA) guidelines for the elderly. The ADA guidelines in the United States are comprehensive and cover a wide range of accessibility aspects to ensure that people with disabilities have equal access to facilities, services, and public spaces. Based on the findings from this study, the data collection of elderly body dimensions presented a valuable reference for designing facilities and tools catered to the elderly population in Thailand. The data provides essential insights into the anthropometric characteristics of this specific demographic, offering valuable information for the development of age-appropriate and user-friendly designs in various sectors. The utilization of this dataset can contribute to enhancing accessibility, safety, and comfort in public spaces, products, and services tailored to the needs of the elderly in the Thai context.

Due to the limited scope of this study on the elderly population in rural Northeastern Thailand, to ensure a more comprehensive representation of the larger population, a broader data collection is deemed necessary. It is recommended to conduct similar studies in different states or regions across the country. This approach will yield additional anthropometric databases, which can greatly assist product designers in developing and identifying the appropriate user characteristics for future products tailored to the needs of the elderly. Further studies with larger sample size will also be needed to strengthen the proof of the relationship statement in this study. Because the subject consisted of more female than male elderly, it should not be expected that the conclusions of this study would apply equally to other elderly population groups. Women have lower maximum skeletal muscular strength and power than men (Stoll et al., 2000 and Glenmark et al., 2004), since muscle mass contributes for roughly 30% of total body weight in a lean woman against 40%–45% in a lean man (Stoll et al., 2000). Additionally, females have around 70% of the maximum isometric muscular strength of males (Stoll et al., 2000). The ankle plantar flexor and trunk extensor muscles are also essential in standing up from a chair, therefore evaluation and training are recommended (Burke et al., 2010). The elderly who took part in this study were in good health, and the experimental setup was a toilet with a handrail. As a result, the results will be unreliable in comparison to similar tests in different populations and settings. Further research into these numerous experimental setups is also highly recommended.

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APPENDIX

APPENDIX A

RAW DATA OF DEMOGRAPHIC DATA AND ANTHROPOMETRY MEASUREMENT

A.1 Sample Size Calculation

The minimum value of sample size of this study will be calculated with equation below.

$$\phi^2 = \frac{naD^2}{2b\sigma^2} \quad (1)$$

The response used is the time required by the elderly in rising up from the sitting position which has calculated on the preliminary observation. From the response data, these following were calculated:

Maximum mean	= 2.034
Minimum mean	= 1.909
Value of maximum difference between means	= 0.125
Sum Square of Error	= 572.866
Degree of freedom	= 3879
Standard deviation	= 0.147

Minimum value of ϕ^2 is

$$\phi^2 = \frac{n(2)(0.125)^2}{2(2)(0.147)^2}$$

$$\phi^2 = \frac{n(0.03125)}{0.086436}$$

$$\phi^2 = 0.36n$$

The significance level (α) is 0.05, therefore the appendix results are as seen as Table A. 1.

Table A. 1 Replication calculation results

n	ϕ^2	Φ	v_1	v_2	β
10	3.6	1.89	1	36	0.32
11	3.96	1.98	1	40	0.23
12	4.32	2.08	1	44	0.19
13	4.68	2.16	1	48	0.17
14	5.04	2.24	1	52	0.15
15	5.4	2,32	1	56	0.14
16	5.76	2.4	1	60	0.083
17	6.12	2.47	1	64	0.065
18	6.48	2.54	1	68	0.055
19	6.84	2.62	1	72	0.045
20	7.2	2.68	1	76	0.039

The number of n= 20 replicates give a β risk of about 0.039. Thus, it is concluded that 20 replicates are considered as the minimum requirements of the amount of the data of the desired sensitivity.

A.2 Demographic Data

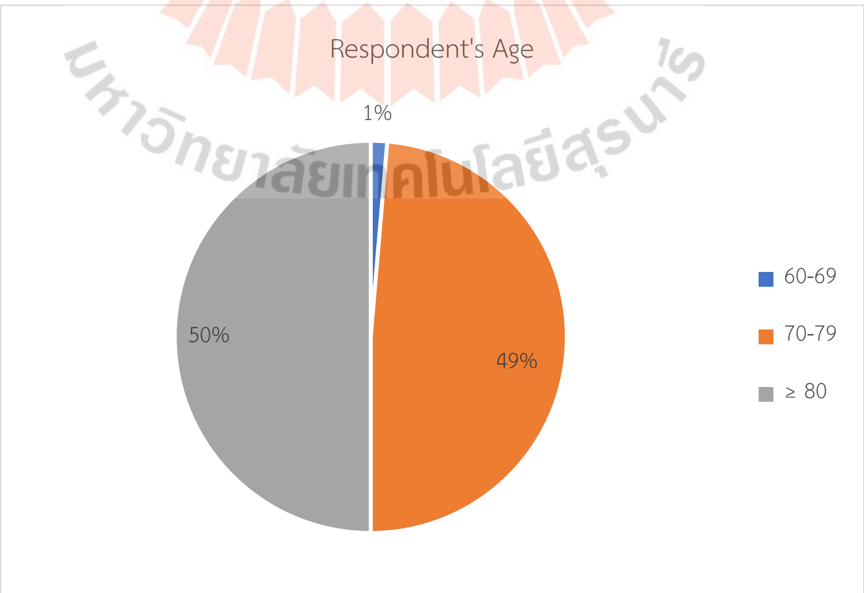

Figure A. 1 Percentage indicating age of the respondents (in years).

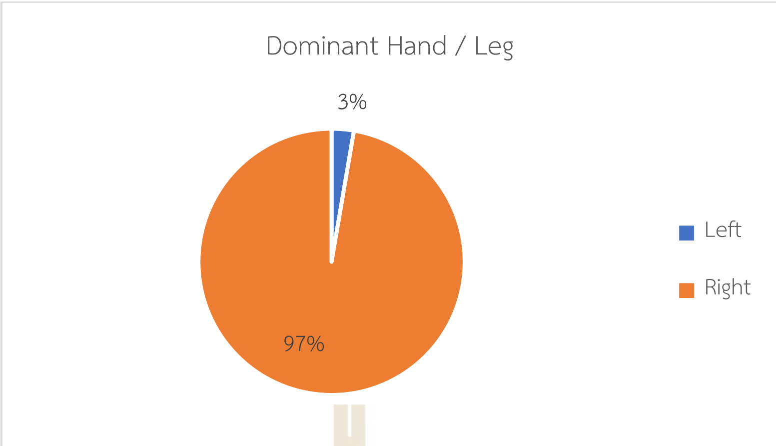

Figure A. 2 Percentage indicating dominant hand or leg of the respondents.

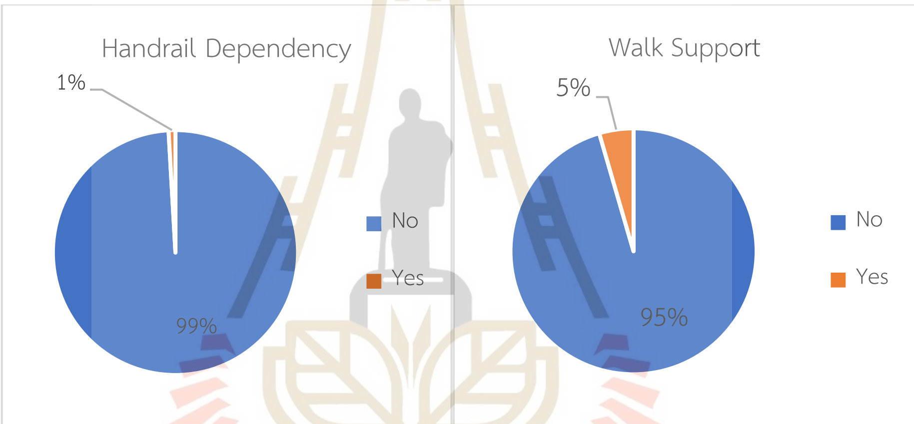

Figure A. 3 Percentage indicating respondent's dependency on handrail and walking support.

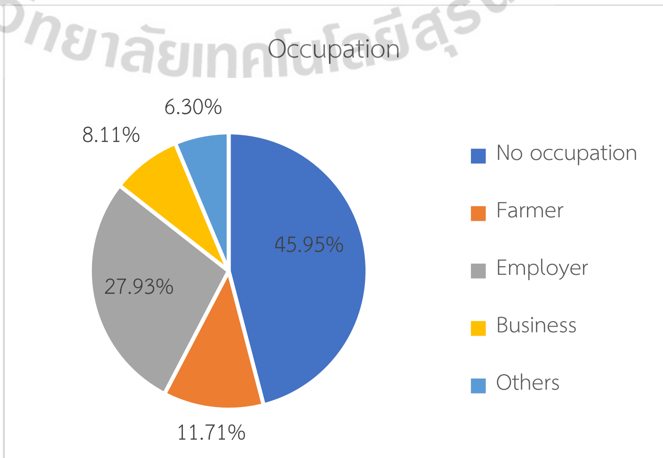

Figure A. 4 The percentage distribution of each occupation among the participating elderly respondents.

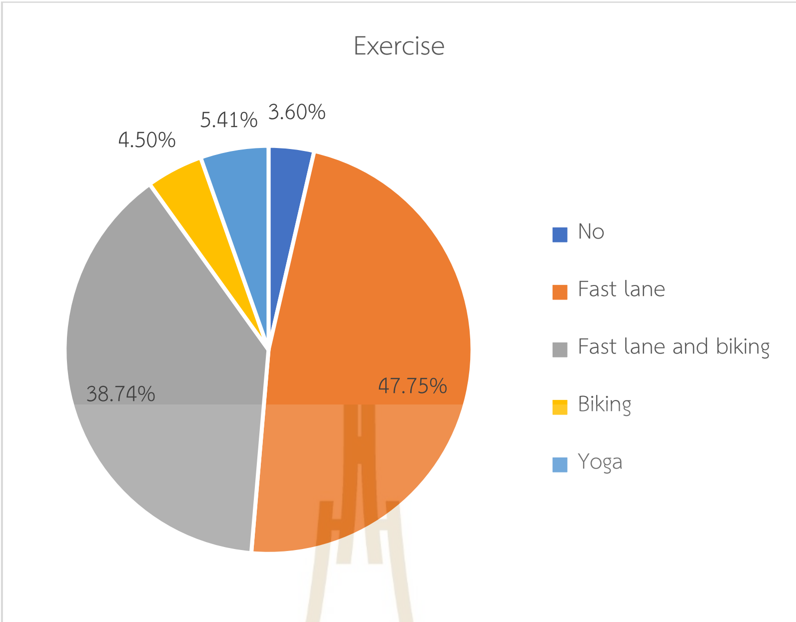

Figure A. 5 The percentage distribution of routine exercise among the participating elderly respondents.

A.3 Anthropometry Data

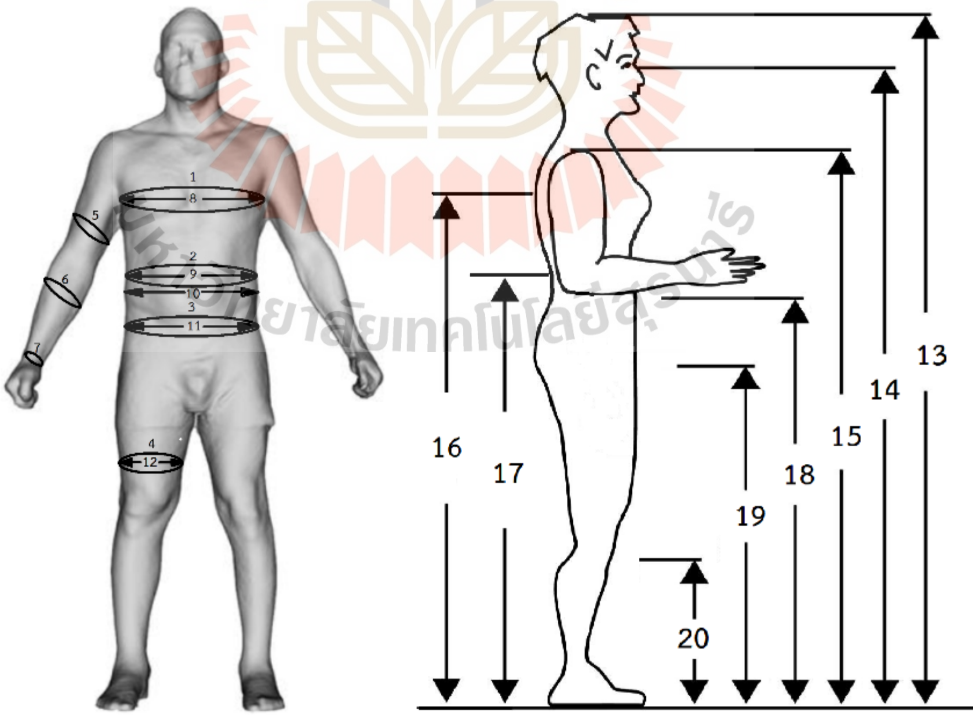

Figure A. 6 Anthropometry body dimension in standing position (Lee et al., 2019, Minetto et al., 2022)

Table A. 2 Anthropometry data of male elderly's standing body dimensions

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
1	Chest	76.20	87.00	109.60	11	Hip breadth	27.70	31.00	36.56
2	Waistline	63.40	82.00	105.40	12	Thigh breadth	8.50	11.00	18.96
3	Hip	83.20	92.00	114.00	13	Stature height	158.20	162.00	178.80
4	Thigh	33.00	44.00	56.00	14	Eye height	140.16	148.50	162.82
5	Upper arm	39.20	46.00	61.60	15	Shoulder height	124.04	133.00	149.36
6	Elbow	21.20	26.00	31.60	16	Back armpit height	110.46	116.90	132.11
7	Wrist	15.20	19.00	21.60	17	Back waist height	90.64	101.40	146.50
8	Chest breadth	26.37	27.80	29.70	18	Elbow bending height	73.62	98.23	108.50
9	Waist breadth	23.46	27.00	33.60	19	Crotch height	56.22	70.60	83.40
10	Abdominal breadth	26.70	28.70	30.43	20	Tibial height	36.88	43.70	49.78

Table A. 3 Anthropometry data of female elderly's standing body dimensions

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
1	Chest	80.00	92.50	104.58	11	Hip breadth	28.89	32.50	37.35
2	Waistline	70.45	90.00	103.55	12	Thigh breadth	9.00	11.80	16.97
3	Hip	87.90	100.50	115.55	13	Stature height	147.28	151.00	160.00
4	Thigh	34.00	44.00	53.42	14	Eye height	132.00	139.25	148.46
5	Upper arm	35.35	50.00	58.10	15	Shoulder height	115.79	123.25	132.14
6	Elbow	21.00	26.00	30.79	16	Back armpit height	97.91	108.23	117.07
7	Wrist	14.00	17.00	19.00	17	Back waist height	85.14	95.60	103.87
8	Chest breadth	24.93	27.00	30.85	18	Elbow bending height	82.00	91.20	99.44
9	Waist breadth	21.60	27.13	31.06	19	Crotch height	58.25	66.65	73.40
10	Abdominal breadth	28.00	30.15	35.22	20	Tibial height	35.65	41.25	48.11

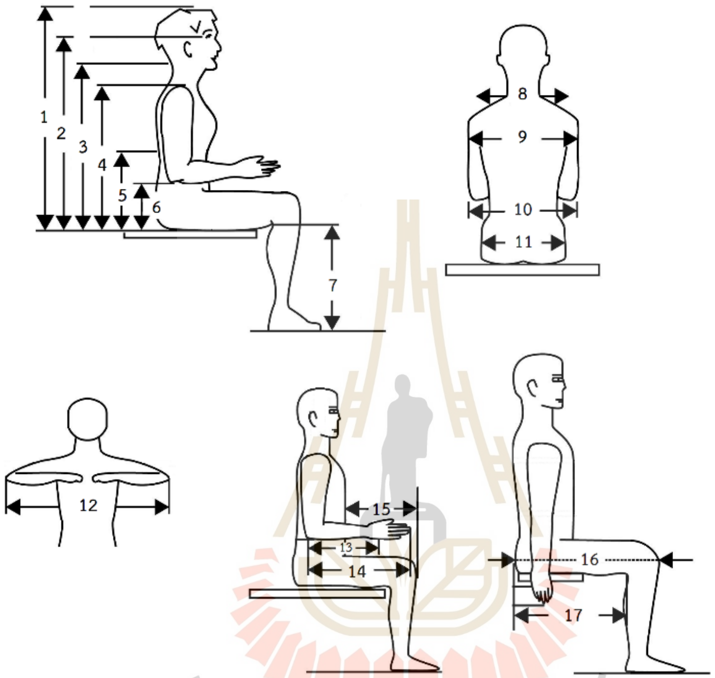

Figure A. 7 Anthropometry body dimension in sitting position (Lee et al., 2019)

Table A. 4 Anthropometry data of male elderly's sitting body dimensions

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
1	Sitting body height	79.50	84.00	92.96	10	Elbow to elbow breadth	28.6	42.5	57.4
2	Sitting eye height	63.40	73.00	79.00	11	Hip breadth	31.40	33.40	37.00

Table A. 4 Anthropometry data of male elderly's sitting body dimensions (continued)

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
3	Sitting cervicale height	52.33	60.00	64.48	12	Elbow to elbow extension breadth	73.40	82.50	91.20
4	Sitting shoulder height	46.66	55.17	59.52	13	Elbow to center of fist length	31.60	34.30	37.84
5	Sitting waist height	23.04	27.70	36.20	14	Elbow to fingertip length	43.17	45.73	51.72
6	Sitting bending elbow height	12.50	20.60	25.70	15	Abdomen to knee length	30.60	35.53	43.27
7	Popliteal height	42.30	43.80	45.43	16	Buttocks to knee contact length	49.20	54.00	62.76
8	Shoulder biacromical breadth	28.20	31.50	35.32	17	Buttocks to popliteal length	42.10	43.80	46.00
9	Shoulder bideltoid breadth	35.56	41.50	47.76					

Table A. 5 Anthropometry data of female elderly's sitting body dimensions

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
1	Sitting body height	75.08	78.00	80.50	10	Elbow to elbow breadth	35.89	42	49.9
2	Sitting eye height	60.56	67.20	73.70	11	Hip breadth	33.00	34.90	37.48

Table A. 5 Anthropometry data of female elderly's sitting body dimensions (continued)

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
3	Sitting cervicale height	49.25	55.10	61.28	12	Elbow to elbow extension breadth	65.96	76.50	83.56
4	Sitting shoulder height	45.20	51.00	55.55	13	Elbow to center of fist length	29.00	31.90	35.57
5	Sitting waist height	19.26	24.83	32.94	14	Elbow to fingertip length	39.64	42.70	46.67
6	Sitting bending elbow height	11.89	18.67	23.11	15	Abdomen to knee length	24.18	29.95	36.55
7	Popliteal height	40.75	42.60	44.20	16	Buttocks to knee contact length	46.31	51.90	57.08
8	Shoulder biacromical breadth	25.55	29.60	34.19	17	Buttocks to popliteal length	40.83	42.75	45.23
9	Shoulder bideltoid breadth	34.00	37.95	41.91					

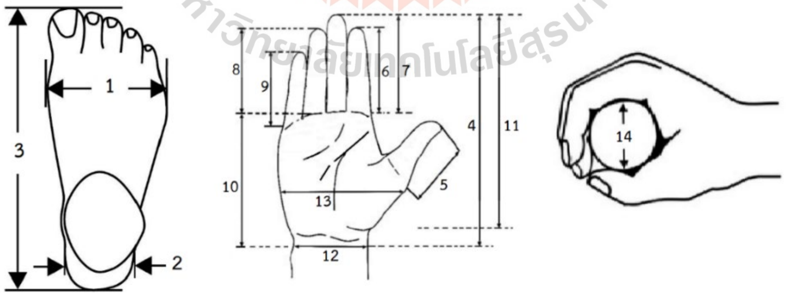

Figure A. 8 Anthropometry of foot and hand body dimensions (Çakıt et al., 2014, Lee et al., 2019, Shahriar et al., 2020).

Table A. 6 Anthropometry data of male elderly's foot and hand body dimensions

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
1	Front foot width	10.00	10.90	12.00	8	Ring finger length	6.70	7.27	8.74
2	Heel width	5.84	7.00	9.00	9	Little finger length	4.80	5.90	6.43
3	Maximum foot length	24.00	25.00	28.80	10	Palm length	10.20	10.50	11.00
4	Maximum palm length	19.20	22.00	24.80	11	Tip of the index finger – base of the thumb	9.80	11.40	12.18
5	Thumb length	5.69	6.40	7.90	12	Palm width	8.00	8.50	8.80
6	Index finger length	6.42	7.00	7.76	13	Hand width	8.93	11.00	13.50
7	Middle finger length	7.04	7.70	8.86	14	Largest grip diameter	5.90	7.00	7.30

Table A. 7 Anthropometry data of female elderly's foot and hand body dimensions

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
1	Front foot width	9.31	10.00	10.55	8	Ring finger length	6.00	6.78	7.60
2	Heel width	5.35	6.30	9.28	9	Little finger length	4.80	5.50	6.00

Table A. 7 Anthropometry data of female elderly's foot and hand body dimensions (continued)

No	Body Dimension	Percentile (cm)			No	Body Dimension	Percentile (cm)		
		5	50	95			5	50	95
3	Maximum foot length	22.00	23.00	24.00	10	Palm length	9.50	10.00	10.39
4	Maximum palm length	18.00	20.00	21.55	11	Tip of the index finger – base of the thumb	8.50	10.40	11.84
5	Thumb length	5.20	5.90	6.96	12	Palm width	7.31	7.58	7.82
6	Index finger length	6.00	6.75	7.70	13	Hand width	8.18	9.52	11.67
7	Middle finger length	6.51	7.27	8.00	14	Largest grip diameter	4.61	6.13	7.46

A.4 Comparison of Body Dimensions in Different Populations

Table A. 8 Comparison of elderly body dimensions in different populations

Body dimensions	Mean (SD) in cm					
	Present study	Australian[a] (2001)	Indonesian[b] (2020)	Singaporean[c] (2019)	Malaysian[d] (2009)	Thai[e] (2005)
Stature height	162.1(6.12)	165.8(7.9)	156.08(7.3)	163.5(4.9)**	162.3(7.5)**	161.4
Eye height	149.9(5.55)	153.2(7.0)	143.31(7.02)	152.4(4.9)**	149.9(6.1)**	149.9
Elbow height	96.5(7.32)	104.3(5.0)	98.46(4.65)	106.0(4.8)**	97.1(5.8)**	98.9
Bideltoid breadth	41.36(2.7)	-	39.43(2.42)	42.1(1.9)**		43.4

Table A. 8 Comparison of elderly body dimensions in different populations (continued)

Body dimensions	Mean (SD) in cm					
	Present study	Australian[a] (2001)	Indonesian[b] (2020)	Singaporean[c] (2019)	Malaysian[d] (2009)	Thai[e] (2005)
Hand length	21.9(1.49)	18.4(1.0)	-	18.1(0.7)**	17.8(1.2)**	-
Sitting body height	83.3(5.3)	84.3(5.6)	-	83.2(2.0)**	83.1(4.3)**	82.9
Sitting eye height	72.1(4.46)	72.9(4.6)	107.52(8.11)	72.1(2.4)**	71.6(5.6)**	73.4
Popliteal height	44.2(2.31)	41.6(2.5)	42.90(3.08)	39.4(1.7)**	39.6(2.4)**	40.1
Knee height	51.8(3.36)	51.5(3.1)	-	47.5(1.7)*	49.8(2.9)**	47.8
Buttock – knee length	54.53(3.47)	54.9(3.8)	-	57.1(1.5)**	53.7(3.6)*	-
Buttock – popliteal length	44.2(2.49)	45.2(3.8)	42.33(4.73)	46.2(1.3)**	45.5(2.7)**	-
Sitting hip breadth	34.2(3.76)	33.6(2.8)	34.71(3.61)	30.0(1.6)	35.0(3.5)**	35.4
Foot length	24.99(1.64)	-	-	26.1(1.0)**	24.6(1.1)**	-
Foot breadth	11.1(1.29)	-	-	10.0(0.6)*	10.2(0.7)**	-

Measurements are in cm.

*Significant ($p < 0.05$), **Significant ($p < 0.01$)

[a] Kothiyal and Tettey (2001), [b] Rahmawati *et al*. (2020), [c] Lee at al. (2019), [d] Rosnah *et al*. (2009), [e] Jarutat *et al*. (2005)

A.5 Proposed Design of Bathroom for Elderly

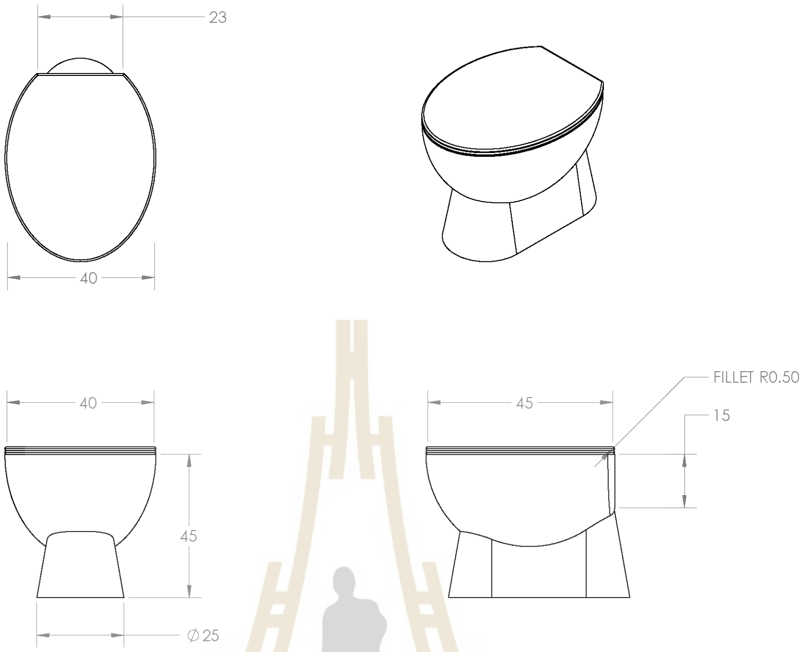

Figure A. 9 The proposed design of anthropometry applications for toilet seat specifically designed for elderly.

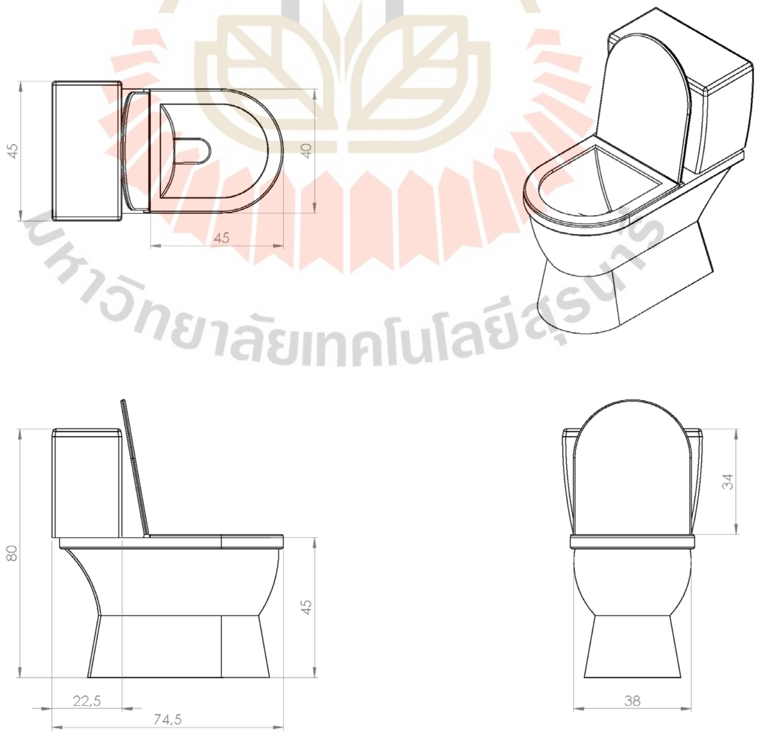

Figure A. 10 The proposed design of anthropometry applications for modern toilet specifically designed for elderly.

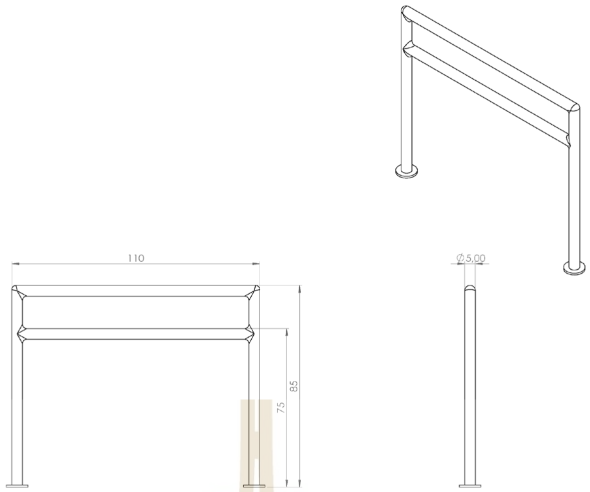

Figure A. 11 The proposed design of anthropometry applications for toilet handrail specifically designed for elderly.

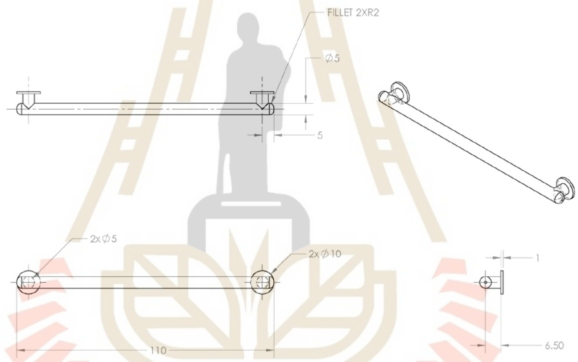

Figure A. 12 The proposed design of anthropometry applications for grab bar for walking support of the elderly.

Figure A. 13 Illustration of the proposed toilet design application in a bathroom.

A.6 Correlations Coefficients Between Body Dimensions

Table A. 9 Correlations coefficients between some of the body dimensions

	Chest Circ.	Thigh Circ.	Chest breadth	Abdominal breadth	Body height	Shoulder height	Sitting body height	Popliteal height	Hip breadth	Buttocks to popliteal length	Front foot width	Max. foot length	Palm length	Palm width
Chest Circ.	1													
Thigh Circ.	.562**	1												
Chest breadth	.710**	.515**	1											
Abdominal breadth	.740**	.499**	.529**	1										
Body height	0.069	.219*	.288**	0.035	1									
Shoulder height	-0.008	0.131	.231*	0.009	.933**	1								
Sitting body height	0.088	.279**	.336**	-0.027	.689**	.640**	1							
Popliteal height	0.125	.302**	.226*	0.135	.473**	.426**	.375**	1						
Hip breadth	.676**	.633**	.601**	.665**	.289**	.217*	.223*	.329**	1					

Table A. 9 Correlations coefficients between some of the body dimensions (continued)

	Chest Circ.	Thigh Circ.	Chest breadth	Abdominal breadth	Body height	Shoulder height	Sitting body height	Popliteal height	Hip breadth	Buttocks to popliteal length	Front foot width	Max. foot length	Palm length	Palm width
Buttocks to popliteal length	0.065	0.011	-0.093	0.088	.317**	.311**	0.094	0.056	0.084	1				
Front foot width	0.080	0.150	0.115	0.020	.363**	.304**	.342**	0.179	0.186	0.157	1			
Maximum foot length	0.100	0.088	.199*	0.092	.614**	.614**	.327**	.267**	.239*	.288**	.266**	1		
Palm length	0.065	0.184	.286**	0.159	.285**	.308**	.223*	0.034	0.178	0.071	0.081	.253**	1	
Palm width	0.106	.222*	0.174	0.043	.435**	.452**	.397**	0.149	0.164	.195*	.240*	.257**	.250**	1

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

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

APPENDIX B

STAND-TO-SIT AND SIT-TO-STAND TIME MEASUREMENT

B.1 Descriptive Statistics of Stand-to-Sit and Sit-to-Stand Time Measurement for Conventional Toilet

Table B.1 Descriptive statistics of stand-to-sit and sit-to-stand time measurement for conventional toilet

Activities	Descriptive Statistic	Handrail height				
		75 cm	80 cm	85 cm	90 cm	95 cm
Stand to Sit	Mean (s)	6.0499	6.1404	6.2630	6.1775	6.3369
	Std. Dev.	1.59741	1.73755	1.77838	1.64863	1.62100
Sit to Stand	Mean (s)	3.2581	3.4385	3.3515	3.2878	3.4284
	Std. Dev.	1.09680	1.15530	1.23880	1.00400	1.13634

Table B.2 Descriptive statistics of stand-to-sit and sit-to-stand time measurement for modern toilet

Activities	Descriptive Statistic	Handrail height				
		75 cm	80 cm	85 cm	90 cm	95 cm
Stand to Sit	Mean (s)	5.9894	5.8824	5.9239	6.0717	6.0120
	Std. Dev.	1.62365	1.56854	1.50871	1.63534	1.49295
Sit to Stand	Mean (s)	3.3196	3.3259	3.4037	3.3906	3.3553
	Std. Dev.	1.03991	1.02893	1.18503	1.04865	1.04781

B.2 Time Comparison of Stand-to-Sit and Sit-to-Stand Time Measurement for Conventional Toilet and Modern Toilet Based on Gender Group

Table B. 3 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on gender group

Conventional Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
Male	Mean (s)	6.24	3.21	6.29	3.49	6.47	3.45	6.39	3.49	6.64	3.46
	SD	1.95	1.09	1.73	1.27	2.09	1.40	1.88	1.09	1.73	1.27
Female	Mean (s)	6.00	3.27	6.10	3.43	6.21	3.33	6.12	3.24	6.26	3.42
	SD	1.50	1.10	1.75	1.13	1.70	1.20	1.59	0.98	1.59	1.11

Modern Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
Male	Mean (s)	6.33	3.76	6.19	3.59	6.29	3.63	6.23	3.48	6.37	7.72
	SD	1.99	2.15	2.16	1.49	2.17	1.63	1.90	1.67	2.65	1.31

Table B. 3 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on gender group (continued)

Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
Female	Mean (s)	5.82	3.26	5.82	3.37	5.95	3.36	6.02	3.41	5.98	3.34
	SD	1.54	0.97	1.49	1.39	1.55	1.11	1.57	1.07	1.56	0.98

B.3 Time Comparison of Stand-to-Sit and Sit-to-Stand Time Measurement for Conventional Toilet and Modern Toilet Based on Age Group

Table B. 4 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on age group

Conventional Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
60-69	Mean (s)	5.61	2.87	5.60	3.11	5.66	2.93	5.74	2.91	5.73	2.93
	SD	1.51	0.92	1.52	1.03	1.63	1.01	1.60	0.87	1.45	0.87
70-79	Mean (s)	6.11	3.38	6.13	3.47	6.29	3.40	6.16	3.43	6.44	3.56
	SD	1.22	1.01	1.34	0.96	1.50	1.03	1.13	0.84	1.34	0.90

Table B. 4 Time comparison for stand-to-sit and sit-to-stand activity on toilet based on age group (continued)

Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
80-90	Mean (s)	7.15	4.11	7.65	4.28	7.87	4.42	7.42	4.08	7.83	4.56
	SD	1.92	1.20	2.09	1.39	1.70	1.51	1.98	1.13	1.57	1.31
Modern Toilet											
Handrail height		75 cm		80 cm		85 cm		90 cm		95 cm	
Activities		Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand	Stand to sit	Sit to stand
60-69	Mean (s)	5.42	2.94	5.40	3.09	5.49	2.95	5.57	3.06	5.55	3.06
	SD	1.42	0.77	1.36	1.50	1.40	0.83	1.56	0.93	1.43	0.82
70-79	Mean (s)	5.92	3.38	5.79	3.52	6.10	3.52	6.24	3.55	6.04	3.37
	SD	1.26	0.86	1.12	0.79	1.33	0.92	1.33	0.99	1.33	0.92
80-90	Mean (s)	7.32	4.50	7.46	4.14	7.36	4.51	7.16	4.22	7.47	4.15
	SD	2.07	2.24	2.23	1.74	2.24	1.83	1.80	1.76	2.73	1.41

APPENDIX C

MUSCLE STRENGTH MEASUREMENT

C.1 Descriptive Statistics of Lower Limb Strength and Hand Grip Strength

Table C.1 Lower limb strength descriptive statistics

Activities	Mean (Nm)	Std. Deviation
Extension	9.31	3.04
Flexion	8.36	2.86

Table C.2 Hand grip strength descriptive statistics

Grip position (cm)	Mean (kg)	Std. Deviation
Span 3.4	9.14	4.94
Span 4.7	14.58	7.11
Span 6	15.06	6.94
Span 7.3	13.62	6.39
Span 8.5	11.23	5.84

C.2 Correlation Coefficients Between Lower Limb Strength and Stand-to-Sit and Sit-to-Stand Time

Table C.3 Pearson correlation between flexion strength and stand-to-sit time

Handrail height		Stand-to-Sit Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Flexion Strength	Pearson Correlation	-.437**	-.369**	-.434**	-.369**	-.360**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	111	111	111	111	111

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

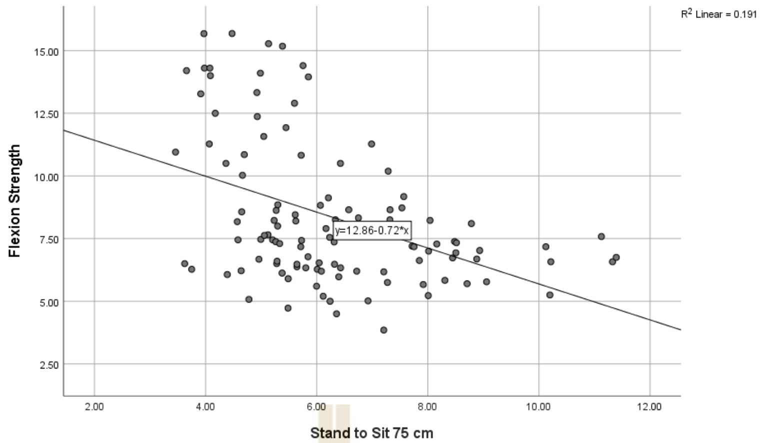

Figure C.1 Correlation between flexion lower limb strength and stand-to-sit time for 75 cm handrail height on conventional toilet

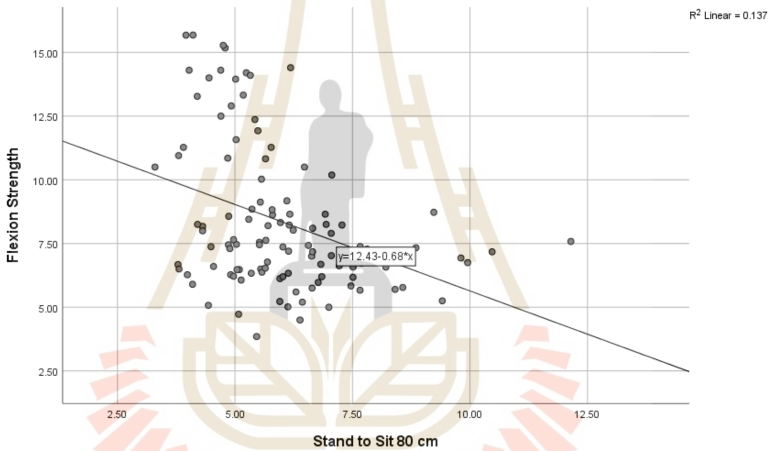

Figure C.2 Correlation between flexion lower limb strength and stand-to-sit time for 80 cm handrail height on conventional toilet

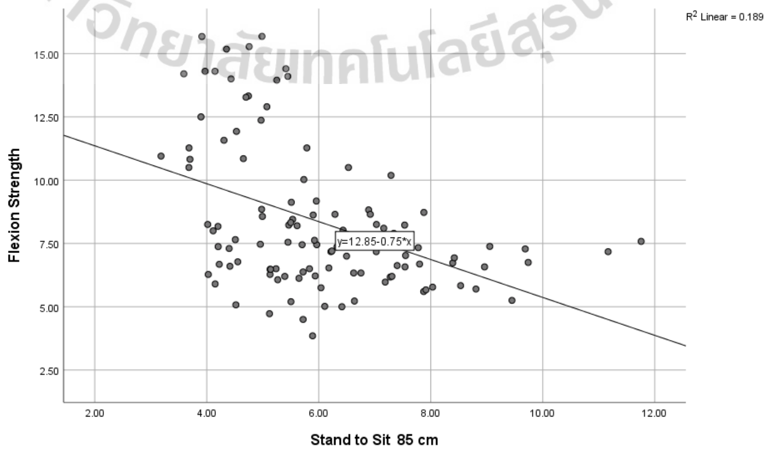

Figure C.3 Correlation between flexion lower limb strength and stand-to-sit time for 85 cm handrail height on conventional toilet

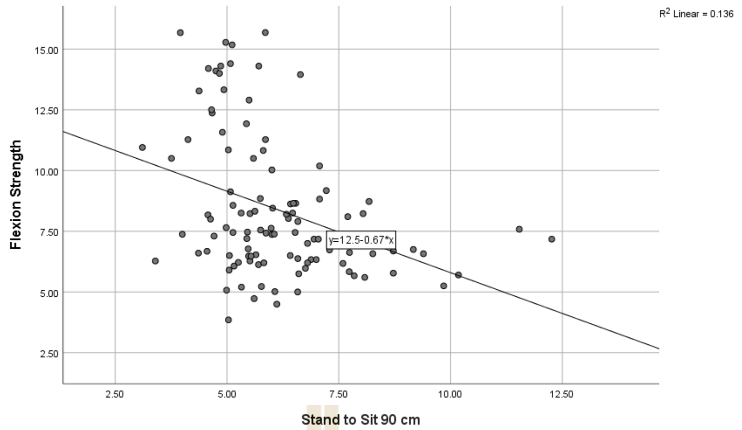

Figure C.4 Correlation between flexion lower limb strength and stand-to-sit time for 90 cm handrail height on conventional toilet

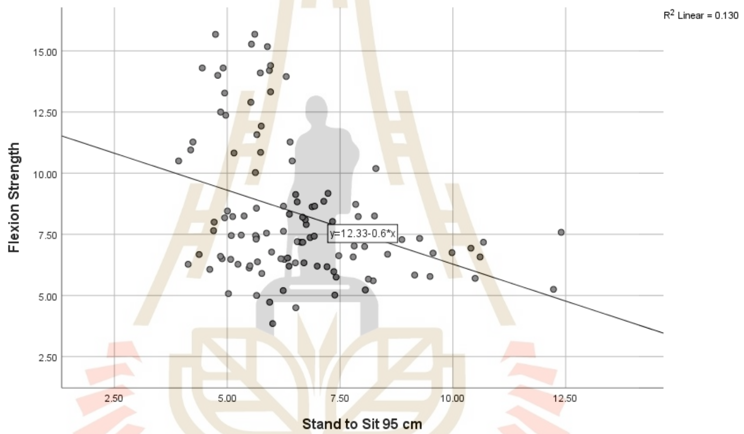

Figure C. 5 Correlation between flexion lower limb strength and stand-to-sit time for 95 cm handrail height on conventional toilet

Table C. 4 Pearson correlation between extension strength and sit-to-stand time

Handrail Height		Sit-to-Stand Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Extension Strength	Pearson Correlation	-.595**	-.614**	-.601**	-.600**	-.573**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	111	111	111	111	111

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

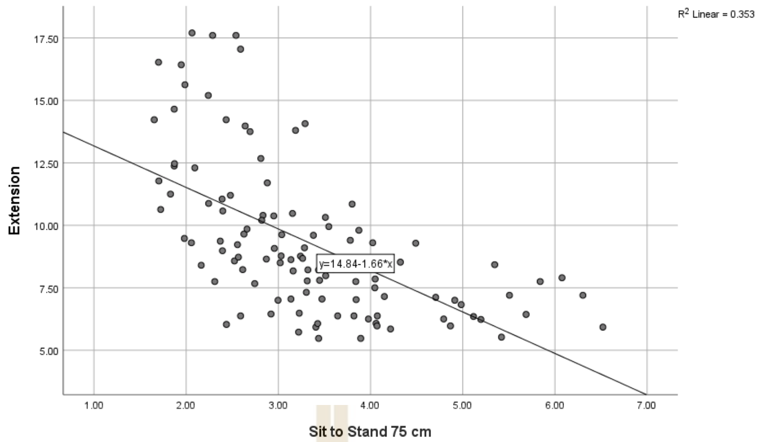

Figure C. 6 Correlation between extension lower limb strength and sit-to-stand time for 75 cm handrail height on conventional toilet

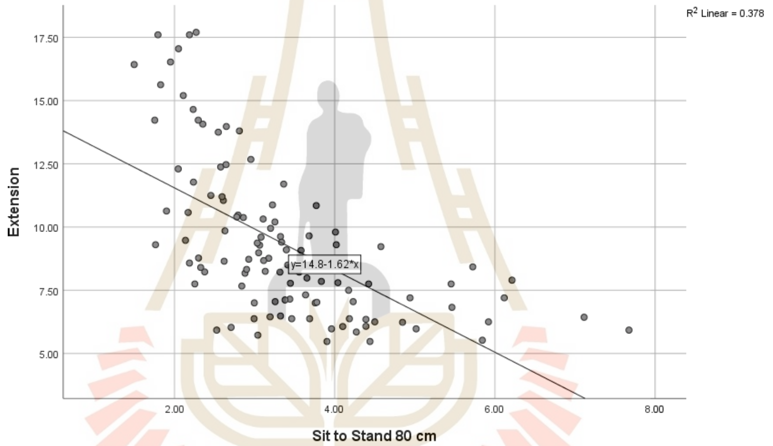

Figure C. 7 Correlation between extension lower limb strength and sit-to-stand time for 80 cm handrail height on conventional toilet

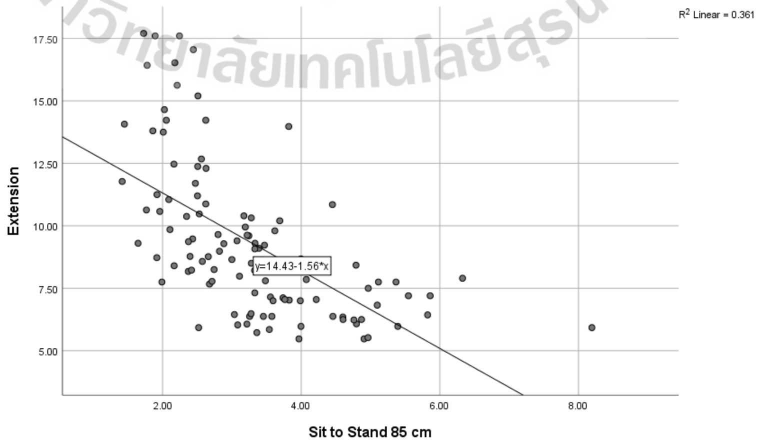

Figure C. 8 Correlation between extension lower limb strength and sit-to-stand time for 85 cm handrail height on conventional toilet

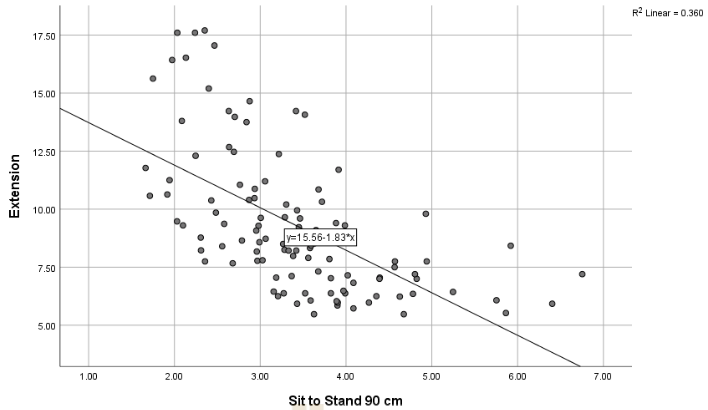

Figure C. 9 Correlation between extension lower limb strength and sit-to-stand time for 90 cm handrail height on conventional toilet

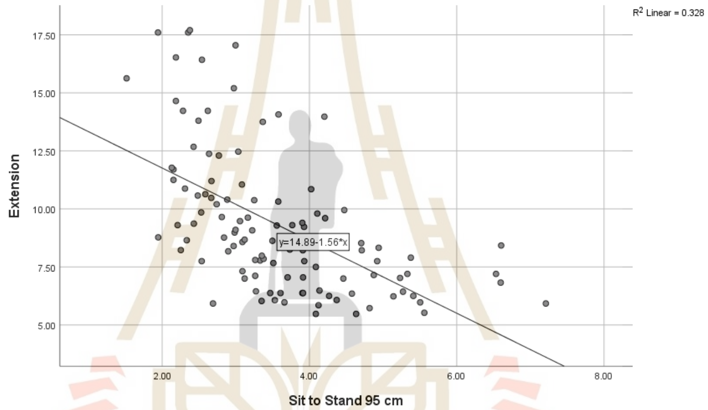

Figure C. 10 Correlation between extension lower limb strength and sit-to-stand time for 95 cm handrail height on conventional toilet

Table C. 5 Pearson correlation between flexion strength and stand-to-sit time on modern toilet

Handrail height		Sit-to-Stand Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Extension Strength	Pearson Correlation	-.564**	-.439**	-.509**	-.554**	-.504**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	111	111	111	111	111

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

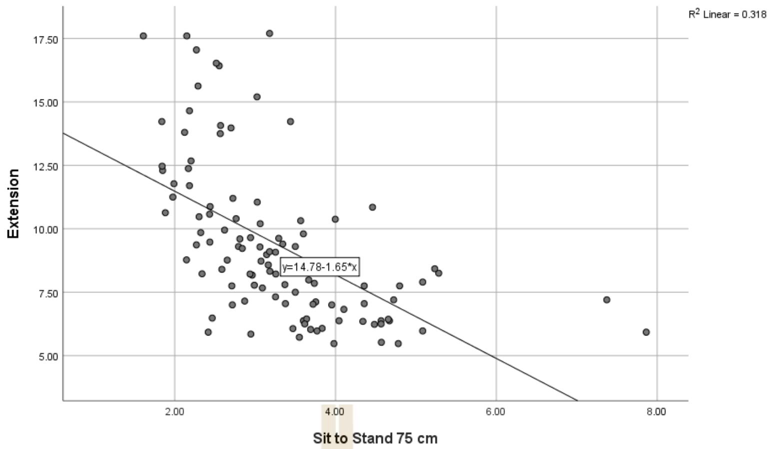

Figure C. 11 Correlation between flexion lower limb strength and stand-to-sit time for 75 cm handrail height on modern toilet

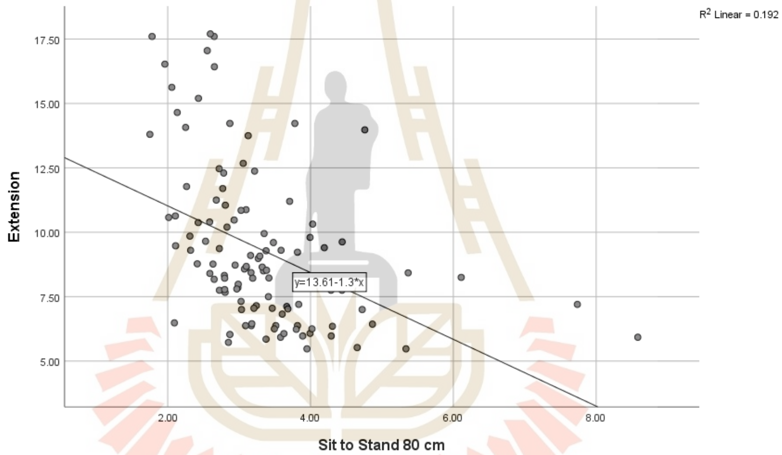

Figure C. 12 Correlation between flexion lower limb strength and stand-to-sit time for 80 cm handrail height on modern toilet

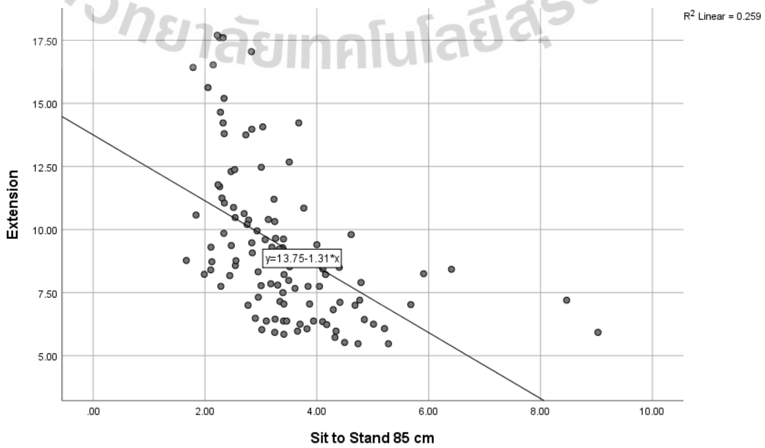

Figure C. 13 Correlation between flexion lower limb strength and stand-to-sit time for 85 cm handrail height on modern toilet

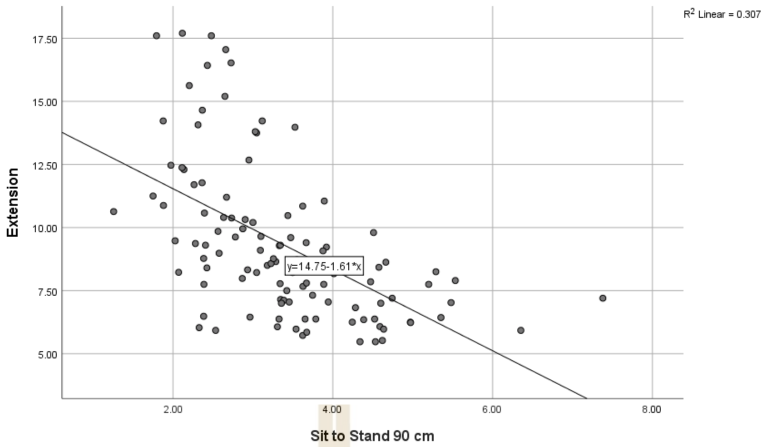

Figure C. 14 Correlation between flexion lower limb strength and stand-to-sit time for 90 cm handrail height on modern toilet

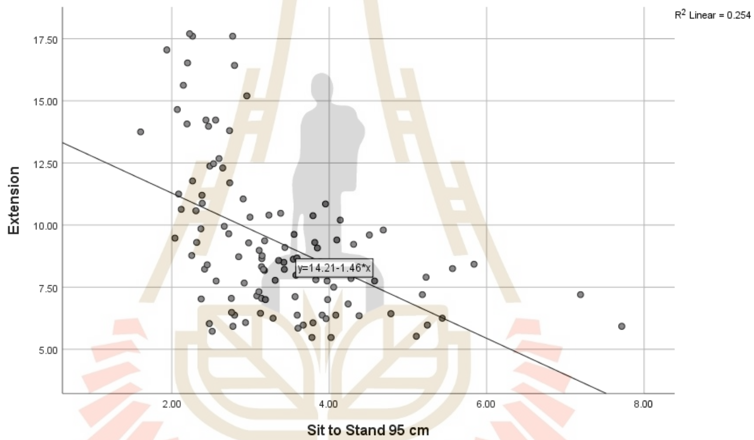

Figure C. 15 Correlation between flexion lower limb strength and stand-to-sit time for 95 cm handrail height on modern toilet

Table C. 6 Pearson correlation between extension strength and sit-to-stand time on modern toilet

Handrail height		Stand-to-Sit Time				
		75 cm	80 cm	85 cm	90 cm	95 cm
Flexion Strength	Pearson Correlation	-.376**	-.395**	-.466**	-.365**	-.377**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	111	111	111	111	111

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

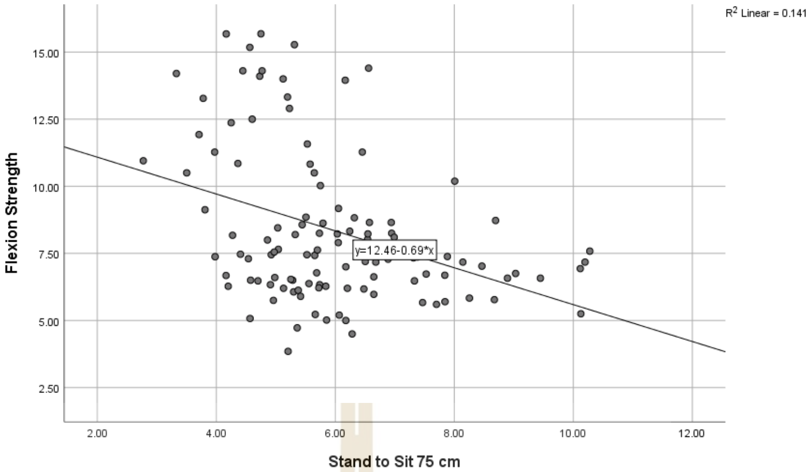

Figure C. 16 Correlation between extension lower limb strength and sit-to-stand time for 75 cm handrail height on modern toilet

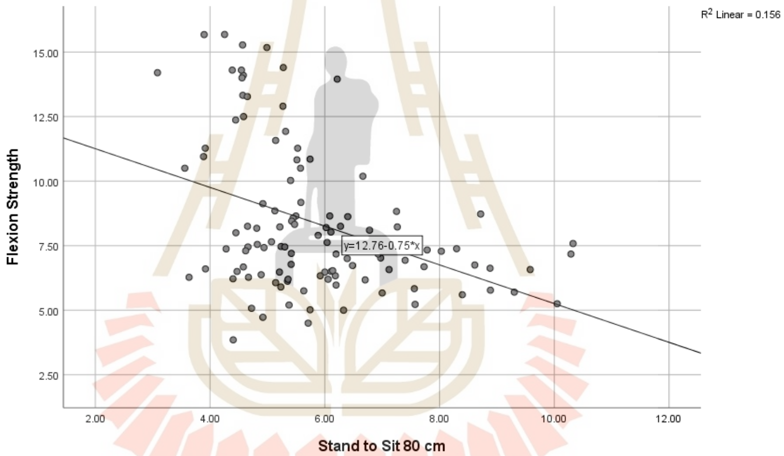

Figure C. 17 Correlation between extension lower limb strength and sit-to-stand time for 80 cm handrail height on modern toilet

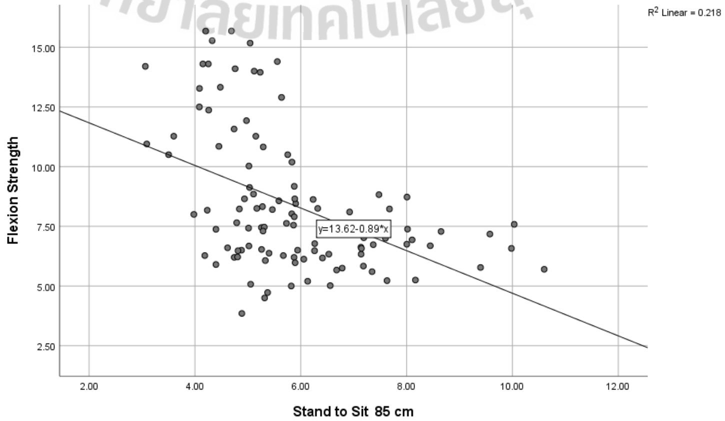

Figure C. 18 Correlation between extension lower limb strength and sit-to-stand time for 85 cm handrail height on modern toilet

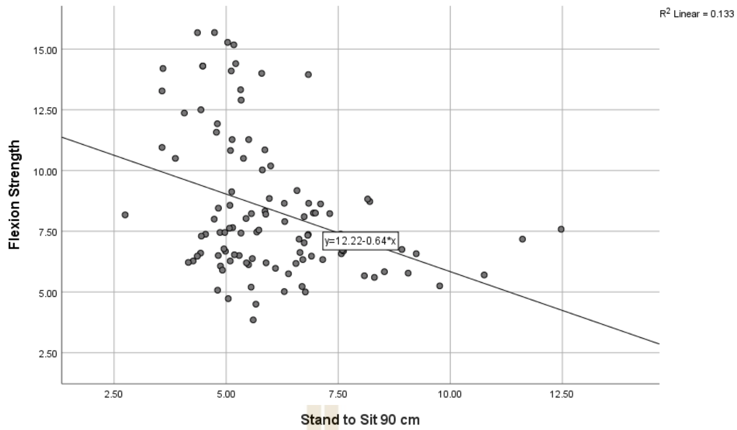

Figure C. 19 Correlation between extension lower limb strength and sit-to-stand time for 80 cm handrail height on modern toilet

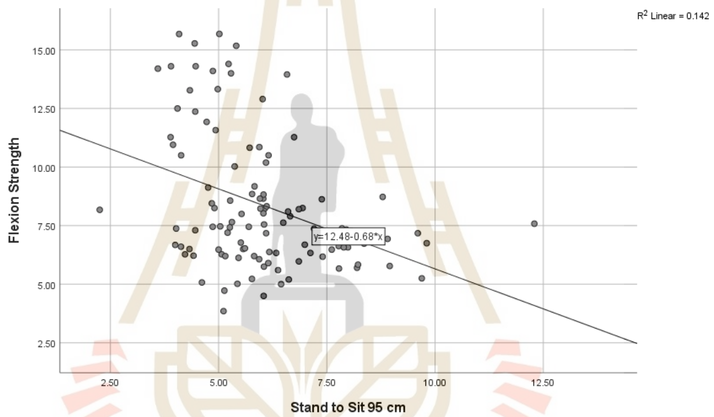

Figure C. 20 Correlation between extension lower limb strength and sit-to-stand time for 95 cm handrail height on modern toilet

APPENDIX D

LIST OF PUBLICATIONS

Kurnia, R. D., Jongkol, P. (2023). Anthropometric Measurement of Thai Elderly in Northeastern Rural Area. *Suranaree Journal of Science of Technology, 30*(1):030094(1-9).

Kurnia, R. D., Jongkol, P. (2023). Sit-to-stand and Stand-to-sit Test in Toilet for Elderly in Rural Northeast Thailand and Its Correlation with Lower Limb Strength. *EAU Heritage Journal Science and Technology*, In Press.

ANTHROPOMETRIC MEASUREMENT OF THAI ELDERLY IN NORTHEASTERN RURAL AREA

Ratih Dianingtyas Kurnia and Pornsiri Jongkol*

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Abstract

Anthropometry takes part in making a difference in managing physical human needs including elderly needs in order to improve their quality of life. The objective of this study was to measure the body dimension of healthy Thai elderly living in rural areas and investigate the relationship among body dimensions. Questionnaire was given to the respondents in order to get their demographic data. Questionnaire and anthropometry measurements were taken on a total of 23 male elderly and 88 female elderly people from rural areas in Northeastern Thailand. Most respondents (49.5%) of the total elderly are in their 60s, 32.4% in their 70s, 17.2% in their 80s, and 1% in their 90s. 54.1% of them are still actively working and 96.4% of them are regularly doing body exercise in keeping their body fit and healthy. The body dimensions measured consist of 22 standing dimensions, 20 sitting dimensions, and 15 foot and hand dimensions. Positive correlations were found between some of the body dimensions. The developed anthropometric data is expected to overcome the information gap related to the dimensions of the body of the elderly and to assist the development of products and other supporting equipment to be anthropometrically compatible for elderly residents of rural areas in the future.

Keywords: **Anthropometry, body dimensions, elderly, rural area**

Introduction

The term "elderly" refers to persons above the age of 65, with "early elderly" referring to people aged 65 to 74 years, and "late elderly" referring to people aged 75 years or more (Orimo *et al.*, 2006). Elderly can be classified in a variety of ways, including physical appearance, major life experiences, and societal roles. Aging is an expected process that is commonly measured by chronological age and according to Kowal and Peachey (2001), most developing countries agree that old age begins at 60 or 65 years old.

Data from World Population Prospects: the 2017 revision (United Nation, 2017) showed that the number of those aged 60 years or over is expected to be more than twofold by 2050 and triple by 2100, where it rises from 962 million globally in 2017 to 2.1 billion in 2050, and 3.1 billion in 2100. Henry *et al.* (2001) in one of their studies stated that

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the number of elderly people in developing countries has quickly extended as a result of the increased access to health and public services. They also stated that the economic growth in Thailand also plays an important role in enhancing the living conditions and extended life potentials of the Thai elderly.

The percentage of people aged over 60 years old in Thailand is around 13 percent of the whole population (UNFPA Thailand, 2006). Elderly living in rural areas has the same concerns related to healthcare access as those living in urban area. However, they may also face challenges related to housing quality, availability of home-based services, and long-term care in their communities. Srithamrongsawat *et al.* (2009) stated that Thailand's elderly needs long-term care due to its rapidly aging population. Syafinas *et al.* (2018) explained that according to WHOQOL (1994), in tandem with the nation's transition to an aging population, the quality of life of the elderly must be examined and enhanced to a higher degree. In 2004, the WHOQOL working group established quality of life guidelines for individuals aged 60 and above, which were tested in several countries (Power *et al.*, 2005). Tiraphat *et al.* (2017) confirmed the importance of age-friendly communities in terms of physical and social environments for older people's quality of life. Therefore, elderly in Thailand also need to assess and improve their quality of life status as it can be one of the indicators of a healthy life where the elderly should be part of the social development resources in the society.

Physical environment can be improved by applying anthropometry and an ergonomic approach in designing facilities for elderly. Anthropometry has been extensively proposed in order to help manage and deal with physical human needs (Hartono, 2018). Anthropometry has an essential role in designing facilities and equipment as it must fit appropriate measures into product characteristics and designs. The appropriate design will utilize the anthropometric data in order to improve productivity and decrease work-related musculoskeletal disorders (Klamklay *et al.*, 2008; Chuan *et al.*, 2010). Humans are varied in dimensions and proportions and this variability needs to be understood and applied well in designing a product or facility (Pheasant and Haslegrave, 2005). Special populations such as children and elderly could have different anthropometric dimensions compared to adults, by taking size and ratio between measures into consideration (Hartono, 2018). Human characteristics variation is also related to ethnicity, gender, and age (Jurgens *et al.*, 1990) in (Abd Rahman *et al.*, 2018). Ethnic diversity is an important factor that influences anthropometric data as it is more prominent among races compared to nations (Abd Rahman *et al.*, 2018). Therefore, the body dimension of a population from one population, nationality, and ethnicity can be a lot more different from that of the others. The use of an appropriate anthropometric database is important to help adapt the facilities and equipment to a particular population group (Wickens *et al.*, 2004).

Knowing the body dimension of elderly in rural area can help design appropriate facilities such as handrail in washroom and toilet seat. Furthermore, this leads to improving safety in the daily activities of elderly in rural area. The objectives of this study were to: 1) measure body dimensions of Thai elderly living in rural area; and 2) investigate the relationship among body dimensions. The anthropometric data developed here was intended to address the lack of information related to the dimensions of the body of the elderly and to assist the development of products and other supporting equipment to be anthropometrically suitable for elderly residents of rural area in the future, such as the manufacture of elderly public facilities and nursing homes supporting tools.

Materials and Methods

Respondents

The respondents participating in this study were selected based on their willingness to respond and to be measured. All respondents were carefully selected corresponding to the intended main criteria which are elderly aged 60-90 years old from Northeastern Thailand. They were able to work and do activity independently. Each elderly was given informed consent which provided sufficient information about the research methodology, protocol, and compensation written in easily understood language. Elderly as research subject was given full right to make the decision in volunteering in this study after studying all aspects of the research and experiment.

A total of 111 elderly consisted of 23 male elderly and 88 female elderly people participated in this study and were measured using the standard body dimensions. All respondents were considered healthy and able to carry out daily activities including working by themselves without any help.

Anthropometric Measurements

Anthropometer was used in this study to measure the standing and sitting dimensions, with a caliper used for measuring the foot and hand dimensions. The measuring tape was used to measure some of body part's circumferences and diameters. Respondent's weight was measured by using a digital weighing scale. The respondents measured were wearing thin clothes and without shoes. The body dimensions measured consisted of 22 standing dimensions, 20 sitting dimensions, and 15 foot and hand dimensions. The measurement was done in 3 repetitive measurements in order to minimize the error value.

The procedure of measurements was explained in detail to the elderly. The respondents were required to keep proper natural posture throughout the measurement in order to get reliable measurement results. When measuring height, the respondents stood with their heels positioned parallelly side by side and vertically in line with their shoulder blades and buttocks. Recapitulation was made for measurement results before being calculated and transformed into a list of percentiles of body dimensions and was elaborated into the form of design.

Statistical Analysis

All experiment results were subjected to a strong statistical analysis that gave a generalization of the cases studied. Anthropometric data analysis helps determine the key anthropometric characteristics that were required to obtain other related anthropometric variables. The average value of each dimension was used in the final statistical measurements. Data were analyzed using statistical software. Statistics frequency was used to see the comparison between each demographic data. Percentiles and data normality was also calculated by using statistical software.

Results and Discussion

Demographic Data Results

The respondents of this study were 23 male elderly and 88 female elderly where 49.5% of the total elderly are in their 60s, 32.4% in their 70s, 17.2% in their 80s, and 0.9% in their 90s. Out of all the elderly, 0.9% of them needed handrail help in some of their activity such as standing up from sitting position, and 4.5% of them needed walk support occasionally, such as walking stick.

Nearly half of the respondents were still actively working. As shown in Figure 1, a total of 45.95% of elderly were not working while the rest of them were working. Furthermore, 11.71% of the total elderly worked as farmer, 27.93% elderlies worked as employer, 8.11% elderly were running business, and 6.30% of them had another job as their occupations.

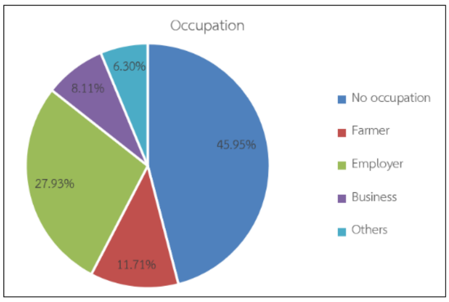

Figure 1. Percentage of subject's occupation

Figure 2 shows that most of the respondents did regular exercise in order to keep their body fit so that they were able to do daily activities and work independently. As seen in Figure 2, 96.40% of total respondents did regular exercise, where 38.74% respondents regularly did fast lane and biking exercise, 47.75% did only fast lane exercise, 4.50% did only biking exercise, 5.41% did yoga regularly, and 3.60% did not do regular exercise.

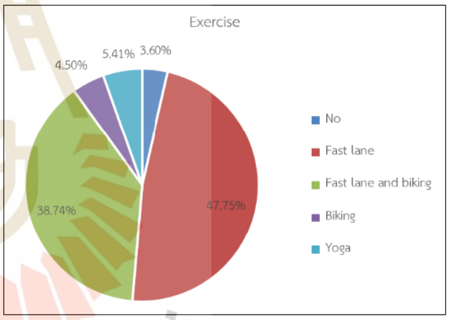

Figure 2. Percentage of subject's routine exercises

Anthropometry

The anthropometric data were analyzed in terms of descriptive statistics data such as mean, standard deviation (SD), 5th, 50th, and 95th percentile. The data obtained were used for designing workplaces, social care centers, as well as interior design. Based on the Kolmogorov-Smirnov normality test result, most body dimensions data had p-value larger than 0.05 which indicates that the data was distributed normally. The anthropometric descriptive statistic such as body dimensions, mean value, standard deviation, 5th percentile, 50th percentile, and 95th percentile of standing dimensions, sitting dimensions, and foot and hand dimensions are presented in Tables 1, 2, and 3, respectively.

Table 1. Descriptive statistics for measured standing dimensions

Male Elderly					
Body Dimension	**Mean**	**Std. Dev.**	**Percentiles 5**	**50**	**95**
Chest circumference	88.35	8.19	76.20	87.00	109.60
Under chest circumference	84.39	9.68	69.20	84.00	107.20
Waistline circumference	83.65	9.94	63.40	82.00	105.40
Abdomen circumference	90.17	9.02	77.20	91.00	109.80
Hip circumference	94.70	8.47	83.20	92.00	114.00
Thigh circumference	43.78	6.13	33.00	44.00	56.00
Upper arm circumference	46.91	5.86	39.20	46.00	61.60
Elbow circumference	26.33	2.62	21.20	26.00	31.60
Wrist	18.28	1.61	15.20	19.00	21.60
Chest breadth	27.77	2.35	23.52	27.80	32.93
Waist breadth	27.02	2.59	23.46	27.00	33.60
Abdominal breadth	28.53	3.40	22.20	28.70	35.46
Hip breadth	31.34	2.17	27.70	31.00	36.56
Thigh breadth	12.05	3.14	8.50	11.00	18.96
Body height	162.16	6.12	152.30	162.00	178.80
Eye height	149.89	5.55	140.16	148.50	162.82
Shoulder height	133.80	6.05	124.04	133.00	149.36
Back armpit height	117.69	5.17	110.46	116.90	132.11
Back waist height	103.54	12.44	90.64	101.40	146.50
Elbow bending height	96.53	7.33	73.62	98.23	108.50
Crotch height	69.52	6.17	56.22	70.60	83.40
Tibial height	44.03	3.60	36.88	43.70	49.78

Female Elderly					
Body Dimension	**Mean**	**Std. Dev.**	**Percentiles 5**	**50**	**95**
Chest circumference	93.16	8.85	80.00	92.50	104.58
Under chest circumference	87.23	8.53	72.75	88.00	100.55
Waistline circumference	88.06	9.37	70.45	90.00	103.55
Abdomen circumference	95.38	9.14	78.45	96.00	109.55
Hip circumference	100.82	8.37	87.90	100.50	115.55
Thigh circumference	44.10	5.58	34.00	44.00	53.42
Upper arm circumference	48.64	6.25	35.35	50.00	58.10

Female Elderly					
Body Dimension	**Mean**	**Std. Dev.**	**Percentiles 5**	**50**	**95**
Elbow circumference	26.13	3.38	21.00	26.00	30.79
Wrist	17.17	1.53	14.00	17.00	19.00
Chest breadth	26.80	2.57	22.39	27.00	30.83
Waist breadth	26.77	2.86	21.60	27.13	31.06
Abdominal breadth	30.17	2.73	25.93	30.15	35.22
Hip breadth	32.69	2.60	28.89	32.50	37.35
Thigh breadth	12.26	4.09	9.00	11.80	16.97
Body height	151.46	5.68	142.25	151.00	160.00
Eye height	139.81	5.53	132.00	139.25	148.46
Shoulder height	123.71	5.04	115.79	123.25	132.14
Back armpit height	108.11	5.52	97.91	108.23	117.07
Back waist height	95.37	5.16	85.14	95.60	103.87
Elbow bending height	90.77	6.42	82.00	91.20	99.44
Crotch height	66.61	4.64	58.25	66.65	73.40
Tibial height	41.66	3.90	35.65	41.25	48.11

Table 1 shows that body height of male elderly was 162.16±6.12 cm with the 5th percentile of 152.30 cm and 95th percentile of 178.80 cm. Meanwhile, female elderly's body height was 151.46±5.68 cm with 142.25 cm and 160.00 cm as the 5th and 95th percentile, respectively.

The value of sitting body height was 83.35±5.30 cm for male elderly and 77.67±4.33 cm for female elderly. The popliteal height value was 44.19±2.31 cm and 42.78±3.24 cm for male and female elderly, respectively. The hip breadth value for male elderly was 34.19±3.76 cm and 35.22±3.35 cm for female elderly. Males and females frequently differ in body size, form and structure. The results showed that most of male elderly's body dimensions has greater value than female elderly except for some body dimensions, such as chest circumference, thigh circumference, abdominal breadth, and hip breadth. Chest circumference showed a value of 88.35±8.19 cm for male elderly and 93.16±8.85 cm for female elderly. Thigh circumference, abdominal breadth, and hip breadth of male elderly were 43.78±6.13 cm, 28.53±3.40 cm, and 31.34±2.17 cm, respectively. Meanwhile the value of female elderly's was 44.10±5.58 cm for thigh circumference, 30.17±2.73 cm for abdominal breadth, and 32.69±2.60 cm for hip breadth. The rest of the measurement details for each dimension can be seen on Table 1 for standing dimensions, table 2 for sitting dimensions, and Table 3 for foot and hand dimensions.

Table 2. Descriptive statistics for measured sitting dimensions

Male Elderly					
Body Dimension	Mean	**Std. Dev.**	**Percentiles 5**	**50**	**95**
Sitting body height	83.35	5.30	71.12	84.00	92.96
Sitting eye height	72.13	4.46	63.40	73.00	79.00
Sitting cervicale height	59.65	3.68	52.33	60.00	64.48
Sitting shoulder height	54.75	3.81	46.66	55.17	59.52
Sitting waist height	27.68	3.28	23.04	27.70	36.20
Sitting bending elbow height	20.16	3.51	12.50	20.60	25.70
Popliteal height	44.19	2.31	39.72	43.80	48.38
Upper part knee length (sitting)	50.63	2.84	46.03	51.00	56.92
Knee height (sitting)	51.80	3.36	45.50	50.50	55.04
Shoulder biacromical breadth	31.90	2.24	28.20	31.50	35.32
Shoulder bideltoid breadth	41.36	2.74	35.56	41.50	47.76
Elbow to elbow extension breadth	82.05	5.68	73.40	82.50	91.20

Male Elderly					
Body Dimension	**Mean**	**Std. Dev.**	**Percentiles 5**	**50**	**95**
Elbow to elbow breadth	42.60	6.72	28.60	42.50	57.40
Hip breadth	34.19	3.76	29.20	33.40	44.60
Elbow to center of fist length	34.42	1.65	31.60	34.30	37.84
Elbow to fingertip length	46.24	2.29	43.17	45.73	51.72
Abdomen to knee length	35.53	3.29	30.60	35.53	43.27
Buttocks to knee contact length	54.54	3.47	49.20	54.00	62.76
Bottom to popliteal length	44.22	2.49	41.06	43.80	49.86
Bottom to upper calf	44.21	2.55	40.06	44.20	50.30

Female Elderly					
Body Dimension	Mean	Std. Dev.	Percentiles 5	50	95
Sitting body height	77.67	4.33	70.45	78.00	84.78
Sitting eye height	66.86	4.20	60.56	67.20	73.70
Sitting cervicale height	54.97	3.87	49.25	55.10	61.28
Sitting shoulder height	50.50	3.33	45.20	51.00	55.55
Sitting waist height	25.00	3.68	19.26	24.83	32.94
Sitting bending elbow height	18.31	3.38	11.89	18.67	23.11
Popliteal height	42.78	3.24	40.75	42.60	44.20
Upper part knee length (sitting)	47.75	2.80	43.33	47.95	52.78
Knee height (sitting)	49.48	2.08	45.88	49.50	52.50
Shoulder biacromical breadth	29.58	2.43	25.55	29.60	34.19
Shoulder bideltoid breadth	37.89	2.46	34.00	37.95	41.91
Elbow to elbow extension breadth	75.77	6.04	65.96	76.50	83.56
Elbow to elbow breadth	42.30	4.24	35.89	42.00	49.90
Hip breadth	35.22	3.35	29.89	34.90	40.44
Elbow to center of fist length	32.09	1.99	29.00	31.90	35.57
Elbow to fingertip length	42.85	2.26	39.64	42.70	46.67
Abdomen to knee length	30.29	4.27	24.18	29.95	36.55
Bottom to knee contact length	51.83	3.86	46.31	51.90	57.08
Bottom to popliteal length	43.02	3.26	38.38	42.75	48.64
Bottom to upper calf	42.79	3.46	37.07	42.85	47.35

Table 3. Descriptive statistics for measured foot and hand dimensions

Male Elderly					
Body Dimension	Mean	Std. Dev.	Percentiles 5	50	95
Front foot width	11.08	1.30	9.06	10.90	13.64
Heel width	7.09	0.88	5.84	7.00	9.00
Maximum foot length	24.99	1.64	21.97	25.00	28.80
Maximum palm length	21.96	1.49	19.20	22.00	24.80
Thumb length	6.50	0.51	5.69	6.40	7.90
Index finger length	7.08	0.38	6.42	7.00	7.76
Middle finger length	7.72	0.43	7.04	7.70	8.86
Ring finger length	7.32	0.47	6.70	7.27	8.74
Little finger length	5.81	0.47	4.80	5.90	6.43
Tip of the finger-center of hand palm	18.17	0.74	16.84	18.27	19.30
Palm length	10.84	1.53	9.65	10.50	16.27
Tip of the index finger – base of the thumb	11.33	0.64	9.80	11.40	12.18
Palm width	8.48	0.45	7.75	8.50	9.28
Hand width	11.24	1.47	8.93	11.00	13.50
Largest grip diameter	6.61	1.01	4.10	7.00	8.08

Female Elderly					
Body Dimension	Mean	Std. Dev.	Percentiles 5	50	95
Front foot width	10.02	1.06	8.38	10.00	11.60
Heel width	6.63	1.24	5.35	6.30	9.28
Maximum foot length	23.01	1.46	20.35	23.00	25.26
Maximum palm length	19.58	1.14	18.00	20.00	21.55
Thumb length	6.01	0.67	5.20	5.90	6.96
Index finger length	6.75	0.46	6.00	6.75	7.70
Middle finger length	7.27	0.45	6.51	7.27	8.00
Ring finger length	6.77	0.46	6.00	6.78	7.60
Little finger length	5.43	0.38	4.80	5.50	6.00
Tip of the finger-center of hand palm	17.01	1.13	14.78	17.00	18.72
Palm length	9.99	1.05	8.50	10.00	11.14
Tip of the index finger - base of the thumb	10.36	0.86	8.50	10.40	11.84
Palm width	7.71	0.75	6.95	7.58	9.08
Hand width	9.68	1.08	8.18	9.52	11.67
Largest grip diameter	6.14	0.82	4.61	6.13	7.46

Correlation Among Body Dimensions

The correlation coefficients between body dimensions were calculated to explore whether these dimensions are correlated with each other. Table 4 shows the body dimensions showing correlation. The strongest correlation value was found between shoulder height and body height (0.933). Most correlation coefficient values which are greater than 0.194 showed that there is positive correlation between some body dimensions, where the correlation is significant at 0.05 level. The positive value on significantly correlated body dimensions indicates that the value of one body dimension will increase as the other body dimension increases. The greater the value of correlation coefficient, the stronger the correlation between body dimensions is. A correlation coefficient values are classified into very weak, weak, moderate, strong, and very strong correlation if the value is of 0.00-0.19, 0.20-0.29, 0.40-0.59, 0.60-0.79, and 0.80-1.00, respectively (Evans, 1996). Based on correlation calculation result, elderly's body height and shoulder height were significantly correlated with almost all measured body dimensions except for chest circumference and abdominal breadth.

Comparison with Data from Other Countries

This study presents comparison of anthropometry data of elderly between few countries. The results of anthropometry statistical analysis showed that there is difference but also similarity in body dimensions among these elderly population, especially in South East region. Table 5 shows the mean and standard deviation for present

Table 4. Correlation coefficients between each body dimensions and standing body dimension

	Chest Circ.	Thigh Circ.	Chest breadth	Abdominal breadth	Body height	Shoulder height	Sitting body height	Popliteal height	Hip breadth	Buttocks to popliteal length	Front foot width	Max. foot length	Palm length	Palm width	Largest grip diameter
Chest Circumference	1														
Thigh Circumference	.562**	1													
Chest breadth	.710**	.515**	1												
Abdominal breadth	.740**	.499**	.529**	1											
Body height	0.069	.219*	.288**	0.035	1										
Shoulder height	-0.008	0.131	.231*	0.009	.933**	1									
Sitting body height	0.088	.279**	.336**	-0.027	.689**	.640**	1								
Popliteal height	0.125	.302**	.226*	0.135	.473**	.426**	.375**	1							
Hip breadth	.676**	.633**	.601**	.665**	.289**	.217*	.223*	.329**	1						
Buttocks to popliteal length	0.065	0.011	-0.093	0.088	.317**	.311**	0.094	0.056	0.084	1					
Front foot width	0.080	0.150	0.115	0.020	.363**	.304**	.342**	0.179	0.186	0.157	1				
Maximum foot length	0.100	0.088	.199*	0.092	.614**	.614**	.327**	.267**	.239*	.288**	.266**	1			
Palm length	0.065	0.184	.286**	0.159	.285**	.308**	.223*	0.034	0.178	0.071	0.081	.253**	1		
Palm width	0.106	.222*	0.174	0.043	.435**	.452**	.397**	0.149	0.164	.195*	.240*	.257**	.250**	1	
Largest grip diameter	-0.002	-0.083	-0.070	-0.049	.260**	.252**	0.076	0.069	0.002	.267**	0.103	.194*	-0.142	.214*	1

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

study, Australian (Kothiyal and Tettey, 2001), Indonesian (Rahmawati *et al.*, 2020), Singaporean (Lee *et al.*, 2019), Malaysian (Rosnah *et al*, 2009), and Thai (Jarutat *et al.*, 2005). A comparison between the results of this study and previous study conducted by Jarutat *et al.* (2005) is also needed to see the difference between body dimensions of Thai elderly in urban area and rural area. The data set in this study does not correspond completely with those studies, therefore some of the body dimensions are removed.

A total of 15 body dimensions were summarized for the comparison between data from present study and other studies. The result on Table 5 indicates that Australian presented the greatest stature, eye height, knee height, and sitting eye height compared to those from other countries. These results also suggest that there are various body dimension differences among elderly from Asian countries. The data in present study shows that Thai elderly have greater popliteal height, hand length, and foot breadth amounted to 44.2±2.31 cm, 21.9±1.49 cm, and 11.1±1.29 cm, respectively. There were also smaller value of buttock-knee length and buttock-popliteal length compared to the other countries. The buttock to knee length of Thai elderly in present study was 54.5±3.47 cm, which was almost the same value as Australian elderly (54.9±3.8 cm) and Malaysian elderly (53.7±3.6 cm), however had smaller length compared to Singaporean elderly with the length of 57.1±1.5 cm. The obvious differences between body dimension of Thai elderly in rural area in this study and those living in urban area from previous study can be seen at the knee height and popliteal height. Present study showed that the knee height and popliteal height of elderly in rural area (51.8±3.36 cm and 44.2±2.31 cm) were greater than Thai elderly in urban area which was 47.8 cm and 40.1 cm for knee height and popliteal height, respectively.

Anthropometry Applications in Engineering Design

A design solution is created by considering the ergonomics aspect to minimize accidents and provide a safe and comfortable environment. Architects and interior designers have a social obligation to adapt and change the environment to make it more accessible to the elderly (Kurnia, 2014).

The anthropometric data is required in order to design product or facility which is specially designed for elderly. It can provide more comfort so the tools and facilities are more user friendly, and this can lead to more productivity and less stress (Lee *et al.*, 2019). The toilet design was developed

Table 5. Comparison of elderly body dimensions in different populations

Body dimensions	Mean (SD)					
	Present study	Australian[a] (2001)	Indonesian[b] (2020)	Singaporean[c] (2019)	Malaysian[d] (2009)	Thai[e] (2005)
Body height	162.2(6.12)	165.8(7.9)	156.1(7.3)	163.5(4.9)**	162.3(7.5)**	161.4
Eye height	149.9(5.55)	153.2(7.0)	143.3(7.02)	152.4(4.9)**	149.9(6.1)**	149.9
Elbow height	96.5(7.33)	104.3(5.0)	98.5(4.65)	106.0(4.8)**	97.1(5.8)**	98.9
Bideltoid breadth	41.4(2.74)	-	39.4(2.42)	42.1(1.9)**		43.4
Forearm (upper arm) hand length	46.9(5.86)	-	-	-	45.5(2.0)**	-
Hand length	21.9(1.49)	18.4(1.0)	-	18.1(0.7)**	17.8(1.2)**	-
Sitting body height	83.4(5.3)	84.3(5.6)	-	83.2(2.0)**	83.1(4.3)**	82.9
Sitting eye height	72.1(4.46)	72.9(4.6)	107.5(8.11)	72.1(2.4)**	71.6(5.6)**	73.4
Popliteal height	44.2(2.31)	41.6(2.5)	42.9(3.08)	39.4(1.7)**	39.6(2.4)**	40.1
Knee height	51.8(3.36)	51.5(3.1)	-	47.5(1.7)*	49.8(2.9)**	47.8
Bottom – knee length	54.5(3.47)	54.9(3.8)	-	57.1(1.5)**	53.7(3.6)*	-
Bottom – popliteal length	44.2(2.49)	45.2(3.8)	42.3(4.73)	46.2(1.3)**	45.5(2.7)**	-
Sitting hip breadth	31.3(2.17)	33.6(2.8)	34.7(3.61)	30.0(1.6)	35.0(3.5)**	35.4
Foot length	24.9(1.64)	-	-	26.1(1.0)**	24.6(1.1)**	-
Foot breadth	11.1(1.29)	-	-	10.0(0.6)*	10.2(0.7)**	-

by adjusting the proportion of body dimensions with the results of anthropometric measurements of the elderly. Designing products with proper body dimensions will help elderly people work or move comfortably and independently. The application is shown as follows.

Toilet Seat

The dimension used in the toilet seat height is 5th percentile of female popliteal height dimension in order to get most elderly population to use it conveniently. Seat heights that are excessively high (more than 120% of lower leg length) or too low (less than 80% of lower leg strength) can create instability in seating during toilet activity and might obstruct safe transfer and result in falls (Capezuti *et al.*, 2008). From this study, the 95th percentile of male hip breadth in sitting position is 44.60 cm. This value is used to set the width of toilet seat.

As for the toilet seat depth, 5th percentile of female bottom - popliteal length with the value of 38.38 cm is used. The 5th percentile of female popliteal height with the value of 40.75 cm is used for the toilet seat height. However, to be practical for the manufacturer, the value of 40.00 cm, 45.00 cm, and 40.00 cm, can be used for toilet seat width, toilet seat depth, and toilet seat height respectively. Figure 3 presents the application of anthropometry in the design of a toilet seat for the elderly.

Toilet Handrail

Some elderly might still have strength in their muscle. However, elderly will experience a decline in independence and quality of life, so as their ability to walk independently. Handrail will help support them as it bears the weight of the elderly and helps stabilize their grip in walking, bending, or rising. The height of the handrail must be comfortable for the elderly to easily reach from sitting and standing positions. The body dimensions used in designing the handrail are 82.00 cm from the 5th percentile of female elbow height for handrail height, and 4.61 cm from the 5th percentile of female grip diameter for handrail diameter. In order to make it feasible for the manufacturer, the value is adjusted to 85 cm for handrail height and 5 cm for handrail diameter. Figure 4 shows the application of anthropometry dimensions to the elderly toilet handrail design.

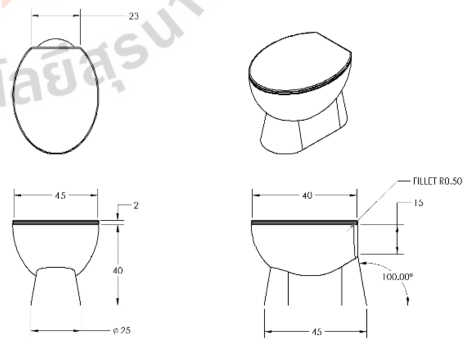

Figure 3. Anthropometry applications on the design of toilet seat

Grab Bar

Elderly are more vulnerable and some of them have difficulty keeping their balance right. Grab bar is a supporting tool to help elderly maintain their balance to prevent falls or slip accidents. For determining the effective grab bar dimensions, 85.00 cm from the 5th percentile of female standing elbow height for the grab bar minimum height and 4.61 cm from the 5th percentile of female largest grip diameter for the bar diameter are to be considered. The female hand dimension is used to design to make sure both genders can have a full grasp on the grab bar in order to get more strength to move. If the diameter is too big in size, the lower population might find it difficult to grasp the bar properly. To be practical for the manufacturer, the value of 90 cm can be used for grab bar height and 5 cm for bar diameter. The anthropometry applications in the design of grab bar for elderly is shown in Figure 5.

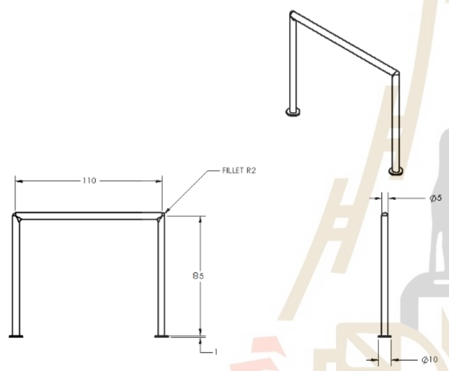

Figure 4. Toilet handrail for elderly

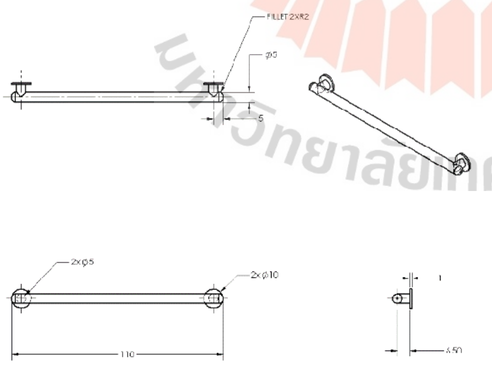

Figure 5. Grab bar for walking support

Conclusions

The conclusions from this study are as follows:

1. A total of 57 body dimensions of Thai elderly consisted of 22 standing dimensions, 20 sitting dimensions, and 15 foot and hand dimensions were measured.
2. The important body dimensions to design elderly's facilities are sitting body height, popliteal height, hip breadth, and buttock to popliteal height for toilet design, also elbow height and grip diameter for handrail design.
3. The relationship among body dimensions showed that elderly's body height and shoulder height were strongly correlated with nearly all measured body measurements except chest circumference and abdomen breadth, according to the correlation calculation results.
4. The anthropometry data of Thai elderly from this study was resulting in a similar result to the previous study conducted by Jarurat *et al.* (2005).

A wider data collection will be necessary as it can be more representative for a bigger population. It is also highly recommended to conduct similar studies in other states or regions of the country so that more databases of anthropometric measurements can be obtained. These anthropometric databases will help to assist product designers in developing and finding the proper user characteristics in the products needed by the elderly in the future.

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