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# The relationship between impairments in muscle performance, functional limitations, and disability in older adults

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# THE RELATIONSHIP BETWEEN IMPAIRMENTS IN MUSCLE PERFORMANCE, FUNCTIONAL LIMITATIONS, AND DISABILITY IN OLDER ADULTS

by

Michael Leonard Puthoff

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Physical Rehabilitation Science
in the Graduate College of
The University of Iowa

May 2006

Thesis Supervisor: Professor David H. Nielsen

# ABSTRACT

Many older adults develop restrictions in the performance of activities that are essential to daily living, referred to as functional limitations. Functional limitations can lead to disability, the inability to complete tasks necessary to function in society. A better understanding of how impairments in body systems affect functional limitations and disability in older adults could lead to improved medical management of older adults. The purpose of this study was to examine how impairments in lower extremity muscle performance (strength, power, and endurance) are related to functional limitations and disability in community dwelling older adults. Thirty-four subjects were recruited to participate in this cross-sectional analysis study with 30 individuals completing the study. The Keiser 420 Leg Press was used to measure impairments in lower extremity muscle performance. Functional limitations were classified through the Short Physical Performance Battery, the Six-Minute Walk Test, the Late Life Function and Disability Index (LLFDI) Functional Limitation Component, and average walking speed, average walking distance and average number of steps per day over a six-day period obtained from the AMP 331 physical activity monitor. Disability was measured through the LLFDI Disability Component Limitation Category. Regression analysis was used to examine the direct effect between impairments in muscle performance and functional limitations. Mediation analysis was used to examine the indirect effect of impairments on disability. The results of this study support a relationship between impairments in lower extremity strength and power to functional limitations and disability in community dwelling older adults. Impairments in lower extremity power consistently demonstrated a stronger relationship than strength to all measures of functional limitations and disability. The results of this study did not support a relationship of impairments in endurance to functional limitations or disability. The overall findings of this study would indicate that community dwelling older adults should focus on maintaining and improving lower extremity strength and power across a range of relative intensities in order to decrease functional limitations and disability.

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee for the thesis requirement for the Doctor of Philosophy degree in Physical Rehabilitation Science at the May 2006 graduation.

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# ABSTRACT

Many older adults develop restrictions in the performance of activities that are essential to daily living, referred to as functional limitations. Functional limitations can lead to disability, the inability to complete tasks necessary to function in society. A better understanding of how impairments in body systems affect functional limitations and disability in older adults could lead to improved medical management of older adults. The purpose of this study was to examine how impairments in lower extremity muscle performance (strength, power, and endurance) are related to functional limitations and disability in community dwelling older adults. Thirty-four subjects were recruited to participate in this cross-sectional analysis study with 30 individuals completing the study. The Keiser 420 Leg Press was used to measure impairments in lower extremity muscle performance. Functional limitations were classified through the Short Physical Performance Battery, the Six-Minute Walk Test, the Late Life Function and Disability Index (LLFDI) Functional Limitation Component, and average walking speed, average walking distance and average number of steps per day over a six-day period obtained from the AMP 331 physical activity monitor. Disability was measured through the LLFDI Disability Component Limitation Category. Regression analysis was used to examine the direct effect between impairments in muscle performance and functional limitations. Mediation analysis was used to examine the indirect effect of impairments on disability. The results of this study support a relationship between impairments in lower extremity strength and power to functional limitations and disability in community dwelling older adults. Impairments in lower extremity power consistently demonstrated a stronger relationship than strength to all measures of functional limitations and disability. The results of this study did not support a relationship of impairments in endurance to functional limitations or disability. The overall findings of this study would indicate that community dwelling older adults should focus on maintaining and improving lower

extremity strength and power across a range of relative intensities in order to decrease functional limitations and disability.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# CHAPTER I. INTRODUCTION

## Background

As individuals age, many will develop difficulties in performing basic daily activities. Twenty-seven percent of community-dwelling Medicare beneficiaries over the age of 65 have difficulty performing one or more activities of daily living with 13% reporting difficulty completing instrumental activities of daily living.[1] Over 15% of individuals age 65-74 years are unable to ascend a flight of steps with this figure increasing to 50% for those over the age of 85.[2] Declines in function can progress to a severity that will cause problems in older adults' ability to live in society and negatively affect quality of life.[3]

One theoretical model used to explain why some older adults lose the ability to perform daily activities is the disablement model.[4] The disablement model describes how chronic and acute conditions lead to deficits in the function of specific body systems, fundamental physical and mental tasks, and activities of daily living. The disablement model has four main levels or steps. The first level is pathology. Pathology is defined as the presence of biochemical and physiological abnormalities in the body caused by an acute or chronic disease state. These changes begin on a cellular level and may progress slowly over time. Age-associated changes in physiological systems can be considered as a stimulus for the start of pathology. Pathological changes can progress to a point that will cause significant dysfunctions and abnormalities in specific body systems, referred to as impairments, the second level. Impairments can then lead to the third level, functional limitations. Functional limitations are restrictions in the performance of activities that are essential to daily living. The final level of the disablement model is disability. At this point in the disablement process, functional limitations have progressed to a level that the individual has difficulty performing activities that are essential to complete expected or specific societal tasks.

An individual can move between the different levels of the disablement model based on changes in health status or through therapeutic interventions that address specific impairments. Many researchers and healthcare professionals have tried to identify which impairments increase the likelihood that an older adult will develop functional limitations and disabilities. If this relationship were understood, then therapeutic interventions could focus on improving specific impairments as a means to increase function and ultimately minimize disability in older adults.[5] The study of the relationship of specific impairments to functional limitations and disability in older adults has been identified by both the American Geriatric Society and American Physical Therapy Association as a vital issue that necessitates further examination and understanding.[6, 7]

Older adults demonstrate an overall decline in muscle mass with a specific atrophy of Type II muscle fibers.[8-10] This loss of skeletal muscle due to the aging process, termed sarcopenia, is a pathological condition that can lead to the development of impairments in muscle performance.[11, 12] The age-associated changes in muscle are thought to lead to impairments in muscle performance of older adults. Muscle performance is defined as the overall capability of a muscle or muscle group and is represented by the integrated status of muscle strength, power, and endurance.[13] Muscle strength is defined as the ability of a muscle or muscle group to exert a maximal force or torque at a specific velocity during a muscle contraction.[14] Muscle power is characterized by the product of force production and the velocity at which the force is produced.[14] Muscle endurance is referred to as the ability of the muscle to sustain repeated muscle contractions or resist fatigue during repeated contractions.[15]

Muscle strength and power have both been shown to decline with the aging process with power declining at a faster rate than strength.[8, 16, 17] Questions still remain whether endurance also declines with aging.[15, 18, 19] Since daily activities involve a diverse set of physiological demands, it is likely that older adults will require some amount of all three aspects of muscle performance to maintain their abilities to complete functional tasks. Using the disablement model as a foundation, various researchers have tried to better understand how impairments in strength, power, and endurance affect the degree of functional limitation and disability in older adults.

## Impairments in Muscle Performance and Functional Limitations

The examination of the relationship between impairments in strength, power, and endurance to functional limitations in older adults has been studied in varying depths. The relationship of impairments in strength to functional limitations has received the greatest attention. A loss of strength in the hip abductors, hip extensors, knee extensors, ankle plantarflexors and ankle dorsiflexors has been identified as links to functional limitations in older adults.[20, 21] Investigators have found that 37-40% of the overall variance in self-selected and maximum gait speed can be explained by hip extension, knee extension, and ankle plantar flexion strength.[21, 22] Lower extremity strength has also been shown to be related to the ability to get in and out of a chair, and the rate of falls in older adults.[20, 23, 24] Longitudinal studies have shown low strength to be predictive of developing functional limitations five to 25 years later in individuals who did not demonstrate limitations at baseline assessment.[25, 26]

The relationship of muscle power to functional limitations has received increased examination within the last decade. In a group of nursing home residents, leg extensor peak power was strongly related to chair rising speed ($r = 0.65$), stair climbing speed ($r = 0.81$) and walking speed ($r = 0.80$).[27] A 2003 study by Bean et al found that in a group of community-dwelling elderly females with mild to moderate mobility limitations, lower extremity peak power explained 27-44% of the total variance in stair climbing time, gait speed, balance, and sit to stand time.[28]

Some investigators have studied the relationship of power production at low relative intensity to functional limitations in comparison to the relationship of power production at high relative intensity to functional limitations. Cuoco et al found that power at 40% one repetition maximum (1-RM) explained more of the variance in habitual gait speed than power at 70% 1-RM.[29] The investigators concluded because walking is a low intensity activity, power capability at a lower relative intensity will affect walking more than power at a higher intensity, even if power at the higher intensity is greater. This is one of a few studies that have compared the relationship of power at different intensities to functional limitations. Additional studies that examine how power at a range of relative intensities relates to functional limitations could provide better insight on the importance of muscle power.

Research is limited in examining the relationship of muscle endurance to functional limitations in older adults. In a study by Schwendner et al, lower extremity endurance was compared between a group of 29 young women, a group of 26 older women with functional limitations, and a group of 27 older women with no functional limitations.[30] There was no significant difference in knee extension strength between the two groups of older women. However, the older women with functional limitations demonstrated significantly less knee extension endurance in comparison to both the younger and older women with no limitations in function. This led the authors to conclude that impairment in lower extremity muscle endurance is an important factor in affecting functional limitations in older adults. Another study examining community-dwelling older females found that endurance was related to self-reported functional abilities.[31] In contrast, no relationship was found between lower extremity endurance and functional limitations in a group of frail institutionalized older adults.[32] Very few studies have examined the importance of muscle endurance to functional limitations in older adults. In those studies that have been completed, conflicting findings have been presented.

In studies that have examined the relationships of multiple aspects of muscle performance to functional limitations, impairments in power have repeatedly been shown to be better predictors of functional limitations than strength. In one study that examined the relationships of ankle plantarflexion and dorsiflexion strength and peak power to functional limitations in 34 older women (75.4 ± 5.1 years), plantarflexor peak power was a better predictor of the ability to rise from a chair, and dorsiflexor power was a better predictor of stair climbing time than strength.[33] Another study examined the association between different aspects of physical fitness, including muscle strength, power, and endurance, to a self-reported rating of functional limitations in 80 elderly women (74.8 ± 5.0 years). The results showed that while many aspects of physical fitness, including muscle strength and endurance, were related to functional limitation, lower extremity power was the best physical predictor of self-reported functional status ($r = 0.47$).[31] In a study by Bean et al in 2002, investigators showed that while there was a high degree of interrelationship between strength and power ($r = 0.89$), power was an equal or greater predictor of functional limitations in comparison to strength.[34] At the present time, no studies have contrasted the relationship of all three measures of muscle performance to actual functional limitations.

## Impairments in Muscle Performance and Disability

The relationships of impairments in muscle strength, power, and endurance to disability has received less attention than the relationships of these impairments to functional limitations.[35] A relationship between strength and disability has been demonstrated. In a cross-sectional study using data from the Women's Health and Aging Study, strength of the upper and lower extremities was associated with the presence of motor disabilities in a group of 1002 women aged 65 years or older.[36] In a different study of 567 community-dwelling older adults, low levels of strength were associated with dependency in activities of daily living.[24] Within this same cohort, 227 functionally independent subjects were reassessed five years later. Those originally in the lowest third of muscle strength had a two to three times greater risk of developing a disability in activities of daily living than those in the highest third.[24]

The literature examining the relationships of power and endurance to disability in older adults is lacking. While lower extremity power has been shown to have strong relationships to activities that predict disability, no researcher has examined the influence of power on disability.[28, 31] Further, the link between impairments in endurance to disability has not been explored in older adults.

## Limitations in Current Research

While the literature supports the importance of muscle strength, power, and endurance to functional limitations and that impairments in muscle power may have a stronger effect on functional limitations than strength, there are some shortcomings in these studies. First, the degree of functional limitations has typically been defined through tools that are speed dependent, performed for short periods of time and only address small aspects of function.[27, 34] For example, functional limitations have been characterized as the time to climb a flight of steps, ability to quickly stand from a chair, or gait speed over a short distance. While these tasks are vital to function, they neglect the importance of repetitive activities. These activities are also all performed in a laboratory setting and do not account for how impairments in muscle performance could impact the volume and intensity of community activity. The influence of muscle performance on functional limitations could be better understood if the classification of functional limitations was expanded to also include tools that assess repetitive functional activities over longer time periods. By also examining the volume and intensity of activity completed in the community setting, additional comprehension of functional limitations could be achieved.

Second, understanding the relationship of muscle performance to functional limitations could be enhanced if other measures besides strength and peak power were used in the analysis. Cuoco et al have demonstrated that power at a low relative intensity has a stronger relationship to walking than power at greater intensities. The findings of this study would support the importance of power production across a range of intensities, not just examining peak power. The impact of impairments in muscle endurance on functional limitations in older adults has been examined in few studies with conflicting results.[30, 31, 37] A further examination is necessitated before conclusive statements about the relationship between endurance and functional limitations can be made.

Third, according to the disablement model, impairments in muscle performance will first cause functional limitations and then lead to the development of disability. One limitation of previous studies that have examined how impairments in muscle performance affect disability is that the mediating effect of functional limitations has been neglected. The relationships between impairments and disability have been viewed as a direct relationship.[38] Using a statistical model that would allow the examination of how the intermediary step of functional limitations affects the relationships between impairments and disability would provide a better understanding of disability in older adults.

Finally, in many of the studies that have examined how impairments affect disability, the meaning of disability has been unclear. This is due to different models of disablement and conflicting definitions of disability used in the literature.[38, 39] While the Nagi disablement model defines disability as the inability to perform socially defined roles, the World Health Organization's International Classification of Impairments, Disability and Handicap defines disability as a lack of ability to perform a task or an activity in the manner considered normal for a human being.[39] These conceptual differences have led to confusion in the literature and the lack of a standard measure of disability. In order to properly investigate disability, a definition of disability from a theoretical model that focuses on the development of disability needs to be identified.[40] The measurement tool used to assess disability needs to then fit within the theoretical framework of disability.

## Purpose

While much research has been done to better understand how impairments in muscle performance affect functional limitations and disability in older adults, there are still many aspects of these relationships that need further exploration and clarification. The purpose of this study was to examine the relationships between impairments in lower extremity muscle performance to functional limitations and disability in community-dwelling older adults. Muscle performance was examined through the assessment of lower extremity strength, peak power, power at a low relative intensity (40% 1-RM), power at a high relative intensity (90% 1-RM), and endurance. In contrast to previous studies on this topic, the assessment of functional limitations was expanded to account for the diverse types of activities that older adults need to perform on a daily basis. The six measurements of functional limitations were the Short Physical Performance Battery (SPPB), the Six-Minute Walk Test (SMWT), the functional limitation category of the Late Life Function and Disability Instrument (LLFDI), and the average steps per day (AMP steps), distance traveled per day (AMP distance) and average walking speed (AMP speed) from the AMP 331 activity monitor. Disability was classified through the Disability Category Limitation Component of the LLFDI.

## Specific Aims

The first aim of this study was to examine the relationships between impairments in lower extremity strength, power, and endurance to functional limitations in community-dwelling older adults. Previous research has demonstrated that impairments in strength and power are directly related to functional limitations in older adults. When impairments in strength and power have been directly compared, power has been shown to have a stronger relationship to functional limitations than strength. However, the role of impairments in muscle endurance has been neglected in most studies. When power has been included as a variable in most previous reports, only peak power has been considered. Additionally, functional limitations have been characterized through limited activities such as gait speed, ability to rise from a chair or time needed to complete a task.

This specific aim allowed a better understanding of the importance of impairments in muscle performance by comparing the individual relationships of impairments in lower extremity strength, a range of power values and endurance to a broader classification of functional limitations. Also, by examining how much of the total variability in each measure of functional limitations was explained by the combined effect of impairments in muscle performance, information on the overall importance of muscle performance in older adults was gained.

The hypothesis of specific aim one was that impairments in all three aspects of muscle performance would be significantly related to all measures of functional limitations. Lower extremity power would explain more of the variance in measures of functional limitations that are performed for short periods of time and require high velocity movements. Power at a low intensity would better explain lower intensity activities such as walking. Power at a high intensity would better explain higher intensity activities such as getting out of a chair. There would be minimal differences between the measures of impairments in muscle performance when functional limitations were classified through longer duration activities. A secondary hypothesis of specific aim one was that all three aspects of muscle performance would significantly contribute to the explanation of each measure of functional limitations.

The second aim of this study was to examine the relationships between impairments in lower extremity strength, power, and endurance to disability in community-dwelling older adults. The relationships between impairments in strength and disability have been previously examined with modest relationships demonstrated. The relationships of impairments in power and endurance to disability have not been studied. Examining the individual relationships between impairments in strength, power, and endurance to disability provided a better understanding of the impact of muscle performance on disability. It was hypothesized that impairments in all three aspects of muscle performance would be indirectly related to disability through functional limitations.

In order to account for criticism of previous research studies that have attempted to examine the relationship of impairments to disability, two approaches were taken. First, mediation analysis was used to relate impairments in muscle performance to disability. Mediation analysis allowed the examination of how impairments are related to disability and how these relationships acted through functional limitations. Second, the LLFDI was used to classify disability. The LLFDI measures disability and was created to fit within the disablement model. Because the LLFDI can assess disability across a wide spectrum of degrees, its use enhanced the ability to properly measure disability in community-dwelling adults.[40]

## Definition of Terms

Strength - The ability of a muscle or muscle group to exert a maximal force or torque at a specific velocity during a muscle contraction.[14]

Power - The product of force production and the velocity at which the force is produced.[14]

Endurance - The ability of the muscle to sustain repeated muscle contractions or resist fatigue during repeated contractions.[15]

Pathology - The presence of biochemical and physiological abnormalities in the body caused by an acute or chronic disease state.[4]

Impairment - Dysfunctions and abnormalities in specific body systems.[4]

Functional Limitation - Restrictions in the performance of activities that are essential to daily living.[4]

Disability - Difficulty performing activities that are essential to complete expected or specific societal tasks.[4]

# CHAPTER II. REVIEW OF LITERATURE

## Trends in Aging and Disability

In the year 2000, 12.4% of Americans were over the age of 65.[1] Due to the aging of the baby boomer segment of our population, along with the longer life expectancy enjoyed in our society, this percentage is expected to grow to 21.2% by the year 2050 with the largest growth taking place in the 85 year old and higher segment.[1] Issues dealing with aging continue to grow in importance as this population shift takes place. One issue that has great importance for our aging population is what factors lead to the loss of independence.

With advancing age, there is increased susceptibility to deficits in strength, balance, aerobic capacity, flexibility, and cognitive ability.[41] Additionally, many older adults suffer from chronic health conditions such as heart disease, diabetes, and arthritis that lead to further physiological deficits. These factors can cause the development of limitations in older adults' abilities to perform daily activities. In the year 1999, 27.3% of community-dwelling Medicare beneficiaries over the age of 65 had difficulty performing one or more activities of daily living with 13% reporting difficulty in instrumental activities of daily living.[1] Over 15% of individuals age 65-74 years are unable to ascend a flight of steps with this number increasing to 50% for those over the age of 85.[2]

Over the last decade the incidence of disability and functional limitations in older adults has declined.[3] However, this decline is likely due to advances in diagnostic technology and improvements in medical interventions. With the impending population shift in our society and high costs associated with treating chronic health conditions, there is a great need to expand the body of knowledge addressing methods to prevent or reverse disability in older adults beyond medical interventions. Exercise based interventional programs that address specific deficits to improve older adults' quality of life hold great potential due to their low cost and ease of implementation. However, research needs to be completed to determine physiological factors that lead to functional limitations and disability in order to design the most appropriate exercise programs for older adults.

## Disablement Model

Various theoretical models have been developed to better understand why age-associated deficits in physiological systems lead to functional declines in older adults.[4, 42, 43] One model that has received wide acceptance by researchers and healthcare professionals is the disablement model (Figure 1). The disablement model describes how chronic and acute conditions lead to deficits in the functioning of specific body systems, fundamental physical and mental tasks, and activities of daily living.[4] This model has been used extensively to explain how age-associated changes in the body can cause deficits in older adults' abilities to complete societal tasks.

The disablement model has four main levels or steps. At the start of the disablement model is pathology. Pathology is defined as the presence of biochemical and physiological abnormalities in the body caused by an acute or chronic disease state.[4] These changes begin on a cellular level and can progress slowly over time. Pathology is typically described through the presence of diseases or health conditions such as sarcopenia, heart disease, neurological diseases or osteoarthritis.[44] Age-associated changes in physiological systems can also be considered a stimulus for the development of pathology. Small amounts of pathology may have no immediate effect on bodily function. Over time, pathological changes can progress to a point that will cause significant dysfunctions and abnormalities in specific body systems, referred to as impairments.[4] When impairments are present, body systems are not able to operate at their optimal ability. Impairments are typically classified through results of clinical examinations, medical tests or assessment of physiological systems.

Impairments can progress to a level that they begin to affect mobility and the performance of functional tasks. These restrictions in performing activities that are essential to daily living are referred to as functional limitations.[4] Functional limitations can be assessed through physical performance tests, self-report questionnaires, or by monitoring daily activity levels.

The final level of the disablement model is disability. At this point the individual has difficulty completing activities that are needed to perform expected or specific societal roles.[4] Disability represents a gap between the individual's personal capacity and environmental demands. Physical or mental limitations, environmental obstacles or lack of motivation can all influence disability.[4, 44] Disability is typically measured through self-report questionnaires due to the prohibitive cost of observing individuals in their home environment.

This progression from pathology to disability is not a unidirectional relationship. Individuals can move between the different levels of the disablement model based on changes in health status, interventions addressing pathology and impairments, or changes in their environment. The progression through the disablement model can also be hastened or attenuated based on the presence of risk factors. Risk factors are behaviors or attributes that affect the chances of developing a functional limitation or disability when pathologies are present.[4] Examples of risk factors that have been shown to affect progression through the disablement model include gender, age, education level, and body composition.[5] Intra-individual factors, such as lifestyle and psychosocial attributes, and extra-individual factors, such as medical care, social environment, and external support, can also affect the development of disability.

Many studies have shown that the disablement model provides a valid conceptualization of how older adults become disabled. In a group of over 6800 non-disabled adults age 70 years or higher, the presence of pathology in the form of chronic health conditions was shown to predict functional limitations four years later.[44]

Impairments in various aspects of physical fitness have been shown to be related to functional limitations in both cross-sectional and longitudinal studies.[25, 28, 45, 46] Individuals with difficulty in the performance of functional tasks have also been shown to have a higher rate of disability.[47] Impairments in strength and balance demonstrate an indirect effect on disability levels in older adults.[5, 45]

The disablement model has been used as the foundation of numerous cross-sectional, longitudinal, and interventional studies involving older adults. Some researchers have examined the relationship between only two levels (impairment to functional limitation) of the disablement model and others have addressed how three or more levels (impairments to functional limitation to disability) interact and influence each other.[34, 45] When researchers examine two adjacent levels, they can be directly compared to each other. Special considerations must be adopted when examining levels that are not directly related to each other.[38] For example, it is not appropriate to directly compare impairments to disability. This action would neglect the mediating effect of functional limitations and undermine the basis of the disablement model. In order to understand how impairments influence disability, it must be determined how much of this relationship acts through functional limitations. One proposed statistical method to account for this relationship is through mediation analysis.

## Mediation Analysis

Mediation analysis is a statistical procedure that allows the examination of how an independent variable (IV) influences a dependent variable (DV) through an intervening or a mediator variable (M).[48] Stated another way, mediation analysis assesses how one variable affects a second that in turn affects a third variable. This relationship is graphically depicted in Figures 2 and 3. Figure 2 demonstrates the total effect that the IV has on the DV represented through *pathway c*. Figure 3 shows how the mediating variable, M, affects the relationship between the IV and the DV. *Pathway a* represents the relationship between the IV and the M. *Pathway b* represents the relationship between the M and the DV controlling for the IV. *Pathway c′* represents the direct effect of the IV on the DV controlling for the M. The indirect effect of the IV on the DV, or the portion of the total effect of the IV on the DV mediated through M can be calculated by subtracting *pathway c′* from *pathway c* (c – c′).

Following recommendations by Baron and Kenny, mediation analysis traditionally requires the computation of a series of regression analyses in order to determine the significance and strength of the relationships.[49] Below are the three regression analyses that are performed during simple mediation analysis (i represents the intercept).[50]

Equation 1: $DV = i_1 + c\,IV$

Equation 2: $M = i_2 + a\,IV$

Equation 3: $DV = i_3 + c'\,IV + b\,M$

Baron and Kenny proposed a four step approach to establish if mediation is present.[49] In step one, *pathway c* must be significant in order to first show that the IV is related to the DV (Equation 1). In step two, *pathway a* must be significant in order to show that IV is related to M (Equation 2). In step three, the M must be significantly related to the DV, controlling for the IV variable (*pathway b*) (Equation 3). Controlling for the IV variable is essential, otherwise a significant relationship between the M and the DV may be solely based on the fact that both the M and the DV are correlated with the IV. The fourth step determines whether the effect of the IV on the DV is mediated through the M. The relationship of the IV to the DV, controlling for M, is examined (*pathway c′*). If the coefficient *pathway c′* is not significant in equation 3, then mediation has taken place.

While the Baron and Kenny approach for establishing mediation works well with large sample sizes, when subject pools are less than 50 and the variables demonstrate a non-normal distribution, this method has been shown to have low statistical power.[51] This is because not only does *pathway c′* have to be tested, but *pathway a, b,* and *c* also have to be examined and found significant for mediation to be present. According to the Baron and Kenny criteria, if either *pathway a* or *b* is shown to be not significant, no mediation has occurred even if *pathway c* is significant and *c′* is shown not significant. Since sample sizes less than 50 are common and many variables do not have a normal distribution, there is an increased risk of type II errors with the Baron and Kenny approach.[52]

One variation that has been proposed is the Sobel Test.[49] The Sobel Test compares the estimated indirect effect of IV on DV to the null hypothesis value of zero. The indirect effect is defined as the difference in regression coefficients between *pathway c* and *c′*. The product of coefficients from *pathways a* and *b* (a x b) can also be used to represent this indirect effect (c-c′ = a x b).[51] Using the standard errors from *pathways a* and *b,* the standard error of the indirect effect can be calculated. The indirect effect is then divided by the standard error of the indirect effect to produce a standardized score or a z score [$z = (a \times b)/SE_{ab}$]. Confidence intervals (CI) can then be created around this z score using information from the standardize normal curve. If the confidence interval does not include zero, then a significant indirect effect is present. This provides support that the effect of the IV on DV is mediated through another factor. This technique better addresses mediation and only requires one statistical test in comparison to multiple tests with the Baron and Kenny approach.[50]

When using z scores there is an assumption that the distribution is normal and that subjects are representative of the population in which the results will be applied. Previous investigators have found that multiplying the coefficients of *pathways a* and *b* produces a non-normal distribution with an excess kurtosis even if the distributions of the coefficients were normal to begin with.[52] This violation leads to decreased statistical power to detect significant indirect effects with z scores. One method that can be used instead of the z score transformations to account for these violations is a resampling with replacement approach, otherwise known as bootstrapping. Bootstrapping involves creating a sample size of *n* by choosing one observation from the data set, returning that sample and then repeating the process until *n* observations have been selected. The sample size of *n* is usually set at the size of the original sample. Regression analysis is completed using the selected sample and from this analysis the indirect effect is estimated. This process is repeated anywhere from 1000-10,000 times to create a pseudo-population of indirect effects. This process creates an empirical approximation of the sampling distribution from the available data versus reliance on theoretical assumptions about the general population. Bootstrapping does not require meeting any assumptions about the shape of the sampling distribution for the indirect effect and provides a powerful test on the significance of the indirect effect with a low Type I error rate.[52]

From the distribution of indirect effects following bootstrapping, CI can be created. These CI's are based on the actual distribution of the indirect effects, not from a theoretical distribution as when using z scores. Values are placed in rank order from lowest to highest. Then based on the precision of the CI's desired, the upper and lower limits can be calculated. For example, if 1000 samples were drawn and 95% CI's were sought, the lower limit would have the value associated with the 25$^{th}$ ranked sample (1000 x 0.025 = 25). The upper limit would be the value associated with the 975$^{th}$ ranked sample (1000 * 0.975 = 975).

Some investigators have found that using the percentile approach to calculate CI's can lead to an asymmetrical CI.[53] To correct for this, the use of bias-corrected bootstrapping has been recommended in calculating CI.[52] This method corrects for bias in the central tendency of the estimates and leads to a more powerful and accurate CI.

Certain assumptions are present with mediation analysis. First there is also an assumption that the relationships among variables are linear. Second, when setting up a mediation analysis model, there must be some evidence or theory lending support to the relationship among variables. Finally, mediation analysis does not provide proof of causation. It only establishes the possibility of an indirect effect between the IV and the DV acting through the identified M. In reality, there could be multiple other factors that could account for the relationship between IV and DV.

Mediation analysis provides an ideal method to examine how impairments affect disability in older adults. Mediation analysis allows a method to acknowledge the foundation of the disablement model and it is a proven statistical test with good statistical power to detect indirect effects among variables.

## Age-Associated Changes in Skeletal Muscle

Age-associated changes in the muscular, neurological, metabolic, and hormonal systems have been identified as factors leading to a loss in skeletal muscle mass and performance. This generalized loss of skeletal muscle mass that takes place due to the aging process has been termed sarcopenia and is considered a factor leading to the development of impairments, functional limitations, and disability in older adults.[11, 12]

Total muscle mass has been shown to peak during the third decade of life and is well maintained until the age of 50.[8] After the age of 50 there is a significant decline in muscle mass. Young et al compared a group of healthy older women (age 70-79) to a group of healthy younger women (age 20-29) and found that the older women had 33% lower quadriceps cross-sectional area than the younger women.[9] Through whole body magnetic resonance imaging Jansseen et al found that after the age of 50, there is a significant loss of muscle mass with a greater loss of muscle mass in the lower extremities in comparison to the upper extremities.[54] Those older adults who also suffered from chronic diseases such as arthritis or heart disease experience an even greater loss of skeletal muscle mass.[55] While the performance of high intensity resistance training throughout the aging process can attenuate these changes, a loss of skeletal muscle mass will still be experienced.[56, 57]

A decline in the number of overall muscle fibers is considered the largest mechanism responsible for the loss in muscle mass. Through a series of studies using cadavers, Lexell et al demonstrated that older adults experience a decline in the number of muscle fibers and that this decline accounts for most of the loss in muscle mass.[8, 58, 59] In these studies, the number of Type I and Type II muscle fibers lost were equal.

While the loss of Type I and Type II muscle fibers is uniform, the remaining Type II fibers atrophy while Type I fibers are relatively unaffected.[8, 10] Due to this atrophy, Type I fibers make up a greater percentage of the cross-sectional areas of the muscle and contribute more to the force production than Type II fibers.[60] Since Type I muscle fibers have lower force and contraction velocity capabilities, this will impair muscle's ability to produce high force and high velocity contractions.

Other changes take place in skeletal muscle that affects the quality and function of the remaining muscle fibers. A loss in the specific tension, defined as force production per unit of muscle, has been found to result through the aging process.[61] This finding could be due to the increased amount of intramuscular fat and connective tissue contained in the muscle of older adults.[62] Another factor that affects skeletal muscle activity is an increased amount of co-activation of antagonist muscle groups during voluntary contractions.[63] This co-activation requires the agonist to perform greater amounts of work and lowers the net force production during activity.

The nervous system also undergoes age-associated declines that affect skeletal muscle performance. A slowing of the conduction velocity of the nervous system has been found in older adults.[64] This is due to the age-associated loss of motor neurons, especially fast twitch motor neurons.[65] Muscle fibers that were previously innervated by fast twitch motor neurons tend to be reinnervated by slow twitch motor neurons.[66] These changes affect the speed at which muscle can be activated.

The ability of muscle to sustain repetitive activity is dependent of the oxygen delivered to muscle mitochondria through the vascular system. Skeletal muscle of older adults demonstrates a 19-40% decline in capillary density in comparison to younger adults. Skeletal muscle of older adults also shows a decline in mitochondrial density and aerobic enzymes.[67, 68] These changes affect the ability of muscle to receive oxygen and use oxygen to form adenosine triphosphate (ATP). This causes skeletal muscle to use glycolytic pathways more frequently and earlier in activities instead of the oxidative energy system.[15] This leads to a greater build up of anaerobic byproducts such as lactate and hydrogen ions that affect performance of muscle and lead to fatigue.[69]

## Muscle Performance

The age-associated changes that take place in skeletal muscle can have significant implications on muscle performance. Muscle performance is defined as the overall capability of a muscle or muscle group and is represented by the integrated status of muscle strength, power, and endurance.[13] Muscle strength is defined as the ability of a muscle or muscle group to exert a maximal force or torque at a specific velocity during a muscle contraction.[14] Muscle power is characterized by the product of force production and the velocity at which the force is produced.[14] Muscle endurance is referred to as the ability of the muscle to sustain repeated muscle contractions or resist fatigue during repeated contractions.[15]

These three aspects of muscle performance each represent a separate and specific capability of skeletal muscle, but some interrelationships are present. Strength and power measures are closely related because power is based on force production and contraction velocity of the muscle. Because of this relationship, if an individual has low strength, low power will also likely be present.

Contraction velocity and relative force production are inversely related and are described through the force velocity curve.[14] As the velocity of contraction increases, the force that a muscle can develop decreases. When force production is high, contraction velocity will be small, with no movement present at maximum force production (isometric contraction). Because power is dependent on both force and velocity, peak power is usually achieved at a level of performance when moderate amounts of force and velocity are being produced. Power at the extremes (a low load when velocity is high and a high load when velocity is low) will result in low overall power. Most studies have reported that peak power is achieved at 30% of maximum shortening velocity.[14]

A relationship between strength and endurance is also present. As the relative intensity of performing a task increases, the duration for which force production can be maintained will be decreased.[13] For example, if endurance is measured using an absolute load, the stronger individual will be able to move the load more times in comparison to a weaker individual because the absolute load represents a lower percentage of maximal strength. When endurance is measured with a relative load (a certain percentage of strength) for each person, the relationship between strength and endurance is lessened.

The pathological changes in skeletal muscle during the aging process affect the three aspects of muscle performance in different manners. The impairments in muscle performance can then have unique implications on functional limitations and disability in older adults.

## Impairments in Muscle Strength to Functional Limitations and Disability

The loss of muscle mass during the aging process has a significant impact on strength. Some studies show that 90% of strength declines can be explained through sarcopenia.[70] Muscle strength is estimated to decrease 1-5% per year after the age of 65.[14, 16, 71] By the seventh to eighth decade of life, healthy individuals demonstrate 20-40% less strength than their younger counterparts.[72] The lower extremities musculature of older adults demonstrate a greater decline in strength in comparison to the upper extremities.[18]

Loss of muscle strength has been shown to have implications on functional limitations and disability in older adults. Loss of strength in the hip abductors, hip extensors, knee extensors, ankle plantarflexors, and ankle dorsiflexors have all been identified as links to functional limitations in community-dwelling and institutionalized older adults.[20, 21] Lower extremity strength has been shown to be significantly related to Six-Minute Walk Test performance, ability to get in and out of a chair, speed of climbing steps, and level of disability.[32] Longitudinal studies have shown that low strength in a variety of muscle groups is predictive of developing functional limitations five to 25 years later in individuals who did not demonstrate limitations at baseline assessment.[25, 26] In a cross-sectional study using data from the Women's Health and Aging Study, strength of the upper and lower extremities was associated with the presence of motor disabilities in a group of 1002 women aged 65 years or older.[36] Rantanen et al found that in a group of 567 community-dwelling older adults, low levels of strength were associated with dependency in activities of daily living.[24]

Impairments in Muscle Power to Functional Limitations and Disability

Similar to strength, power is based on the ability of the muscular system to produce force. However, power is also dependent on the neural system to quickly recruit motor units to produce movement.[14] Muscle power has also been shown to decrease with the aging process with a earlier onset and faster rate of decline than strength.[16, 17, 73] This is due to the specific atrophy of Type II muscle fibers, which produces four times the amount of power of Type I fibers, and the shift to more slow twitch motor units.[16, 17, 73] The loss of power production has been shown in both the upper and lower extremities of older adults and found to be similar between genders.[61]

Impairments in muscle power demonstrate a relationship to functional limitations in older adults. In a group of nursing home residents, leg extensor power was strongly related to chair rising speed (r = 0.65), stair climbing speed (r = 0.81), and walking speed (r = 0.80).[27] In a 2003 study Bean et al, investigators found that in a group of community-dwelling elderly females with mild to moderate limitations, lower extremity power explained 27-44% of the total variance in stair climbing time, gait speed, balance, and sit to stand time.[28]

In most studies that have examined the relationship between lower extremity muscle power to functional limitations in older adults, peak power has been used in the analysis. However, investigators have begun to examine how power production at different relative intensities is related to function. Cuoco et al hypothesized that since functional activities like walking require a lower percentage of maximum force, power production at low relative intensities may be more important than power production at high relative intensities.[29] In a study of 48 older adults with physical disability, power at 40% of one repetitions maximum (1-RM) explained more of the variance in habitual gait speed than power at 70% of 1-RM. Previous studies have found that peak power takes place at 70% 1-RM for most subjects, thus power at 70% 1-RM was used to represent peak power in this and other reports.[29, 74] Power at 40% of 1-RM explained similar amounts of the variance in stair climbing ability and chair rise performance as power at 70% of 1-RM. This study demonstrated that impairments in power at different external loads may affect functional limitations in varying manners. No studies have examined how power in the lower extremities is related to disability.

## Impairments in Muscle Endurance to Functional Limitations and Disability

While both strength and power have been shown to decline with the normal aging process, it is unclear if endurance also degrades with aging.[15] Some studies have shown a decline in endurance due to aging, while others have shown that older adults have as much, if not more, relative endurance in comparison to younger adults.[15, 18, 19] Some investigators credit this conflict in the literature to the wide range of assessment techniques used to measure endurance in older adults.[75]

While there is some controversy in how the aging process affects muscle endurance, in general, it appears that most studies support the observation that older adults demonstrate greater relative endurance than younger adults. This finding has been termed the fatigue paradox due to the fact that endurance is maintained through the aging process while strength is lost.[66] The fatigue paradox is thought to take place because Type I fibers do not atrophy and account for a greater proportion of the total muscle size than Type II fibers for older adults in comparison to younger adults.

Some investigators have hypothesized that endurance capabilities might have a large impact on function and disability in older adults due to the varieties of activities that require repetitive motion.[18, 76] For example, walking requires muscle to generate and sustain repetitive dynamic muscle contractions.[77] However, the research examining the relationship between impairments in muscle endurance to functional limitations is minimal. In a study by Schwendner et al, lower extremity endurance and time to recover following a fatiguing event was compared between a group of 29 young women, a group of 26 older women with functional limitations and a group of 27 older women with no functional limitations.[30] There was no significant difference in knee extension strength between the two groups of older women. However, the older women with functional limitations demonstrated significantly less knee extension endurance and required longer time periods to recover in comparison to both the younger women and the older women with no limitations in function. This led the authors to conclude that impairments in lower extremity muscle endurance are an important factor affecting functional limitations in older adults. Another study examining community-dwelling older females found that endurance was related to self-reported functional abilities.[31] In contrast, no relationship was found between lower extremity endurance and functional limitations in a group of frail institutionalized older adults.[32]

No research examining how impairments in muscle endurance are related to disability in older adults has been completed. This demonstrates the necessity of future research examining how impairments in muscle endurance are related to functional limitations and disability.

## Assessment of Muscle Performance

Muscle performance is measured through one of three methods; isometric, isokinetic or isotonic testing protocols. During an isometric muscle contraction, muscle performance is measured in a set position by fixing the joint at a certain angle. The benefits of this form of testing are that it eliminates the need to control contraction velocity and provides an easily reproducible form of testing. However, a major drawback of isometric testing is that muscle performance is only assessed at one angle. This form of testing has less applicability to functional activities that are dynamic and require force production across a range of movements.[76, 78] Also isometric contractions lead to occlusion of blood vessels and an increase in systemic blood pressure. For an older adult with a possibly compromised vascular system, this rapid increase in pressure could have harmful effects.

During isokinetic testing, the velocity of contraction is held constant across the motion of the joint using a dynamometer. The advantages of the isokinetic dynamometers are they allow torque to be measured across a range of movements and velocity is in theory held constant. This leads to very detailed information on muscle performance that no other form of testing provides. The drawbacks of isokinetic dynamometers are they typically require testing in positions that do not reflect everyday activities and usually only allow testing of one muscle group.[66] For example, a common method to assess the lower extremity involves the assessment of knee extensor and flexor performance in a sitting position. Almost no functional activity requires isolated contraction of the knee extensors or flexors in a sitting open chained manner. Also, controlling the velocity of contraction does not mimic every day functional activities.[79] In most daily activities the load that must be moved is held constant (body weight, groceries, or children) and the velocity of movement is adjusted based on the force requirements needed to complete the task. While isokinetic dynamometers provide detailed and specific information on muscle performance, their application to everyday functional activities is questionable in older adults.

During isotonic contractions, the external load that the muscle contracts against is held constant and the subject moves the load through a range of movement. The velocity of movement is controlled by the subject and the force production of the muscle will vary based the torque created by the external load. The benefits of using isotonic contractions to assess muscle performance are that the testing is being performed across a range of motion and the mode of testing can be designed to mimic functional activities.[79] This allows a better understanding of how muscle performance is related to functional activities. The drawback of this method of testing is that the torque production of muscle changes throughout the range of movement and this value cannot usually be assessed. Additionally, the velocity of movement cannot be controlled.

## Lower Extremity Strength Assessment

When strength is measured isometrically, subjects are instructed to forcefully contract as hard as they can against an immovable object and to hold this contraction for three to five seconds.[80, 81] Strength is defined as the force measured through a load cell or the level of muscle activation measured through electromyography.

During isokinetic assessment the peak torque production at a certain contraction velocity is used to determine strength.[30, 82, 83] During isokinetic strength testing, subjects are instructed to contract as forcefully as possible against the lever arm of the dynamometer. The dynamometer controls the speed at which the limb moves while simultaneously measuring force production through the range of motion.

The maximal amount of mass that can be moved safely with correct form throughout a range of movement, 1-RM, is considered the gold standard for measuring strength isotonically. Weight is progressively increased until the subject fails to safely and correctly complete a full range of motion. This load is referred to as the 1-RM. The speed of movement during 1-RM testing is low due to the maximal force production, however, the velocity is subject dependent.

## Lower Extremity Power Assessment

The assessment of muscle power is more challenging due to the need to simultaneously measure force and velocity. Three main modes of testing, isokinetic dynamometers, the Rottingham Rig, and the Keiser equipment, have typically been used to assess muscle power in older adults. During the measurement of power with the isokinetic dynamometer, force production is multiplied by the velocity of movement to calculate power. Power is usually tested across a range of velocities.

The Rottingham Rig involves subjects sitting in an adjustable seat, placing their hands on their lap, one foot on a foot plate and the other foot on the floor.[84] During testing, the subject applies a maximal force through the foot plate which then accelerates the flywheel connected to the foot plate. Power is calculated by the final velocity of the flywheel, amount of rotation of the wheel, the moment of inertia of the flywheel, and the time to complete the motion. Velocity is measured using an infra-red switch that is triggered every quarter turn. The advantage of the Rottingham Rig is that it tests power in a closed chain manner and tests muscles needed for daily activities such as climbing stairs and getting in and out of chairs. The major drawback of the Rottingham Rig is that power production can only be measured under one situation. It is not possible to adjust the amount of resistance provided by the flywheel. This limitation prevents the measure of power across a range of external loads.

The Keiser equipment incorporates a piston pneumatic system that allows the use of air pressure to create resistance.[85] Pedals or handles are connected to a piston inside the cylinder. As the piston moves inside the cylinder, pressure builds and resistance increases. Resistance can then be adjusted by adding or removing air from the cylinder prior to the movement of the pedals or handles.

Inside the cylinders, a transducer sensor samples pressure changes and another transducer measures the positional changes of the piston at a rate of 400 Hz.[85] Both measures demonstrate accuracy of greater than 99% (correspondence with Keiser Chief Engineer Gus Gustafson and information provided in operational manual[85]). The resistance provided by the cylinder is calculated based on the air pressure in the cylinder and the area of the piston. Power is then calculated as the product of the cylinder resistance and movement velocity of the piston. The circuitry of the equipment interfaces with a computer and software designed by the Keiser Corporation. Data from the cylinder is converted through the software to calculate the force and power production at each pedal or handle of the equipment.

To assess power using the Keiser equipment, the most frequently used protocol involves first determining 1-RM. Then power is assessed across a range of relative intensities. The external resistance is set at a percentage of 1-RM and subjects are instructed to move the load as quickly as possible. Power values across a range of relative intensities can then be examined through this method.

The benefits of the Keiser equipment are power can be measured against a range of loads and the resistance is created through air, allowing a smoother and more consistent resistance. The drawback of the Keiser equipment is that some of the machinery can be difficult for older adults to use and the velocity of movement cannot be controlled like an isokinetic machine.

Lower Extremity Muscle Endurance Assessment

Endurance can be measured through isometric, isokinetic, and isotonic means. When endurance is assessed through an isometric contraction, the time a contraction can be maintained is used as an outcome measure.[82, 86, 87] Subjects are instructed to hold the contraction as long as possible. When the force production falls below a certain threshold, the test is completed and time of contraction recorded.

When using an isokinetic dynamometer, the decline in force across multiple contractions is used to assess endurance.[80, 83, 88, 89] Subjects are instructed to perform a series of contractions as forcefully as possible. Subjects usually complete 25-50 repetitions at velocities ranging from $120^{o}$/sec to $180^{o}$/sec. Then the force from the start of the test is compared to the force at the end of the test.

Based on recent studies indicating that power is vital to function in older adults, some investigators suggest endurance should be assessed through the ability to maintain power across multiple contractions.[89, 90] This method of measuring endurance has been shown to be a reliable and valid measure in older adults using isokinetic machines.[89, 90] However, no investigator has examined how the decline in power during an endurance test relates to functional limitations or disability in older adults.

When endurance is tested isotonically, the maximum number of contractions that can be completed at a relative intensity is used to classify endurance.[32, 37, 87, 91, 92] The load is set at anywhere from 50% 1-RM up to 90% 1-RM. The load is usually chosen so the subject fatigues within the first 1-2 minutes of activity in order to stress the glycolytic energy system.[93] The cadence of contraction is usually controlled through a metronome or a rhythmic signal.

Activity Monitors as a Measure of Functional Limitations

The measurement of functional limitations through standardized assessment tools such as the SMWT and the SPPB provide an effective and valid manner to evaluate older adults' capabilities. However, these tools only capture abilities within a laboratory environment and may not represent what individuals do in their normal environment.[94] Currently accelerometry-based activity monitors are one of the more objective and increasingly common methods used for assessing free living physical activity.[95] Accelerometry-based activity monitors measure both the frequency and intensity of movements, collect data for extended periods of time and can be worn on the waist or lower extremity in an unobtrusive manner.[96] Data are collected for a series of days with number of steps, distance traveled, walking intensity, or caloric expenditure used as outcome measures.[96]

Accelerometry-based activity monitors have been successfully used in a variety of patient populations including healthy adults, patients with pulmonary disease, patients with heart failure and older adults.[97-99] The greatest advantage of accelerometry-based activity monitors is they are able to classify physical activity levels by both the volume and intensity of activity over an extended time period within a person's natural environment. Drawbacks of this method include their inability to record non-ambulatory activities such as biking, swimming or upper extremity activities. The validity of activity monitors is dependent on patient compliance with donning the activity monitors.

## Assessment of Disability

In many of the studies that have examined how impairments affect disability, the definition of disability has been unclear due to differences between theoretical models of disablement.[38, 39] While the Nagi disablement model defines disability as the inability to perform socially defined roles, the World Health Organization's International Classification of Impairments, Disability, and Handicap defines disability as a lack of ability to perform a task or an activity in the manner considered normal for a human being.[39]

The different concepts of what is disability have led to various tools being used to measure disability. Some measures of disability only consider basic and instrumental activities of daily living, neglecting higher level activities and performance of tasks in society.[100, 101] Other measurement tools simultaneously assess health symptoms, health status, physical performance, and emotional status making no distinction between what represents disability, functional limitations or impairments.[102] Other limitations of measurement tools used to classify disability include significant ceiling and floor affects in community-dwelling older adults or the measurement tool treats disability as a dichotomous factor.[40, 103]

The various definitions of disability and the numerous tools used to measure disability have disguised the true nature of disability for many older adults and limit conclusions that can be made about treating and preventing disability. In order to properly investigate disability, first a definition of disability needs to come from a theoretical or conceptual framework that focuses on the development of disability.[40] Second the measurement tools for disability need to assess the multiple aspects of disability and fit within the identified theoretical and conceptual framework. Questionnaires that strictly measure disability and account for varying degrees of disability would provide a better means to understand how older adults become disabled.

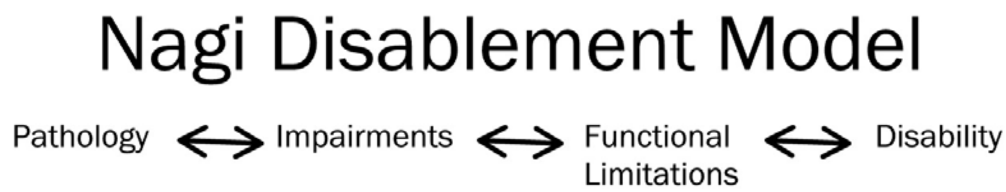


Figure 1. Nagi Disablement Model.

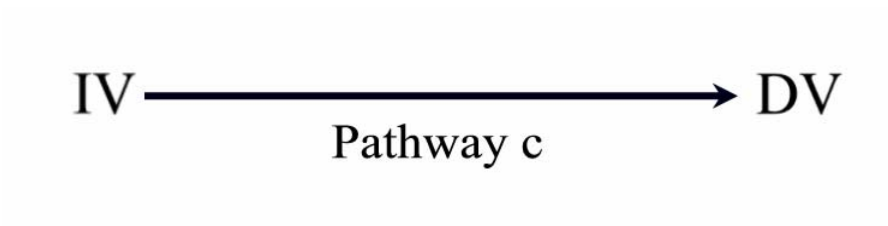


Figure 2. Total Effect of the Independent Variable on the Dependent Variable.

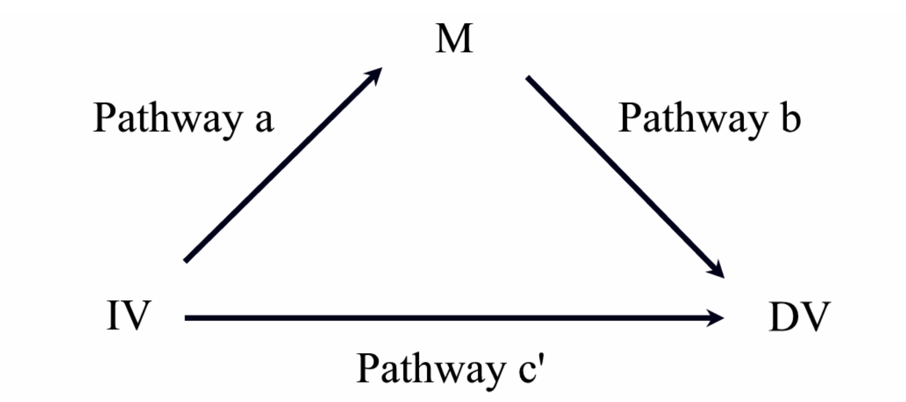


Figure 3. Mediation Model.

# CHAPTER III. PROCEDURES

## Subjects

Thirty community-dwelling adults with self-reported mild to moderate functional limitations, 65 years of age or older, were recruited to participate in this study. Subjects were recruited from the community through local agencies that interact with older adults and from independent senior living complexes. Self-reported mild to moderate limitations were defined as a self report of at least one limitation on the physical function subscale of the Medical Outcome Survey (SF-36) (Appendix A).[102, 104] Subjects with acute or terminal illnesses, myocardial infarction in the last six months, moderate or severe chronic obstructive pulmonary disease, uncontrolled hypertension, uncontrolled metabolic disease, acute orthopedic injuries, recent unhealed fractures, neurological disease, muscular disease, or significant cognitive impairments (<23 on the Folstein Mini Mental State Examination[105]) were excluded from participation in this study.

Results of previous reports that have examined the relationships between impairments in muscle performance and functional limitations in community-dwelling older adults, found correlation coefficients approximating 0.60.[31, 34, 106] Based on these findings, the current study was designed to detect correlation coefficients of similar magnitude between measures of impairments and functional limitations. To detect a correlation coefficient of 0.60 as significant, assuming a significance level of $\alpha = 0.05$, it was determined a sample size of 20 subjects was needed to provide 80% power and a sample size of 25 subjects was needed to provide 90% power.

## Measurements

### Impairments in Muscle Performance

Impairments in lower extremity strength, power, and endurance were assessed on the Keiser Air 420 leg press machine (Keiser Corporation, Fresno, CA). This machine

(Figure 5) tests the ability of the lower extremities to produce force against a set external resistance. In a sitting position subjects placed their feet on two connected pedals which then aligned their hips and knees in a flexed position. Subjects extended their hips and knees against the resistance to move the pedals away from their body. The motion required on the leg press machine provides an overall assessment of lower extremity muscle performance by testing the hip extensors, knee extensors, and ankle plantarflexors concurrently across a functional range of motion.[107-109]

Inside the cylinders of the leg press, one transducer sensor samples pressure changes and another transducer samples position changes of the piston at a rate of 400 Hz.[85] The resistance provided by the cylinder is measured based on the air pressure in the cylinder and the area of the piston. Power is then calculated by the product of the cylinder resistance and movement velocity of the piston. The circuitry of the leg press machine interfaces with a desktop computer and software designed by the Keiser Corporation. Data from the cylinder are converted through the software to calculate the force and power production at each pedal of the leg press. This conversion is calculated based on the design dimensions of the leg press and the positional relationship between the pedals and the cylinders. A three-step process is used to establish the zero point of the pressure transducer sensor, the zero point of the position transducer sensor, and the range of the position transducer sensor. Calibration of the pressure span is done by the manufacturer prior to delivery.

Impairments in Lower Extremity Strength

Lower extremity strength was assessed through the measurement of a one repetition maximum (1-RM) (Appendix E describes the testing protocol for muscle performance trials). One repetition maximum is defined as the maximum amount of weight lifted one time using proper form during a standard exercise. The 1-RM is considered a valid measurement of strength in older adults.[110] This method of strength testing has been shown to be safe in older adults with various forms of health conditions when conducted with proper supervision and instruction.[111-114] Additionally, this method of muscle performance testing has been used in numerous studies involving older adults with no report of serious injuries.[115, 116] After one session of familiarization to 1-RM testing procedures, this measure of strength demonstrates good stability and between session reliability (r = 0.98).[117]

Impairments in Lower Extremity Power

Lower extremity power was measured at each of the following external resistances; 40, 50, 60, 70, 80, and 90% of 1-RM. Three trials at each percentage of 1-RM were measured and the highest trial value was used for analysis. This technique is routinely used in older adults to measure lower extremity power, demonstrates high test-retest reliability and shows good agreement with other forms of lower extremity power testing.[118, 119]

In the current study, three measures of power were used to represent impairments in lower extremity muscle power. Overall peak power, regardless of the external load achieved, was used for analysis along with power at 40% 1-RM and power at 90% 1-RM. Power at 40% 1-RM and power at 90% 1-RM were chosen to represent power at a low load/high velocity and power at a high load/low velocity respectively.

Impairments in Lower Extremity Muscle Endurance

Muscle endurance was measured by instructing subjects to perform as many contractions as possible at 60% of 1-RM. Repetitions were completed at a rate of one every three seconds and subjects were instructed to perform each concentric contraction as quickly and forcefully as possible in order to produce the highest power possible. This testing protocol was designed to fatigue the lower extremities and to cause a steady decline in power with each repetition due to the high power output associated with each repetition.

Three measures of lower extremity endurance were used in the current study. First, the total number of contractions completed during the testing protocol was used. This measure provided a traditional assessment of endurance commonly employed when assessing endurance through isotonic means. The second and third measures were novel approaches that have not been previously used in the literature. The measures involved examination of the decline in power across the first 10 repetitions and the decline in power across the first 15 repetitions of the endurance protocol. These measures could be used due to the capability of the Keiser 420 Leg Press to measure the power production of each repetition.

Because it was unclear how much fatigue would take place with this protocol, power declines across two ranges of repetitions were chosen as outcome measures. Based on the relationship between the relative intensity used for testing (60% 1-RM) and the number of repetitions most individuals should be able to complete at this load, it was determined that all subjects should be able to complete 10 repetitions, most should be able to complete 15 repetitions, but some might have difficulty achieving 20 repetitions. This was the rationale used to examine power decline across 10 and 15 repetitions.

The peak power values from the first three repetitions to the average power of repetitions 8-10 were used to calculate the percent decline in power across the first ten repetitions. Peak power values from the first three repetitions to the average power of repetitions 13-15 were used to calculate the percent decline in power across the first fifteen repetitions. The peak value from the first three repetitions was used because previous reports have found that when using a similar testing protocol with isokinetic machines, most individuals do not achieve peak power until the second or third repetition.[89] Using an average of the first two to three repetitions would lead to an artificial lowering of the peak power capabilities of the individual.

# Functional Limitations

## The Short Physical Performance Battery

The Short Physical Performance Battery (SPPB) is an assessment tool used to measure function during tasks that mimic daily activities (Appendix C). This tool was developed based on results from more than 5000 older adults who participated in the Established Populations for Epidemiological Studies of the Elderly (EPESE).[104] The SPPB measures three areas, 1) the ability to maintain static balance in a feet together, semi-tandem and tandem posture, 2) time to walk a four meter distance at a normal pace, and 3) time to complete five sit to stand transfers as quickly as possible. Each category is scored on a 0-4 scale with zero being unable to complete the task and four being the highest level of performance. Scores for each category are added to create a summary score between zero and 12.

The SPPB has been shown to have high test-retest reliability demonstrated by an ICC = 0.88-0.92.[120] Validity studies have shown that those individuals with higher scores have a lower rate of disability.[47] The SPPB has high predictive validity in identifying those at greater risk for mortality, nursing home admission, and incidence of disability over a one-year and four-year time period.[121] A one-point change in SPPB represents a clinically significant difference in the risk of mortality and disability and this relationship is present throughout a full spectrum of functioning.[104] The SPPB has also been shown to be sensitive to changes in health status in older females with moderate functional limitations.[120] The SPPB provides a reliable, valid, and sensitive measure of functional limitations and an estimate of the probability of future disability.

The total score of the SPPB was used in analysis as a measure of functional limitations. The subscale scores of the SPPB were also used in data analysis to provide information on the influence of impairments in muscle performance on specific functional activities.

Six-Minute Walk Test

The Six-Minute Walk Test (SMWT) is a commonly used tool to assess functional status in older adults (Appendix D). The SMWT has been shown to moderately correlate with other measures of function in older adults, such as time to stand from a chair ($r = 0.67$), tandem balance ($r = 0.52$), and walking speed ($r = 0.73$).[122] It has also shown a relationship to self-report measures of disability, quality of life, and limitations in activities of daily living for older adults.[122, 123] In a study of 515 older adults without cardiovascular or pulmonary disease, it was found that sensorimotor function, balance, pain, psychological, and general health measures were all related to results from the SMWT.[124] Based on this information and the fact that the SMWT examines mobility over greater distances than the SPPB, using the distance ambulated during the SMWT as a measure of functional limitations provided a more inclusive understanding of function in older adults.

AMP 331 Activity Monitor

The AMP 331 Activity Monitor (Dynastream Innovations, Cochrane Alberta, Canada) is a triaxial accelerometer worn on the ankle that utilizes acceleration data along with the angular position of the shank to tabulate cadence, determine the length of each step, and the time duration of each step (Figure 4). From this information gait speed and distance traveled are calculated. Activity is classified into one of three categories, inactive, active or locomotion. The inactive category is when there is no movement by the subject for over 20 seconds.[125] The active category is when subjects are up and about, but take occasional steps in a noncontinuous pattern. The locomotion category is when 20 or more continuous steps are taken. Data are downloaded to a computer via a radio frequency link and viewed in a spreadsheet format. Data can be viewed in epochs of one minute to one hour.

The manufacturer of the AMP 331 reports the accuracy of the units to be over 98% for activity classification, over 98% for step count, and over 95% for walking speed and distance.[126] In a study involving a group of eight children, eight adults, and eight older adults, the AMP 331 demonstrated a 94% accuracy for distance traveled and a step count accuracy of over 99% when these individuals traveled at various speeds over known distances.[127] In a study of 41 healthy young adults, the AMP 331 demonstrated a level of accuracy in measuring step count, distance traveled, and walking velocity that would be clinically acceptable when subjects' activity is primarily walking.[128] However, this study did question the ability of the AMP 331 to accurately assess running stride length and running speed.

The average number of steps per day (AMP steps), distance traveled per day (AMP distance), and average walking speed per day (AMP speed) were determined from six full days of wearing the AMP 331. AMP steps and AMP distance were chosen in order to capture the volume of activity subjects complete during a typical day. AMP speed was chosen to capture the intensity of daily activity levels. Since self-selected walking velocity has been shown to be associated with disability in older adults, AMP speed provided a great contribution to examining how muscle performance affects functional limitations and disability in older adults.[129-131]

<u>The Late Life Function and Disability Instrument –</u>
<u>Function Limitation Component</u>

The LLFDI is a self-report questionnaire specifically designed to evaluate the functional limitations and disability component of the Nagi disablement model (Appendix B). The function limitation component of the LLFDI assesses how much difficulty older adults have in performing 32 different activities without the help of someone else and without the use of an assistive device (Appendix B). During an interview process subjects are asked how much difficulty they have in performing activities. Subjects provide one of the following responses; none, a little, some, quite a lot, cannot do. Raw scores are converted to a 0-100 scaled summary score. Scores that approach 100 signify high levels in ability to perform actions and scores that approach zero indicate low levels in ability to perform actions. There are three categories in the functional limitation component of the LLFDI; upper extremity function, basic lower extremity function, and advanced lower extremity function. Upper extremity function reflects tasks such as unscrewing the lid off a jar, holding a full glass of water and reaching behind the back. Basic lower extremity function involves standing, stooping, and fundamental walking activities. Advanced lower extremity function includes activities such as running, walking a mile or more, going up and down steps, and walking on a slippery surface. Correlation analysis revealed some overlap between the categories (advanced to basic lower extremity function, r = 0.87; advanced lower to upper extremity function, r = 0.64; basic lower to upper extremity function, r = 0.69).

The functional limitation component of the LLFDI has also been shown to have a high reliability (ICC = 0.91-0.99) and can discriminate between groups of older adults with different functional abilities.[40] The functional limitation component of the LLFDI has a strong correlation with the physical function subscale of the SF-36 (r = 0.51-0.74) and shows significant correlation with gait speed from the 400 meter walk test and SPPB results (r = 0.63-0.73).[103]

The total score for the function limitation component of the LLFDI was used as a measure of functional limitations. The total score provided a global assessment of functional limitations by assessing various aspects of daily activities that could not be feasibly assessed in a laboratory setting.

## Disability

### The Late Life Function and Disability Instrument – Disability Component

The disability component of the LLFDI assesses how frequently older adults perform 16 socially defined life tasks and how limited they feel in completing these tasks.[40] Subjects are asked how often they perform a particular task with response options of very often, often, once in a while, almost never, or never. Subjects are then asked to what extent they feel limited in performing a particular task with response options of not at all, a little, somewhat, a lot, or completely. Raw scores are converted to a 0-100 scaled summary score. Scores approaching 100 signify high levels in the frequency in performing life tasks or high capability of performing life tasks, and scores approaching zero indicate low frequency or low capability of performing life tasks. Separate scores are calculated for the frequency total and the limitation total with separate domains under each category.

Under the frequency of disability category, there are two domains, social role domain and personal role domain. Social role domain score reflects the frequency of performing various social and community tasks. The social role domain includes items such as visiting friends and family, traveling out of town, going out with others to public places, and taking part in active recreation. Personal role domain reflects the frequency of performing various personal tasks such as taking care of own health, running local errands, and preparing meals. The correlation between the social and personal role domains based on factor analysis was $r = 0.43$, indicating that each domain is measuring different aspects of disability.[40]

Under the limitation category there are two domains, instrumental role domain and management role domain. Instrumental role domain reflects limitations in activities at home and in the community, and includes activities such as providing care or assistance to other, taking care of the inside of the home, traveling out of town, and running local errands. Management role domain involves limitations in organizing or managing social tasks involving minimal mobility and physical activity. This involves activities such as keeping in touch with others, taking care of one's own health and completing household business and finances. The correlation between the social and personal role domains based on factor analysis is r = 0.57, indicating that each domain is measuring different aspects of disability.[40]

The disability component of the LLFDI demonstrates good reliability and validity. In the initial development and evaluation of the LLFDI, the disability component showed good test-retest reliability (ICC = 0.68-0.82) and was able to differentiate between groups of older adults with varying functional abilities. In other studies, the disability component of the LLFDI was significantly associated with the London Handicap Scale (r = 0.47-0.66) and demonstrated moderate to weak correlations with gait speed and SPPB.[103] The LLFDI has minimal floor and ceiling effects while other measures of disability demonstrate ceiling effects of up to 31% when used with community-dwelling older adults.[103]

The limitation category of the LLFDI disability component was chosen as the measure of disability in the current study. The limitation category has been shown to more closely mimic other measures of disability, has higher reliability than the frequency domain, and has been chosen by previous researchers as a more appropriate measure of disability versus the frequency domain.[40, 103, 132]

## Procedures

All potential subjects underwent a screening session prior to acceptance into the study. Potential subjects were asked about their past medical history, current medication use, and highest education level achieved. Subjects who reported at least one limitation on the physical fitness subscale of the SF-36 (Appendix A) and did not present with medical conditions that limited participation in this study were invited to participate in the study.

Data were collected over three test sessions. During the first session, data on subject's height to the nearest 0.5 cm, weight to the nearest 0.1 kg, resting heart rate (bpm), and resting blood pressure (mm Hg) were assessed. Subjects performed the SPPB to assess their level of functional limitations (Appendix C). Following the SPPB, subjects completed the Geriatric Depression Scale (Appendix F).[133] A score greater than nine is an indication of clinical depression. Subjects who scored greater than nine were informed of their score.

Using guidelines established by the American Thoracic Society, The SMWT test was then performed followed by completion of the LLFDI (Appendix B and C).[134] At completion of the LLFDI, subjects completed an orientation session on the leg press so they were prepared for muscle performance testing in the following sessions. Subjects practiced high velocity contractions using the endurance test cadence. Submaximal weights were used during this orientation session.

At the completion of the orientation session, subjects were oriented to the use of the AMP 331 Activity Monitor. Subjects were instructed to place the AMP 331 around their right ankle when they get out of bed in morning and to wear the activity monitor continuously (except for bathing, showering, or swimming) until they went to bed in the evening. Subjects were asked to wear the AMP 331 for a one-week time period.

The second session took place seven-days following the first session. Lower extremity strength was first assessed using the Keiser 420 leg press machine (see Appendix E for detailed description of muscle performance testing protocol). Subjects completed a warm-up trial with 10-15 repetitions at 50-60% of their predicted 1-RM followed by 5-10 repetitions at 70-80% of their predicted 1-RM. After a three minute rest, subject's 1-RM was tested. Subjects were given a two to three minute rest between trials with the goal of determining 1-RM within five trials.

At the completion of lower extremity strength testing, lower extremity power was assessed. Power measurements were taken at 40%, 50%, 60%, 70%, 80%, and 90% of the measured 1-RM. Subjects were instructed to extend their legs as quickly as possible against the set resistance and then slowly return the pedals to the start position. Three attempts were given at each stage with the highest trial value recorded for analysis. A 30-60 second rest was given between each of the three attempts.

Finally, lower extremity endurance was assessed using the Keiser 420 leg press machine. Resistance was set at 60% of the 1-RM. Subjects were instructed to perform the concentric phase of the contraction as quickly and forcefully as possible to produce the greatest amount of power possible with each repetition. Subjects were given up to one second to complete the concentric phase of the movement and two seconds to return the pedals to the starting position before having to repeat another contraction. Prerecorded audio cues were played for the subject to ensure a uniform pattern of contraction between subjects. The prerecorded cues were as follows; "One and two and go, one and two and go…". The tester also gave verbal encouragement during the endurance testing. The test ceased under one of the three situations; 1. the subject felt he or she could no longer complete the exercise, 2. the subject was unable to complete a full repetition, or 3. the subject was no longer able to keep pace with the audio cues.

During the third session (2-7 days after the second session), lower extremity strength, power, and endurance measures were repeated following the same protocol used during the second session. A second trial of muscle testing was performed to account for any possible learning effect associated with muscle performance testing in older adults.[117] The greater of two strength measures were used for analysis. The power and endurance testing results associated with the highest strength measurement were used for analysis. If a subject had the same strength measurements between the two trials, the higher power and endurance results were used for analysis.

## Analysis

Descriptive statistics (mean, SD) on all variables were calculated. Normality of the distribution of all variables was examined. Analysis was completed to determine if any gender differences were present in measures of muscle performance, functional limitations or disability.

### Specific Aim #1

Regression analysis was used in order to address specific aim 1, the examination of the relationships between impairments in lower extremity strength, power, and endurance to functional limitations in community-dwelling older adults. Separate linear regression analysis was used to determine the relationship between each measure of impairments in muscle performance (strength, peak power, power at 40% 1-RM, power at 90% 1-RM, number of reps, power decline over 10 repetitions, power decline over 15 repetitions) to each measure of functional limitations (SWMT distance, SPPB total score, and subscales, AMP steps, AMP distance, AMP speed, and LLFDI Functional Limitation Domain score). Functional limitations were the dependent variable and impairments in muscle performance were the independent variable. Regression coefficients, standard errors, and coefficients of determination ($R^2$) were examined for each analysis. Age and gender were considered as possible covariates. If age or gender was significantly associated with the measures of functional limitations, they were entered into the model prior to the measure of muscle performance.

Previous studies have demonstrated a curvilinear relationship between strength and functional limitations, and power and functional limitations.[34, 45] Analysis was performed to determine if a curvilinear relationship was present between each impairment and functional limitation. Scatterplots were first visually inspected for any signs of a non-linear relationship. Each measure of muscle performance was then centered (linear term). Then the centered term was squared (quadratic term). Centering involves subtracting the mean of the variables. Centering eliminated the collinearity between the linear term and the non-linear term, but still allowed for the examination of non-linear relationships. The squared centered term was added to the regression equation to determine if the model was significantly improved with the addition of this new variable. If the model did improve, this was an indication that a curvilinear relationship was present.

Stepwise regression analysis was used to determine which combination of impairments in muscle performance explained measures of functional limitations. Age and gender were considered as possible covariates and added to the analysis as necessary. The significance level for entrance into the regression equation was set at $p < 0.05$ and the significance level for removal was set at $p > 0.10$. Stepwise linear regression analysis achieved two goals. First, it demonstrated which measure of muscle performance was initially entered into the regression equation and thus explained more of the functional limitations in comparison to the other measures of impairments in muscle performance. This process provided a method to determine which measure of muscle performance would be considered most important to each measure of functional limitation. Second, stepwise linear regression analysis provided information on how much total variance in functional limitations could be explained by multiple measures of muscle performance. This provided some guidance on whether multiple aspects of muscle performance affected functional limitations in unique ways and how much of the total variance in functional limitations could be explained through a combination of muscle performance characteristics.

Regression diagnostics were investigated for all models. If a standardized residual was three or more standard deviations from the mean, it was considered an outlier. The influence of each case on the regression equation was examined through Cook's Distance. Cases with Cook's Distance values greater than one were identified as cases that should be considered for exclusion. The leverage statistic was also examined to determine if one case had a greater influence on the regression model than other cases. Data points with leverage values greater than 0.5 were examined and considered for possible exclusion from further analysis. Finally, when multiple independent variables were entered into a regression equation, collinearity between the variables was examined. A tolerance less than 0.20 was an indication of collinearity and the need for further analysis.

## Specific Aim #2

Mediation analysis was used to address specific aim 2, the examination of the relationship between impairments in lower extremity strength, power, and endurance to disability in community-dwelling older adults. Mediation analysis is a statistical procedure that allows the examination of how an independent variable influences a dependent variable through an intervening or a mediator variable[48] (See Chapter II for a detailed explanation of Mediation Analysis). While there were over 50 possible mediation analyses that could have been performed, only the analyses presented in Table 1 were completed. These analyses were chosen *a priori* because they allowed each mpairment to be related to disability through two standard and accepted measures of functional limitations.

The SPPB has been shown to be a strong predictor of disability in older adults and is a commonly used measurement tool in studies involving older adults. Since the SPPB measures function through short duration, high velocity activities, it may be biased towards the finding that power is more related to disability. The SMWT test was chosen as a second mediation factor because it has also been shown to be a predictor of disability in a wide range of patient populations. In contrast to the SPPB, the SMWT requires a longer duration of activity and measures function through different means. Based on these facts, the SMWT may have a different mediation effect in comparison to the SPPB.

For each *a priori* mediation analysis in Table 1, resampling with replacement (bootstrapping) was used to create a sample size equal to the number of data sets appropriate for analysis (if 29 subjects had valid data, a sample size of 29 was created through bootstrapping). A series of regression analyses were completed on this data and the indirect effects was calculated by multiplying the regression coefficient from the equation examining the relationship between the independent variable (IV) to the M (mediator) (M = i + aIV) and the regression coefficient from the equation examining the relationship between the M and dependent variable (DV), controlling for the IV (DV = i + c′ IV + bM) (a x b). This process was repeated 5000 times and resulted in 5000 estimates of the indirect effect of the IV on the DV. From these 5000 estimates of indirect effect, 95% confidence intervals (CI) were created using a bias-corrected method to determine if zero was included in the range. If zero was not within the 95% CI, then it was concluded that the indirect effect of the IV on the DV acting through the M was significant.

Table 1. *A Priori* Simple Mediation Analysis.

| Independent Variable | Mediation Variable | Dependent Variable |
|---|---|---|
| Strength | SPPB | LLFDI Limitation Domain |
| Strength | SMWT | LLFDI Limitation Domain |
| Power | SPPB | LLFDI Limitation Domain |
| Power | SMWT | LLFDI Limitation Domain |
| Endurance | SPPB | LLFDI Limitation Domain |
| Endurance | SMWT | LLFDI Limitation Domain |

SPPB – Short Physical Performance Battery.

SMWT – Six-Minute Walk Test.

LLFDI – Late Life Function and Disability Index.

Figure 4. AMP 331 Activity Monitor.


Figure 5. Keiser Air 420 Leg Press.

# CHAPTER IV. RESULTS

## Demographic Information

A total of 46 individuals contacted the principal investigator with interest in becoming a participant in the study. Twelve individuals did not meet inclusion criteria or decided not to participate after learning more about the requirements of their participation. Thirty-four individuals consented to participation in the study. Four individuals did not complete the study. One subject broke his foot between the first and second data collection session. One subject decided between the first and second session to withdraw due to concerns of aggravating her knee pain. One subject experienced low back discomfort with the sit to stand test during the first session and decided that the leg press might further exacerbate her symptoms. One subject experienced anginal chest pain during the Six-Minute Walk Test (SMWT) and decided to withdraw from the study (this subject's chest pain was relieved with rest and vital signs were normal). Thirty subjects completed the study. Demographic data with gender breakdown are listed in Table 2. No significant differences were found between genders for age, weight, or body mass index. Males were significantly taller than females.

## Impairments in Muscle Performance

### Muscle Performance Repeatability

All subjects completed muscle performance testing without major complications. Three individuals chose not to complete the third session (second muscle performance trial) secondary to discomfort they experienced after the second session (first muscle performance trial). One subject's muscle performance data from the second session were lost due to a computer error.

The 26 subjects who completed both muscle performance data collection trials demonstrated high repeatability for strength, power, and endurance. The ICC for one repetition maximum (1-RM) between session one and two was 0.99 with only a 70.0 Newton difference (Figure 6). The ICC for peak power was 0.99 between the two muscle performance trials. Between trial power comparisons at each external load (40%, 50%, 60%, 70%, 80%, and 90% 1-RM) had ICC's ranging from 0.93-0.99. Repeatability was higher at the more intense loads than at the less intense loads (Figure 7). Between session reliability for the number of repetitions completed at 60% 1-RM was good (ICC of 0.74) with only a two repetition mean difference between the number of repetitions completed.

Due to the high reliability between sessions, it was determined acceptable to use the results for the subjects who only completed one trial of muscle performance testing. Since the purpose of this study was to compare impairments in muscle performance to functional limitations and disability, it was most appropriate to use subjects' best performance in analysis as opposed to results from either trial one or two. Of the 26 subjects who completed both muscle performance sessions, 20 subjects' results from the second muscle performance trial (session three) and six subjects' results from the first muscle performance trial (session two) were used for analysis.

Since the amount of strength or power needed to perform functional activities such as walking or getting out of a chair requires the movement and control of the body, strength and power data were normalized to body weight for analysis. This created a more normal distribution for strength and power values and provided a better means to make inter-subject comparisons. This method of analysis has been recommended by previous investigators and is commonly used in this line of research.[16, 21, 22, 45]

## Impairments in Strength

Strength results are displayed in Table 3. A normal distribution was demonstrated and no gender differences were present (p = 0.059).

## Impairments in Muscle Power

Power could not be tested at 40% 1-RM for four subjects and at 50% 1-RM for one subject secondary to the lowest amount of resistance the leg press could provide being greater than these values. The distribution of power results used for analysis across all external loads is displayed in Figure 8. Results for peak power, power at 40% 1-RM, and power at 90% 1-RM values are listed in Table 4. A normal distribution was demonstrated for all three power measures. Men demonstrated greater power at peak power and power at 40% 1-RM; no differences were present at 90% 1-RM.

Subjects achieved peak power across a range of external resistances. This finding was in contrast to previous reports that found peak power consistently taking place at 70% 1-RM.[29] Two subjects achieved peak power at 40% 1-RM, nine at 50% 1-RM, nine at 60% 1-RM, four at 70% 1-RM, two at 80% 1-RM, and four at 90% 1-RM. Because of the variation in the external load at which peak power was achieved between subjects, analysis was completed to determine if there were differences in demographic information, muscle performance data, functional limitations or disability levels for those individuals who achieved peak power at high versus low external loads. Subjects who achieved peak power at 40, 50, or 60% of 1-RM were put into one group (20 subjects) and those who achieved peak power at 70, 80 or 90% 1-RM were put in another group (10 subjects). Student's t-test analysis with adjustment for unequal variance identifies no differences between these groups. The external load at which peak power is achieved does not appear to be related to overall muscle performance, functional limitations, or disability levels.

## Impairments in Endurance

Endurance was assessed through the total number of repetitions subjects completed at 60% 1-RM until fatigue. Endurance was also assessed by examining the decline in power across the first 10 and 15 repetitions of the endurance testing protocol.

The percentage change from the peak power of the first three repetitions to the average of repetition 8, 9, and 10 was calculated to determine the change over 10 repetitions. The percentage change from the peak power of the first three repetitions to the average of repetition 13, 14, and 15 was calculated to determine the change in power over 15 repetitions. In reviewing each subject's endurance test, seven subjects did not achieve their maximum power within the first three repetitions. This was an indication that these subjects did not maximally exert themselves and did not achieve the purpose of the endurance testing protocol. These subjects' endurance data were excluded from all further analysis in examining the relationship between impairments to endurance to functional limitations and disability.

One subject did not reach 10 repetitions and five subjects did not reach 15 repetitions. These subjects were excluded from the analysis of power decline across 15 repetitions and across 10 repetitions, respectively. Results of the number of repetitions completed, power decline over 10 repetitions, and power decline over 15 repetitions for the remaining subjects are displayed in Table 5. A normal distribution was found for all measures of endurance with no significant gender differences present. Figure 9 illustrates the mean values for peak power over the first three repetitions, average power for repetitions 8-10, and average power for repetitions 13-15. As this figure demonstrates, power values decline from the peak to the average of 8-10 and then further drop at the average of 13-15.

Since the examination of power declines across isotonic contractions was a novel approach to measuring muscle endurance, analysis was performed to determine if the decline in power was significant across 10 repetitions and 15 repetitions. A significant decrease in power was present from peak power to the average power of repetitions 8-10 and peak power to average power of repetitions 13-15 ($p < 0.01$).

## Comparison between Measures of Impairments in Muscle Performance

Since strength, power, and endurance are based on characteristics of skeletal muscle, all were expected to be interrelated. However, some differences should be present because these values represent different aspects of skeletal muscle function. The correlation matrix for measures of muscle performance is listed in Table 6. Strength showed a high correlation with peak power and power at 40% 1-RM with a lower relationship to power at 90% 1-RM. This finding was somewhat surprising. Since the load at 90% 1-RM is so close to subjects' actual 1-RM and velocity will be low during 90% 1-RM power testing, it was thought these two values would have the strongest relationship. Since power at 40% 1-RM is a high velocity action and velocity is low at 1-RM, it was expected that these two values would not be as strongly related. This was not the case.

There was a high degree of correlation between peak power and power at 40% 1-RM. This is likely due to the fact that 20 subjects achieved their peak power at 40%, 50%, or 60% 1-RM and there were minimal differences between these three values (Figure 8). A weaker relationship was found between peak power and power at 90% 1-RM, and between power at 40% 1-RM and power at 90% 1-RM. This would indicate that subjects who have high power may not also have high power at greater relative intensities. One way repeated measures analysis of variance with Bonferroni corrections during follow-up testing were conducted to determine whether the three measures of power were different from each other. A significant F value was found ($F = 19.70$, $p < 0.01$) and follow-up testing demonstrated all three values of power were statistically different from each other. These findings lend support to examining not just how peak power is related to functional limitations and disability, but also considering power at 40% 1-RM and power at 90% 1-RM.

Endurance measurements showed no significant correlation with each other or with any strength or power values. This indicated that the measures of endurance had the potential to have different relationships to functional limitations and disability and that each endurance measure represented a different aspect of muscle performance than strength and power values.

## Functional Limitations

### Short Physical Performance Battery

All aspects of the Short Physical Performance Battery (SPPB) were completed without difficulty. Five subjects demonstrated a ceiling affect by achieving a maximum score of 12/12. A normal distribution was found for SPPB total score and the three subscales. Only the balance subscale demonstrated a significant gender difference. Descriptive data with gender breakdown are provided in Table 7. Table 8 lists descriptive data for gait speed calculated from the four meter walk portion of the SPPB and the time to complete five sit to stands from the chair stand portion of the SPPB. Table 9 provides a breakdown of how many subjects achieved each score on the balance subscale of the SPPB.

Six subjects were unable to complete five sit to stands and had no value for time to complete this aspect of the SPPB. These subjects tended to be have the lowest level of muscle performance and the greatest level of functional limitations and disability. Excluding these subjects from analysis might lead to the finding of a weaker relationship between muscle performance to the ability to get out of chair than was actually present. To account for this possibility, the individuals who could not complete five sit to stands were given a time that was higher than the rest of the subjects and then rank transformation was performed. The rank transformed data were used for analysis.

## Six-Minute Walk Test

Results of Six-Minute Walk Test (SMWT) are displayed in table 10. A normal distribution was found with no gender differences.

## AMP Activity Monitor Data

One subject's activity data were lost due to a computer error and the subject refused to wear the activity monitor for another week. This left 29 data sets for the AMP measurements. If subjects did not wear the AMP for a total of eight hours a day, that day's data were eliminated from analysis. Eight subjects had one-day of data eliminated from analysis and one subject had two-days eliminated. For the 20 subjects with six valid days of data, the AMP steps, AMP distance, and AMP speed across the first four-days was compared to the average of all six-days to determine whether it would be acceptable to include those subjects with less than six-days of data in further analysis. Intraclass correlations ranged from 0.98 – 0.99 with no significant differences between AMP steps, AMP distance, and AMP speed. These results supported including subjects who did not have six full days of data in future analysis. Table 11 lists results from the AMP activity monitor. All values demonstrated normal distributions and no gender differences were present.

## Late Life Function and Disability Index Functional Limitation Component

All subjects completed the Late Life Function and Disability Index (LLFDI) Functional Limitation Component without difficulty and no subjects abstained from answering any of the questions. A normal distribution was found with no gender differences present. Descriptive results are listed in Table 12.

## Disability

### Late Life Function and Disability Index Disability Category Limitation Component

All subjects completed the LLFDI Disability Category without difficulty and no subjects abstained from answering any of the questions. One subject's score was determined to be an outlier and she was excluded from all further disability analysis. Results from the disability limitation domain total score are listed in Table 12. Data demonstrated a normal distribution and no gender difference was present.

## Specific Aim 1

The first aim of this study was to examine the relationship between impairments in lower extremity strength, power, and endurance to functional limitations in community-dwelling older adults. Separate regression analyses were used to determine the relationship between each measure of muscle performance to each measure of functional limitation. If either age or gender were shown to be significantly related to the measures of functional limitation ($p < 0.05$), they were entered into the regression equation prior to entering the measure of muscle performance. All regression equations passed the diagnostics unless otherwise noted.

Results of the regression analysis between each measure of impairment in muscle performance to each measure of functional limitations are listed in Tables 13, 14, and 15. Beta coefficients, standard errors, partial $R^2$ values, and p values associated with each measure of muscle performance are listed. If either gender and/or age were significantly related to the measure of functional limitation, the variable was added to the regression equation and is indicated in the tables. Outliers were found in some regression models where AMP steps and AMP distance were the dependent variables. These situations are indicated in Table 15.

Overall, strength and all three values of power were significantly related to the measures of functional limitations. One exception was that power at 40% 1-RM was not significantly related to the SPPB total score (Table 13). Additional exceptions included peak power and the number of repetitions completed during endurance testing which were the only independent variables related to average steps from the AMP activity monitor (Table 15).

The only situation in which a measure of endurance was related to functional limitations was number of repetitions to AMP steps. One possible consideration for the weak relationship between endurance measures and functional limitations was the high number of subjects who were excluded from the endurance data set. Not achieving 10 or 15 repetitions was a criterion for exclusion from the analysis of power decline across repetitions. A possibility of this exclusion criterion is that those with low endurance were eliminated from analysis and this led to only subjects with moderate to high endurance remaining in the data set. To address this issue, the one subject who did not complete 10 repetitions and the five subjects who did not complete 15 repetitions were put back in the data set. Rank transformation was performed for the power decline endurance data. The relationships between rank transformed power decline data and all measures of functional limitations were examined. Scatter plots revealed no visual trends and no statistically significant relationships were found. Because there was no advantage of performing rank transformation, all further analysis with power decline data only included those individuals who completed 10 or 15 repetitions.

As the results in Figures 10 and 11 and as listed in Tables 13-15 demonstrate, peak power consistency explained more of the variation in measures of functional limitations that involved walking in comparison to other measures of muscle performance. At no time did power at low load/high velocity (power at 40% 1-RM) explain more of the variance in functional limitations involving walking than peak power. Power at 90% of 1-RM explained more of the variation in the SPPB total score than the other measures of power. Because the SPPB measures three separate aspects of function, linear regression analysis was performed on the three subscales. When the time to complete five sit to stands from the SPPB and the walking speed calculated from the SPPB four meter walk test were examined separately, power at 90% 1-RM was most strongly related to sit to stand while peak power was most strongly related to gait speed.

Because the scores from the balance subscale were ordinal and the distribution was non-normal, as was presented in Table 9, a non-parametric approach had to be used to examine the relationship between impairments in muscle performance to balance subscale results. Those who scored a 4/4 were placed in one group and those who scored a 1/4, 2/4, or 3/4 were placed in another group. A Mann-Whitney U Test was done to determine if muscle performance differed in these groups. Results showed no significant differences between the groups in strength, power, or endurance. Muscle performance did not demonstrate a relationship to static balance.

The self report of functional limitations as part of the LLFDI included questions describing one's perceived difficulty in completing activities such as going up and down steps, preparing meals, dressing, and getting out of a chair. Peak power explained more of the variability in this measure of functional limitation that included a multitude of functional activities than the other measures of muscle performance.

To explore if curvilinear relationships between impairments and functional limitations were present, each muscle performance value was centered and then squared. These variables were then entered into the regression model to see if the squared term significantly improved in its explanation of the dependent variable. The centered squared term for strength and peak power significantly improved the relationship to AMP steps (Table 16). The $R^2$ value for the regression equation between strength to AMP steps went from 0.097 to 0.247 went the centered squared term was added. The $R^2$ value for the regression equation for peak power to AMP steps went from 0.157 to 0.308 when the centered squared term was added. No violation of collinearity was present when the centered squared term was added to the equation. Because of this finding, all further analysis considered both the centered linear and centered squared term together for strength and peak power when examining how muscle performance was related to average steps.

A separate stepwise linear regression analysis was then performed for each measure of functional limitation using measures of muscle performance as possible independent variables. Age and gender were first entered into the equation to determine if they were significantly related to the measure of functional limitations.

Stepwise linear regression analysis achieved two goals. First, it demonstrated which measure of muscle performance was initially entered into the regression equation and thus explained more of the functional limitation in comparison to the other measures of muscle performance. This provided a method to determine which measure of muscle performance would be considered most important to each measure of functional limitation. Second stepwise linear regression analysis provided information on how much variance in functional limitations can be explained by the multiple measures of muscle performance. This provided some guidance on whether multiple aspects of muscle performance affect functional limitations in unique ways and how much of the total variance in functional limitations could be explained through muscle performance.

Only strength, peak power, and power at 90% 1-RM were considered as possible independent variables for the stepwise linear regression analysis. Power at 40% 1-RM and peak power were highly correlated ($r = 0.97$), and at no time did power at 40% 1-RM explain more of the variance in any measure of functional limitations. The benefit of including power at 40% 1-RM as a possible independent variable was minimal. Measures of endurance were not included in the analysis because they were not significantly related to functional limitations in the prior analysis except for one instance. Another reason for not using power at 40% 1-RM and endurance data is this would have led to a large loss of statistical power. Four subjects had no data for power at 40% 1-RM and eight subjects did not have an appropriate endurance test. Including these values would have led to 10 subjects being excluded from stepwise linear regression analysis. In weighing the benefits and drawbacks of including power at 40% 1-RM and endurance data as independent variables, it was decided that maintaining high statistical power was more important than including factors that had been shown to have only weak relationships to functional limitations in previous analysis.

Results of the stepwise linear regression analysis are listed in Table 17. Power values consistently explained more of the variance in functional limitations than strength. Peak power was entered first for measures of functional limitation that involved walking and for the LLFDI Functional Limitation Component. Power at 90% 1-RM was entered first for the sit to stand time from the SPPB and the total SPPB score. Only one variable of muscle performance was entered into each regression analysis for measures of functional limitations.

After completing this set of stepwise linear regression analyses, regression diagnostics showed a high degree of collinearity between strength and the measures of power. This collinearity likely led to strength not entering any of the regression equations. Since power is based on force and velocity, and since the amount of weight used during power testing was based on performance during strength testing, this is what likely accounted for the collinearity. One method that has been used by previous researchers to address this collinearity is to substitute the velocity associated with each power value, for the power value itself in stepwise regression analysis.[135] Velocity during power testing had a much lower relationships to strength (r = 0.05-0.67) but was highly related to power (r =0.62-0.88). This method helped decrease the collinearity between values and increased the possibility of more variables entering the regression model. Examining velocity separate in this stepwise regression analysis also provided some insight into whether it is the velocity of contraction or the force production during power production that had the largest relationship to functional limitations.

A separate stepwise linear regression analysis for each measure of functional limitations using strength and the velocities associated with peak power and power 90% 1-RM as independent variables was performed. Results of the regression analysis are displayed in Table 18. Regression diagnostics demonstrated that collinearity was not present for any model. While there were some situations in which strength and velocity values were both entered as independent variables, at no time did the combination of these independent variables explain more of the variance in functional limitations than power values alone (compare total $R^2$ values in Tables 17 and 18). Strength was also the first value entered into all of the regression models. This indicates that force production is more important than contraction speed. It is the combination of force production and contraction speed that makes power such an important factor to function and disability.

These findings support the hypothesis that impairments in strength and power are related to functional limitations with power having a greater relationship. The hypothesis that endurance values would be related to functional limitations was not supported through this study. Power at 90% 1-RM had the strongest relationship to higher intensity functional limitations, while peak power had the strongest relationship to lower intensity functional limitations and measures of overall functional limitations (LLFDI Functional Limitation Domain). This finding supports the hypothesis that different impairments in muscle performance will have varying levels of importance based on the activity used to define functional limitations.

## Specific Aim 2

The second aim of this study was to examine the relationships between impairments in lower extremity strength, power, and endurance to disability in community-dwelling older adults. The disablement model states that impairments affect disability by first acting on functional limitations which then leads to disability. Stated another way, the effects of impairments on disability are mediated through functional limitations. Because of this indirect relationship between impairments and disability, mediation analysis was used to study their relationship. Mediation analysis allows the calculation of the indirect effect of one variable [Independent Variable (IV)] acting on another variable [Dependent Variable (DV)] through a mediator (M). The indirect effect is calculated by multiplying the regression coefficient from the equation examining the relationship between the IV to the M (M = i + aIV) and the regression coefficient from the equation examining the relationship between the M and DV, controlling for this IV (DV = i + c′ IV + bM) (a x b). Bootstrapping was used to address the low power associated with mediation analysis and the common non-normal distributions found during mediation analysis.

As was determined *a priori*, the Disability Category Limitation Component from the LLFDI was used as the measure of disability and distance from the SMWT and SPPB total score was used as possible mediators (Table 1, Chapter 3). Since neither age nor gender was significantly related to the measures of functional limitations and disability used in this analysis, they were not included in mediation analysis.

Tables 19 and 20 list the indirect effect and 95% bias-corrected confidence intervals (CI) for each mediation analysis performed. The 95% CI's demonstrated that measures of impairments in strength and power had an indirect effect on disability through limitations in SMWT distance and SPPB total score. No measure of impairments in endurance had a significant indirect effect on disability acting through either measure of functional limitation. Measures of power tended to have a stronger indirect effect than strength. Power at 40% 1-RM had the greatest indirect effect when the SMWT was the mediator and power at 90% 1-RM had the greatest indirect effect when the SPPB total score was the mediator.

These results support the hypothesis that impairments in lower extremity strength and power affect the amount of disability experienced by community-dwelling older adults by first acting on activities such as walking, ability to get out of a chair, and static balance. These limitations in function then affect disability levels experienced in this population. The hypothesis that endurance would be related to disability was not supported by the findings of this study.

Table 2. Demographic Data for Subjects.

| | Age (years) | Weight (kg) | Height (m) | BMI (kg/m$^2$) |
|---|---|---|---|---|
| Total (30 subjects) | 77.3 (7.0) | 76.8 (18.2) | 1.61 (0.12) | 29.8 (8.1) |
| Females (25 subjects) | 76.8 (7.3) | 73.8 (18.3) | 1.57 (0.09) | 30.2 (8.9) |
| Males (5 subjects) | 79.8 (5.1) | 90.6 (9.2) | 1.79 (0.07) * | 28.2 (1.3) |

* Indicates results significantly different than females (p < 01).

Note: Mean (Standard Deviation).

Table 3. Normalized Strength Results.

| | Normalized Strength (Newtons/kg) |
|---|---|
| Total | 15.5 (4.0) |
| Females | 14.8 (3.7) |
| Males | 18.5 (4.9) |

Note: Mean (Standard Deviation).

Table 4. Normalized Power Results.

| | Peak Power (W/kg) | Power 40% 1-RM (W/kg) | Power 90% 1-RM (W/kg) |
|---|---|---|---|
| Total | 7.6 (2.7) | 7.1 (2.7) | 5.7 (2.4) |
| Females | 7.2 (2.5) | 6.6 (2.5) | 5.7 (2.5) |
| Males | 9.8 (3.0) * | 9.2 (2.9) * | 5.6 (2.2) |

* Indicates results significantly different than females ($p < 0.05$).

Note: Mean (Standard Deviation).

Table 5. Endurance Results.

| | Number of Reps | Power Decline Over 10 Reps | Power Decline Over 15 Reps |
|---|---|---|---|
| Total | 23.0 (10.1)<br>23 subjects | 10.7% (4.6)<br>22 subjects | 16.8% (7.0)<br>18 subjects |
| Females | 24.6 (10.4)<br>19 subjects | 10.8% (4.5)<br>18 subjects | 16.2% (7.0)<br>16 subjects |
| Males | 15.5 (2.7)<br>4 subjects | 10.2% (5.7)<br>4 subjects | 21.8% (6.6)<br>2 subjects |

Note: Endurance data only includes subjects who reach peak power within the first three repetitions.

Note: One subject who did not achieve 10 repetitions and five subjects who did not achieve 15 repetitions were excluded from the power decline over 10 repetitions and over 15 repetitions analysis.

Note: Mean (Standard Deviation).

Table 6. Impairments in Muscle Performance Correlation Matrix.

| | Strength | Peak Power | Power at 40% 1-RM | Power at 90% 1-RM | Number of Reps | Power Decline 10 Reps | Power Decline 15 Reps |
|---|---|---|---|---|---|---|---|
| Strength | | 0.89* | 0.86* | 0.56* | -0.24 | -0.08 | -0.22 |
| Peak Power | | | 0.97* | 0.70* | -0.12 | -0.09 | -0.12 |
| Power at 40% 1-RM | | | | 0.51* | -0.24 | -0.11 | -0.03 |
| Power at 90% 1-RM | | | | | -0.05 | 0.13 | -0.33 |
| Number of Reps | | | | | | -0.26 | -0.30 |
| Power Decline over 10 Reps | | | | | | | 0.38 |

* Indicates a significant correlation coefficient ($p < 0.01$).

Note: Correlation analysis completed with non-normalized values for strength and power results.

Table 7. Short Physical Performance Battery Results With Gender Breakdown.

| | Balance Score | Walk Score | Sit to Stand Score | Total Score |
|---|---|---|---|---|
| Total | 3.2 (1.0) | 3.6 (0.6) | 2.1 (1.5) | 8.9 (2.5) |
| Females | 3.4 (1.0) | 3.5 (0.7) | 2.2 (1.4) | 9.0 (2.5) |
| Males | 2.4 (0.9) * | 3.8 (0.5) | 1.8 (1.8) | 8.0 (2.6) |

* Indicates results significantly different than females ($p < 0.05$).

Note: Mean (Standard Deviation).

Table 8. Walk Speed and Time to Complete Five Sit to Stands from Short Physical Performance Battery.

| | Walk Speed (m/s) | Chair Stand Time (seconds) |
|---|---|---|
| Total | 0.97 (0.23) | 13.35 (3.09) |
| Females | 0.92 (0.18) | 13.43 (3.24) |
| Males | 1.21 (0.33) * | 12.75 (2.06) |

* Indicates results significantly different than females ($p > 0.01$).

Note: Chair time score only includes those subjects who could complete five sit to stands within in one minute. Six subjects could not meet this criterion.

Note: Mean (Standard Deviation).

Table 9. Breakdown of Subjects Who Received Each SPPB Balance Subscale Score.

| | 1/4 | 2/4 | 3/4 | 4/4 |
|---|---|---|---|---|
| Total | 1 | 9 | 3 | 17 |
| Females | 1 | 5 | 3 | 16 |
| Males | 0 | 4 | 0 | 1 |

Table 10. Six-Minute Walk Test Results.

| | Six-Minute Walk Test (meters) |
|---|---|
| Total | 418.2 (83.6) |
| Females | 414.1 (88.2) |
| Males | 439.0 (57.8) |

Note: Mean (Standard Deviation).

Table 11. Results From the AMP Activity Monitor.

| | Steps | Distance (meters) | Speed (m/s) |
|---|---|---|---|
| Total | 6384.36 (2370.77) | 2173.98 (898.28) | 0.72 (0.17) |
| Females | 6458.60 (2567.25) | 2148.65 (933.79) | 0.71 (0.17) |
| Males | 6028.03 (1120.39) | 2295.58 (782.47) | 0.79 (0.15) |

Note: Mean (Standard Deviation).

Table 12. Late Life Function Disability Index Scores.

| | LLFDI Functional Limitation Component – Total Score | LLFDI Disability Component Function Limitation Category – Total Score |
|---|---|---|
| Total | 54.71 (6.47) | 65.19 (6.38) |
| Females | 54.15 (6.76) | 64.95 (5.95) |
| Males | 57.49 (4.21) | 66.33 (8.86) |

Note: Mean (Standard Deviation).

Table 13. Regression Analysis Results for Each Measure of Muscle Performance with Short Physical Performance Battery Scores.

| | Coefficient | SE | Partial $R^2$ | p value |
|---|---|---|---|---|
| **SPPB Total Score** | | | | |
| Strength | 0.32 | 0.10 | 0.28 | 0.003 * |
| Peak Power | 0.46 | 0.15 | 0.26 | 0.004 * |
| Power at 40% 1-RM | 0.31 | 0.16 | 0.14 | 0.063 |
| Power at 90% 1-RM | 0.64 | 0.15 | 0.39 | 0.000 * |
| Number of Repetitions | 0.03 | 0.05 | 0.02 | 0.512 |
| Decline in Power over 10 Reps | 0.08 | 0.11 | 0.03 | 0.484 |
| Decline in Power over 15 Reps - G | 0.11 | 0.08 | 0.09 | 0.182 |
| **SPPB Gait Speed** | | | | |
| Strength – G | 0.03 | 0.01 | 0.31 | 0.000 * |
| Peak Power – G | 0.05 | 0.01 | 0.35 | 0.000 * |
| Power at 40% 1-RM – G | 0.05 | 0.01 | 0.31 | 0.001 * |
| Power at 90% 1-RM – G | 0.05 | 0.01 | 0.24 | 0.002 * |
| Number of Repetitions – G | 0.00 | 0.01 | 0.00 | 0.835 |
| Decline in Power over 10 Reps – G | 0.00 | 0.01 | 0.00 | 0.804 |
| Decline in Power over 15 Reps | 0.00 | 0.01 | 0.00 | 0.798 |
| **SPPB Chair Stand – Rank Transformed Data** | | | | |
| Strength | -1.18 | 0.35 | 0.29 | 0.002 * |
| Peak Power | -1.75 | 0.51 | 0.29 | 0.002 * |
| Power at 40% 1-RM | -1.40 | 0.56 | 0.20 | 0.020 * |
| Power at 90% 1-RM | -2.12 | 0.56 | 0.34 | 0.001 * |
| Number of Repetitions | -0.19 | 0.17 | 0.05 | 0.296 |
| Decline in Power over 10 Reps | -0.01 | 0.39 | 0.00 | 0.987 |
| Decline in Power over 15 Reps - G | -0.34 | 0.25 | 0.08 | 0.192 |

SE – Standard Error.

G – Indicates gender was significantly related to dependent variable and entered into the regression model prior to entering measures of muscle performance.

Table 14. Regression Analysis Results for Each Measure of Muscle Performance with Six-Minute Walk Test Distance and LLFDI Functional Limitation Domain Score.

| | Coefficient | SE | Partial $R^2$ | p value |
|---|---|---|---|---|
| **SMWT Distance** | | | | |
| Strength | 12.84 | 3.08 | 0.38 | 0.000 * |
| Peak Power | 21.39 | 4.20 | 0.48 | 0.000 * |
| Power at 40% 1-RM | 19.68 | 4.65 | 0.43 | 0.000 * |
| Power at 90% 1-RM | 23.78 | 4.81 | 0.47 | 0.000 * |
| Number of Repetitions | -0.19 | 1.78 | 0.00 | 0.918 |
| Decline in Power over 10 Reps | 5.93 | 3.90 | 0.10 | 0.144 |
| Decline in Power over 15 Reps | 1.72 | 3.12 | 0.02 | 0.597 |
| **LLFDI Functional Limitation** | | | | |
| Strength | 0.91 | 0.25 | 0.32 | 0.001 * |
| Peak Power - ^ | 1.27 | 0.33 | 0.35 | 0.001 * |
| Power at 40% 1-RM | 1.17 | 0.37 | 0.31 | 0.004 * |
| Power at 90% 1-RM | 1.15 | 0.41 | 0.22 | 0.010 * |
| Number of Repetitions | 0.02 | 0.13 | 0.00 | 0.912 |
| Decline in Power over 10 Reps | 0.50 | 0.28 | 0.14 | 0.092 |
| Decline in Power over 15 Reps | 0.11 | 0.21 | 0.02 | 0.604 |

SE – Standard Error.

^ – Indicates one subject's data were excluded from analysis due to being an outlier.

Table 15. Regression Analysis Results for Each Measure of Muscle Performance with AMP Activity Monitor Data.

| | Coefficient | SE | Partial $R^2$ | p value |
|---|---|---|---|---|
| **AMP Steps** | | | | |
| Strength | 184.15 | 107.85 | 0.10 | 0.099 |
| Peak Power | 340.99 | 152.08 | 0.16 | 0.033 * |
| Power at 40% 1-RM | 237.41 | 160.68 | 0.09 | 0.153 |
| Power at 90% 1-RM | 351.73 | 175.81 | 0.13 | 0.056 |
| Number of Repetitions - ^ | 145.05 | 52.22 | 0.29 | 0.012 * |
| Decline in Power over 10 Reps - ^ | -51.14 | 83.56 | 0.02 | 0.548 |
| Decline in Power over 15 Reps | 30.29 | 91.67 | 0.01 | 0.744 |
| | | | | |
| **AMP Distance** | | | | |
| Strength | 108.22 | 37.64 | 0.23 | 0.008 * |
| Peak Power - ^ | 201.68 | 44.28 | 0.44 | 0.000 * |
| Power at 40% 1-RM - ^ | 187.40 | 47.63 | 0.41 | 0.001 * |
| Power at 90% 1-RM | 217.08 | 57.88 | 0.34 | 0.001 * |
| Number of Repetitions - ^ | 41.13 | 21.06 | 0.17 | 0.066 |
| Decline in Power over 10 Reps | 25.85 | 40.85 | 0.02 | 0.534 |
| Decline in Power over 15 Reps | 15.81 | 32.82 | 0.02 | 0.637 |
| | | | | |
| **AMP Speed** | | | | |
| Strength | 0.026 | 0.006 | 0.39 | 0.000 * |
| Peak Power | 0.042 | 0.008 | 0.50 | 0.000 * |
| Power at 40% 1-RM | 0.038 | 0.01 | 0.38 | 0.001 * |
| Power at 90% 1-RM | 0.047 | 0.01 | 0.48 | 0.000 * |
| Number of Repetitions | -0.002 | 0.004 | 0.02 | 0.523 |
| Decline in Power over 10 Reps | 0.013 | 0.008 | 0.13 | 0.103 |
| Decline in Power over 15 Reps | 0.007 | 0.006 | 0.08 | 0.291 |

SE – Standard Error.

^ – Indicates that one subject's data were excluded from analysis due to being an outlier.

Table 16. Regression Analysis Curvilinear Model for AMP Steps.

| | Coefficient | SE | Partial $R^2$ | p value | Total $R^2$ | p value |
|---|---|---|---|---|---|---|
| **Strength** | | | | | | |
| Linear Model | | | | | 0.10 | 0.099 |
| Linear Term † | 184.15 | 107.85 | 0.01 | 0.099 | | |
| Curvilinear Model | | | | | 0.25 | 0.025 * |
| Linear Term † | 275.61 | 108.13 | 0.01 | 0.099 | | |
| Quadratic Term ‡ | -41.35 | 18.17 | 0.15 | 0.031 | | |
| **Peak Power** | | | | | | |
| Linear Model | | | | | 0.16 | 0.033 * |
| Linear Term † | 340.99 | 152.08 | 0.16 | 0.033 | | |
| Curvilinear Model | | | | | 0.31 | 0.008 * |
| Linear Term † | 535.05 | 162.22 | 0.16 | 0.033 | | |
| Quadratic Term ‡ | -98.38 | 41.22 | 0.15 | 0.025 | | |

SE – Standard Error.

† – (AMP Steps – Mean of AMP Steps).

‡ – $(\text{AMP Steps} - \text{Mean of AMP Steps})^2$.

Table 17. Stepwise Linear Regression Analysis Using Strength, Peak Power, and Power 90% 1-RM as Independent Variables and Each Measure of Functional Limitations as a Dependent Variable.

| | Coefficient | SE | Partial $R^2$ | p value | Total $R^2$ | p value |
|---|---|---|---|---|---|---|
| **SPPB Total Score** | | | | | 0.39 | 0.000 * |
| Power 90% 1-RM | 0.64 | 0.15 | 0.39 | 0.000 | | |
| **SPPB Gait Speed** | | | | | 0.57 | 0.000 * |
| Gender | 0.14 | 0.08 | 0.22 | 0.009 | | |
| Peak Power | 0.05 | 0.01 | 0.35 | 0.000 | | |
| **SPPB Chair Stand** | | | | | 0.34 | 0.001 * |
| Power 90% 1-RM | -2.12 | 0.56 | 0.34 | 0.001 | | |
| **SMWT** | | | | | 0.46 | 0.000 * |
| Peak Power | 21.29 | 4.20 | 0.46 | 0.000 | | |
| **LLFDI Functional Limitation** | | | | | 0.35 | 0.001 * |
| Peak Power | 1.27 | 0.33 | 0.35 | .001 | | |
| **AMP Steps** | | | | | 0.31 | 0.008 * |
| Peak Power Linear Term | 535.05 | 162.22 | 0.16 | 0.033 | | |
| Peak Power Quadratic Term | -98.38 | 41.22 | 0.15 | 0.025 | | |
| **AMP Distance** | | | | | 0.36 | 0.001 * |
| Peak Power | 195.05 | 50.30 | 0.36 | 0.001 | | |
| **AMP Speed** | | | | | 0.49 | 0.000 * |
| Peak Power | 0.04 | 0.01 | 0.49 | 0.000 | | |

SE – Standard Error.

Table 18. Stepwise Linear Regression Analysis Using Strength, Velocity at Peak Power, and Velocity at Power 90% 1-RM as Independent Variables and Each Measure of Functional Limitations as a Dependent Variable.

| | Coefficient | SE | Partial $R^2$ | p value | Total $R^2$ | p value |
|---|---|---|---|---|---|---|
| **SPPB Total Score** | | | | | 0.39 | 0.001 * |
| Strength | 0.32 | 0.09 | 0.28 | 0.003 | | |
| Velocity at 90% 1-RM | 6.75 | 3.02 | 0.11 | 0.034 | | |
| **SPPB Gait Speed** | | | | | 0.53 | 0.000 * |
| Gender | 0.16 | 0.09 | 0.22 | 0.016 | | |
| Strength | 0.03 | 0.01 | 0.31 | 0.001 | | |
| **SPPB Chair Stand** | | | | | 0.29 | 0.002 * |
| Strength | -1.18 | 0.35 | 0.29 | 0.002 | | |
| **SMWT** | | | | | 0.46 | 0.000 * |
| Strength | 12.48 | 2.82 | 0.38 | 0.000 | | |
| Velocity at 90% 1-RM | 235.17 | 93.09 | 0.12 | 0.018 | | |
| **LLFDI Functional Limitations** | | | | | 0.35 | 0.001 * |
| Strength | 0.86 | 0.22 | 0.35 | 0.001 | | |
| **AMP Steps** | | | | | 0.25 | 0.025 * |
| Strength Linear Term | 275.61 | 108.13 | .10 | 0.099 | | |
| Strength Quadratic Term | -41.35 | 18.17 | .15 | 0.031 | | |
| **AMP Distance** | | | | | 0.23 | 0.008 * |
| Strength | 108.22 | 37.64 | 0.23 | 0.008 | | |
| **AMP Speed** | | | | | 0.505 | 0.000 * |
| Strength | 0.02 | 0.01 | 0.39 | 0.000 | | |
| Velocity 90% 1-RM | 0.44 | 0.19 | 0.11 | 0.027 | | |

SE – Standard Error.

Table 19. Mediation Analysis for Measures of Muscle Performance with Disability Using Six-Minute Walk Test Distance as the Mediator.

| **Independent Variable** | **Mediator** | **Dependent Variable** | **Indirect Effect** | **95% CI †** |
|---|---|---|---|---|
| Strength | SMWT | Disability Limitation | 0.479 | 0.087 – 1.014 * |
| Peak Power | SMWT | Disability Limitation | 0.968 | 0.126 – 1.959 * |
| Power 40% 1-RM | SMWT | Disability Limitation | 1.038 | 0.290 – 2.141 * |
| Power 90% 1-RM | SMWT | Disability Limitation | 0.887 | 0.041 – 1.861 * |
| Number of Repetitions | SMWT | Disability Limitation | -0.021 | -0.090 – 0.128 |
| Power Decline over 15 Repetitions | SMWT | Disability Limitation | 0.100 | -0.056 – 0.190 |
| Power Decline over 10 Repetitions | SMWT | Disability Limitation | 0.108 | -0.008 – 0.396 |

CI – Confidence Interval.

SMWT – Six-Minute Walk Test.

† – Bootstrapping with bias-correction.

* Indicates significant indirect effect.

Table 20. Mediation Analysis Between Measures of Muscle Performance to Disability Using Short Physical Performance Battery Total Score as the Mediator.

| Independent Variable | Mediator | Dependent Variable | Indirect Effect | 95% CI † |
|---|---|---|---|---|
| Strength | SPPB | Disability Limitation | 0.395 | 0.069 – 0.896 * |
| Peak Power | SPPB | Disability Limitation | 0.564 | 0.074 – 1.263 * |
| Power 40% 1-RM | SPPB | Disability Limitation | 0.394 | 0.014 – 1.059 * |
| Power 90% 1-RM | SPPB | Disability Limitation | 0.817 | 0.167 – 1.819 * |
| Number of Repetitions | SPPB | Disability Limitation | 0.012 | -0.022 – 0.114 |
| Power Decline over 15 Repetitions | SPPB | Disability Limitation | 0.045 | -0.085 – 0.306 |
| Power Decline over 10 Repetitions | SPPB | Disability Limitation | 0.064 | -0.077 – 0.387 |

CI – Confidence Interval.

SPPB – Short Physical Performance Battery.

† – Bootstrapping with bias-correction.

* Indicates significant indirect effect.

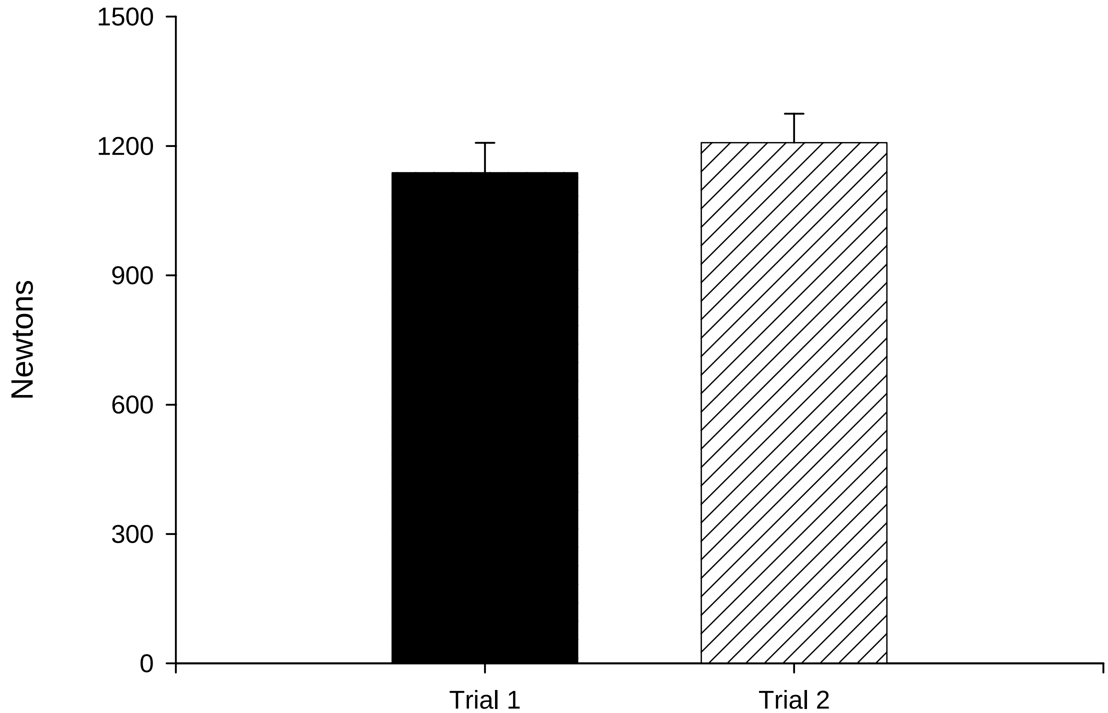


Figure 6. Repeatability of strength test between muscle performance data trial one and two.

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Note: Mean values with standard error bars.

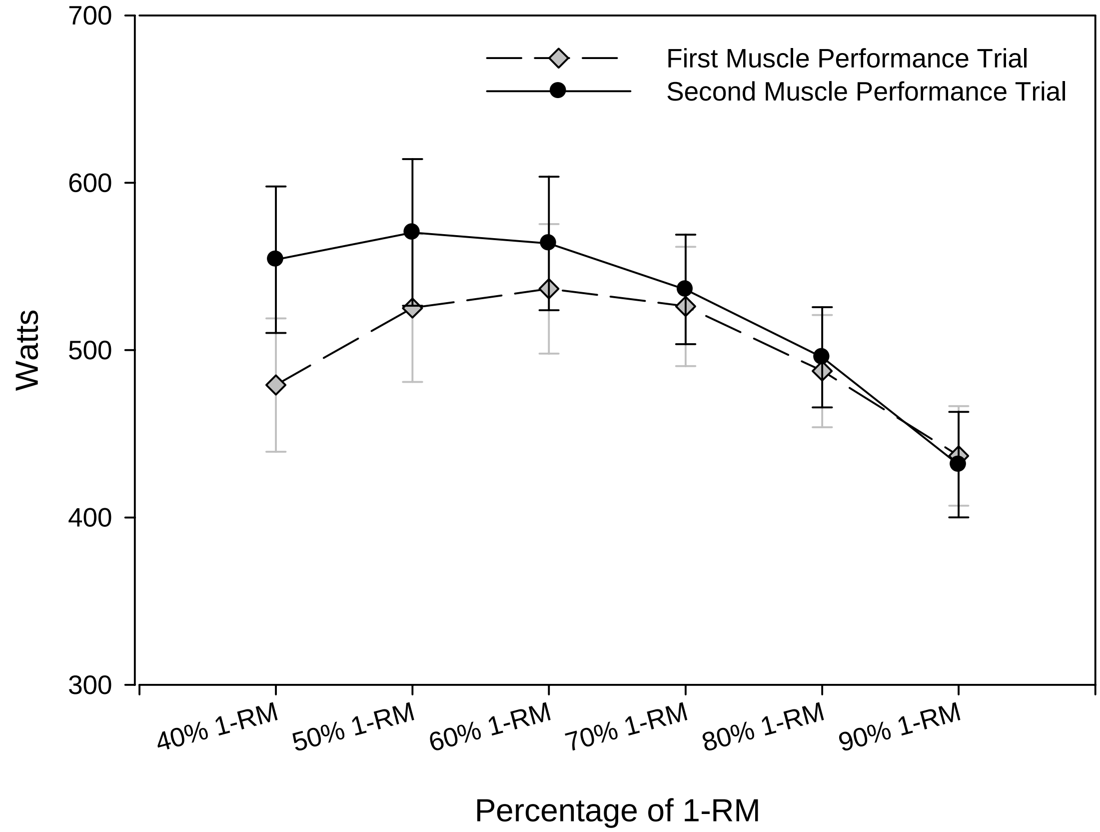


Figure 7. Repeatability of power tests across external resistances between muscle performance data trial one and two.

Note: Mean values with standard error bars.

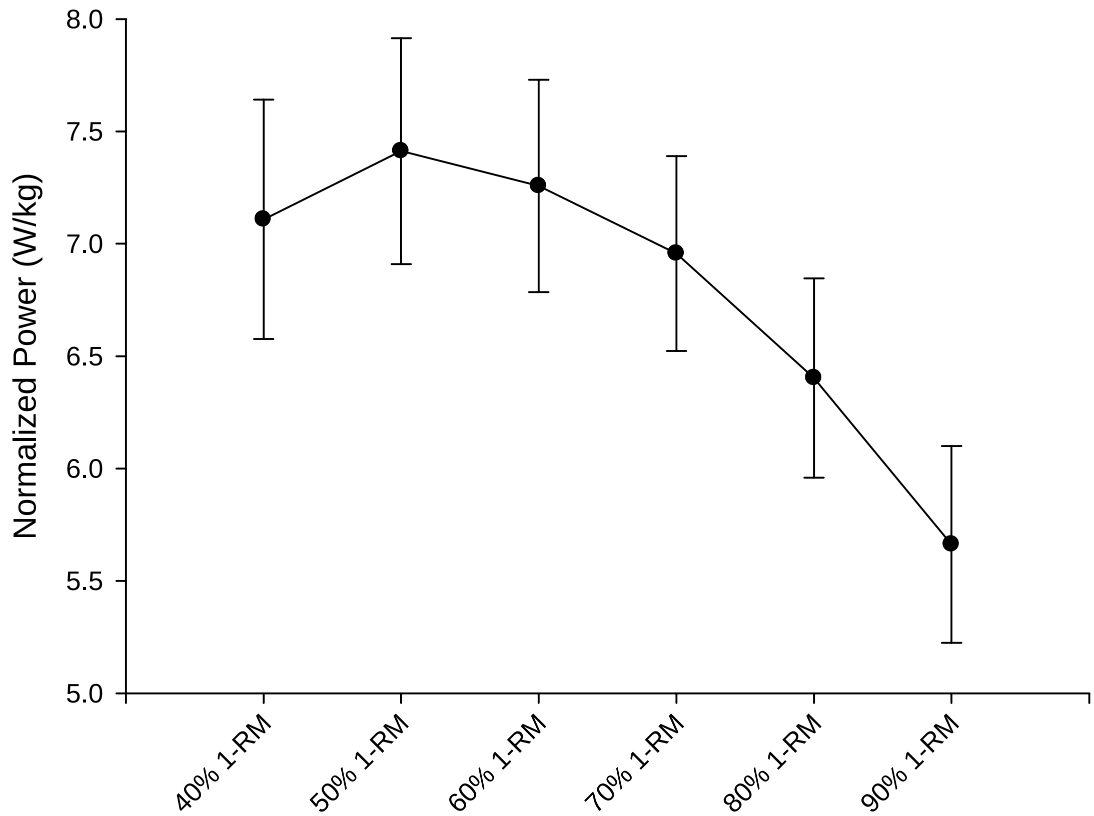


Figure 8. Power results across external resistances used for analysis.

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Note: Mean values with standard error values.

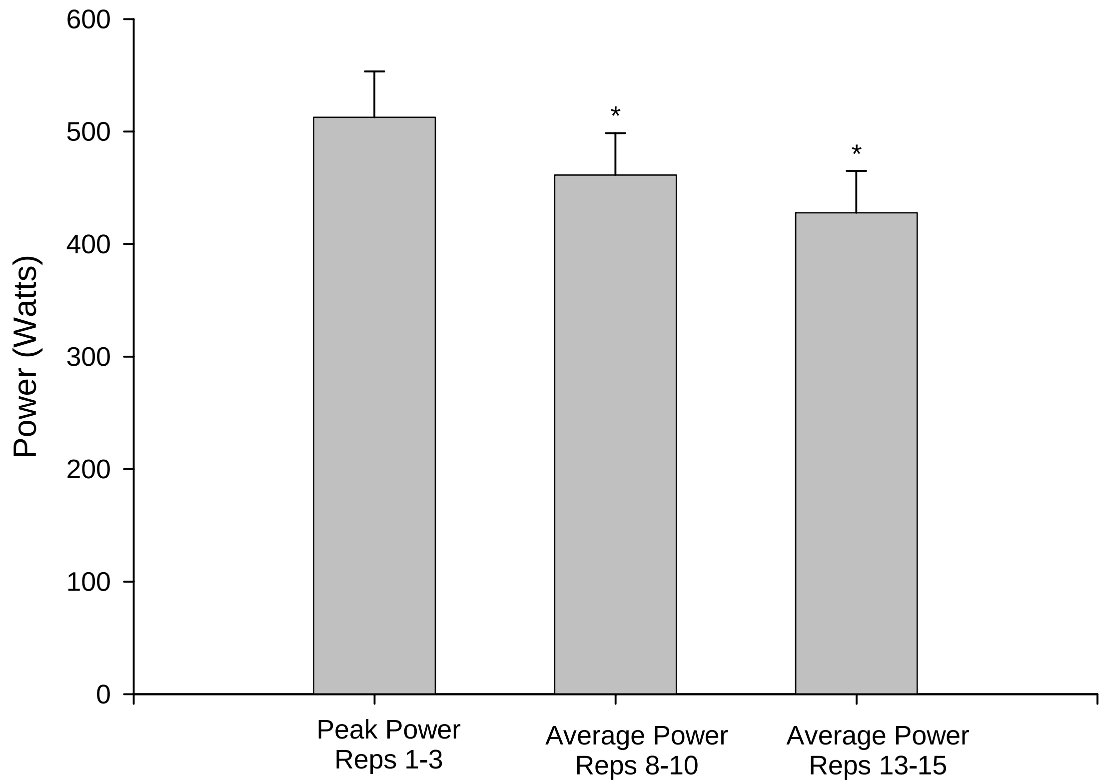


Figure 9. Power values during endurance test.

Note: Mean values with standard error bars.

Note: Only includes data from individuals who reached peak power within the first three repetitions and those who completed 15 repetitions. (n = 18)

* Indicates results significantly different from peak power for reps 1-3 ($p < 0.01$).

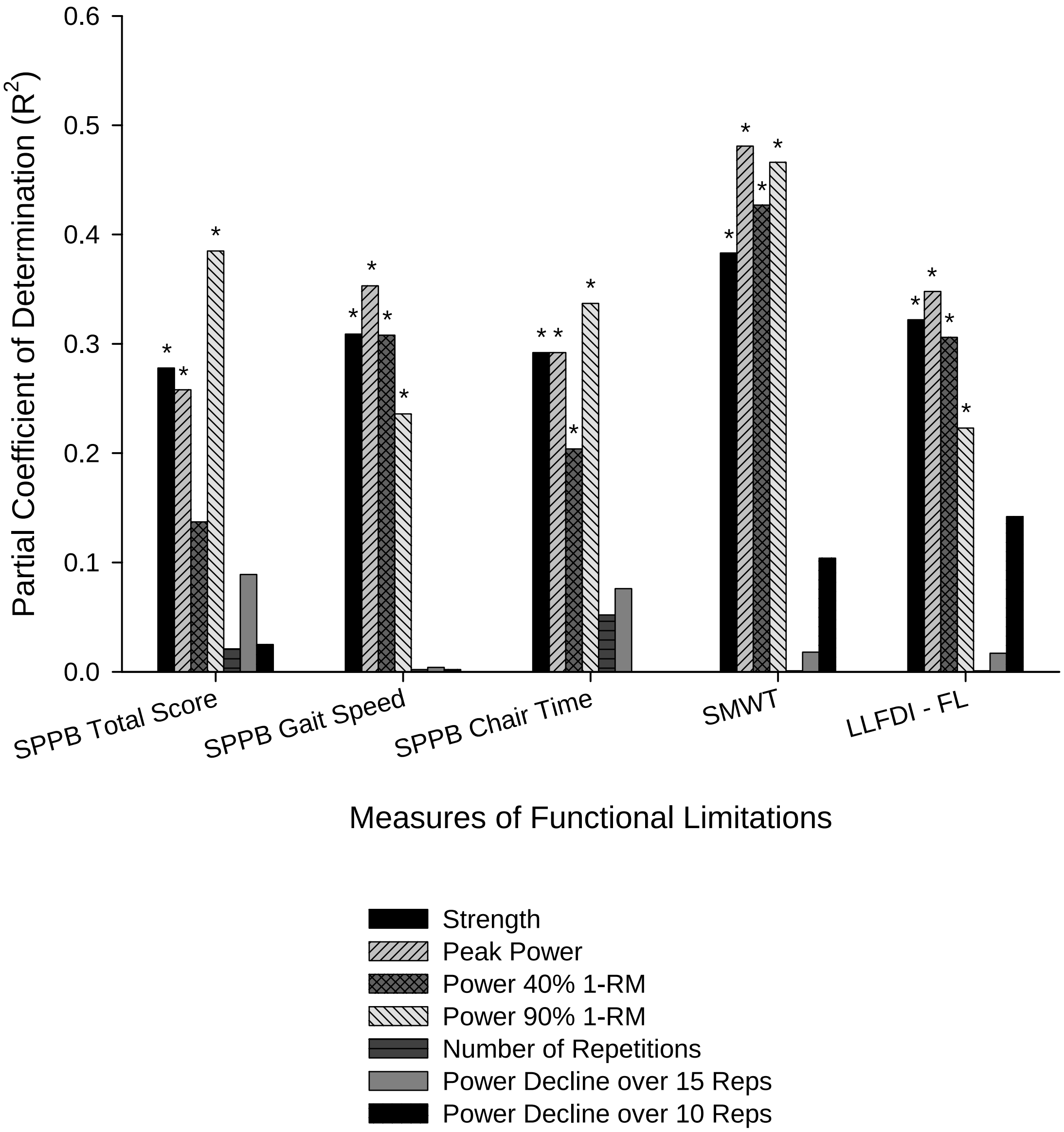


Figure 10. Partial Coefficient of Determination for each measure of muscle performance to measures of functional limitations.

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* Indicates results significant ($p < 0.05$).

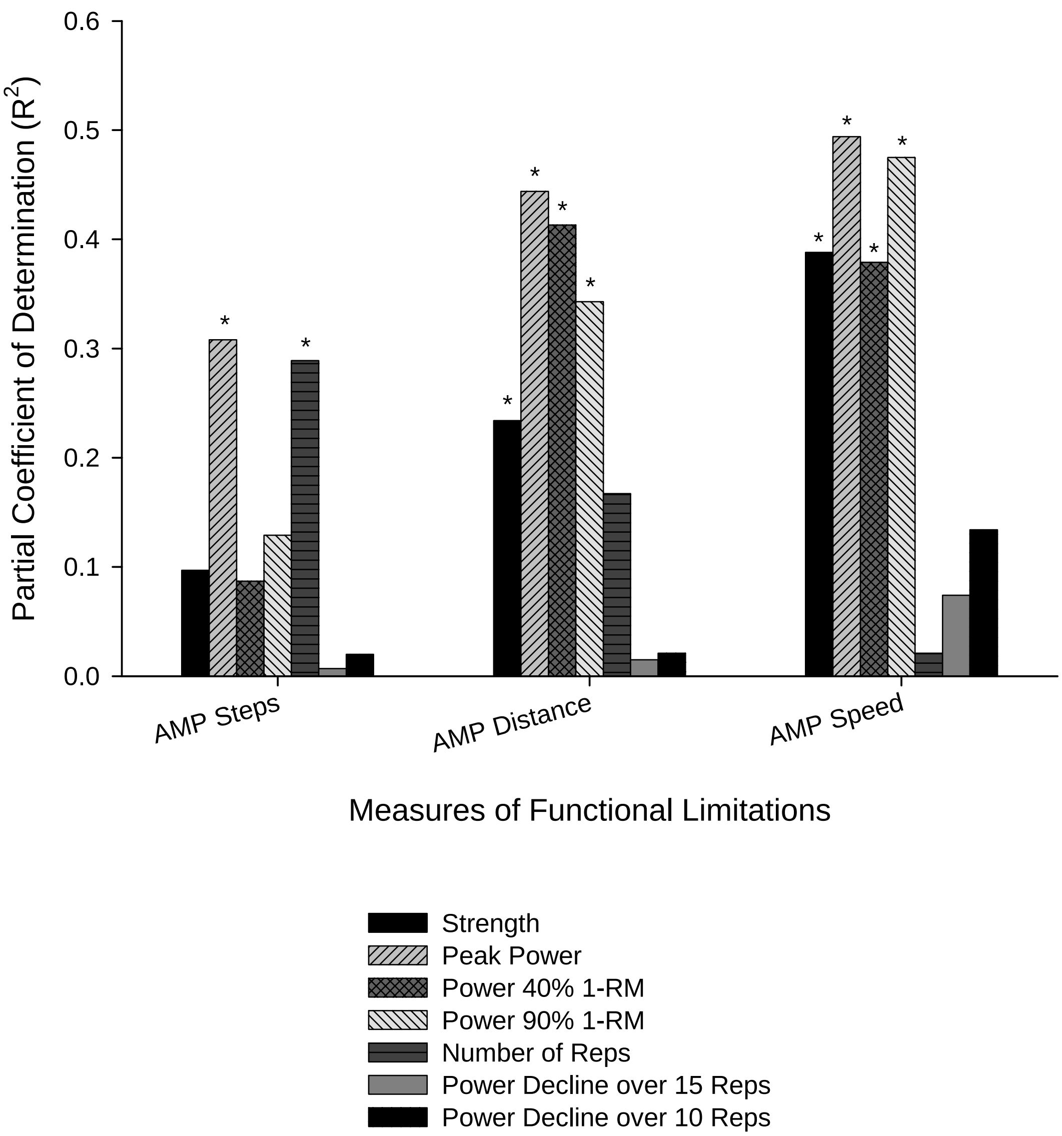


Figure 11. Partial Coefficient of Determination for each measure of muscle performance to AMP activity monitor data.

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* Indicates results significant ($p < 0.05$).

# CHAPTER V. DISCUSSION

The results of this study support the relationship between impairments in lower extremity strength and power to functional limitations and disability in community-dwelling older adults. Impairments in lower extremity strength were found to be significantly related to functional limitations and disability. Impairments in lower extremity power consistently demonstrated a stronger relationship to all measures of functional limitations and disability. Impairments in lower extremity endurance had almost no relationship to functional limitations or disability. The results of this study provided many interesting points of discussion and analysis.

## Subject Description

In order to examine how impairments in muscle performance were related to functional limitations and disability, a pool of subjects with functional limitations and disability present was needed. A group of subjects who were diverse in age and gender was also seen as a beneficial attribute of the individuals in the study population.

### Demographic Information

The participants in this study demonstrated a wide age range (Table 2). While there was a disproportionate number of females to males, this is ratio is not uncommon in the gerontology literature.[29, 34] The participants in this study (Table 2) tended to be overweight (BMI > 25 kg/m$^2$) and some were obese (BMI > 30 kg/m$^2$). This is also a typical finding given changes in body composition that take place during the aging process along with a decrease in physical activity levels seen in older adults.[136]

### Impairments in Muscle Performance

Subjects' results for lower extremity strength were similar to other studies that examined muscle performance in older adults with mild to moderate functional limitations using the Keiser Equipment.[29, 31, 135, 137] Subjects in the current study tended to have higher lower extremity power values. Lower extremity power measures at 40% of 1-RM ranged from 2.3 – 3.8 W/kg in previous studies while subjects in the current study achieved an average of 7.1 (2.7) W/kg.[29, 137] Peak power ranged from 3.8 – 6.8 W/kg in previous studies, while subjects in the current study achieved an average peak power of 7.6 (2.7) W/kg.[31, 34, 138] Subjects in the current study also achieved peak power at a lower percentage of 1-RM. The majority of subjects in this study achieved peak power between 40% – 60% of 1-RM. In previous studies using the similar testing modes, peak power was achieved closer to 70% 1-RM.[29, 31, 74, 118]

One possible explanation for these differences is that the subjects in the current study had higher levels of lower extremity power. However, when the subjects' strength measures and measures of functional limitations results in the current study were compared to subjects in the other studies, there were minimal differences. Since a strong relationship has been shown between lower extremity power and these measures, if subjects in the current study actually possessed higher amounts of power, between study differences in strength and functional limitations would have also been expected.

A more plausible explanation is that the power testing protocol used in the current study accounted for the differences. In most previous studies, subjects' lower extremity power was measured in one session and subjects only performed one attempt at each external load (% of 1-RM).[29, 74, 139] In contrast, subjects in the current study performed two muscle performance testing trials on separate days. Also at each external load, three attempts were given. This was done to account for possible learning effects with high velocity muscle contractions and ensured that subjects' achieved their best performance. In other reports, measures at 40% and 50% 1-RM might not have reflected a subject's best performance as subjects were still learning how to recruit the lower extremity musculature to produce high velocity contractions. Achieving peak power at 70% 1-RM might have been a function of becoming more efficient in performing a high velocity muscle contraction.

A novel approach was used in this study to assess lower extremity endurance. Subjects were instructed to complete as many contractions as possible at 60% 1-RM and all repetitions were performed at the highest velocity possible. This method of testing allowed endurance to be assessed through the number of repetitions completed and also by examining how power declined across each repetition. Because subjects were maximally exerting themselves, a decline in power production with each repetition due to the onset of fatigue was expected. Unfortunately, seven subjects did not demonstrate a pattern of achieving peak power in the beginning of the test with a decline in power as the test continued. These subjects had to be eliminated from the endurance data analysis. Not achieving peak power in the first three repetitions gave these subjects an advantage in the number of repetitions they could complete because they were not maximally exerting themselves from the start of the test. Their decline in power values would be artificially smaller or a decline in power might not even be present if they did not properly exert themselves from the beginning to the end of the test. A more extensive critique of the endurance testing protocol is included in the discussion of the results for Specific Aim #1.

## Functional Limitations

Subjects enrolled in this study appeared to demonstrate mild to moderate functional limitations. A total score between 7-9 on the Short Physical Performance Battery (SPPB) is considered an indication of moderate functional limitations in older adults.[47] The subjects in the current study demonstrated an average SPPB total score of 8.9 (2.5). Additionally, these scores were similar to findings of other studies that examined older adults with mild to moderate functional limitations.[135, 138, 139] Total distances walked during the Six-Minute Walk Test (SMWT) for participants in this study were below age and gender normalized values.[106, 122, 140] This indicated that individuals in the current study did not have the same functional capacity as healthy, non-impaired adults of similar age. These findings verify that this study's sample population was representative of older adults with mild to moderate functional limitations.

## Disability

Subjects in the current study had similar scores on the Late Life Function and Disability Index (LLFDI) Disability Component as subjects in previous reports that included older adults with mild to moderate functional limitations.[40, 132] These findings demonstrate a degree of disability in the current study's population and provide the foundation for examining how muscle performance is related to disability.

## Specific Aim #1

### Impairments in Strength and Functional Limitations

Strength was significantly related to every measure of functional limitation except AMP steps. Partial Coefficients of Determination ($R^2$) for strength to measures of functional limitations ranged from 0.23 – 0.39. These values tended to be similar to or higher than previous studies that examined the association between impairments in lower extremity strength and functional limitations.[31, 34] Some reports have shown that the relationship between strength and lower intensity activities, such as normal walking speed, is lower in comparison to higher intensity activities, such as rising from a chair or stair climbing.[141] The findings of this study did not support this idea. The $R^2$ between strength and gait speed from the SPPB was 0.31 versus the $R^2$ between strength and SPPB chair stand was 0.29.

The ability of muscles to produce force is the foundation of all functional activities. Walking requires dynamic force production to move the limbs and static force production to stabilize the body. Getting out of a chair or off the floor involves creating enough force to move the body against the resistance of gravity. The more strength a person can produce, the easier it is to perform functional activities and the less fatigued a person feels after completing such activities. For example, if getting out of chair requires almost all of an individual's strength or if they cannot get out of a chair at all, this person will demonstrate functional limitations. Additionally, the individual will be less likely to do these activities repeatedly because of the difficulty associated with these tasks. When they do complete the relatively intense activity, their potential to perform other tasks will be less because of the fatigue experienced from the activity.

Because of the relationship between strength and function the results of the analysis are not surprising. If an individual presents with impairments in his or her ability to generate a certain level of force, functional abilities will be limited and some activities may even be impossible to complete.

## Impairments in Power and Functional Limitations

Impairments in lower extremity power consistently explained more of the variance in measures of functional limitations than lower extremity strength. The findings of this study mirror results of other reports.[29, 31, 34] As was stated in the previous section, a certain amount of force production is needed for all functional activities. In addition to force production, the speed at which the force can be produced also affects functional abilities. For example, strength is needed to walk, but the rate at which force is produced will affect the velocity of walking.[142] Strength is needed to get out of a chair, but an individual also needs to produce motion to over come the resistance to movement provided by gravity in order to lift oneself out of the chair.

It is reasonable to expect both strength and power to be related to functional limitations with power explaining more of the variance in functional limitations. In this study, strength and power values had a high degree of relationship (r = 0.70 - 0.92). This can be explained through two factors. First the loads used for power testing were based on strength performance. The design of this study thus created a link between strength and power. Secondly force production capability is one of two variables that influence power. If a subject has low strength, they would also be expected to have low power.

If strength and power showed similar $R^2$ values in regression analysis examining the relationships between impairments in muscle performance and measures of functional limitations, one conclusion could be that power is only related to functional limitations due to its high collinearity with strength. However, power consistently explained more of the variance in functional limitations than strength and this difference was large in most cases. The difference in $R^2$ values for strength and power would indicate the contraction velocity associated with force production affects functional limitations more than force alone. Contraction velocity is an important factor to function in older adults and has to be considered during the management of older adults.

Similar to the hypothesis that strength has different relationships to functional limitations based on the intensity of the activity, the same idea has been applied to the relationship of power and functional limitations. A handful of research teams have looked at how power at different relative intensities is related to various functional limitations. Accordingly, they have hypothesized that power at low load/high velocity is more important than power at high load/low velocity for activities such as walking. Their hypothesis is based on the assumption that walking is a lower intensity activity. An inverse relationship would be present when considering high intensity activities such as climbing steps and getting out of a chair.

Cuoco et al addressed this question by comparing the relationships of power at 40% 1-RM and power at 70% 1-RM to stair climbing, standing from a chair, and habitual gait speed.[29] A 40% 1-RM load was chosen to represent power at low load/high velocity, while power at 70% 1-RM was chosen to represent peak power since most individuals achieved peak power at this external load in previous studies. The results showed that power at 40% 1-RM explained as much or more of the variability in functional limitations than 70% 1-RM with the greatest difference in $R^2$ values seen for gait speed.

The investigators concluded that power at low load/high velocity might have a greater influence on function than peak power, especially at lower intensity activities like walking. They stated that future studies should examine if training to improve power in this range will lead to better changes in function versus training at high load/low velocity.

There are some weaknesses with the Cuoco et al study and other studies that have used a similar design to compare different power values.[29, 135, 137] First, not every subject achieves peak power at the same percentage of 1-RM (as seen in the current study). Therefore, power at 70% 1-RM may not truly be peak power for every subject. To conclude that low load/high velocity power is more important than overall peak power may not actually be supported. Second, power at 70% 1-RM has been referred to as a high load/low velocity power in some studies.[135, 137] A better measure of high load/low velocity power would be power at 90% 1-RM.

In an attempt to build upon the shortcomings of previous investigations when making comparisons between different measures of power, the following designs were incorporated into the current study. First, peak power for each individual subject was used in the peak power analysis versus simply choosing power at a set external load where most individuals achieved peak power. While this leads to using power values at different external loads for each subject, this better accounted for individual differences among subjects. Next, analysis in this study included power at 40% 1-RM because previous reports have found this to be such an important power value. Third, instead of using power at 70% 1-RM to represent power at high load/low velocity, power at 90% 1-RM was used. Since so many older adults need to use almost all their strength to do some daily activities, choosing a power value close to 1-RM may provide better contrasts when comparing different power values. Including these three measures of power was one of the novel aspects of this study.

As demonstrated in Tables 13-15 and Figures 10 and 11, peak power was the primary measure that explained variability in functional limitations involving walking.

This finding was in contrast to Cuoco et al who concluded that power at low load/high velocity was more strongly associated to walking than peak power.[29] There are a series of possible explanations for these findings. First of all, walking may not be a low relative intensity activity for all individuals. Some individuals have low strength and will need to use a higher relative intensity to move and control the body. For these subjects, power production abilities at higher relative intensities might have a greater affect on walking. Other factors such as obesity and postural abnormalities might also affect the relative intensity of ambulation. Individual factors could lead to a higher relative force production during walking in comparison to individuals who are of normal weight and demonstrate proper postural alignment.

Power at 40% 1-RM represents power capabilities only at an arbitrary level. Some individuals will be able to produce high amounts of power at this relative low intensity while others will perform better at higher relative intensities. This might have to do with individual factors such as muscle fiber type ratio, absolute strength, or life experience with high intensity activities. Peak power production likely explained more of the variability in functional limitations because this value represents the overall power capabilities of the lower extremities. During daily activities it is likely more important what the greatest amount of power that can be produced independent of what relative intensity peak power is achieved.

In contrast to the findings that peak power has the greatest influence on walking performance, power at 90% 1-RM explained more of the variability in SPPB total score. The $R^2$ values for power at 90% 1-RM associated with SPPB was 0.25 units greater than power at 40% 1-RM and 0.13 units greater than peak power. These large differences in the relationship to SPPB total score have some meaningful implications. The SPPB is one of the most commonly used functional assessment tools in the geriatric literature. The tool assesses three separate and important aspects of function (static balance, walking speed, ability to get out of a chair) and has been shown to predict such important factors as development of disability, nursing home admissions, and death in older adults.[121] Based on the findings of the current study, the argument could be made that power at high load/low velocity is the most important power value in older adults and interventions should be designed to focus on improving this area of muscle performance. This finding is in contrast to the Cuoco et al study that found almost no difference in the $R^2$ associated with SPPB total for power at 40% 1-RM and power at 70% 1-RM (0.43 vs. 0.41).[29]

Before making a broad statement that power at high load/low velocity is the most important factor of muscle performance, the examination of the subscales of the SPPB provided more insight into the relationship between impairments in power and functional limitations. When the subscales of the SPPB were individually examined, power at 90% 1-RM explained more of the variability in the chair stand subscale. Peak power explained more of the variability in gait speed calculated from the four meter walk test subscale. There were no differences in any measures of muscle performance for those participants who scored a four out of four on the balance subscale versus those who scored less than a four.

The demands on the musculoskeletal system to complete a chair stand are more than double the requirements of normal walking.[141] Power at almost maximum force production (90% 1-RM) would intuitively have a stronger relationship to this task in comparison to power at lower intensities. This would be especially true for older adults with impairments in muscle performance who may require almost all their strength/power to get out of a chair. The relationship of muscle performance to walk speed from the SPPB mirrors the results of SMWT and AMP data. No significant relationships between muscle performance and the balance subscale were seen. This likely has more to with the sensitivity of the balance score as opposed to no relationship being present between muscle performance and balance since other studies have found a relationship between these two factors.[143]

The reason for power at 90% 1-RM having a stronger relationship to SPPB total score is likely due to the stronger relationship of power at 90% 1-RM to chair stand than peak power. There is also a possibility that power at 90% 1-RM might have some kind of relationship with balance that was not detected with the Mann Whitney U Test. A relationship to balance may account for power at 90% 1-RM having such a greater relationship to SPPB total score in comparison to the other measures of muscle performance. The most appropriate conclusion to make from these findings would be that power across a range of intensities is important. Power at varying relative intensities affects functional limitations in different ways.

The LLFDI Functional Limitation Component provides an overall self assessment of functional limitations. The questions ask about functional activities ranging from stair climbing, getting dressed, running, pouring water or opening a door (Appendix B). Although this test is a self assessment, it does provide a wider range of functional limitations than the physical performance tests used in the study. The results demonstrated that peak power explained more of the variability in LLFDI Functional Limitation Domain than the other measures of power. When functional limitations were defined through a broad range of activities, peak power was found to be more important than power at a low load/high velocity or power at a high load/low velocity.

Because of the high collinearity between strength and power, stepwise linear regression analysis was repeated using velocity values in place of power values. This eliminated the collinearity between the independent variables. In some regression equations, both strength and velocity values were significantly related to the measure of functional limitations and were entered into the model. In these situations, strength was always entered first and explained more of the variability than velocity. This would indicate that force production is a vital aspect of function and is more important than contraction velocity. While contraction velocity is important, if strength is lacking, function will be negatively affected. This is in contrast to the findings of Sayers et al who found that contraction velocity during power testing at 40% 1-RM explained more of the variability in gait speed than strength for both men and women and more of the variability in SPPB total score in women.[135] Their results might lead some to conclude that the focus of exercise training should be primarily on contraction velocity and less on strength. The findings of the current study would counter that conclusion.

The multiple analyses of power values to functional limitations would seem to indicate that peak power, power at high load/low velocity, and power at low load/high velocity are all related to functional limitations. The amount of influence that these aspects of power have on functional limitations is based on the activity being considered. Walking is more influenced by peak power whereas high intensity activities, such getting out of a chair, are more influenced by power at 90% 1-RM. Low load/high velocity power was found to be significantly related to multiple measures of functional limitations, but at no time did this measure explain more of the variability in functional limitations than peak power or power at 90% 1-RM. This is likely due to the high correlation between peak power and power at 40% 1-RM. The fact that four individuals did not have power values at 40% 1-RM could have also contributed to the weaker relationship between this measure of power and functional limitations. The loss of data for four participants decreased the statistical power to find a relationship between power at 40% 1-RM and measures of functional limitations.

## Impairments in Endurance and Functional Limitations

One of the surprising findings in this study was that lower extremity endurance had almost no relationship to functional limitations in older adults. The only measure of functional limitations that endurance showed a significant relationship to was AMP steps. Because so many of our daily tasks involve repetitive activity over long durations of time, it was hypothesized that endurance would have a stronger relationship to functional limitations measures such as SMWT distance and AMP data. This was not the case.

Various explanations can be given for these findings. First, the testing protocol used to measure endurance might have been too complex for the assessment of impairments in endurance in older adults. Seven subjects had to be excluded due to testing performance that demonstrated a lack of maximal effort with all repetitions. Subjects were given multiple opportunities to practice the testing protocol during their orientation session to the leg press and then prior to actual testing sessions. A lack of familiarity with the testing protocol should not have been responsible for these seven subjects being excluded.

A more likely explanation would be that subjects might not have been exerting themselves maximally due to apprehension about performing multiple high velocity contractions until fatigue. This could have been due to concerns about injury or perceived possible discomfort associated with the test. In future studies, better monitoring of performance should be carried out to ensure proper completion of the testing protocol. One possibility would be to practice with the actual weight that the subject will use during the test as opposed to a lighter weight. This would allow practice that is more similar to the actual testing protocol. One concern of using the actual weight rather than a light weight would be causing fatigue prior to the actual test. To try to avoid the fatigue, the subject could perform five repetitions at maximal velocity and then the investigator could examine the trend of the power values. If the subject peaked within the first three repetitions and started to decline in repetition four and five, this would be an indication of proper performance of the test. If the subject does not meet this criterion, more instruction and practice could be provided. Five repetitions should be adequate to determine if the subject is properly completing the test but still not be enough work to overly fatigue the subject. Recovery could be expected in 10 minutes or less.

Another alteration to the testing protocol in the hope of achieving better performance from subjects would be to measure decline in power over a set number of repetitions as has been done in previous studies that used isokinetic testing protocols.[80, 83, [88, 89] This would give subjects a clear end point to the test. Subjects in the current study could deduce that the more repetitions they achieved, the better their performance. Some subjects might not have been maximally exerting themselves in the early repetitions so they could complete a high number of overall repetitions. A clear end point in the number of repetitions might eliminate this possibility by relieving some of the apprehension associated with a maximal exertion test. Subjects would not be asked to continue until fatigue, but rather to just complete "X" repetitions. This method of testing was not done in the current study because of the assessment of power decline through an isotonic mode was a novel approach. Concurrently assessing the number of repetitions completed and power decline was viewed as a way to ensure that one standard measure of endurance was obtained in case the power decline data were not appropriate for analysis.

Another explanation of why no relationship was found between endurance and measures of functional limitations could be that the testing protocol was not adequate to cause fatigue. Using 60% of 1-RM might not have been a high enough load to facilitate lower extremity fatigue. Previous researchers have used greater masses with some investigators using up to 90% 1-RM to test endurance.[31, 37] The major difference between the current study's testing protocol and other studies is that maximal contraction velocity was sought for each repetition. The high contraction velocity increased the stress on the musculature and led to quicker fatigue than performing at a slower set pace. This was the rationale of choosing a 60% 1-RM load for the endurance test.

The time to complete the testing protocol in this study would support the decision to use 60% 1-RM for the endurance test. A local muscle endurance test should facilitate fatigue in less than two minutes.[93] This was achieved through the testing protocol of this study. The cadence of the test allowed three seconds to complete each repetition, one second for the concentric phase and two seconds for the eccentric phase. The average number of repetitions was 23 (test time of 69 seconds) and only one subject achieved greater than 40 repetitions (test time of 120 seconds). If 60% 1-RM was too low of a relative load to use during the test, subjects would not have fatigued as quickly as they did.

When the power decline across the first 10 and 15 repetitions was examined, subjects averaged just a 10.7% and a 16.8% decline respectively (Table 5). In other studies that had used the decline in power across repetitions to assess endurance, power declines ranged from 25-60%.[80, 83, 86] So while statistically there was a significant decline, it is questionable whether the power declines with this study were meaningful. This finding leads to a conflict of information. Subjects were maximally fatigued because they could not perform further contractions, yet the decline in power was minimal. One explanation is that the testing protocol did not allow for a gradual decline in power. Because of the intensity of the testing protocol, fatigue came on very quickly and the subjects just stopped. In the previous studies, a lower intensity was used so as to allow more repetitions to be completed. In future studies using the Keiser equipment, use of a lower relative intensity to allow a more gradual decline in power might be considered.

Another explanation for the lack of a relationship between endurance and functional limitations would be that older adults in this study had all the endurance they needed to perform daily activities. Just as with strength and power, there may be a threshold of endurance needed to perform daily activities.[34, 144] Once an individual possesses this level of endurance, endurance no longer affects function. As was stated in Chapter II, older adults demonstrate a fatigue paradox.[66] Their strength declines with aging, but they actually have greater relative endurance in comparison to younger individuals. It is quite possible that older adults in this study presented with impairments in strength and power, but did not have impairments in endurance at a magnitude that would affect function.

The other explanation of why almost no measures of endurance were related to functional limitations could be that muscle endurance truly does not affect functional limitations in older adults. Endurance may not be an important aspect of muscle performance in older adults. This could be because when older adults perform activities over long periods of time, they choose a rate of performance that does not lead to excessive fatigue. For example, if an older adult goes grocery shopping, he or she might choose to walk at a slower pace then when walking shorter distances. This decreased intensity of activity would allow the oxidative energy system to be the main provider of energy and prevent stressing the glycolytic energy system. The need for high levels of local muscle endurance would not be necessary if this kind of strategy was implemented.

One way to address this issue would be to more closely examine daily activities with an activity monitor. The bouts of walking that last greater than two minutes could be examined and compared to bouts of walking with duration less than two minutes. The average walking speed across these categories of walking could be compared to see if they differ. If the rate of walking speed decreases for longer duration activity bouts, this would indicate an adjustment in the intensity of the activity to prevent fatigue. If maximum oxygen uptake values for each subject were known, the estimated relative intensity of walking at durations greater than or less than two minutes could be compared. Unfortunately, aerobic capacity was not measured in this study and the epoch of the AMP was set to one hour, so this type of analysis could not be performed.

The conclusion that muscle endurance is not related to function in older adults is hard to fathom. There are many aspects of function that involve repetitive activity, such as walking long distances. More investigation has to be done into the most appropriate manner in which to assess endurance in older adults considering the shortcomings in the endurance test used in this study and the conflicting methods used in the literature (see Chapter II). Once these issues are worked through, a better understanding of how endurance is related to functional limitations in older adults can be studied.

## Curvilinear Relationships between Muscle Performance and Functional Limitations

While previous investigators have found a curvilinear relationship between measures of impairments in muscle performance and functional limitations, that was not the case in this study. The only curvilinear relationship found was between peak power and AMP steps. The lack of a curvilinear relationship might be due to the levels of functional limitations demonstrated in this study population. Most subjects were likely below the strength and power threshold needed to perform functional activities without difficulty. This led to a linear versus curvilinear relationship. The other possibility is that due to the relatively small number of subjects in this study, it was difficult to identify a significant curvilinear relationship.

## AMP 331 Activity Monitor Data

One of the novel aspects of this project was the inclusion of an activity monitor to track each subject's daily activity. No studies known to this investigator have used this means of assessment to examine factors that affect functional limitations in older adults. The activity monitor data provide a unique perspective on functional limitations by capturing activities in the community and home setting over extended periods of time.

As was stated earlier, peak power was the factor of muscle performance that explained more of the variability in walking performance than the other factors of muscle performance. In addition to this conclusion about factors influencing community activity levels, various other interesting points can be discussed based on the AMP data.

Muscle performance was found to have a stronger relationship to AMP speed than to AMP distance and AMP steps. One explanation for this would be that while physiological factors like muscle performance affect the volume of walking (distance and steps), the volume of walking is also affected by non-physiological aspects. These non-physiological factors include household responsibilities, activities outside the home, environmental factors, and the importance placed on physical activity. The volume of walking a person chooses to perform each day will be affected to a degree by muscle performance, but if a person places greater value on activity or has a loved one to care for, they will achieve higher volumes of activity in comparison to someone who lives alone and prefers playing cards instead of exercising. According to the disablement model, these would be referred to as intra-individual and extra-individual factors. These factors are outside the main pathway of the disablement model, but still affect functional limitations and disability in older adults.

Whether individuals walk at 1.0 m/s or 0.8 m/s has more to do with how much strength, power, aerobic capacity, and dynamic balance they possess than intra-individual and extra-individual factors. Walking speed is a more of an automatic activity based on physiological capabilities such that it would be reasonable to expect AMP speed to be more related to muscle performance than AMP distance or steps.

The assessment of the number of AMP steps provides some information on activity levels, but has limitations that need to be addressed and considered when analyzing the results of the current study. AMP steps provide little information on the type of task performed, the distance achieved while taking those steps, or the intensity of the activity. Although, two people might achieve the same number of steps each, the manner of obtaining those steps may differ dramatically. For example, one might do it through 30 minutes of brisk walking, while another might reach the steps during a job that requires them to be on their feet all day. While both are a form of physical activity, they are not of the same intensity and can have different implications for health and function.

The assessment of the number of steps per day in older adults has to been done cautiously. Older adults have been shown to have a shorter step length than younger adults.[145] Additionally, older adults who have greater functional limitations demonstrate a smaller step length than older adults who do not have functional limitations.[146] These findings have direct implications in analyzing the AMP steps data. The older subjects and those subjects with greater amounts of functional limitations likely took a greater number of steps to cover the same distance in comparison to the younger subjects and those who had a lower amount of functional limitations. If AMP steps was used as the only outcome measure, older adults with functional limitations would appear to be more active than the other subjects when in fact this may not be the case. These shortcomings of measuring steps in older adults are likely why impairments in muscle performance have weaker relationships to AMP steps. These findings also highlight the benefits of the AMP 331 in its ability to measure step length and walking speed.

The relationships between strength to AMP steps and peak power to AMP steps were found to be curvilinear. This would imply that the amount of lower extremity power possessed by an older adult will affect the number of steps taken up to a point. Once the threshold amount of power is present, those intra-individual and extra-individual factors such as physical activity beliefs or environmental factors will affect the number of steps completed each day. This conclusion makes sense and would align with the explanations of other investigators who have found curvilinear relationships between impairments and functional limitations. However, it is questionable why a curvilinear relationship was not also found between muscle performance and AMP distance. Because of the previously mentioned limitations for the measurement of AMP steps, the conclusion of a curvilinear relationship between muscle performance and functional limitations in this study's population is difficult to strongly support.

Number of repetitions completed was the only measure of impairments in endurance that was related to was AMP steps. If this finding was viewed in isolation, it could be concluded that endurance does affect functional limitations and is an important aspect of muscle performance. However, as stated above, there are shortcomings in the assessment of number of steps in older adults. If endurance is truly an important factor in the volume of physical activity, it is surprising that a similar relationship was not found between endurance and AMP distance. Also, endurance was not significantly related to any of the other many measures of functional limitations. While a significant relationship is present, these data alone do not provide strong support for a link between lower extremity muscle endurance and functional limitations in older adults.

## Specific Aim 2

One of the other novel aspects of this research study was the examination of the relationship between impairments in muscle performance to disability in older adults. The design of the current study attempted to build upon the shortcomings of previous research. Mediation analysis provided a unique approach to address the indirect relationship between impairments in muscle performance and disability taking into consideration the basic principles of the disablement model. Including measures of functional limitations and disability that fit within the disablement model allowed an expansion of the examination of the relationship between impairments in muscle performance and disability.

As can be seen in Tables 19 and 20, lower extremity strength and the three values of power are all related to disability acting through functional limitations. At no time was there a significant indirect effect between measures of endurance and disability. Two different mediators were used in the mediation analysis. SMWT distance and SPPB total score. The SMWT was chosen to represent functional activities that require longer durations to complete while the SPPB total score was chosen to represent functional activities that were shorter in duration and required quick movements. Both have been shown to have significant relationships to disability in older adults and were justifiable to be used as mediators.

Previous investigators have examined the relationship between strength and disability. The results of the current study support previous findings that strength impairments may lead to the development of disability in older adults. This is the first study, to the investigator's knowledge, that has examined how power and endurance are related to disability in a manner that is cognizant of the indirect relationship between impairments and disability. These results will hopefully contribute to a better understanding of how muscle performance affects disability.

Comparison of the indirect effects from the mediation analysis provides some interesting discussion points. Power measurements consistently had stronger indirect effects than strength measurements. This is likely due to the same reasons power had stronger relationships to functional limitations than strength.

Peak power and power at 40% 1-RM both had greater indirect effects on disability than power at 90% 1-RM when the mediator was SMWT distance. This may have been due to the fact that SMWT distance is based on the ability to ambulate. Since walking for most individuals is not a high intensity activity, it would make sense that power at 40% 1-RM and peak power had a stronger indirect effect on disability than power at 90% 1-RM to SMWT distance.

When using SPPB total score as the mediator, power at 90% 1-RM presented with a stronger indirect effect on disability than peak power and power at 40% 1-RM. Since the SPPB involves higher intensity activities and since power at 90% 1-RM had the strongest relationship to SPPB total score in the analysis for specific aim 1, these findings would be expected.

These data support both strength and power being important factors in affecting disability. The factor of power that is more important is based on the mediator used to link impairments and disability. These findings are consistent with the findings of specific aim 1. These results would also support the importance of muscle performance across a range of relative intensities since functional tasks vary in their level of difficulty.

## Limitations

This study had some limitations that need to be addressed. First, the sample size of the study was small. With only 30 subjects, the application of these results to the general population of older adults with mild to moderate functional limitations needs to proceed with caution. Additionally, there was a poor gender balance in this study. Some previous investigators have found that gender might affect the relationship between muscle performance to functional limitations and disability.[135] This issue could not be examined in more detail due to the small number of males enrolled in the study.

Not having data for four subjects' power at 40% 1-RM was also a weakness in this study. The lowest amount of resistance that the Keiser Air 420 leg press could provide was approximately 36 kilograms. So unless subjects achieved a 1-RM of 91 kilograms, power at 40% 1-RM could not be tested. The subjects who did not have data at 40% 1-RM typically were females of lower body weight. Their normalized strength and power values were in the lower half of the distribution, but they were not the most impaired subjects for muscle performance. The need to exclude these women lowered the statistical power of the test.

The AMP 331 provides a measure of physical activity that no other activity monitor can through its ability to assess distance and walking speed. However, one drawback of this unit is that is does not have a strong track record for reliability and validity as other more commonly used accelerometer-based activity monitors. Each unit in this study was meticulously tested by the principal investigator before its use in the field. This investigator felt comfortable with the reliability and validity of the specific units in this study, but further research into the generalized performance of these units should be done before their use in larger scale studies.

Inclusion of higher intensity measures of functional limitations activities would have been helpful. For example, including a stair climbing test or a measurement of maximal walking speed would have provided more insight into whether the relationship of power to functional limitations changes based on the relative intensity of the functional task. The results of the chair stand subscale of the SPPB do allow this issue to be examined, but an another high intensity measure would have provided additional knowledge.

Muscle performance is just one aspect of physical capabilities. Other factors such as aerobic capacity and balance may also affect functional limitations and disability in older adults.[147-149] Older adults tend to have deficits in multiple interrelated systems due to the aging process. While the results of this study would indicate that improving strength and power would lead to greater function and less disability, other physiological aspects also need to be considered in the exercise prescription. Improvements in muscle performance alone will not be the magic bullet that solves all older adults' problems in functional limitations and disability levels.

This study utilized a cross-sectional design. While the results of this study are exciting and could have many applications, none of these results prove a causal relationship between impairments in muscle performance to functional limitations and disability in older adults. Interventional studies where certain aspects of muscle performance are improved through exercise and then functional limitations and disability levels are examined need to be done to support a causal link. Longitudinal studies that involve tracking impairments in muscle performance, functional limitations and disability would also establish a causal relationship.

## Recommendations

The results of this study have some meaningful implications for clinicians who work with older adults. Based on the findings from this study, the following recommendations appear to be warranted in the management of older adults with mild to moderate functional limitations based. The first recommendation is that exercise should focus on improving both strength and power. Strength is important, but power affects function in ways that strength does not. It is vital to have high amounts of force production, but also to be able to produce force quickly. Designing an exercise program to improve both strength and power does not add any additional time requirements on the individual. By performing a resistance training program at a high velocity versus a low velocity, power increases to a significantly higher level without any detrimental effects on strength gains.[74] Once the individual demonstrates proper technique in the performance of resistance training exercises at a low velocity, the contraction velocity should be increased to a high velocity to facilitate improvements in both strength and power.

While the overall results of this study demonstrate that peak power explains a greater amount of the variability in most functional activities, there are certain situations where power at high intensity is necessary to function. Because of these findings, older adults should train at varying relative intensities. Older adults will benefit from improving power at both low and high loads. The best way to accomplish this would be through a periodization resistance training program. Periodization involves routinely adjusting the training mode, volume, and intensity to facilitate continued gains in muscle performance.[110] This approach to resistance training would involve some training at low loads with progression to training at high loads. Routine adjustments in the dosage of resistance training helps prevent plateau in improvements and provides a means of training across a range of intensities. The American College of Sports Medicine has recently stated in a position statement that periodization should be considered in the design of programs for healthy older adults.[150] Research on the effects of a periodization program for older adults with mild to moderate functional limitations is lacking at this time. While many factors would suggest the benefit of a periodization training program in older adults with functional limitations, such as the results of this study, this is an issue that will have to further be explored.

## Future Research

As with any research study, the discovery of some answers leads to more questions. Since this was a cross-sectional design, further research needs to be performed to determine if improvements in strength and power will ultimately lead to change in functional limitations and disability. Previous research would support the notion that improvements in muscle performance lead to improvement in functional limitations, but the link to disability needs to be further explored.

This study brought up some points of interest about how power at different intensities and velocities is related to functional limitations and disability. Interventional studies that compare exercise programs designed to improve power at low intensities should be compared to exercise programs designed to improve power at high intensities. The changes in functional limitations and disability between groups could be studied as a way to learn more about the importance of power at varying intensities. Interventional studies should also be performed to examine the effects of a periodization resistance training program for older adults with functional limitations.

The measurement of muscle endurance in older adults has many questions remaining. Endurance has been assessed through a variety of techniques leading to conflicting results and confusion in the literature. Studies that explore different methods to measure endurance in older adults need to be conducted. Once this is completed a better understanding of how muscle endurance influences functional limitations and disability in older adults can be formed.

## Conclusion

In community-dwelling older adults, impairments in lower extremity strength and power are related to functional limitations and disability. Power has a stronger relationship than strength to functional limitations and disability. Peak power appears to have the largest influence on functional limitations and disability, except in the performance of tasks that require high relative intensity.  The results of this study do not support a relationship of endurance to functional limitations or disability in community-dwelling older adults.

# APPENDIX A. PHYSICAL SUB SCALE OF THE SF-36

"The follow items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?"

| | Yes, a lot | Yes, a little | No, not at all |
|---|---|---|---|
| Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports? | | | |
| Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling or playing golf? | | | |
| Lifting or carrying groceries | | | |
| Climbing several flights of stairs | | | |
| Climbing one flight of stairs | | | |
| Bending, kneeling, or stooping | | | |
| Walking more than a mile | | | |
| Walking several blocks | | | |
| Walking one block | | | |
| Bathing or dressing yourself | | | |

# APPENDIX B. LATE LIFE FUNCTION AND DISABILITY INDEX

## Instructions for Disability Questions

In this set of questions, I will ask you about everyday things you do at this time in your life. There are two parts to each question.

First, I will ask you *How often* you do a certain activity.
Next, I will ask you *To what extent do you feel limited* in doing this activity.

Explain each question and subsequent answer options:

For the first question (*How often do you do the activity?*), please choose from these answers:

Very often
Often
Once in a while
Almost never
Never
[Show the visual aid to interviewee]

For the second question (*To what extent do you feel limited in doing the activity?*), please choose from these answers:

Not at all
A little
Somewhat
A lot
Completely
[Show the visual aid to interviewee]

For example, you might feel limited because of your health, or because it takes a lot of mental and physical energy. Please keep in mind that you can also feel limited by factors outside or yourself. Your environment could restrict you from doing these things; for instance, transportation issues, accessibility, and social or economic circumstances could limit you from doing things you would like to do. Think of all these factors when you answer this section.

For each question, please select the one answer that comes closest to the way you have been feeling. Let's begin…

**Disability Questions**

How often do you…?/To what extent do you feel limited in…?

D1. Keep (Keeping) in touch with others through letters, phone, or email.

D2. Visit (Visiting) friends and family in their homes.

D3. Provide (Providing) care or assistance to others. This may include providing personal care, transportation, and running errands for family members or friends.

D4. Take (Taking) care of the inside of your home. This includes managing and taking responsibility for homemaking, laundry, housecleaning, and minor household repairs.

D5. Work (Working) at a volunteer job outside your home.

D6. Take (Taking) part in active recreation. This may include bowling, golf, tennis, hiking, jogging, or swimming.

D7. Take (Taking) care of household business and finances. This may include managing and taking responsibility for your money, paying bills, dealing with a landlord or tenants, dealing with utility companies or governmental agencies.

D8. Take (Taking) care of your own health. This may include managing daily medications, following a special diet, scheduling doctor's appointments.

D9. Travel (Traveling) out of town for at least an overnight stay.

D10. Take (Taking) part in a regular fitness program. This may include walking for exercise, stationary biking, weight lifting, or exercise classes.

D11. Invite (Inviting) people into your home for a meal or entertainment.

D12. Go (Going) out with others to public places such as restaurants or movies.

D13. Take (Taking) care of your own personal care needs. This includes bathing, dressing, and toileting.

D14. Take (Taking) part in organized social activities. This may include clubs, card playing, senior center events, community or religious groups.

D15. Take (Taking) care of local errands. This may include managing and taking responsibility for shopping for food and personal items, and going to the bank, library, or dry cleaner.

D16. Prepare (Preparing) meals for yourself. This includes planning, cooking, serving, and cleaning up.

Instructions for Functional Limitations Questions

In this following section, I will ask you about your ability to do specific activities as part of your daily routines. I am interested in your *sense of your ability* to do it on a typical day. It is not important that you actually do the activity on a daily basis. In fact, I may mention some activities that you don't do at all. You can still answer these questions by assessing how difficult you think they would be for you to do on an average day.

Factors that influence the level of difficulty you have may include: pain, fatigue, fear, weakness, soreness, ailments, health conditions, or disabilities.

I want to know how difficult the activity would be for you to do without the help of someone else, and without the use of a cane, walker, or any other assistive walking device (or wheelchair or scooter).

Please choose from these answers:

**None**
**A little**
**Some**
**Quite a lot**
**Cannot do**
[Show the visual aid to interviewee]

Let's begin…

**Function Questions**

How much difficulty do you have…? (Remember this is without the help of someone else and without the use of any assistive walking device.)

F1. Unscrewing the lid off a previously unopened jar without using any devices

F2. Going up & down a flight of stairs inside, using a handrail

F3. Putting on and taking off long pants (including managing fasteners)

F4. Running 1/2 mile or more

F5. Using common utensils for preparing meals (e.g., can opener, potato peeler, or sharp knife)

F6. Holding a full glass of water in one hand

F7. Walking a mile, taking rests as necessary

F8. Going up & down a flight of stairs outside, without using a handrail

F9. Running a short distance, such as to catch a bus

F10. Reaching overhead while standing, as if to pull a light cord

F11. Sitting down in and standing up from a low, soft couch

F12. Putting on and taking off a coat or jacket

F13. Reaching behind your back as if to put a belt through a belt loop

F14. Stepping up and down from a curb

F15. Opening a heavy, outside door

F16. Rip open a package of snack food (e.g. cellophane wrapping on crackers) using only your hands

F17. Pouring from a large pitcher

F18. Getting into and out of a car/taxi (sedan)

F19. Hiking a couple of miles on uneven surfaces, including hills

F20. Going up and down three flights of stairs inside, using a handrail

F21. Picking up a kitchen chair and moving it, in order to clean

F22. Using a step stool to reach into a high cabinet

F23. Making a bed, including spreading and tucking in bed sheets

F24. Carrying something in both arms while climbing a flight of stairs (e.g. laundry basket)

F25. Bending over from a standing position to pick up a piece of clothing from the floor

F26. Walking around one floor of your home, taking into consideration thresholds, doors, furniture, and a variety of floor coverings.

F27. Getting up from the floor (as if you were laying on the ground)

F28. Washing dishes, pots, and utensils by hand while standing at sink

F29. Walking several blocks

F30. Taking a one mile, brisk walk without stopping to rest

F31. Stepping on and off a bus

F32. Walking on a slippery surface outdoors

# APPENDIX C. SHORT PHYSICAL PERFORMANCE BATTERY SCORE SHEET

Balance Score

| | |
|---|---|
| Unable to hold side by side stance for > 9 seconds | 0 point |
| Side by side stance for 10 sec, but unable to hold semitandem for 10 seconds | 1 point |
| Semitandem for 10 sec, unable to hold full tandem for > 2 seconds | 2 points |
| Full tandem for 3-9 seconds | 3 points |
| Full tandem for 10 seconds | 4 points |

Walk Score (4 Meters or 13.12 feet)

| | |
|---|---|
| If time is more than 8.70 seconds | 1 point |
| If time is 6.21 to 8.70 seconds | 2 points |
| If time is 4.82 to 6.20 seconds | 3 points |
| If time is less than 4.82 seconds | 4 points |

Chair Stand Score

| | |
|---|---|
| If the participant was unable to complete the 5 chair stands | 0 points |
| If chair stand time is 16.7 seconds or more | 1 points |
| If chair stand time is 13.7 to 16.6 seconds | 2 points |
| If chair stand time is 11.2 to 13.6 seconds | 3 points |
| If chair stand time is 11.1 seconds or less | 4 points |

Total Score ______________________

# APPENDIX D. SIX-MINUTE WALK TEST DIRECTIONS

1. Subject should be well rested (at least 10 minutes of sitting) and demonstrate a normal resting heart rate.

2. Don Polar Heart Rate monitor, record resting heart rate, resting rating of perceived exertion (RPE), and resting blood pressure

3. Provide the subject the following instructions…
   "The object of this test is to walk as far as possible for six-minutes. You will walk around this track. Six-minutes is a long time to walk, so you will be exerting yourself. You will probably get out of breath and become tired. You are permitted to slow down, to stop and to rest as necessary. You may lean against the wall while resting, but resume walking as soon as you are able.

   I am going to keep track of the number of laps you complete. I will also record your heart rate and your rating of exertion using the 0-10 scale at two, four, and six-minutes.

   Remember that the object is to walk AS FAR AS POSSIBLE for six-minutes, but don't run or jog. You may start whenever you are ready."

4. Once the subject begins walking start the timer. Do not walk with the subject or talk to the subject.

5. Record the heart rate from the Polar Heart Rate Monitor at two, four, and six-minutes. Ask subject to rate his or her RPE with the modified Borg Scale at two, four, and six-minutes.

6. Provide the following standard cues during the testing
   Minute 1: You are doing well. You have five minutes to go.
   Minute 2: Keep up the good work. You have four minutes to go.
   Minute 3: You are doing well. You are halfway done
   Minute 4: Keep up the good work. You have only two minutes left
   Minute 5: You are doing well. You have only one minute to go
   Minute 5:45: In a moment I'm going to tell you to stop. When I do, just stop right where you are and I will come to you
   Minute 6: Stop

7. Ask the question, "what if anything, kept you from walking farther?"

8. Record the distance covered and allow patient to rest.

9. Reassess BP, HR, and RPE in sitting. Allow subject to rest for 10 minutes

# APPENDIX E. TESTING PROTOCOL FOR MUSCLE PERFORMANCE

Orientation Session

1. Subject will first be oriented to the leg press machine, instructed in proper breathing technique to use during testing and introduced to the 0-10 rating of perceived exertion (RPE) scale that will be used during 1-RM testing.

2. Subject will be seated in the machine and the seat will be adjusted to place the hips and knees as close as possible to a 90 degree angle. Seat level will be recorded. Goniometry will be used to confirm proper alignment.

3. Resistance will be set at 50% of predicted 1-RM based on normalized value in the *American College of Sports Medicine Guidelines for Exercise Testing and Prescription* and previous studies that have testing 1-RM of the lower extremities in older adults.

4. Subject will be instructed to perform 5-10 repetitions at a slow controlled pace utilizing proper breathing technique. RPE will be assessed at the completion of the repetitions.

5. Power testing protocol will be explained to the subject. Using 50% of predicted 1-RM, the subject will be instructed to perform a high speed muscle contraction. Following 2-3 high speed contractions, subjects will then be instructed to complete 3-5 maximal speed contractions. A one minute rest period will be given between each contraction

6. Endurance testing protocol will be explained to the subject. Using 50% of the predicted 1-RM, the subject will be instructed to complete 10-20 consecutive repetitions following the prerecorded audio cues. The subjects will be given up to one second to complete the concentric phase of the motion and two seconds to return the pedal to the start position before having to perform the next contraction.

Muscle Performance Trial 1, Testing Session 2

*Strength Testing*

1. The purpose of testing and the protocol will be explained to the subject. Subject will be seated on the leg press and the seat will be adjusted to the previous recorded level. Subject will complete a warm-up trial with 5-10 repetitions at 50% of his or her predicted 1-RM. RPE will be assessed and a one minute rest period will be given.

2. The next weight will be chosen at appropriately 70-80% of their predicted 1-RM and the subject will complete 2-3 repetitions. RPE will be assessed and a two minute rest will be provided.

3. The subject will then attempt his/her 1-RM. Resistance will be set based on their previous responses to warm-up loads and RPE scores. Subjects will be given a two to three minute rest between each trial.

4. Resistance will continue to be increased until the subject is unable to complete a full contraction. The highest resistance moved through the full range of motion will be the 1-RM. The goal is to determine 1-RM within five trials.

*Power Testing*

1. Power measurements will be taken at 40, 50, 60, 70, 80, and 90% of the measured 1-RM. Subjects will be instructed to extend their legs at maximal speed against the resistance. Three trials will be given at each stage, with the highest trial value recorded for analysis. A 45-60 second rest will be given between each of the three trials.

*Endurance Testing*

1. Resistance will be set at 60% of the 1-RM. Subject will be instructed to complete as many repetitions as possible before volitional fatigue. Subject will be instructed to complete the concentric phase as quickly as possible, allow two seconds for the eccentric phase and then complete another concentric phase as quickly as possible. Audio cues will be provided. The test will be terminated when subject is no longer able to complete a full concentric contraction within a two second time period or he/she feels they are unable to continue.

Muscle Performance Trial 2, Testing Session 3

Follow same protocol as Testing Trial 1. Data from the first session will be used to minimize the number of attempts needed to achieve 1-RM.

# APPENDIX F. GERIATRIC DEPRESSION SCALE

1. Are you basically satisfied with your life? YES / NO

2. Have you dropped many of your activities and interests? YES / NO

3. Do you feel that your life is empty? YES / NO

4. Do you often get bored? YES / NO

5. Are you hopeful about the future? YES / NO

6. Are you bothered by thoughts you can't get out of your head? YES / NO

7. Are you in good spirits most of the time? YES / NO

8. Are you afraid that something bad is going to happen to you? YES / NO

9. Do you feel happy most of the time? YES / NO

10. Do you often feel helpless? YES / NO

11. Do you often get restless and fidgety? YES / NO

12. Do you prefer to stay at home, rather than going out and doing new things? YES / NO

13. Do you frequently worry about the future? YES / NO

14. Do you feel you have more problems with memory than most? YES / NO

15. Do you think it is wonderful to be alive now? YES / NO

16. Do you often feel downhearted and blue? YES / NO

17. Do you feel pretty worthless the way you are now? YES / NO

18. Do you worry a lot about the past? YES / NO

19. Do you find life very exciting? YES / NO

20. Is it hard for you to get started on new projects? YES / NO

21. Do you feel full of energy? YES / NO

22. Do you feel that your situation is hopeless? YES / NO

23. Do you think that most people are better off than you are? YES / NO

24. Do you frequently get upset over little things? YES / NO

25. Do you frequently feel like crying? YES / NO

26. Do you have trouble concentrating? YES / NO

27. Do you enjoy getting up in the morning? YES / NO

28. Do you prefer to avoid social gatherings? YES / NO

29. Is it easy for you to make decisions? YES / NO

30. Is your mind as clear as it used to be? YES / NO

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