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I, Pantawat Tongrod, hereby submit this original work as part of the requirements for the degree of Master of Design in Design.

It is entitled:

LOWER BODY STRENGTH TRAINING EQUIPMENT DESIGN STUDY FOR OLDER ADULTS TO COMBAT MUSCLE WEAKNESS

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Lower Body Strength Training Equipment Design Study for Older Adults to Combat Muscle Weakness

A thesis submitted to the Graduate College

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College of Design, Architecture, Art and Planning by

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ABSTRACT

The older adult age group is a significant and growing population. After 60, older adults experience up to 3% decrease in muscle mass a year. This reduces their mobility and activity to exercise and often leads to loss of independence. Additionally, there are not many in-home exercise solutions for older adults to combat muscle weakness in the current market. Therefore, it is essential to explore these challenges and find an in-home exercise solution for older adults to combat muscle weakness, especially for those who are losing their independence.

Literature reviews, market research, a survey of older adults, and interviews with geriatric physicians and personal trainers are conducted to establish an informed approach to designing lower body exercise equipment to combat muscle weakness and improve mobility. As older adults are an extensive age range, an exploration into mobility evaluation tools is conducted. A mobility level map is developed from a combination of Gross Motor Function Classification System (GMFCS) and Walking Speed Test to further pinpoint the target group's motor skills and used as design criteria.

Research results suggested that squats are one of the best lower body exercises that older adults can do to improve lower body strength and balance. Additionally, it is found that health, growth, and social connection are the primary motivations in the life of older adults. These indicate a need for a design solution composed of an in-house equipment for exercise and an app for motivating users. These were developed through three design phases. After each phase, a design review surveys with older adults and design review interviews with experts are conducted to collect feedback and suggestions for the following development.

At the end of the development process, it is found that the function and design of the machine are in the right direction, but further testing and development are needed. Additionally, market positioning research should be conducted to designate the product's price point. As a result, a 3-year development timeline for the machine is developed as a guideline for future development and research.

In conclusion, it has been found that knowledge from experts is crucial to facilitating the informed development of specialized equipment, especially for design review. Secondly, mobility evaluation tools can pinpoint target groups with a wide range of mobility. It is found to be useful for both identifying the motor skills of the target group and as a design review tool for concept sketches. Lastly, the ergonomic map created from anthropometric data is crucial in the early development of exercise equipment. However, further ergonomic testing with the physical prototype is still required for further machine development.

Keywords: Older adults, Strength Training Exercise, Accessibility, Exercise Equipment, Mobility

CONTENT

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1. HISTORY

Research interest in this topic stems from personal experience with an older adult who experienced rapid muscle mass decline due to medical issues. Figure 1.1 illustrates the mobility journey that this older adult has experienced.

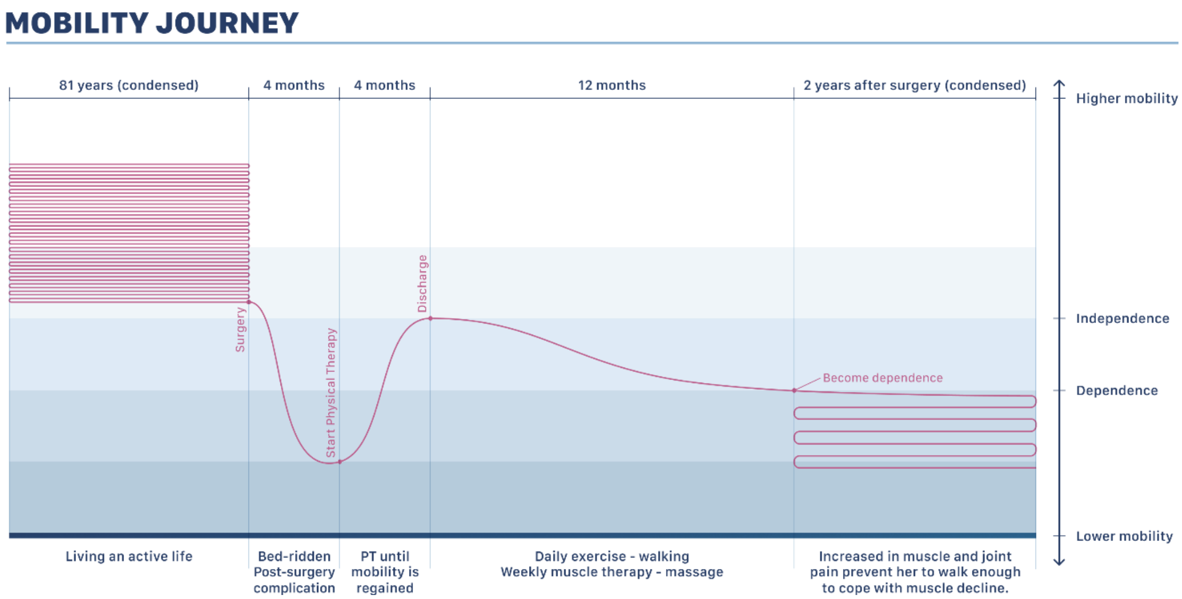

Figure 1.1 - Mobility Journey

This older adult maintained an active and healthy lifestyle well into her early eighties, relying on physically demanding work to stay strong and vital. While she didn't participate in formal exercise or sports, her daily activities provided valuable fitness benefits. Unfortunately, at the age of eighty-two, she received a hernia diagnosis and underwent surgery. The procedure was a success, and her loved ones expected a speedy recovery based on medical advice. Although her initial progress was encouraging, minor complications arose soon after the surgery, extending her hospital stay and bed rest period. This, in turn, led to a further decline in muscle mass. Following the surgery, she underwent four months of physical therapy, eventually regaining the ability to walk. Upon discharge, her doctor advised daily exercise to maintain muscle strength and independence.

Upon returning home, she struggled to resume her work routine and was unfamiliar with any exercise methods. Daily walking became her sole option for exercise. While she was initially hopeful about maintaining her mobility, her motivation dwindled due to various challenges such as pain, lack of progress, and an unengaging exercise regimen. As a result, her exercise habits declined, leading to a continuous deterioration of her muscle mass. This decline ultimately resulted in a loss of independence, forcing her to hire a caregiver to assist with daily activities. This study aims to address this avoidable decline in muscle mass and mobility.

2. INTRODUCTION

2.1 PROJECT PROCESS OVERVIEW

The project was conducted in two phases: (1) Research process and (2) Design process. Figure 2.1 summarizes the project timeline.

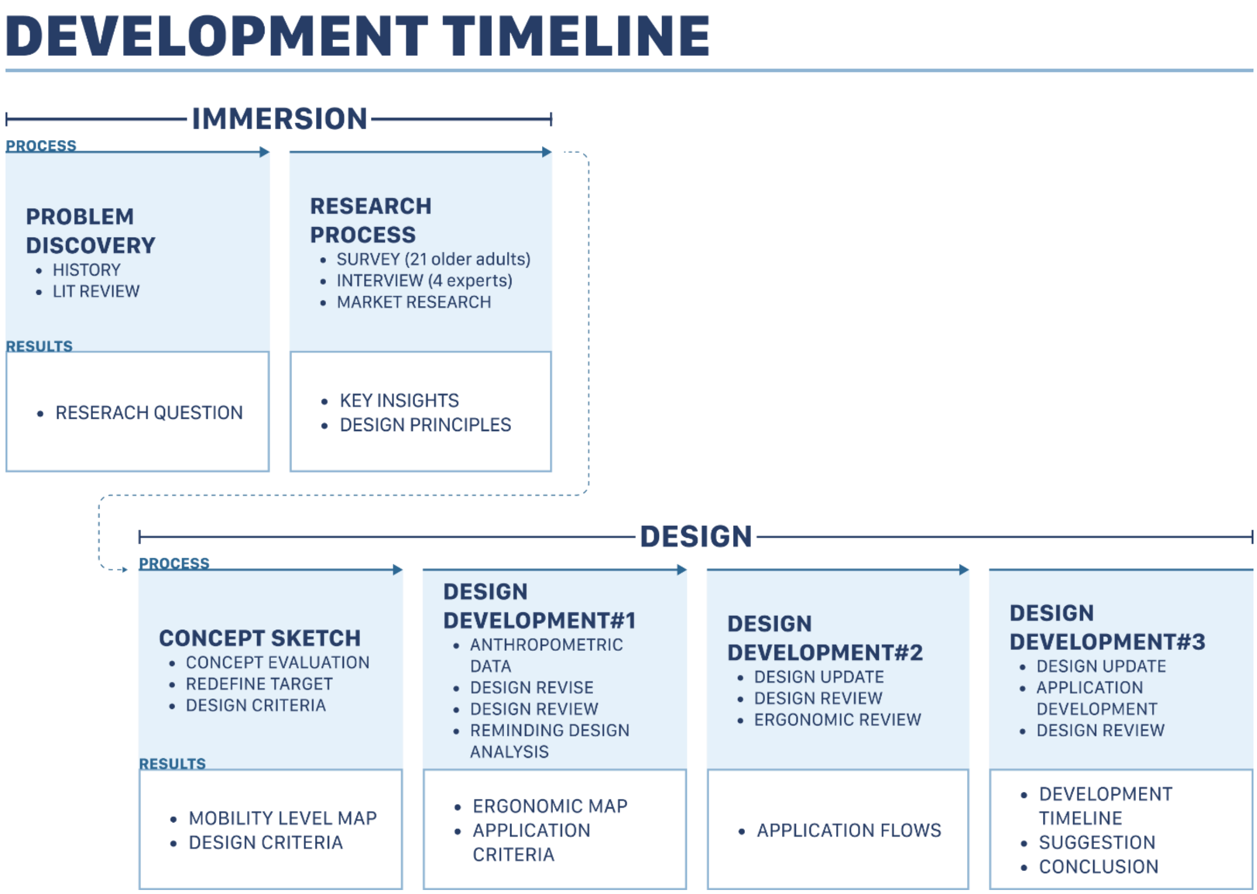

Figure 2.1 - Development Timeline

The process of research involved gathering data and developing an initial approach to concept development. It began with exploring the topic of older adults and continued with a literature review on the challenges related to muscle weakness. It was found that muscle weakness is a common issue that occurs after the age of 50 (Von Haehling et al., 2010), and strength training exercises can be the best solution to tackle it (Latham & Liu, 2010). Furthermore, mobility is crucial for older adults to maintain an active lifestyle and continue exercising. As a result, the focus was aimed toward lower body muscles needed to generate movement and maintain a balanced upright position, which is vital for older adults' ability to exercise and maintain independence (Rantanen, 2013).

The acquired knowledge served as the basis for developing survey and interview questions for older adults and experts. The survey gave valuable insights regarding the respondents' current exercise routines, exercise preferences, and the factors motivating them to stay active. It was revealed that a majority of older adults are struggling with muscle weakness, which is significantly impacting their everyday lives. The survey findings also indicated that their primary reasons for exercising are to maintain a healthy lifestyle, to experience progress or growth, and to foster social connections. Interestingly, the last two motivations highlighted the need for digital integration in the exercise design.

Through interviews with personal trainers and geriatric physicians, valuable insights on solutions to combat muscle weakness in older adults are gathered. Firstly, three previously highlighted motivations were crucial for older adults to remain engaged in physical activity. Secondly, strength-based exercises were confirmed as a significant medical treatment for muscle decline. Additionally, the interviewees recommended squats as an excellent lower-body strength exercise for improving mobility. These insights were synthesized into design principles, which served as a guideline for developing initial design concepts. Furthermore, geriatric physicians suggested exploring mobility evaluation tools used in the medical field to better understand the target group's needs.

The process of designing the equipment begins with an exploration of two mobility evaluation tools: (1) The Gross Motor Function Classification System and (2) the 10 Meter Walk Speed Test. The conjunction is found between the two evaluation tools. This finding led to the creation of the Mobility Level Map through the combination of both tools. The Mobility Level Map categorizes older adults into five primary mobility levels, with mobility level 2 having three sub-levels (mobility level 2.1, 2.2, and 2.3). The research focuses on mobility level 2 as it coincides with the interdependency stage, which is the focus of this research.

After the target group is clarified, 34 concepts aimed for mobility level 2 are developed. From these concepts, 17 are selected as the most relevant design principles and are reviewed by geriatric physicians. During the review, each concept is explained to the experts, who then identify the mobility level for which each concept is most suitable. The knowledge and feedback gathered from this activity are used to develop a design criterion that guides further design development.

The design development process consists of three rounds, each followed by a design review survey and interviews. The feedback gathered from these surveys and interviews is then used as a guide for the subsequent round of development. While the development of the machine and digital integration are carried out in parallel, the primary focus remains on the physical machine, with digital integration playing a secondary role. The most recent design review resulted in a summary of the development process and the conclusion of the design, as well as the establishment of the next steps in the development timeline. This timeline was created by the lead designer, drawing on the expertise of researchers in the product development field and other professionals such as engineers, legal experts, and marketing specialists.

2.2 LITERARURE REVIEW

The term "older adult" refers to individuals over 65, encompassing a wide range of people with varying mobility and cognitive abilities. Due to medical advancements, many more people now live beyond 65 years of age, making this age group limitless and resulting in an ever-increasing population within this age group. Developed countries, such as Japan, have the largest population of older adults, with 30.2% of the population being over 65, according to Richter (2024). These percentages may seem small, but they translate to a significant portion of the population in raw numbers. As for the US, the percentage of the aging population is projected to reach 20% or around 18 million by 2030, according to the University of Minnesota Rural Health Research Center & NORC Walsh Center for Rural Health Analysis (2019).

Sarcopenia, or muscle decline with age, is expected in the older population and is one of the main conditions affecting their mobility (Walston, 2012). Physiologically, muscle mass and strength are lost as age increases. Observational studies by Seguin (2003) indicate that approximately 1% of muscle mass is lost yearly after the fourth decade of life. The study conducted by Fragala et al., (2019) found that “muscle mass decreases by 1.0–1.4% per year in the lower limbs” (p. 2020). One of the critical reasons for muscle decline is metabolic changes in muscle, which contribute to the reduction in the overall physical fitness capacity of older adults and are an essential component of the decrease of around 30% in the ability to utilize oxygen during exercise. With less oxygen moving to the muscle, less force can be expected (Volpi et al., 2004).

Sarcopenia leads to many risks in older adults. The most substantial risk is decreased physical function, leading to increased falls and fall-related injuries, requiring costly hospitalization and extended rehabilitation (Chang et al., 2021). Reduced physical activity can lead to obesity, lower quality of life, osteoporosis, and metabolic health issues, as it restricts movement and social contact. (Hunter et al., 2019). A study by Billot et al. (2020) stated that "while 85% of people at the age of 60 years have a normal gait, this proportion drops to 18% in people aged 85 years" (p. 1680).

A decrease in muscle strength makes it harder for older adults to move and conduct various activities, hence reducing mobility, one of the most necessary components in their lives. Reduced mobility prevents older adults from accessing commodities, public facilities, and social activities (Rantanen, 2013). Additionally, older adults with reduced mobility exercise less, which leads to an increased rate of muscle decline and, eventually, loss of mobility and forced to become dependent (Rantanen, 2013). Muscle decline also prevents older adults from quickly regaining mobility. Due to this, only half of disabled older adults regain independence (Hardy & Gill, 2005).

Decreased mobility leads to more challenges, such as difficulty maintaining social connections. According to research by the World Health Organization (2023), older adults are more vulnerable to social isolation than the rest of the population, mainly due to reduced mobility. Shrinkage of their social network through many reasons that come with age, such as bereavement and relocation, also affected their social spheres. Older adults who are socially isolated are less likely to exercise and be more depressed. They are also observed to be more likely to be "disabled, be in poorer health, and report lower levels of well-being than those who are socially connected" (Zaine et. al., 2019, p. 2).

Research conducted by Steptoe et al. (2015) and Blythe et al. (2015) also supports that social interaction is significant in enticing an active lifestyle and is directly related to the well-being of older adults. A lack of social connection can lead to a decrease in physical activity and, in turn, makes the population even less active (Zaine et al., 2019). Similarly, the same research found that social interaction plays a significant role in enticing an active lifestyle and is directly related to the well-being of older adults. The study also suggested that a lack of social connection can decrease physical activity and, in turn, make the population even less active. Research by Schutter & Vandenabeele (2008) also suggested that seniors are motivated to participate more in activities with a purpose or value, meaning there should be some educational or cultural benefit from the activity. Cultivating oneself or others was highly valued. Therefore, it is essential to not only provide a solution to combat muscle weakness, but the solution must empower older adults to be socially connected and motivated to exercise.

According to research by Yuan and Larsson (2023), sarcopenia is estimated to influence 10%–16% of older adults worldwide. Additionally, patients had a higher rate of diagnosed sarcopenia than the overall population (Yuan & Larsson, 2023). A study of medical records of 552 participants with a mean age of 74.6 ± 6.7 years found that sarcopenia, including severe sarcopenia, was detected in 22.3% of all participants, 17.3% of men, and 24.5% of women, with the rates increased with the age of participants (Kurose et al., 2020). According to the same study, sarcopenia does not only affect muscle mass but also muscle composition, contractile and material properties of muscle, and function of tendon. These effects do not lead to a net loss in body weight but to a significant reduction in muscle strength. This means that sarcopenia is often not observable and hard to identify (Kurose et al., 2020).

Treatment of sarcopenia is challenging due to various issues, such as the symptoms being hard to identify; many different approaches have been pursued. Nutrition and exercise programs are the best combination to managing sarcopenia and combat frailty (Billot et al., 2020). Additionally, a study by Von Haehling et al. (2010) suggested that exercise and physical activity are the primary approaches for treatment and prevention. Physical activity can improve muscle strength, which improves mobility, which in turn decreases the fall risk. Research from Chang et al. (2021) also provides evidence that regular physical activity sustains mobility and prevents falls. Additionally, physical activity is significant for health and longevity.

Strength training exercises (structured resistance training, targeted exercise, weightlifting, or progressive resistance training) are founded to reduce significant loss and long-term loss of mobility. It can substantially combat sarcopenia (Billot et al., 2020). Research from Fragala et al. (2019) states that various forms of strength training can improve muscle strength, muscle mass, and power output. Additionally, strength training is observed to enhance balance and preserve bone density, independence, and vitality (Latham & Liu, 2010). Researchers also believe that routine practice of strength training can “reduce the risk of numerous chronic diseases, such as heart disease, arthritis, type 2 diabetes, and osteoporosis while improving psychological and cognitive benefits” (Fragala et al., 2019, p. 2021).

According to Rodrigues et al. (2022), regularly performed strength training programs at adequate intensity and volume lead to favorable neuromuscular adaptations in both healthy older adults and those with chronic conditions. The study suggested that an adequate routine for a resistant exercise training program is 2–3 days per week with an adequate volume of 2-3 sets per exercise and adequate intensity of 70-85% of 1 Repetition Maximum. In this case, the term Repetition Maximum is a unit used to determine the intensity of exercise, which refers to the maximum number of repetitions a person can do at a specific intensity. For example, if a person can squat without additional weight ten times, that person's Repetition Maximum is 10. Various studies also provide similar conclusions regarding frequency, intensity, and volume.

Despite medical awareness of the benefits of physical activity and the potential detriments of a sedentary lifestyle, the activity level of the U.S. population needs to be increased (Fragala et al., 2019). According to a study by Seguin (2003), “Participation rates become even more dismal when you look at the number of older adults who perform any strength-training exercises on a regular basis. Current data indicate that less than 10% of the older population participates in regular strength training” (p. 148). Therefore, studying, developing understanding, and creating design guidelines for solutions to combat muscle weakness in older adults is essential.

3. METHOD USED DURING RESEARCH PHASE

3.1 SURVEY

A survey has been designed to gain insight into the daily lives of older adults, including their exercise routines, preferences, equipment usage, and motivations (see APPENDIX B). This survey has been distributed through electronic newsletters from reputable organizations such as OLLI (Osher Lifelong Learning Institute), The Yoga Groove, and Parkinson Community Fitness. It comprises thirty-nine questions that mix binary, multiple-choice, and open-ended formats.

Twenty-one responses were gathered, representing respondents aged between 60 and 86, with an average age of 72 and a median age of 75. Twelve of the respondents were female, while nine were male. Two of the respondents are not exercising and are excluded from exercise questions.

3.2 EXPERT INTERVIEWS

Semi-structured interviews with four experts are conducted. The interviews consist of twenty open-ended questions. The questions are organized into four sections: (1) Personal information, (2) Exercise in older adults, (3) Resistant Exercise Training, and (4) Motivation to exercise in older adults (see APPENDIX C).

For medical experts, two geriatric physicians were interviewed. Both are practitioners from Veteran Hospital, and most patients are older adults. One expert is a resident doctor; the other is a lead physical therapist from the same hospital. The interviews focused on medical information relating to the impact of resistance training in older adults and best practices in conducting resistance training. The interviews take around 60 minutes. At the end of the interviews, the experts were asked to participate further in the research as expert advisors, and both agreed.

For trainer experts, two personal trainers that offer older adults tailored exercise programs were interviewed. The interviews focused on general knowledge about resistance training, general exercise programs that older adults are participating in, the behavior of older adults in training, and motivation to exercise in older adults. The interview takes around 45 minutes. Both personal trainers also agreed to participate further in the development process.

The goal of the two types of experts is to compare the knowledge, thoughts, and beliefs of practitioners in a medical environment with those in a broader personal environment. The need for exercise can be less medical and more psychological.

3.3 MARKET RESEARCH

Market investigation of exercise equipment available in the market is conducted. Unit price, exercise method, dimension, and design are collected. Thirteenth general categories of exercise equipment for older adults are discovered. A two-axis evaluation map is created to validate each type of machine. Initially, three evaluation maps are created: (1) Affordability x Physical Results, (2) Accessibility x Affordability, and (3) Accessibility x Physical Results. As the project's primary goal is to identify the best solution to combat muscle decline in the lower body, it is decided not to involve affordability, and the third map becomes the main focus of the study.

Each type of equipment is mapped into the accessibility x physical results map according to the data gathered from the market investigation. The map with exercise equipment is then reviewed with geriatric physicians to validate the evaluated equipment. The map (see Figure 4.1) leads the study to focus on finding alternatives for leg press machines that offer the best accessibility and physical results but are usually used in the gym and physical therapy.

4. INITIAL RESEARCH RESULTS

4.1 EXERCISE ROUTINE, GOAL, AND MOTIVATION

According to the survey, 12 out of 21 respondents (around 57%) answered that they're experiencing muscle decline due to age. Out of 12 participants, eight answered that muscle decline negatively impacts their lifestyle in one way or another. The reasons given are (1) Experiencing reduced mobility, (2) Experiencing reduced balance, and (3) Experiencing an increase in pain. 6 out of the 12 participants said they had experienced the effect for over five years.

18 of 21 respondents said that they've participated in strength-based exercises before. Of 18 respondents, all believe exercise helps strengthen their muscles and improve their mobility. According to their responses, walking and weightlifting are the most popular exercise methods.

19 of 21 respondents exercise regularly. All acknowledged that maintaining health is the primary motivation to exercise. In this case, maintaining health includes maintaining mobility, living a whole life, and avoiding pain. They expressed wanting to live a longer, active life or love to the fullest. Another acknowledged goal is to maintain and cultivate social connections. One expressed that a large cadre of friends who participate in these activities with them improves enjoyment and engagement of exercise.

11 out of 19 respondents who exercise regularly expressed that they enjoy and prefer having company during exercise. The main reasons expressed are (1)

exercise is more fun with a group of people, (2) peer pressure helps drive him to exercise, and (3) encouragement from friends increases motivation. The added joy from exercise with a group of people also reduces the time perceived during the exercise, shortens the perceived pay period from aching muscles and tendons, and leads to more extended exercise periods. Also, older adults with friends and social groups exercise more frequently and with volume (but not intensity), which means they exercise more often and with longer sessions. This is related to information gathered from literature reviews and emphasizes the need for digital integration.

Respondents also expressed that they prefer exercise in an exercise program with a personal trainer over exercising at home. Exercising at home requires qualities that the personal trainer usually provides, such as advice on suitable exercise programs, progress feedback, and posture assurance. Without guidance and feedback, the participants became unsure of their progress and the benefits of exercise. They are conducting an exercise routine and cannot perceive the progression from exercise. Not only that, but they also need more verbal assurance from professional trainers who remind them that they are doing something meaningful and are making progress.

On the other hand, 8 of 19 participants (around 38%) expressed that it is better to exercise alone. The main reasons expressed are (1) the absence of distraction, (2) exercise is integrated as part of their daily routine, and (3) exercise helps concentrate on thoughts and self-reflection. The respondents' sole focus on exercise seems to be cultivating, maintaining, and improving their health.

Expert interviews have revealed that muscle weakness is a significant concern among older adults, particularly those with preexisting health conditions. Health-related pain and complications can impede exercise and lead to a rapid decline in muscle strength. While physical therapy can temporarily restore mobility, it's unlikely that older adults who have lost mobility will regain it without consistent exercise. A study by Hardy & Gill (2005) found that only half of disabled older adults can regain independence.

Additionally, experts consider mobility to be one of the crucial components in the lives of older adults. It highlights the significance of lower body muscles, including the quadriceps, gluteus, hip flexors, and hamstring. According to Latham & Liu (2010), lower body muscle mass reduces by up to 40%, while other body parts experience a decrease of 1% per year, as suggested by longitudinal studies.

4.2 STRENGTH TRAINING EXERCISE

According to experts, strength training is crucial in combating muscle weakness. It can significantly improve muscle strength, enhance motor skills, and increase overall capability in older adults. However, experts also stress the importance of balance, as mobility is a combination of strength and balance. While strength alone can aid in movement, a lack of balance can lead to falls and injuries. Therefore, it is essential to identify exercises that can improve strength and balance for older adults.

Regarding exercise type, experts suggested that squats are one of the best lower body strength exercises older adults can do. Simple bodyweight squats have been shown to provide many significant benefits, such as:

(1) Squats improve lower Body Strength. Squats help build lower body strength by targeting major muscle groups like the quadriceps, hamstrings, glutes, and calves. This muscle growth improves overall ability in daily functional activities such as standing up, getting up from bed or chair, and going up the stairs. (Nigro & Bartolomei, 2020)

(2) Squats improve core strength. In addition to lower body muscles, squats also engage the core muscles, including the spine and abdominal muscles. Strength in this muscle group improves body balance. (Clark et al., n.d.)

(3) Squats increased Bone Density. Weight-bearing exercises like squats stimulate the bones, promoting increased bone density and reducing the risk of osteoporosis, which is especially beneficial for individuals at risk for bone-related issues. (Young et al., 2007)

(4) Squats reduce the Risks of Injury. Strengthening of lower body muscles and core muscles led to better posture and balance. Squats also improve ligaments, tendons, and bone density. The increase in stability lowers the risk of injury, fall, and fall injury. (Case et al., 2020)

Although squats offer many benefits, especially in terms of mobility improvement, they also come with many challenges. According to the interviews, challenges such as lack of proper exercise knowledge, lack of noticeable progress, and lack of suitable programs are shared across various strength training exercises.

A primary factor contributing to the relatively low adoption of strength training exercises is a need for more knowledge among the general population. In contrast, cardio exercises are much more widely practiced. Physical trainers have also noted a shortage of strength training options available. Geriatric physicists advise that more accessible resistance training equipment, such as free weights and resistance bands, can be utilized. However, it should be noted that these tools do not provide support and only increase the difficulty of the exercise. Additionally, they are more complex than stationary equipment and do not offer program guidance. As a result, it is crucial to provide both strength and balance exercises for older adults to promote long-term mobility improvement.

Another obstacle to the widespread adoption of strength training exercises is noticing progress and its effects. Unlike cardio-based exercise, which can produce visible results quickly, strength training relies on slow, weighted movements that may not be as familiar or immediately noticeable to older adults. Additionally, strength-based training tends to produce less perspiration and metabolic increase than cardio, making progress harder to detect. Given the slower process of muscle creation, it is essential to find ways to evaluate progress and set measurable goals that can motivate and engage older adults in strength training exercises.

Lastly, the final challenge discussed during the interview was developing a program that caters to the diverse needs of older adults. This program should feature appropriate repetition levels, volume, and frequency. According to expert literature, repetition levels should be around 80% of an individual's repetition maximum, with the maximum being the highest number of repetitions one can perform at a specific intensity. Personal trainers confirmed that older adults tend to shy away from their maximum repetition levels due to fear of pain. As a result, it's recommended that individuals aim for self-observed results closer to 90% of their repetition maximum rather than 100%. Once an appropriate repetition level is determined, the program's volume and frequency can be adjusted based on the user's age, height, weight, and medical conditions. It's crucial to offer customizable systems that cater to each older adult's unique needs.

4.3 MARKET RESEARCH

During market research, data on various types of exercise equipment was gathered. Subsequently, each equipment category was plotted onto a two-axis map, factoring accessibility as the primary axis and physical outcomes as the secondary axis. Two experienced geriatric physicians were called upon to assess the mapping of each equipment type. The research revealed that of the thirteen equipment categories, only four were classified as strength training machines.

Two of the four were categorized as free weights and resistance bands, while the remaining two were leg presses with differing setups (see Figure 4.1).

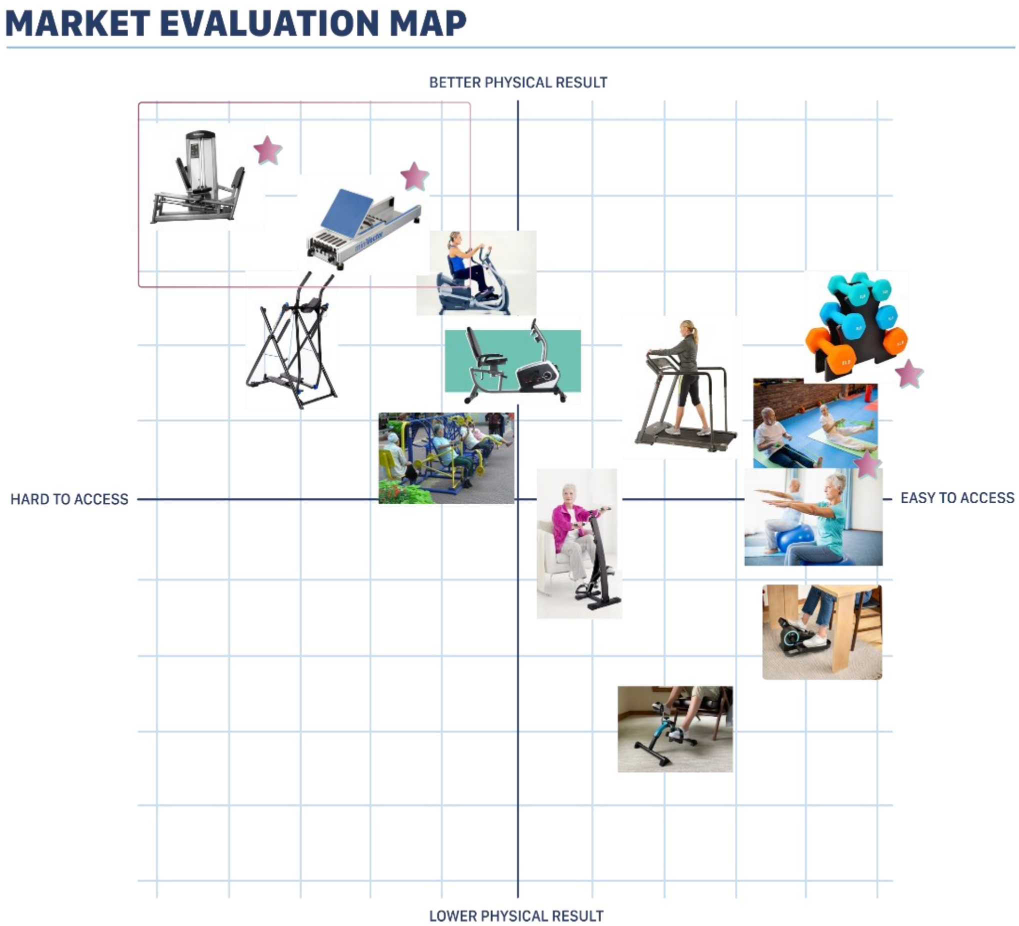

Figure 4.1- Market Evaluation Map

Although leg press machines provide a favorable balance of accessibility and physical results, medical professionals caution against relying solely on these machines for exercise for several reasons. First, they only target the legs and don't improve balance or the ability to sit and stand. Additionally, the machines are not suitable for home use, as the gym version is too bulky, and the medical version requires expert guidance. Based on this information, the researcher aimed to explore alternative exercise methods.

In conclusion, it is found that there is no in-home resistance training exercise equipment for older adults aside from free weights. More explicitly, no squat-based exercise equipment exists for older adults in the market. The closest reference to squat machines is the leg press machines, which offer the best combination of overall accessibility and physical outcome but focus solely on the user's leg in contrast to squats, which impact the lower body and core muscles.

5. DEFINE TARGET GROUP AND MOBILITY LEVEL MAP

5.1 FIVE STAGES OF AGING

The study's initial goal was to offer a solution for older adults, a population of 65 years or older. However, primary and secondary research results suggested that the capability of people within this age range varied greatly. Initial research found that retirement communities, such as the Tealridge Retirement Community, categorize older adults into five stages according to their dependency, further clarifying their different physical capabilities and unique needs. (Malnar, 2017)

1. Self-sufficiency stage (independence stage): Older adults in this stage can live their lives independently without the assistance of others.
2. Interdependence stage: Older adults in this stage can conduct their in-home activity without an assistant, but they require an assistant outside their home.
3. Dependency stage: Older adults in this stage lose most of their motor skills and require assistance with most activities that require mobility, such as standing up and getting out of bed.
4. Crisis management/Complex care stage: Older adults in this stage lose all motor skills and need assistance with all daily activities.
5. Finale stage: Older adults in this stage are bed-bound/hospital-bound.

Based on the five stages, older adults in the second stage (interdependence stage) are the best reflection of the target group of this study. It is a transition stage between independence and dependence. Interviews with experts revealed that interdependent populations within this stage are at higher risk of losing mobility due to their reduced ability to exercise, especially for squats. Providing the population within this stage with an accessible exercise solution can help transition older adults into a self-sufficiency state or at least prevent transitioning into the dependency stage.

5.2 GROSS MOTOR FUNCTION CLASSIFICATION SYSTEM

Although the five stages of aging help us pinpoint the interdependence stage, there is still a wide range of mobility within this group. Other categorizations are also reviewed to specify the target group's needs. One popular tool commonly used in the medical field is GMFCS or The Gross Motor Function Classification System (see Figure 5.1) (Thomason, 2020). The system is widely used to gauge the motor function of children with cerebral palsy into five levels. Medical practitioners have adopted a similar system to categorize the motor function of older adults, as shown below. This system provides more focus on mobility. The GMFCS 1, 2, and 3 resonate closely with the interdependence state from the five stages of aging.

GMFCS 1. Older adults can run and jump on flat ground, but their speed, balance, or coordination are impaired.

GMFCS 2. Older adults can walk on flat ground but have issues with uneven or inclined surfaces.

GMFCS 3. Older adults can walk on uneven surfaces but require assistive devices.

GMFCS 4. Required wheeled assistive device for movement.

GMFCS 5. Little or no voluntary control of movement.

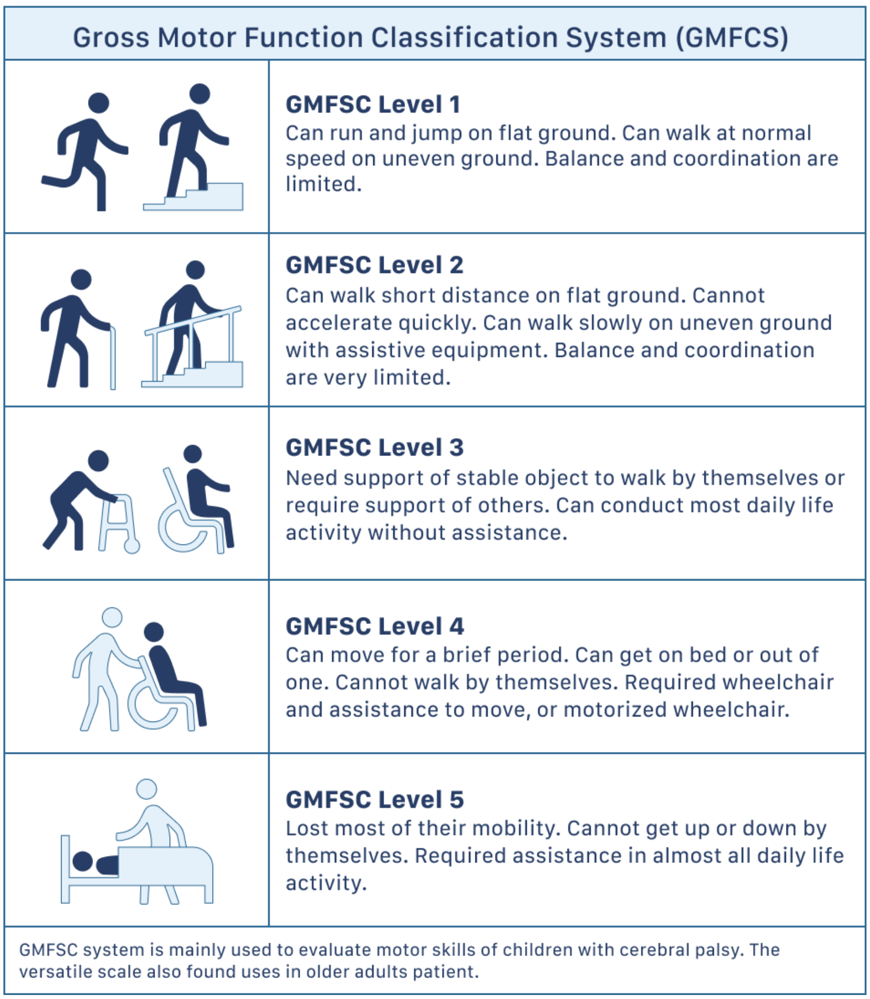

Figure 5.1 – GMFCS

5.3 GAIT SPEED TEST

Additionally, interviews with geriatric physicians revealed the importance of walking speed tests, commonly practiced to gauge mobility or recovering stroke patients (see Figure 5.2). The test tasked patients to a timed, ten-meter walk. The collected time is used to calculate their gait speed. The collected gait speed is used to inform the mobility of the patient. According to a paper by Fritz & Lusardi (2009), patients are categorized into three independence levels, as you can see below:

1. Community Ambulator refers to someone who can walk independently outside their home but needs help with activities requiring quick movement, such as crossing the street. Patients are considered community ambulators if their gait speed is below 1.0m/s but over 0.8m.

2. A Limited Community Ambulator is someone who cannot walk outside their home and requires mobility assistance equipment in their daily life. Patients are considered community ambulators if their gait speed is below 0.8m/s but over 0.4m/s.

3. A Household Ambulator typically requires assistance in daily life and has difficulty climbing stairs in the home. Patients are considered community ambulators if their gait speed is lower than 0.4m/s.

10 Meters Walk Speed Test (Gait Speed Test)

Walk speed result	Classification
>0.8 m/s	**Community Ambulator** someone who can walk independently outside of their home but has a tough time with activities that require quick movement such as crossing the street.
0.4-0.8 m/s	**Limited Community Ambulator** someone who has limited ability to walk outside their home and requires mobility assistant equipment in their daily life.
<0.4 m/s	**Household Ambulator** someone who typically requires assistance in daily life and has difficulty climbing stairs in the home.

Figure 5.2 - Gait Speed Test

5.4 MOBILITY LEVEL MAP

The mobility level scale map combines the gait speed scale and GMFCS. The map uses the gait speed scale to expand the GMFCS 2 into three categories. This results in a GMFCS scale of 2.1 (those with a gait speed of 0.7-0.8m/s), 2.2 (those with a git speed of 0.6-0.7m/s), and 2.3 (those with a gait speed of 0.4-0.6m/s) which are re-labeled as mobility level scale within the map. The additional classifications further clarify the unique needs of the population with an interdependent state, which the design study focuses on (see Figure 5.3).

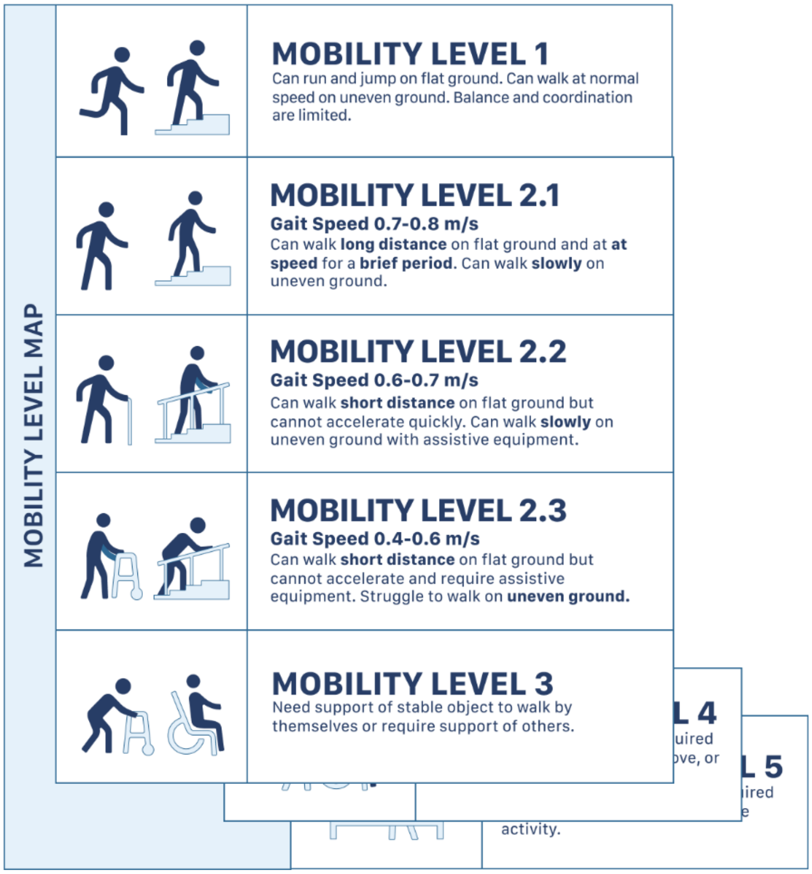

Figure 5.3 - Mobility Level Scale Map

The mobility map further clarifies older adults within interdependence stages who are at risk of losing the ability to exercise, which can catalyst the decrease in muscle mass. Experts expressed that a design solution that offers access to squats for mobility levels 2.1, 2.2, and 2.3 will significantly benefit their mobility, health, and well-being. Squatting routinely would lead to an increase in muscle strength and balance. Both of these led to an improvement in the ability to sit and stand, a critical component of crucial daily activities such as getting out of bed, going to the toilet, and going upstairs. An increase in balance leads to reduced falls, which can lead to injury in older adults.

Although squats are highly beneficial, many challenges prevent older adults from adopting the exercise, according to survey and interview results. One key challenge is that the population within this mobility level might need the ability to do body-weight squats. This led to the realization that the machine needed to support the body weight to reduce the strength required for squatting. There are also other challenges, such as pain, lack of knowledge, lack of engagement, and lack of progress, previously described in section 4.2. Therefore, it is essential to provide additional incentives to exercise, such as tailored programs, connection to the community, and self-progress monitoring and evaluation.

6. DESIGN DIRECTION DEVELOPMENT

6.1 AFFINITY DIAGRAMMING

The design process starts by condensing the research data into critical takeaways through the Affinity Diagramming method. The key takeaways are divided into six categories: health issues, exercise barriers, equipment type, goal of exercise, and accessibility and related issues (see Figure 6.1).

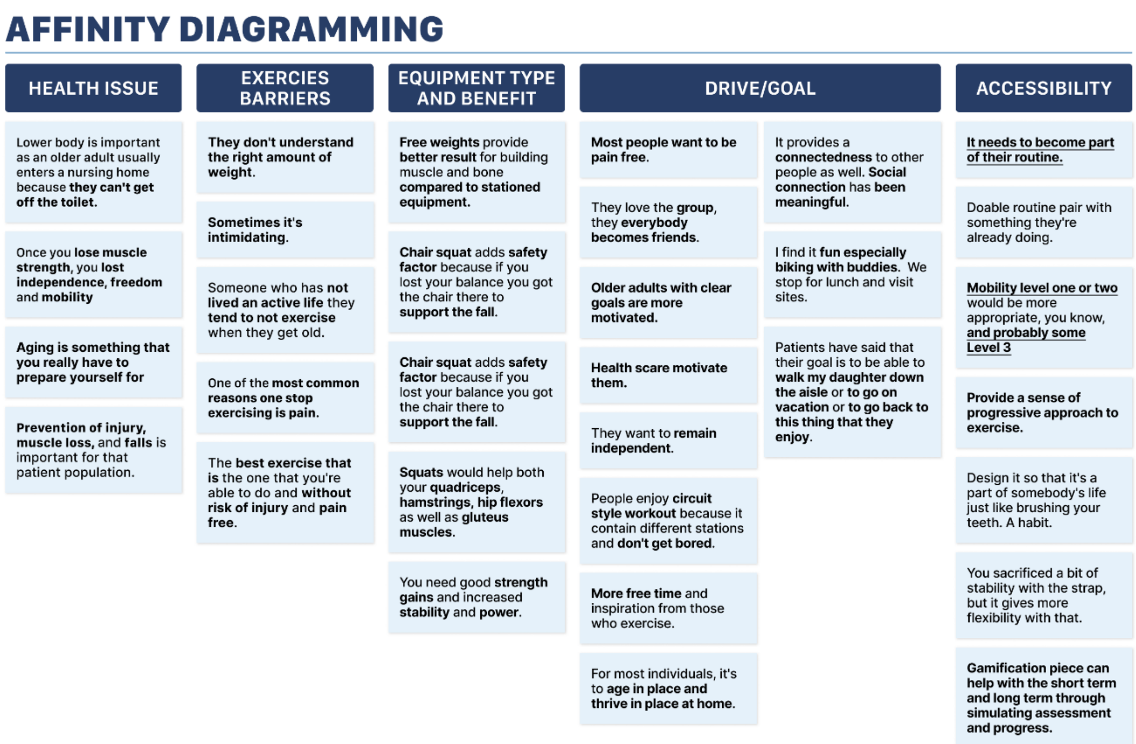

Figure 6.1 - Affinity Diagramming

Regarding physical health, core and lower body strength are among the most critical parts of older adults' lives. A strong lower body helps improve mobility and, in turn, helps increase independence, which allows them to conduct more physical activity and have a better social life. A strong lower body also improves balance and prevents fall risk and injury. However, having a healthy body is perceived as something that one must plan for before one age.

Regarding exercise barriers, survey respondents expressed that they lack the knowledge to exercise correctly, which leads to a feeling of intimidation. Interviews with personal trainers also support the responses. Additionally, the trainers expressed that people who live an active life tend to continue to live actively, and those who do not tend not to exercise. Lastly, pain is another significant barrier and motivation to exercise.

Interviews with personal trainers suggest that participants in their programs with clear goals tend to have better results in terms of drive and motivation to exercise. The most important goals are maintaining health and independence. Many offer more personal goals, such as getting back to specific sports or being able to walk their daughter to the wedding. All these help motivate them to exercise. Many expressed that they have more time after retirement, which leads them to exercise more. Social connection is another reason that drives people to exercise.

Types of equipment play a significant role in setting up a direction for design. According to geriatric physicians, free weights and resistant bands offer better results for building muscle and bone density compared to stationary equipment. The reason is that stationary equipment often provides a single fixed exercise position, which limits movement in a single direction. This means that it impacts only a handful of muscles. On the other hand, free weights offer more freedom of movement during exercise. Free weights and resistant bands are considered more complicated to use correctly due to this fact. However, the freedom of movement also helps users practice balance and strength. Interviews with personal trainers and geriatric physicians revealed that squatting is one of the best exercises for the lower body. Squatting is relatively safe to practice and provides both strength and balance.

Lastly, accessibility concerns are expressed by both experts and target groups alike. Many said that the current equipment in the market could be more inviting to use, and most are not easy to get into. Lack of progress can also reduce motivation to exercise; thus, equipment must regularly provide a sense of progression. Lastly, the response from the survey strongly suggests that they will exercise more if the exercise routine can become part of their daily life.

6.2 GENERATING DESIGN PRINCIPLES

Further synthesis of the affinity map through general summarization is conducted. Key takeaways that can be solved through similar approaches are condensed together into an actionable design principle. Ten design principles were discovered. These principles are categorized into four categories, following the affinity they're discovered from. The principles are overarching criteria for concept development (see Figure 6.2).

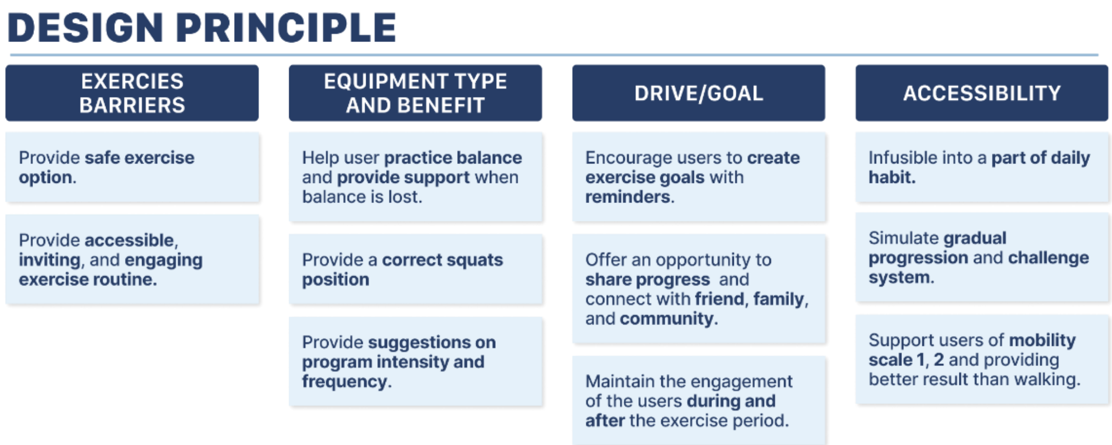

Figure 6.2 - Design Principle

7. CONCEPT IDEATION

7.1 CONCEPT IDEATION AND REVIEW

Three rounds of thumbnail concept sketching are conducted from the principles. A total of 34 concepts are generated. The concepts are benchmarked with design principles, and 17 of the most relevant concepts are selected for detailed sketching.

The review session is conducted with geriatric physicians over the 17 concepts. During the session, each concept is explained and discussed. Afterward, each idea is evaluated and mapped into the Mobility Level Scale Map to clarify each approach's function and benefit (see Figure 7.1). Lastly, the map is reviewed again with geriatric physicians, and the three most promising concepts that best suit the design principle are selected to be used for further iterations.

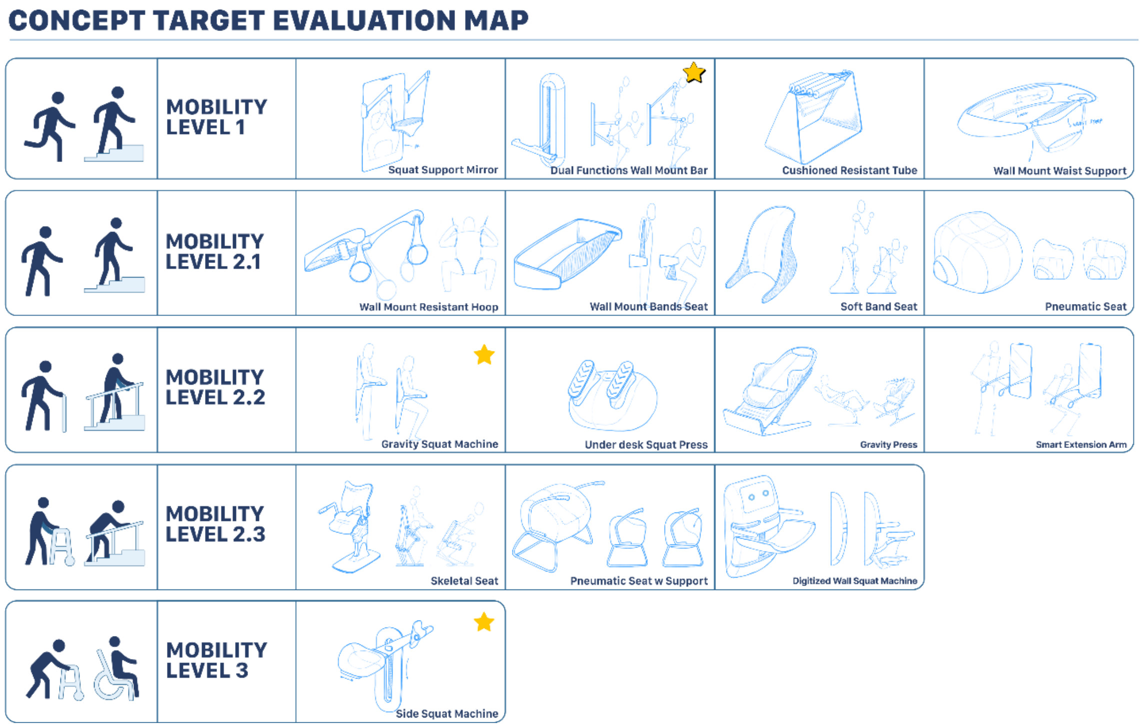

Figure 7.1 - Mobility Level Scale Map with concepts

The first concept is the function of the Wall Mount Bar (Figure 7.2). The idea comes with a leaning bar attached to a telescopic arm. The leaning bar provides support during squat movement. The telescopic arm relates to the hydraulic mechanism to provide weight support, and the telescopic mechanism allows the bar to be extended further for ergonomic purposes. The exact telescopic and hydraulic mechanism also provides the possibility of a second function for weighted squats.

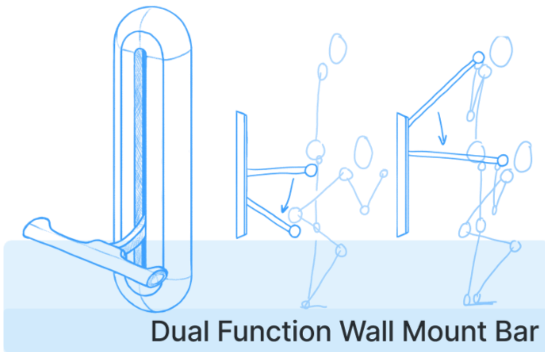

Figure 7.2 - Dual Function Wall Mount Bar Concept

The second concept is called a Gravity Squat Machine (see Figure 7.3). It comes with leaning seats and supportive handles. The body of the unit is attached to a rail mounted to the wall. This weighted rail allows the whole unit to be moved vertically. It generally provides functions similar to those of the Dual-Function Wall Mount Bar but with better support.

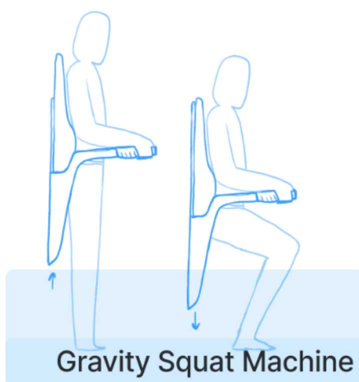

Figure 7.3 - Gravity Squat Machine Concept

The last concept is called a Side-Way Squat Machine (see Figure 7.4). It follows a similar approach to the previous concepts, with the idea of providing a leaning seat and grip. But this version is designed for the user to approach sideways, in contrast to back into the machine. This side-way approach allows the unit to accommodate fewer mobile users than the previous concepts.

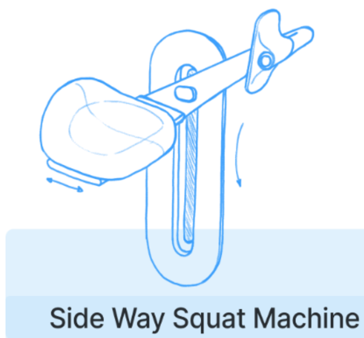

Figure 7.4 - Sideway Squat Machine Concept

7.2 DESIGN CRITERIA

The feedback and suggestions of each concept from the concept review with geriatric physicians were collected and developed into actionable design criteria (see Figure 7.5). The goal of this criteria is to provide tangible requirements for design development. A total of 15 criteria are developed and grouped into six categories. In summary, the device must have fall prevention functions. It must offer dynamic, ergonomic support for users of different sizes. It must offer reminders and exercise status to the user. It must provide upper support and balanced practice. It must be accessible to the user with a mobility level scale of 2. And lastly, it must have a design that can fit into the user's home. According to the design criteria, it is deemed that the combination of the first and second concepts would be the most suitable development direction for the subsequent iterations.

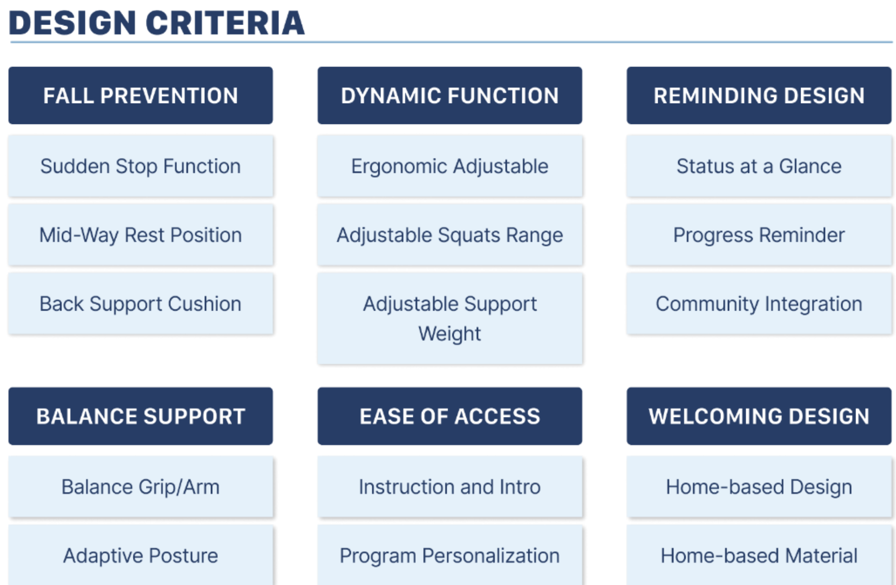

Figure 7.5 - Design Criteria

The remaining design criteria cannot be answered through physical design, which led to the realization that digital integration is needed. With this realization, the remaining design criteria are reviewed and expanded into the application's required functions. The functions include BMI, Progress tracker, Calendar, Progress evaluation, and social connection. Additionally, accessibility functions are explored under ease of access design criteria, and four core functions are developed.

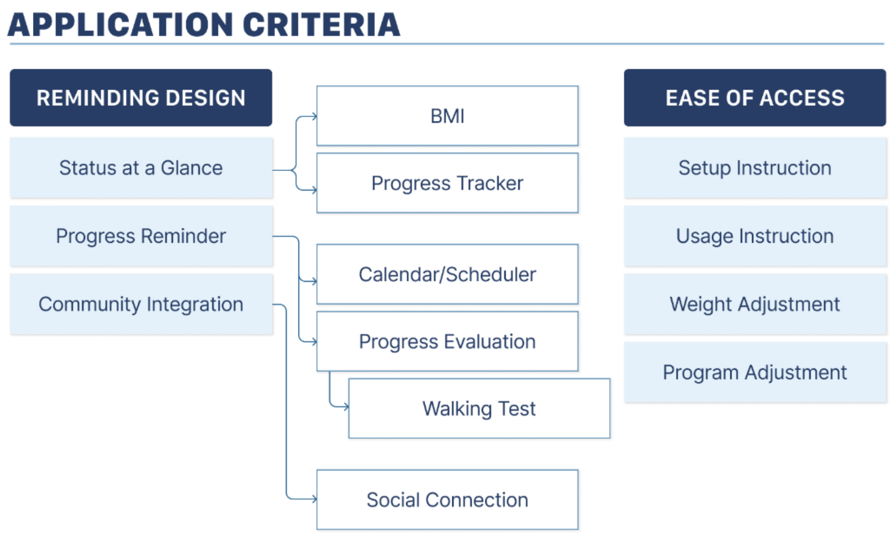

Figure 7.6 - Application Criteria

8. CONCEPT DEVELOPMENT

8.1 CONCEPT DEVELOPMENT PROCESS OVERVIEW

The design development process consists of three rounds. A design review survey with older adults and a design review with geriatric physicians and personal trainers follow each round of development. The first round of development focuses on dimensions, ergonomics, and functions according to design criteria (see Figure 7.5). The application flow follows the requirements (see Figure 7.6). The second round of development focuses on posture collection, ergonomics, and application wireframe. Lastly, the last round of development focuses on dimension updates to better accommodate users and ergonomic posture adjustments for more proper squatting positions. The application integration is updated with functions that connect to and control the equipment.

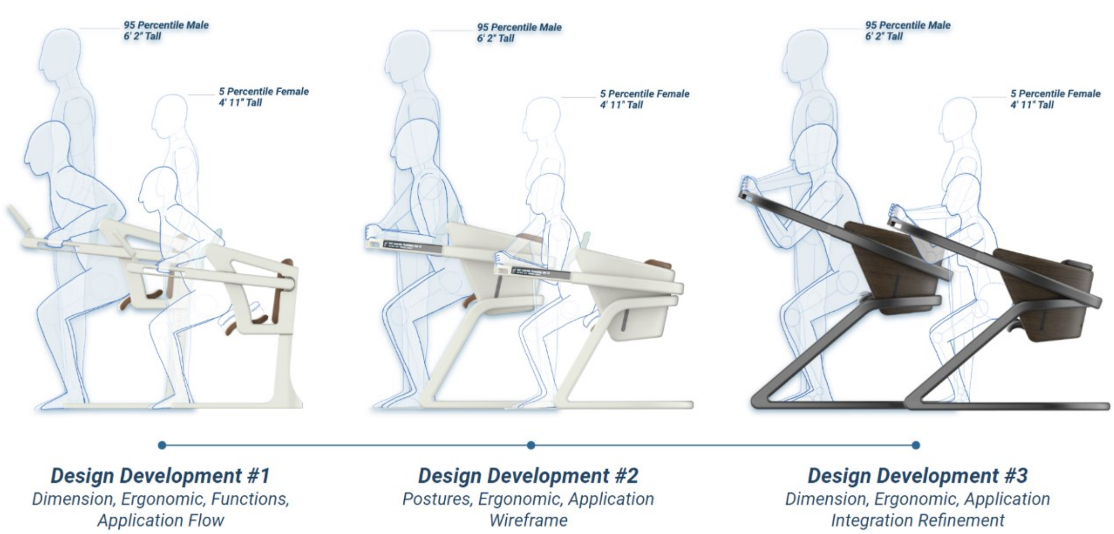

Figure 8.1 - Three Rounds of Development Overview

8.2 ERGONOMIC RESEARCH

Ergonomics research is conducted to offer ergonomically correct functions for the user. The anthropometric data of this research are referenced from The Measure of Man: Human Factors in Design by Henry Dreyfuss (1966). The anthropometric information of 97.5th percentile males and 2.5th percentile females was mapped into an inch-based scaled grid as a standing skeleton body rig (see Figure 8.2).

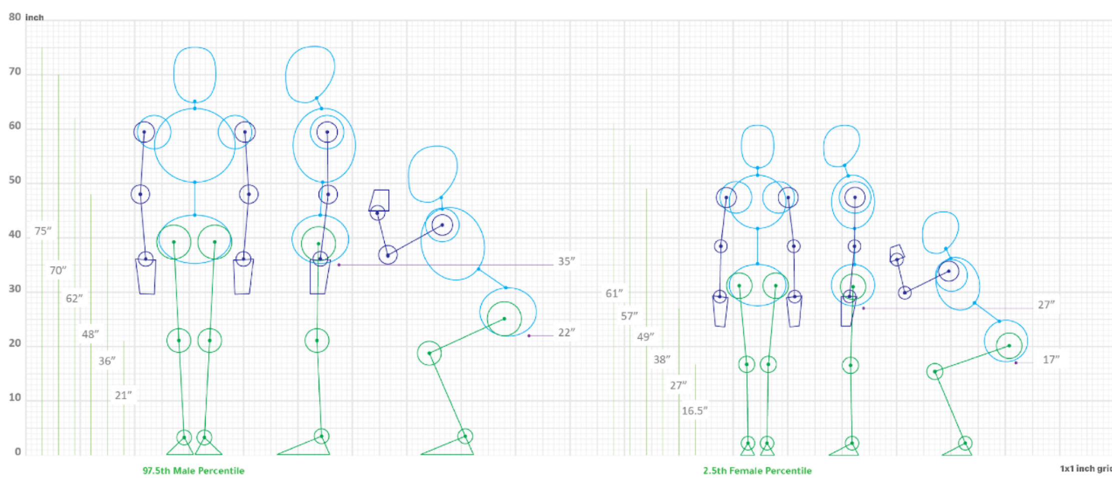

Figure 8.2 - Anthropometric Map - 1: Skeletal Rigs From Anthropometric Data

The standing rigs created the Squat positions of 97.5th percentile males and 2.5th percentile females. The rigs are then used as an ergonomic guideline to develop dimension guidelines for the design iteration. Various iterations of the side-view sketch were drawn to determine the dimension needed for the unit with a squatted rig of 97.5 percentile male. It is found in this stage that, to provide a frontward grip for upper body support, the equipment needs to extend much further than side handle supports. Pursuing a frontward handle position would significantly increase the cost and footprint of the unit. This led to a decision to develop a unit with side handles instead. After an overall dimension is determined, a drawing of the seating position is added with a simple hinge mechanism. The goal is to provide initial validation that the side-view dimension is convenient for the squat movement. After determining the side-view dimension, the front-view dimension is made similarly (see Figure 8.3).

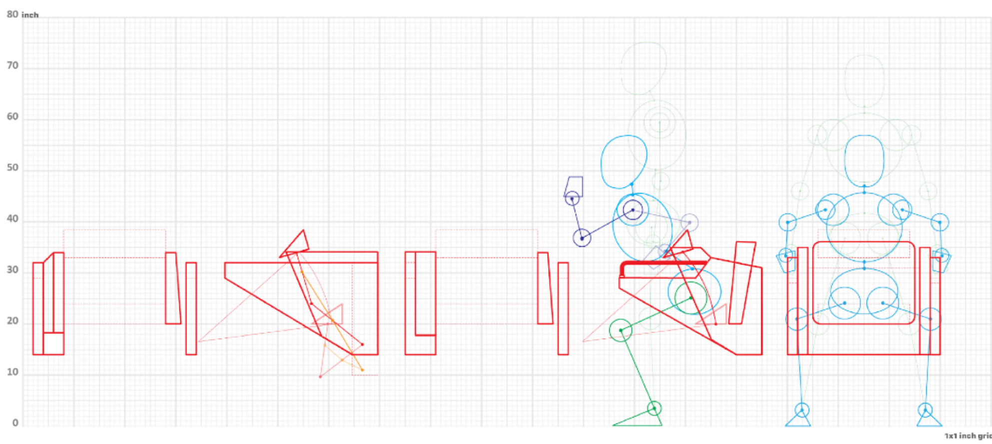

Figure 8.3 - Anthropometric Map - 2: Rigs with Initial Dimension Diagrams

The dimensional diagram was imposed over a squatting rig of 2.5 female percentile. Both front-view and side-view diagrams were compatible with a 2.5 female percentile rig, albeit with a different range of movement on the seat (see Figure 8.4). In this diagram, a slight adjustment has been made to the unit's width to allow more space for movement of the thighs.

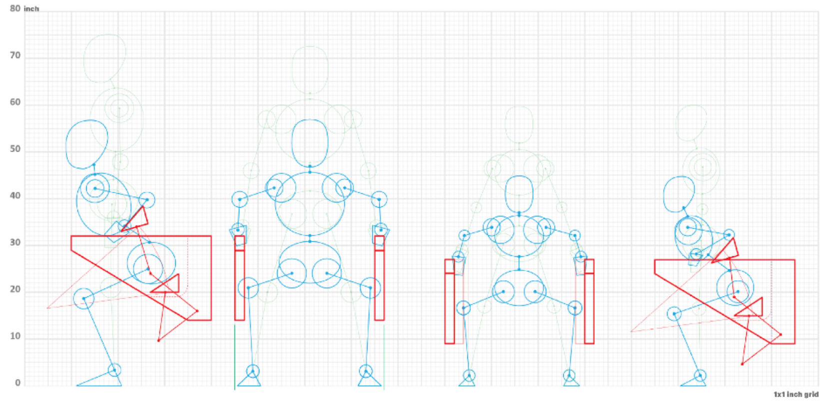

Figure 8.4 - Anthropometric Map - 3: 97.5 Percentile Male and 2.5 Percentile Female

8.3 CONCEPT DEVELOPMENT

With initial function and dimension established, various three-dimensional sketches are developed. Design 1 was created following the anthropometric map's exact width, depth, and height. The model is missing some features, such as handles for balance (see Figure 8.5). During the modeling process, it was found that a blocky shape would not translate well into an inviting final form, leading to the next design.

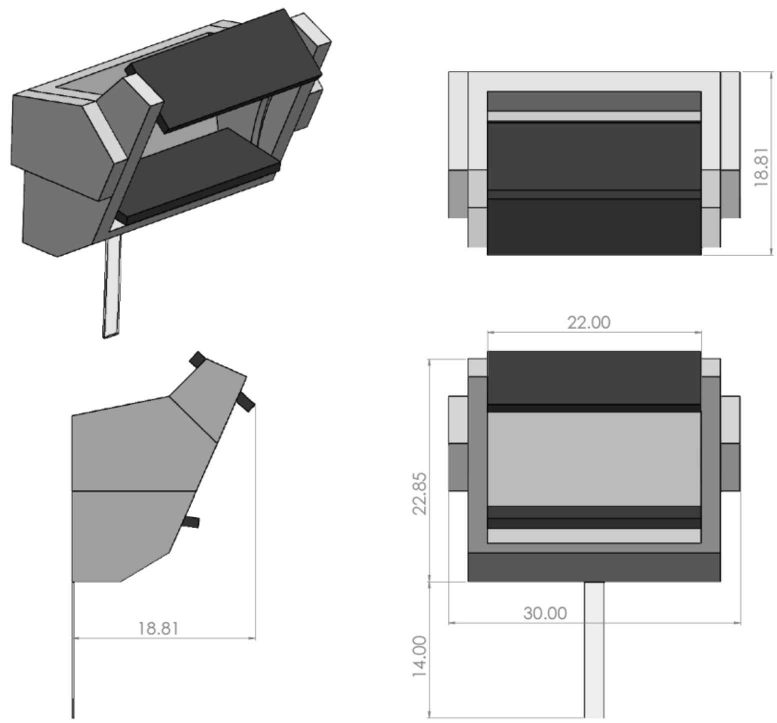

Figure 8.5 - Three-dimensional Model Design 1

Design 2 is developed following Design 1. The main goal of this iteration is to focus on more organic shapes, which, in turn, would lead to more inviting forms. The initial idea is to follow plastic casing bodies commonly found in exercise equipment that are usually used to cover mechanical parts. This plastic casing allows a more organic shape to be built over the skeleton of the equipment, which is generally made from profiled aluminum, metal, or steel tubes. The arms are designed to match the profile nature of the skeleton (see Figure 8.6). It was found that modifying the casing-style model body is very complicated. This led to the development of the next iteration.

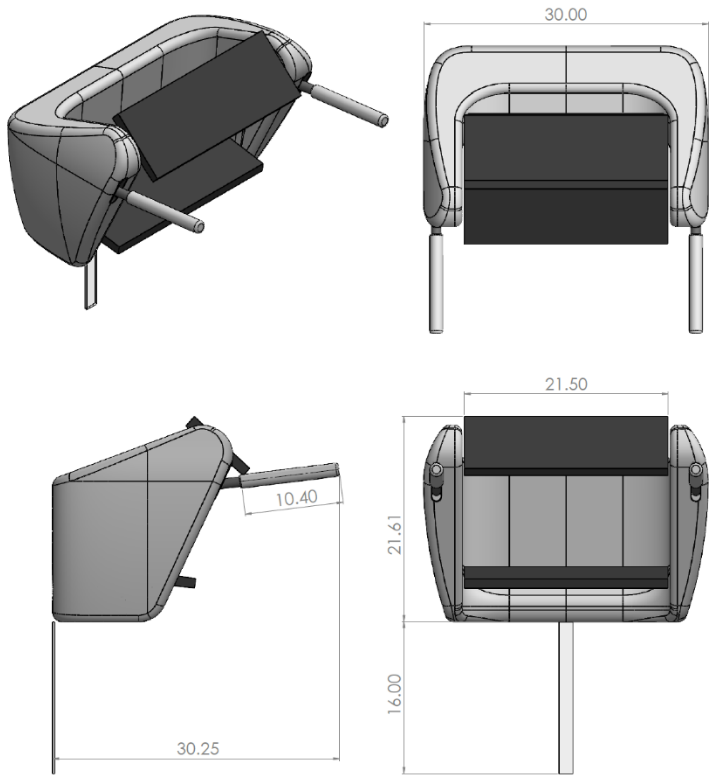

Figure 8.6 - Three-dimensional Model Design 2

Design 3 focuses mainly on the structural needs of the unit. The goal is to make sure that the unit can be manufactured with profile aluminum, steel, or metal tubes commonly used in exercise equipment design, albeit with slight needs adjustments. The design focused on necessity and started with the measured curvature for squat seating. The body is then built around the established dimension. The side arms are designed as an external part and attached to the body through an adjustable tube, which allows the arms to be adjustable within a limited range. A cushion is added to the back of the unit to protect the user during accidental movement (see Figure 8.7). The concept was found to be promising in both function and design and was selected to be developed further into a detailed three-dimensional model.

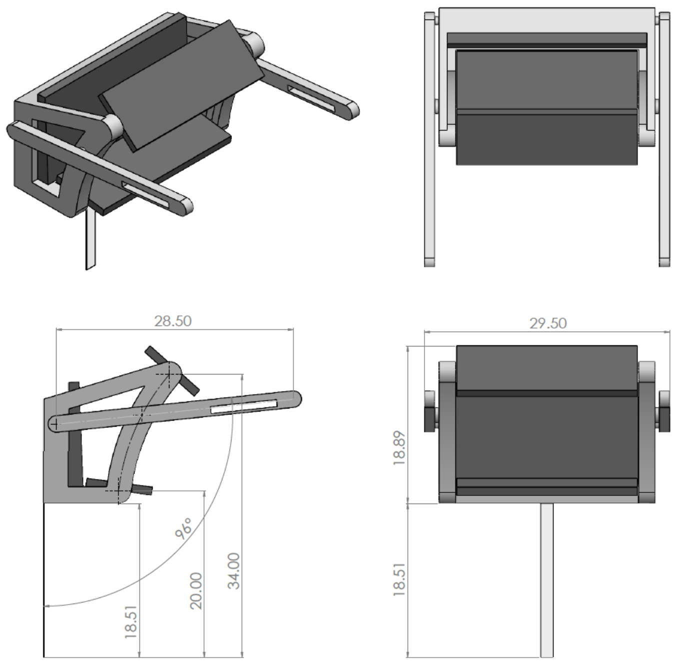

Figure 8.7 - Three-dimensional Model Design 3

8.4 APPLICATION WIREFRAME SKETCH

A wireframe sketch of the application is created. The application is designed with a growth simulation concept. The application offers various types of house plants from which users can select. After selecting the plant, the user will be asked to assign exercise goals associated with the house plant's growth. The plant will grow each time the user exercises. Once the exercise goal is reached, the plant will also get its total growth. The full-grown plant is then moved to a greenhouse in the main menu, and a new plant is added. The user will be asked to select a new plant and exercise goal. It is hoped that the user will continue reaching their goal and populating their greenhouse. Additionally, as the plant grows, the progress will be shared with friends and family, hopefully prompting positive comments to the user and encouraging them to continue to exercise.

At the current stage, the wireframe consists of six elements. The first element is a survey/questionnaire to collect user’s BMI information. The second element is 30-second mobility, which the user can personally conduct to gauge their mobility level. The third element is the greenhouse menu page. The fourth element is an exercise page, which shows an animation of you taking care of the plant while exercising. The fifth element is the progress affirmation page. Lastly, the fifth element shows friends and family's shared progress and comments.

Initial conversations with experts suggested that the application is promising. It offers a unique way to track progress. Using plants as a representation of exercise progress increases the incentive to exercise. It also provides a friendlier view of exercise and its progress. Lastly, sharing progress with friends and family is essential in maintaining social connections with friends and family.

Figure 8.8 - Application Wireframe Sketch

9. DESIGN DEVELOPMENT ROUND 1

9.1 EQUIPMENT DESIGN DEVELOPMENT ROUND 1

Design 3 (see Figure 8.7) is developed further to become the 2nd iteration (see Figure 9.1). Further details were added to the 3D design. Arms are designed to countersunk into the body to reduce the unit's footprint. Movable hinges are added to the space between the arms and the body to provide angular movement to the arms, with a pivot point in the front of the body. This hinge allows the arm to move inside to accommodate smaller users. The back pocket of the arms also provides tolerance for the arms to be rotated up and down for similar purposes (see Figure 9.3). Curvature was added to the seat cushion to reduce contact area and friction. Corners were rounded across the unit surfaces to provide a more welcoming look. A screen is added to the right arm of the unit to act as the interaction between the user and the machine. It provides an exercise guide and offers reminders for the user to exercise.

The name Sthenos, an ancient Greek word means strength, which emphasizes the goal of the equipment is selected for the machine, to provide accessible communication for design review.

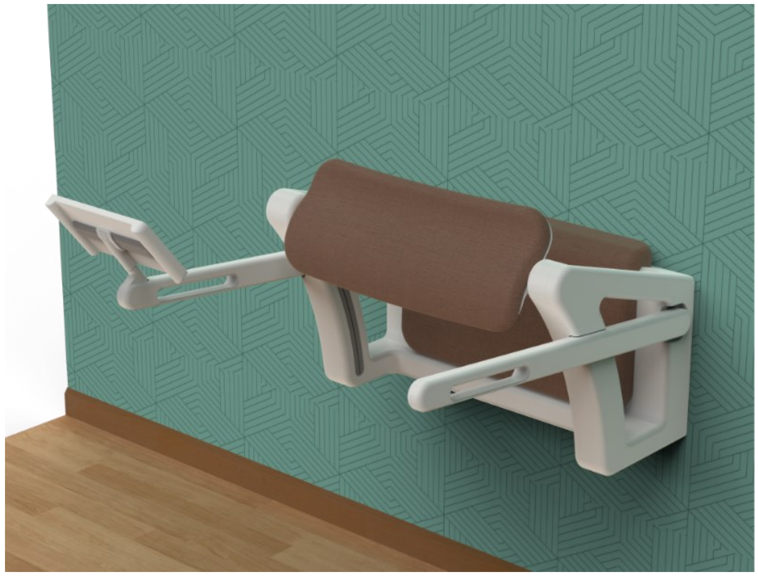

Figure 9.1 - 1st Iteration of Sthenos Machine

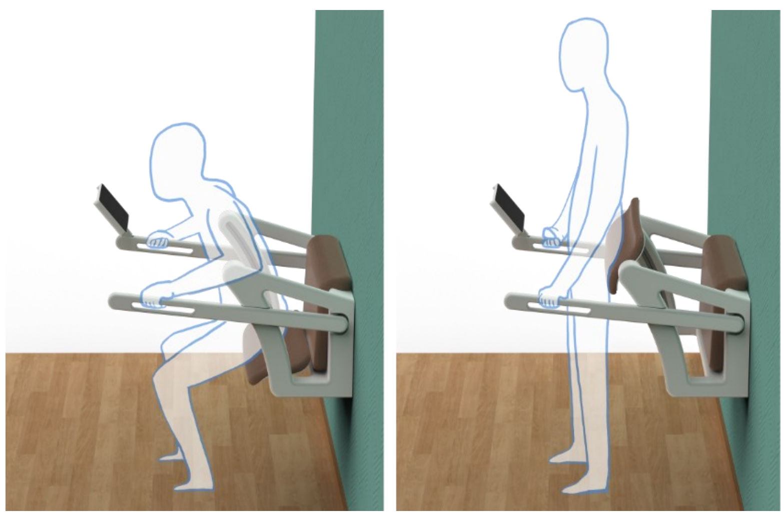

Figure 9.2 - 1st Iteration of Sthenos Machine: Usage Diagram of 97.5 Percentile Male

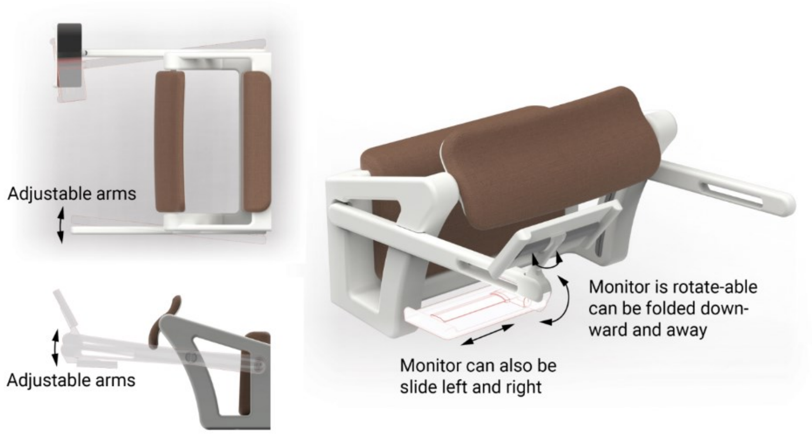

Figure 9.3 - 1st Iteration of Sthenos Machine: Function Diagram

9.2 EQUIPMENT DESIGN ROUND 1 DESIGN REVIEW

Interviews with geriatric physicians and personal trainers are conducted over the design. Both suggested adding a freestanding option, which would allow better freedom of placement. The physicians also suggested adding a support area that patients can stand on with a mat that provides foot guidelines. Following the suggestions, a stand was added to the design, as well as a mat and positioning infographic (see Figure 9.4).

According to the usage diagram, all experts expressed that ergonomics seems proper (see Figure 9.2). However, interviewees also suggested that frontward grips or handles might work better than side handles as they will help improve the user's balance during movement if their hands are in vision range.

On the design side, both geriatric physicians and personal trainers expressed that the design implies medical use due to its style of form over function, coloration, or both. Another comment is that the screen is not correctly integrated into the unit. It looks as if it is attached later in the design.

A two-part design survey was conducted. The first part focuses on the design of the first iteration. The second part compares the first and the second iterations, which will be discussed later in this paper after the second concept development (see APPENDIX D). A total of 31 older adults responded to the survey, with an average age of 66. The youngest respondent is 56, and the oldest respondent is 93.

For the first part of the survey, four questions regarding the design of the first iteration were asked on a Likert scale of 0-4. A scale of 0 represents the most negative feeling, and 4 represents the most positive feeling. The questions are: (1) How comfortable does the first iteration look? (2) How inviting does the first iteration look? (3) How often would you use the first iteration exercise? (4) Do you think the first iteration fits in your home?

The collected data suggested that the first iteration looks 76% comfortable (3 out of 4), 74% inviting (2.97 out of 4), 73% usage rate (2.94 out of 4), and 68% fit within their home environment (2.74 out of 4). This data suggested that the first iteration does not fit well into the user’s home environment and is only partially inviting.

Additional open-ended questions from the survey offer some glimpse into positive and negative comments on the first iteration. The main positive comments are (1) The design looks helpful, (2) the Handles look easy to use, and (3) the Design seems comfortable. The main negative comments are (1) The concept reminds them of medical equipment (2) The unit seems to take up space and might not be suitable for a small home or apartment (3) The feet position does not seem ergonomically proper (4) The machine should offer additive weight option to the upper body.

Lastly, respondents were asked to choose between the wall-mount and freestanding options. 87% of respondents prefer the freestanding option over the wall-mount option. The main reasons are (1) No installation is needed and do not damage the wall (2) Movable-relocatable. On the other hand, the main reason for those who choose the wall-mount option is stability.

According to the interviews and survey, another round of development should be made to improve the design, especially in terms of aesthetics, which answered directly to the established design criteria.

Figure 9.4 - 1st Iteration of Sthenos Machine: Freestanding Version

9.3 APPLICATION DEVELOPMENT ROUND 1

On the application side, it is developed further to display a better representation of each function. This round of development focuses on laying out the flow and features of the application. An initial attempt is made to create a graphic representation of plant growing function and the concept of plant nurturing during exercise.

A review with experts found that the application and function seem on the right track, but there are disconnections between the application and the machine. The expert suggested that the application focus on its core function before moving to stylized representation.

Figure 9.5 - Application Development #1 - BMI Questions

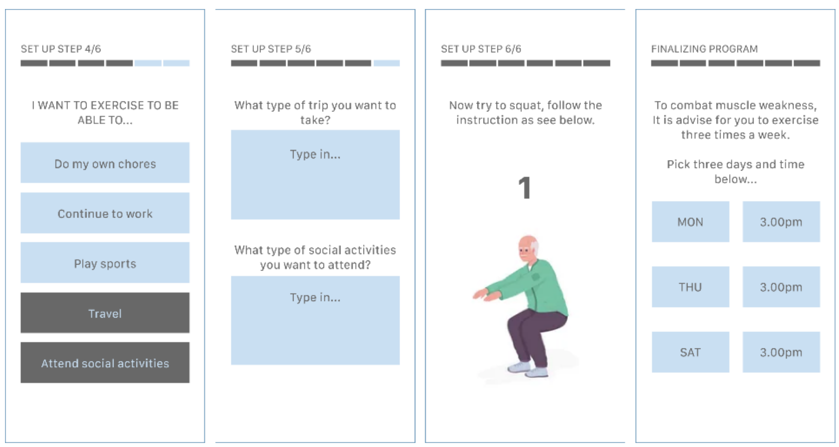

Figure 9.6 - Application Development #1 - Goal, Instruction, and Calendar

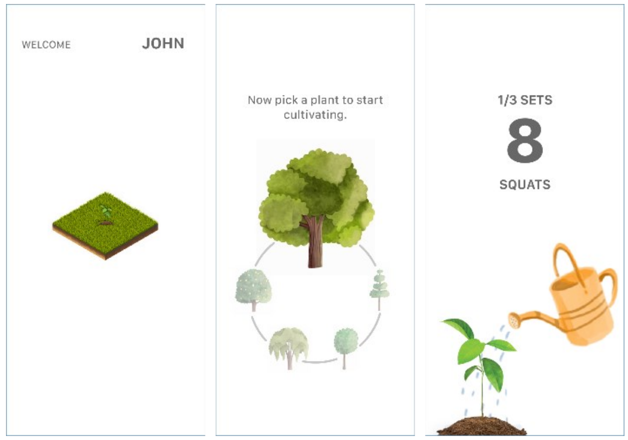

Figure 9.7 – Application Development #1 - Main Menu and Functions

10. DESIGN DEVELOPMENT ROUND2

10.1 EQUIPMENT DESIGN DEVELOPMENT ROUND 2

Following comments from the survey and interviews, the second round of development is conducted. The focus of this iteration is to create a design that can offer frontward handles for the user to balance together with a more inviting design. Iterations of sketches are developed, and a concept with circular telescopic arms is selected due to its compact footprints.

Various materials and colors are considered during this stage. Using The Lounge Chair by Carles and Ray Eames as the primary reference. Designed over 50 years ago, the iconic design of curved plywood and leather surfaces remains iconic today (Green, 2018). The chair's form, material, and colors inspire the equipment's design.

Figure 10.1 – 2nd Iteration of Sthenos Machine: Curved Design Detail 1

A 3D model is developed following sketches and research. The dimensions used are like the previous iteration, but with a curved body shape, the design occupies much less of a footprint than the earlier iterations. One main goal of the design is to offer a protective feeling to the user by having the shape hug around the user's body. A pair of telescopic arms are added to the design. The arms can telescope in and out from a profiled tube housing attached to the body. This function allows the user to move in and out of the machine while support is still available. It also provides support closer to the user's body during exercise. The profiled tube housing is connected to the body via connectors, which allows minor forward and backward adjustments (1-inch movement). The profiled leg is attached to the body similarly into vertical tracks that will adjust the height. Lastly, displays are integrated into the arms to give users handy notifications and instructions.

Figure 10.2 – 2nd Iteration of Sthenos Machine: Curved Design Detail 2

10.2 EQUIPMENT DESIGN ROUND 2 DESIGN REVIEW

The second part of the design survey asked for a comparison between the first and second iterations. Results from the survey suggested that the freestanding version is more desirable as it offers more freedom, and installation is not required. Regarding design, 58% of the respondents think that the second iteration is more desirable than the first iteration (18 out of 31). However, in the follow-up question about ergonomic suitability, only 35% of respondents think the second iteration is more ergonomically suitable (20 out of 31). The reasons provided are (1) the Squat position of the second iteration seems less natural compared to the first iteration (2) The second iteration exercise space seems small compared to the square design (3) The second iteration seems more complicated and less sturdy (4) The second iteration seems more comfortable.

According to the survey results, it is suggested that the current design of the second iteration is inviting and desirable, but it possesses some ergonomic challenges. With this, an anthropometric review is conducted to reevaluate the ergonomic properness of the design. The map shows that the dimensions needed for frontward handles differ significantly from side handles (see Figure 10.3).

Interviews with geriatric physicians and personal trainers provide similar suggestions. The design of the second iteration is in the right direction, but ergonomics must be reevaluated. They also suggested adding additional support to the seat for users with less motor function. Support options advised are cushion bumps, seat belts, and waist harnesses. Lastly, the legs of the design do not seem to provide adequate support for frontward weight, which might lead to the frontward tip of the entire machine.

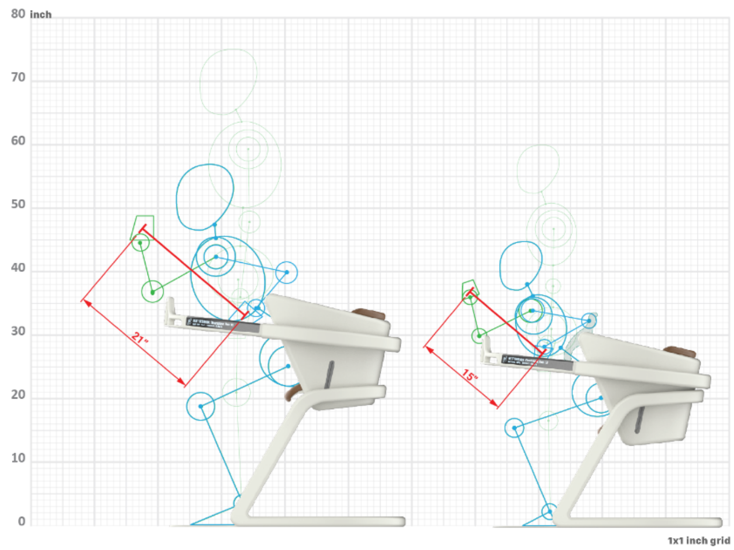

Figure 10.3 - Anthropometric Map - 4: Distances of Side Handles and Frontward Handles

10.3 APPLICATION DEVELOPMENT ROUND 2

The application continues to be developed into a more detailed prototype, focusing solely on providing users with an introduction to the machine. Due to time limitations, using plants to represent progress is withdrawn from the concept. The idea can be infused later with further machine and application development. For this round of development, the instruction flow is fully mapped out with a placeholder for an animated instruction video. The main page of the application is also formed.

Initial reviews with experts suggested that the concept should also show the machine's control. After the questionnaire, the user will be encouraged to use touch control on the machine. Personal trainers also suggested that some leaderboards would help increase the users' anticipation of their progress. It also provides an additional method to stay connected with friends and family.

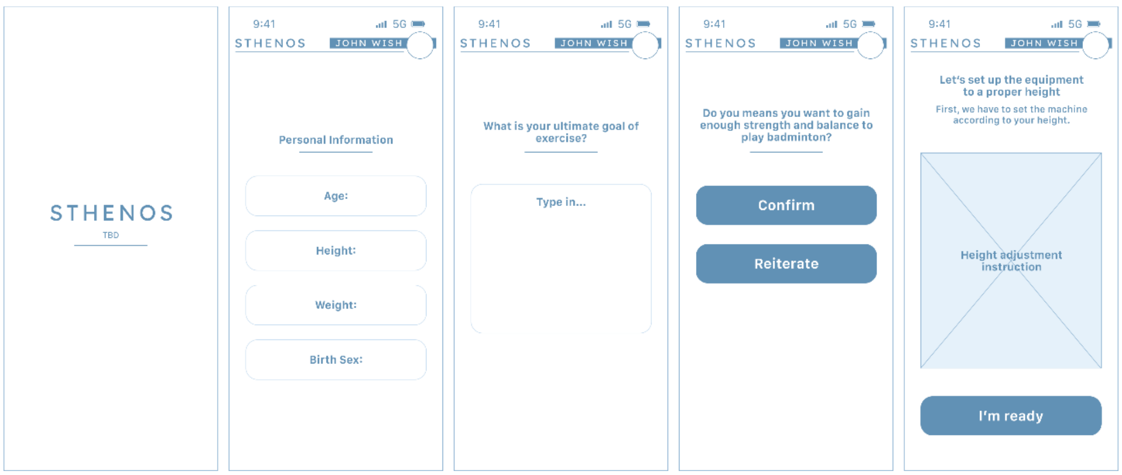

Figure 10.4 - Application Develop #2-1

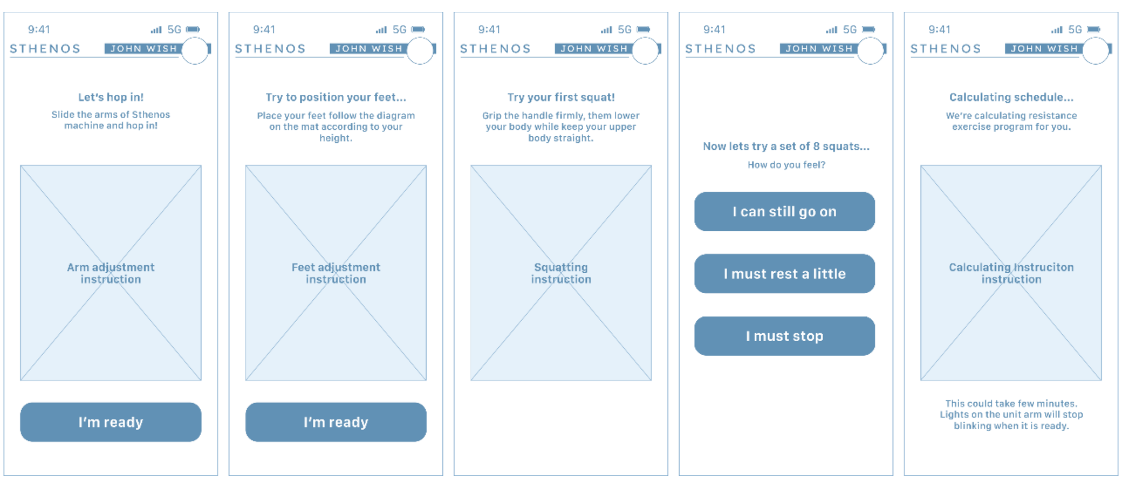

Figure 10.5 - Application Development #2-2

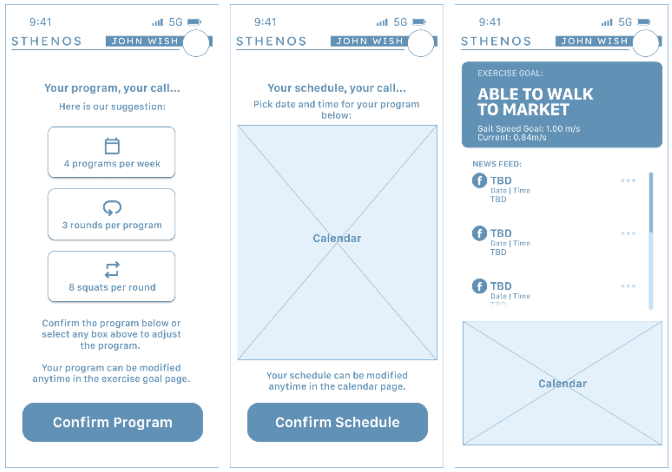

Figure 10.6 - Application Development #2-3

11. DESIGN DEVELOPMENT ROUND 3

11.1 EQUIPMENT DESIGN DEVELOPMENT ROUND 3

The third round of development mainly focused on ergonomic properness (see Figure 11.1). The arms are redesigned according to the previous anthropometric map review. The extended arms allow the user to squat more appropriately (see Figure 11.2). The seats have been widened to accommodate a broader range of users. The feet of the unit have been adjusted to cover more area in the frontward position to prevent tipping. A small convex bump is added to the seat to support and avoid sliding for users with less motor control (see Figure 11.3).

Overall, the main functions of the unit are:

1. Supportive squat seat: Theoretically, the seat provides an upward force set as a percentage of user weight and can be adjusted according to the user's needs. The mechanism can either be hydraulic-based or motorized.
2. Adjustable telescopic arm: The arm can be telescoped back into the housing for entry. The housing cam rotates up and down through the track on the back of the unit. This allows considerable height adjustment of the handle position. The almost 360-degree coverage also acts as a protective support rail that hugs and

protects the user, which the user can hold onto to support their weight.

3. Height Adjustable: According to calculations from the anthropometric map, the unit's height is 5 inches. The adjustment is made from the hydraulic track on the side and back of the unit.
4. Back Cushion: The back cushion is for users who have lost control of their bodies and need emergency back support.
5. Arm Screens: The screen on the arms outside acts as a reminder to the user. It offers two functions: (1) Schedule reminders and (2) Social connection notification. Both aim to maintain users' engagement while the machine is not in use. The screen's inner area is dedicated to the machine's control function and exercise instruction.

Figure 11.1 - 3rd Iteration of Sthenos Machine - Size Comparison

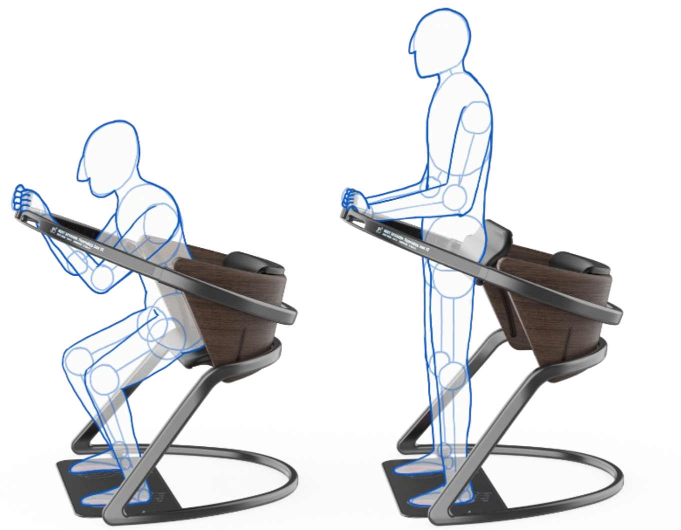

Figure 11.2 - 3rd Iteration of Sthenos Machine - Squat Position

Figure 11.3 - 3rd Iteration of Sthenos Machine with STHENOS Application Prototype

Depiction of the control system on the arm is added to this round of development. A touch-based control near the grip position allows the user to control the machine easily. The proximity to the visual focus area will enable users to maintain balance, which occurs often within this mobility level. The initial control concepts are (1) Slider for seat support adjustment and (2) Squats counting during the exercise routine.

Figure 11.4 - 3rd Iteration of Sthenos Machine - Functions and Controls

Figure 11.5 - 3rd Iteration of Sthenos Machine - Functions and Controls #2

11.2 APPLICATION DEVELOPMENT ROUND 3

A prototype of the Sthenos application is designed to demonstrate how the machine is used. The application includes (1) introductory questionnaires, (2) machine setup, (3) main page (4) subpages.

The introductory questionnaire includes general health questions such as age, weight, height, and exercise goal. The age and weight information will be used as an initial seat support weight guideline. At the same time, the height will be used as a guideline to set up the height of the machine. The exercise goal will be converted to the gait speed needed to conduct that goal. Lastly, the user will be asked to take a timed 30-foot (10-meter) walk to gauge their gait speed. The gait speed will be used to set up the exercise frequency in conjunction with the gait speed goal from the user's exercise goal.

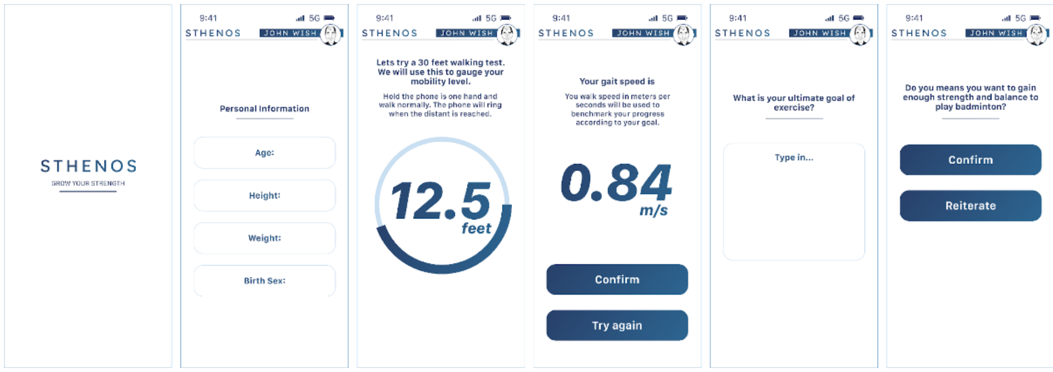

Figure 11.6 - Sthenos Application's Introductory Questionnaire Pages

The setup sequence starts with height adjustment according to user height. Then, a test squat will be conducted. The initial support will be set as a percentage of user weight according to their age and gait speed. During the squat, the user will be asked to adjust the support weight of the seat and retry the squat until the desired weight is confirmed. Afterward, the user will be asked to squat as much as possible to calculate their Repetition Maximum. An exercise program will be created for them with all the information collected. In the next step, the user is asked to pick the date and time they want to exercise or adjust the repetitions and frequency as they see fit. Lastly, the user will be asked to connect to social media and other help applications if they desire to do so. Social media integration offers automatic status update sharing for friends and family to react. In comparison, health app integration will provide better health information. With this step finalized, the user will be sent to the main page.

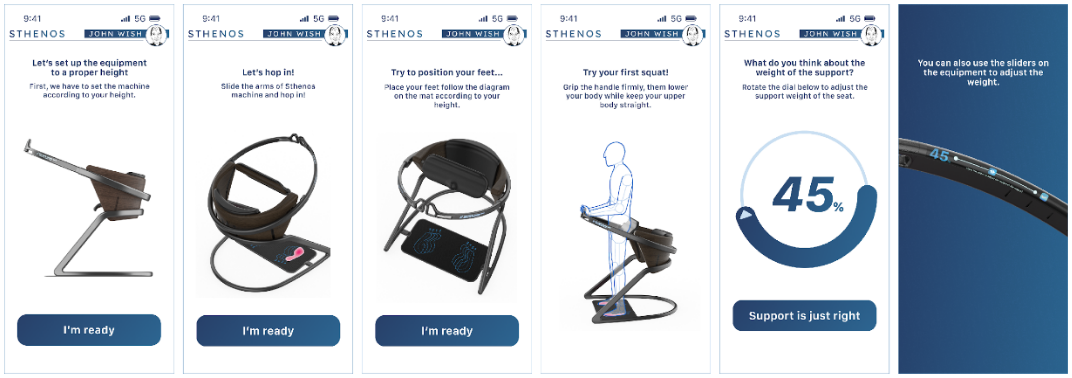

Figure 11.7 – Sthenos Application's Machine Setup Pages 1

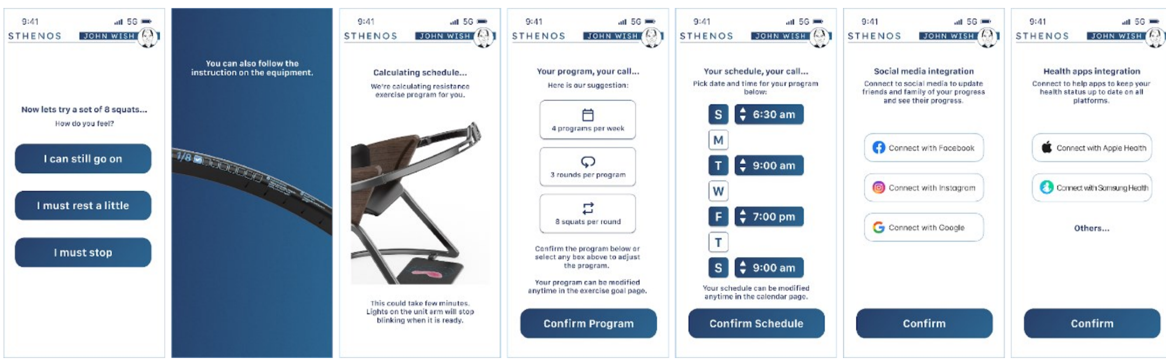

Figure 11.8 – Sthenos Application's Machine Setup Pages 2

The main page includes exercise goals, social media feeds, and a calendar. The exercise goal is shown with the gait speed goal, the user's current gait speed, and the percentage between the two. Using gait speed to compare provides a more tangible way to measure exercise progress. The social feeds offer a collection of the latest social comments on automatic progress posts from exercise routines. The ideal goal for social connection is to provide users with positive encouragement from friends and family during and after exercise routines. It also shows a possibility to provide a way to interact with those posts from the application. Lastly, the calendar aims to remind users about their exercise routine. It can also store other daily tasks that work as additional functions and give the user more reasons to access the application.

Figure 11.9 – Sthenos Application's Main Page And Sub-Pages

The leaderboard and walking test are the subpages that branch from the main page. Users can compare their exercise progress to those of other users from their social and local groups on the leaderboard page. The progress is calculated as a percentage of their gait speed goal. It ranks users by how close they are to their goals. This allows the users to focus on their progress and ideally offers a good comparison across users with different mobility and goals. Lastly, the walking test page will enable users to conduct walking tests at home at any time to measure their progress.

12. DISCUSSION

12.1 DESIGN DEVELOPMENT REVIEW

According to the design review interview with experts, both geriatric physicians and personal trainers expressed that:

1. The function of the supportive squats is in the right direction.
2. The updated dimension is ergonomically proper according to the data from the anthropometric map (see Figure 12.1).
3. The grips are in a more ergonomically proper position, leading to better squat posture in terms of balance.
4. Using the gait speed test as a benchmark is a unique way to track exercise progress and goals.
5. Social features and leaderboards can help motivate users and maintain engagement.

However, further development and research are needed to push the machine and application into the market. Suggestions from the experts are:

1. The design development is at the point that a physical prototype is needed to conduct an ergonomic test.
2. The extended feet might lead to structural weakness of the design and need to be re-engineered.

3. Additional functions, such as a customizable weighted belt, should be added to improve the machine's usability for users that transit into mobility level 1.
4. Consider adding more support functions, such as a seat belt or harness, for users with a mobility level 2.3.
5. In addition to current application instruction, video or in-person instruction is valued by this age group and should be considered. A physical instruction book is also valued.
6. The machine should account for users with disfigured postures often encountered within this age group.

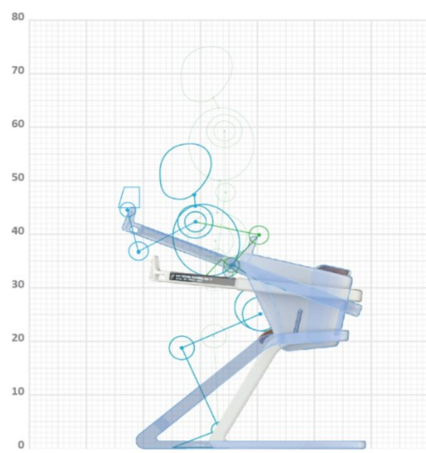

Figure 12.1 - Anthropometric Map - 5: Design Comparison

12.2 IMPACT

The goal of Sthenos is to offer accessible squats to older adults. It is hoped that when adopted after discharge, routine squats would help combat muscle decline and improve muscle strength and balance in older adults. Over time, the machine will prevent users from losing mobility and improve their mobility so that they can regain self-efficiency and live longer and happier lives as older adults.

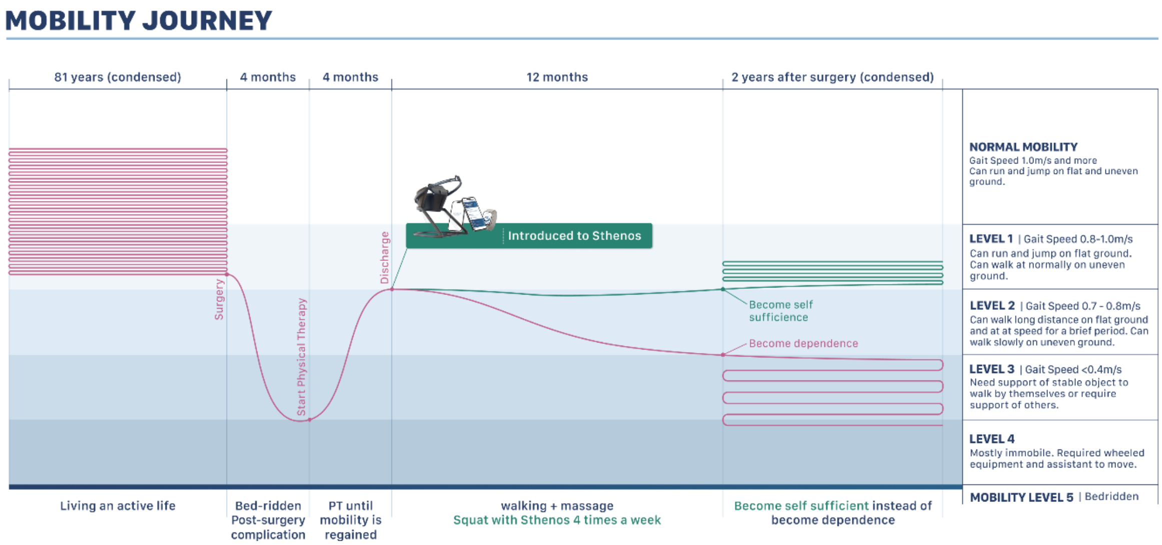

Figure 12.2 - Mobility Map With Sthenos

12.3 FUTURE DEVELOPMENT

Although initially deemed successful, reviews of later development revealed that many aspects still need to be considered. Future research needed includes physical and ergonomic testing, market positioning research, laws and regulations, and physical prototyping. A three-year product development timeline has been created. The development is divided into two prongs: (1) Design and manufacturing timeline. The design and manufacturing timeline focuses on prototyping and manufacturing. It also includes ergonomic and design testing.

Later, the design and manufacturer split into physical and digital aspects of the product. (2) The marketing timeline focuses on market and business research.

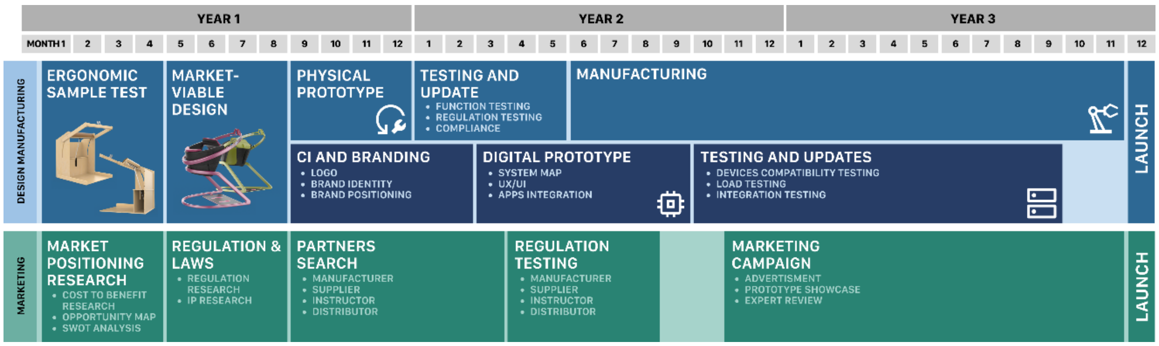

Figure 12.3 - Future Development Map

13. CONCLUSION

Firstly, knowledge from experts is crucial when designing specialized equipment. Interviews with experts can help gather the knowledge needed to establish initial design directions for design development. Additionally, design reviews with experts are crucial to the design development process. Feedback and suggestions from the experts lead to the informed development of the concept through their specialized knowledge of the topic.

Secondly, older adults have a significant age range and a wide range of mobility. To design lower-body exercise equipment for older adults, it is essential to pinpoint the mobility level of the target group for which the machine is intended. Mobility evaluation tools from the medical field, such as GMFCS and Gait Speed Test, can be crucial in identifying mobility. The Mobility Level Map developed from a combination of the tools is critical to deepening the understanding of the target group. Additionally, the Mobility Level Map is vital as a communicator with experts to help explain the concepts during the concept review.

Lastly, the ergonomic map created from anthropometric data can be crucial in designing and developing exercise equipment. The map led to the discovery of dimensions used as a guideline throughout the process. However, using an ergonomic map cannot replace a physical prototype, which is still needed for further development and testing of the machine.

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15. APPENDIX

APPENDIX A IRB FORM

University of CINCINNATI
Institutional Review Board
FWA #: 000003152

EXEMPT DETERMINATION

October 5, 2023

Pantawat Tongrod
DAAP SOD Students

Dear Pantawat Tongrod,

Type of Submission:	Initial Study
Title:	A Study of Motivation Factors in Lower Body Resistant Exercise Equipment to Combat Chronic Muscle Weakness for Older Adults
Investigator:	Pantawat Tongrod
IRB ID:	2023-0457
Funding:	None
Documents Reviewed:	• HRP-503 Motivation Factors to Combat Sarcopenia for Older Adults ResProtocol.2023-0457.pdf
Type of Review:	Exempt
Review Category:	• (3)(i)(B) Benign behavioral interventions (low risk)

On **10/4/2023**, the IRB reviewed the above submission and determined that this protocol meets the criteria for exemption from IRB review in accordance with 45 CFR 46.104.

The IRB has determined the following consent requirements:

- The IRB has waived the requirement to obtain DOCUMENTATION of informed consent for all adult participants.

PI Notification
Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit a new request to the IRB for a determination.

Note: The exemptions at 45 CFR 46.101(b) do not apply to research involving prisoners, fetuses, pregnant women, or human in vitro fertilization, Subparts B and C. The exemption at 45 CFR 46.101(b)(2), for research involving survey or interview procedures or observation of public behavior, does not apply to research with children, Subpart D, except for research involving observations of public behavior when the investigator(s) do not participate in the activities being observed.

Thank you for your cooperation during the review process.

Page 1 of 1

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APPENDIX B SURVEY QUESTIONS

SURVEY: MOTIVATIVE DESIGN TO COMBAT SARCOPENIA FOR OLDER ADULTS

Asterisk (*) means the question will require an answer to proceed.

Personal Information

1. **Year of birth ________*
2. **Gender (Male, Female, Prefer not to answer, Other)*
3. *Height ________*
4. *Weight ________*
5. **Occupation (Full-Time, Part-Time, Seeking Employment, Retired, Other)*
6. **Do you live alone or with your family?*

Health and Sarcopenia

What is sarcopenia? Sarcopenia or gradual loss of muscle mass, strength, and function typically affects people from the age of late 30. Physically inactive people can lose as much as 3% to 5% of their muscle mass each decade after age 30. The effect typically becomes stronger and more noticeable as people grow older.

1. **Have you heard of sarcopenia before? (Y/N)*
2. **Are you experiencing a decrease in muscle strength due to age? (Y/N)*
   a. *How long have you been experiencing the effect?*
      (Less than 1 year, 1-2 years, 2-5 years, More than 5 years)
   b. *Does decrease in muscle strength affect your lifestyle in any way? (Y/N)*
      i. *Can you tell us how? ___________________*
3. **Have you ever taken part in an activity that specifically aims to prevent muscle loss or build muscle strength? (Such as resistant training, Weightlifting, Biking, Hiking, Swimming) (Y/N)*
   c. *Can you describe the activity? __________________*
   d. *Do you think those exercises help strengthen your muscle? (Y/N)*
4. **Are you currently using any mobility-aid equipment? (Select all that apply)*
   (Wheelchair, Cane, Walking frame, None, Other)
5. **How long have you been using the equipment?*
   (Less than 1 year, 1-2 years, 2-5 years, More than 5 years)

Lifestyle and exercise routine

1. **Are you engaging in any of the following physical activities in everyday life? (Select all that apply)*
   (Work that requires physical labor (such as walking/lifting), Daily cleaning/house chores, Travelling, Exercise, No, Other __________)
2. **How much free time do you usually have each day? (1-2 hours, 2-4 hours, 4-6 hours, More than 6 hours)*
3. **How many times do you exercise per week?*
   (I do not routinely exercise, Once a week, Twice a week, Three times a week, More than three times a week)
4. **How much time do you spend exercising each session?*
   (Less than 15 minutes, 15-30 minutes, 30 minutes to 1 hour, 1-2 hours, More than 2 hours)
5. *Do you think you have exercise enough to negate the effect of sarcopenia? (Y/N)*

Motivation to exercise (if participant exercise from previous question 3)

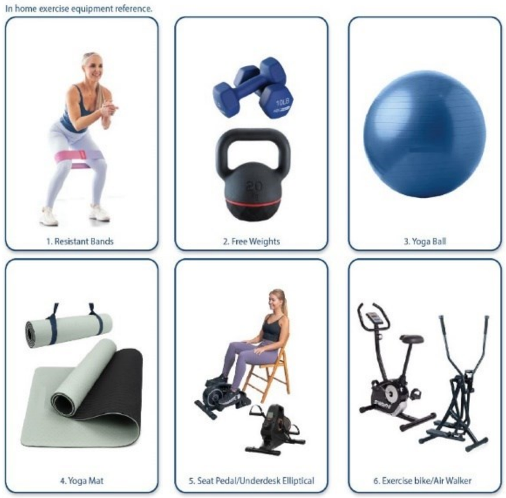
1. *How long have you been routinely exercising?*
   (Less than half a year, 1 – 2 years, 2 – 4 years, More than 4 year, Other)
2. *What is your regular exercise activity?*
   (Yoga/Taichi, Running/Jogging, Walking, Weightlifting, Swimming, Sports (e.g. Pickle Ball, Golfing, Other)
3. *What helps motivate you to exercise? (Select all that apply)*
   (To stay socially connected, To maintain healthy lifestyle, To learn or try new things, Other)
4. *Please tell us why the selected goals are important to you?*
5. *Looking back, have your exercise goals changed from your younger years? (Y/N)*
6. *Do you exercise alone or as part of a group? (Alone/ Group)*
7. *Do you think exercise is better with a group of people? (Y/N)*
   a. *Can you tell us why or why not?*

Motivation to exercise (if participant do not exercise from previous question 3)

1. *Is there any medical restriction that prevents you from exercising? (Y/N)*
2. *Is the condition temporary? (Y/N)*
3. *Can you tell us the reason why you don't exercise? (Select all that apply)*
   (My daily schedule is already active enough, I have no one to exercise with, Muscle weakness makes it hard to exercise, Medical restriction, Other)
4. *Is there anything that would help motivate you to start exercising?__________*

Exercise equipment

In home exercise equipment reference.



1. *Do you currently have any in-home exercise equipment?*
   (1. Resistant bands, 2. Free weights, 3. Yoga ball, 4. Yoga mat, 5. Seat pedal/Under desk elliptical, 6. Exercise bike/Air walker, Other)
2. *Are you currently using any of the equipment? (Y/N)*
   a. *(Y) Could you tell us which equipment you use the most and why?_________*
   b. *(N) Could you tell us why you're not using the equipment? _________*
3. *Do you think any of the following additional features to the exercise equipment would entice you to exercise more?*
   a. *Equipment with game-like challenge*
   b. *Equipment with integrated social interaction that allows to remotely exercise with friends/family.*
   c. *Equipment with customizable intensity.*
   d. *None*
   e. *Other*

Could you tell us why?_________

APPENDIX C INTERVIEW QUESTIONS

EXPERT INTERVIEW DISCUSSION GUIDE
A Study of Motivation Factors in Lower Body Resistant Exercise Equipment to Combat Chronic Muscle Weakness for Older Adults
Introduction

Hello, my name is Fiat, Pantawat Tongrod. I'm a Master of Design Student from School of Design, University of Cincinnati. I'm conducting a study on the effect of sarcopenia, or muscle decline with age, regarding mobility and well-being of older adults. It includes questions about the effects of sarcopenia related to daily life of older adults, how muscle decline impacts life of older adults, and best practice in resistant training activity.

Before we start, do you have any questions?

I will start with preliminary questions required by the internal review board.

- *Have you received the information sheet through email? (Y/N)*
- *Is it alright with you if I record this conversation? Everything is going to be de-identified. Anything mentioned in the interview will not be able to be traced back to you. (Y/N)*

(D) Question for doctor, (T) Question for trainer, (B) Question for both.

Personal Introduction

1. *(B) Please state your current/late profession, and age if wish to be disclosed. (Profession:, Age:)*
2. *(B) What experience do you have related to chronic muscle loss or muscle strength training in the aging population?*
    a. *What type of activity are/were you conducting?*
    b. *Are those activities helpful? (Y/N) (How?)*

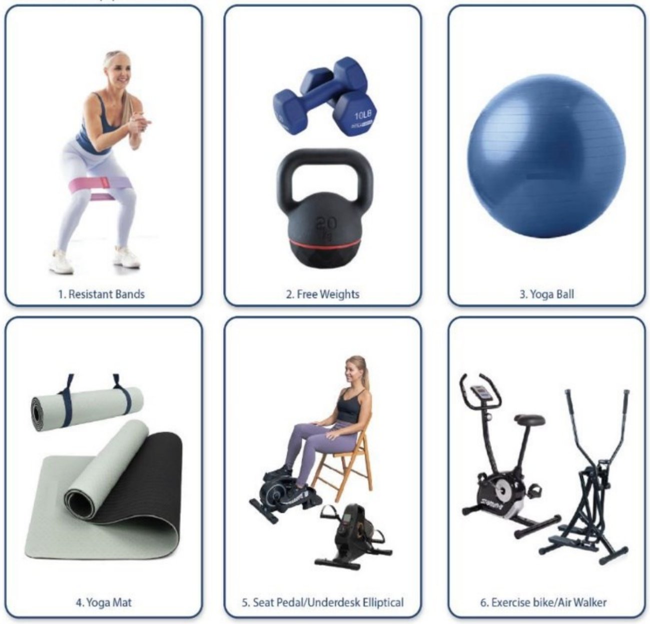
About Aging Populations

1. *(B) Have you heard of resistant exercise training?*
    a. *What are some differences between RET and cardio? (Benefit?)*
2. *(D) What age should inactive aging populations start resistant exercise training? (Why?)*
3. *(B) To maintain a healthy lifestyle, how often should aging populations conduct muscle training exercises each week?*
    a. *55 years_______ Frequency_______ Intensity________ Rounds________*
    b. *65 years_______ Frequency_______ Intensity________ Rounds________*
    c. *75 years_______ Frequency_______ Intensity________ Rounds________*
4. *(B) Aside from RET, is there any other way that would help combat sarcopenia?*

Muscle training

1. *(D) Are there other benefits of leg muscle strength training for aging populations, beyond muscle mass maintenance?*
2. *(B) What are some effective leg muscle strength training exercises for aging adults?*
3. *(T) In your experience, what is the most popular exercise program/activity for the aging population?*
    a. *How long does each session of the activity usually take? How often per week?*
4. *Please rank the following exercise equipment for muscle training. From best to worst. Why?*

In home exercise equipment reference.



5. *(B) From your experience, which equipment is the most engaging for older adults? (Why?)*
   (Type, Activity, Session length)
6. *(B) Would at-home muscle strength training equipment for aging populations help fight/prevent chronic muscle loss? (Why?)*
   a. *What type of activity would be best suited for home environment?*
   b. *What type of equipment would you imagine it be?*
7. *(B) Is there any additional concerns that should be taken into consideration regarding muscle training activity for the aging population?*

Motivation

1. *(B) From your experience, have you encountered more active or inactive aging populations? (More active/More inactive) (What would be the reason for that?)*
2. *(B) Have you met an aging population that stopped living an active life or stop exercise at the old age? (Y/N) (Why?)*
3. *(B) What are some main reasons that lead aging populations to stop exercising? (Medical condition/ Lack of time/ Lack of access to exercise equipment/ Lack of knowledge to activity)*
   a. *From your experience, which are the most common?* ____________________
4. *(B) From your experience, do you think mobility or lack of mobility is one of the main reasons that affect exercise routine in older adults? (Y/N) (Why?)*
5. *(B) Have you met an aging population that just started exercise at old age? (Y/N)*
6. *(B) What are some main reasons that lead aging populations to pick up exercise or start an active lifestyle? (What motivates them?)*

Research

(B) Any additional concerns should be taken into consideration for designing muscle strength training activities?

APPENDIX D DESIGN REVIEW SURVEY QUESTIONS

DESIGN REVIEW SURVEY

DESIGN STUDY OF LOWER BODY STRENGTH EXERCISE EQUIPMENT

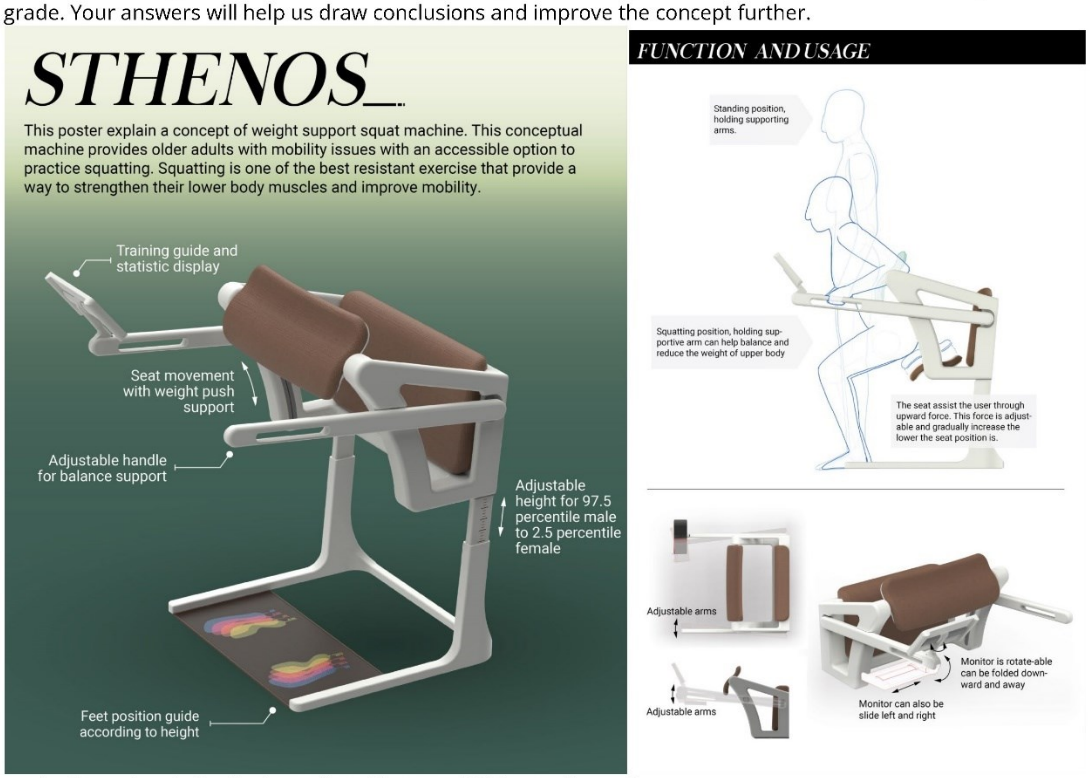
Asterisk (*) means the question will require an answer to proceed.

Personal Information

1. *Year of birth ________
2. *Occupation (Full-Time, Part-Time, Seeking Employment, Retired, Other

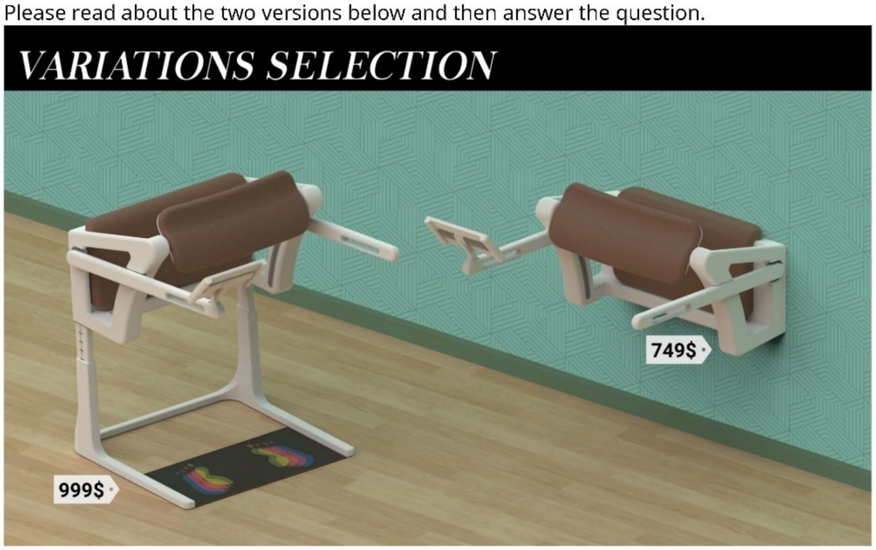
Concept Design Review

Please read the poster below carefully before answering the following questions. Please don't hesitate to follow your feelings and intuition in answering the questions. Negative answers won't affect the survey maker's grade. Your answers will help us draw conclusions and improve the concept further.



1. Does the design look comfortable to use? (1:least – 5:most)
2. Does the design look inviting for you to use? (1:least – 5:most)
3. Do you think the design fit within your home environment? (1:least – 5:most)
4. Would you use the equipment if it is in your home? (1:least – 5:most)
5. Please tell us something you don't like about the design.
6. What would you do to improve the design? (Not required)
7. Please tell us something you like about the design.

Set-up Questions
Please read about the two versions below and then answer the question.

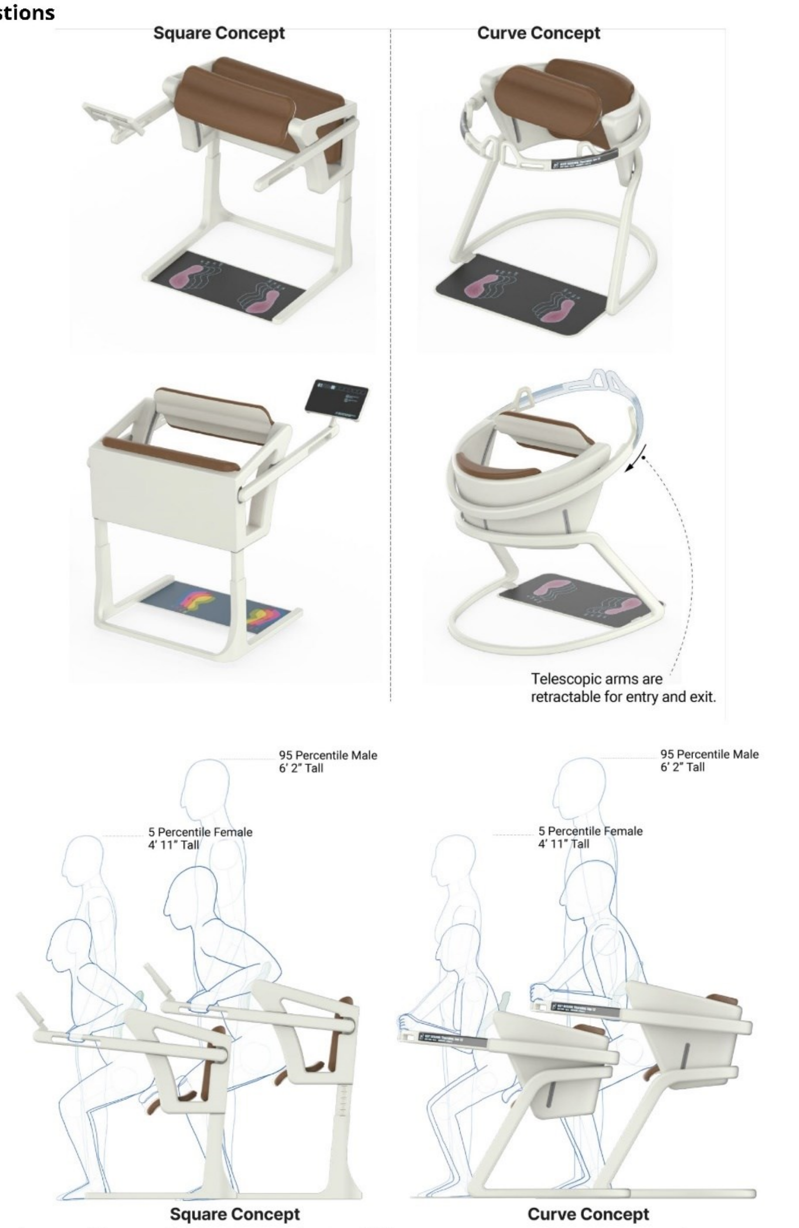


Freestanding version features
- The unit come with feet position guide for proper squatting.
- The unit is height adjustable through built in posts. The height support up to 95 male percetile and 5 female percentile

Wall mount version features
- The unit must be mounted at the correct height by professionals, and might require additional installation fee.
- The unit is adjustable with more limited range.

8. Which option would you prefer? (Freestanding option, Wall-mount option)
9. Can you tell us why? (Not required.)

Variation Questions



10. Which design would you pick between the two? (Square concept, Curve concept)
11. Which design do you think is more ergonomically suitable? (Square concept, Curve concept)
12. Can you tell us why?