

## ABSTRACT

**Title of Thesis:** RACIAL AND SEX DIFFERENCES IN STRENGTH, PEAK POWER, MOVEMENT VELOCITY, AND FUNCTIONAL ABILITY IN MIDDLE-AGED AND OLDER ADULTS

Neil Anthony Doldo, Master of Arts, 2004

**Thesis directed by:** Ben F. Hurley  
Professor  
Department of Kinesiology

To determine sex and race differences in strength, muscle power, movement velocity, and functional ability, knee extensor strength and muscle power normalized for muscle volume was measured in 79 middle-aged and older adults (30 men and 49 women, age range 50-85 yrs). Results indicated that men had 55% greater muscle volume (MV;  $P < 0.001$ ), 24% greater 1 RM strength ( $P < 0.01$ ), 9% greater muscle quality (MQ; 1 RM/MV;  $P < 0.05$ ), 26% greater peak muscle power (PP;  $P < 0.01$ ), and 14% greater MPQ (PP/MV;  $P < 0.001$ ) than women. However, women displayed a 38% faster peak movement velocity than men when expressed per unit of muscle (movement velocity quality) (PV/MV;  $P < 0.001$ ). Race analysis showed that African Americans had 20% greater MV than Caucasians ( $P < 0.001$ ), but 11% lower MQ ( $P < 0.01$ ) and a 17% lower PV/MV ( $P < 0.05$ ) than Caucasians of similar age. Men displayed a 22% faster stair climb time than women, while Caucasians exhibited 19% and 16% faster times in rapid pace gait and 8-ft up-and-go, respectively. Thus, despite greater strength and power per

unit of muscle in men, women have a faster knee movement velocity per unit of muscle than men. Moreover, African Americans have greater knee extensor muscle volume than Caucasians, but exhibit lower muscle quality and movement velocity quality.

RACIAL AND SEX DIFFERENCES IN STRENGTH, PEAK POWER, MOVEMENT  
VELOCITY, AND FUNCTIONAL ABILITY IN MIDDLE-AGED AND OLDER  
ADULTS

by

Neil Anthony Doldo

Thesis submitted to the Faculty of the Graduate School of the  
University of Maryland, College Park in partial fulfillment  
of the requirements for the degree of  
Master of Arts  
2004

Advisory Committee:

Ben F. Hurley, Professor, Chair/Advisor  
Michael D. Brown, Associate Professor  
Stephen M. Roth, Assistant Professor

## ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Ben Hurley, for his assistance and guidance throughout the Master's program and in the completion of this thesis. I would also like to thank Dr. Michael Brown and Dr. Stephen Roth for their assistance, time, and support in serving on my thesis committee. This project would not have been possible without the help of the members of the GUSTO team, particularly Matt Delmonico, Dr. Karma Rabon-Stith, and Jason Bailey, as their assistance was greatly appreciated. I would also like to extend a special thanks to all of the participants of the GUSTO study for their hard work and dedication.

Finally, without the loving support of my parents, friends, and especially Faith, this project would not have been possible. They have offered unending encouragement through these stressful times.

## TABLE OF CONTENTS

LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF ABBREVIATIONS	vii
INTRODUCTION	1
METHODS	5
Subjects	5
Body composition assessment	5
One-repetition maximum	7
Muscle power and movement velocity	8
Functional ability	9
Statistical analysis	11
RESULTS	12
Physical characteristics	12
Sex differences	12
Race differences	13
Combined group correlations	14
DISCUSSION	14
TABLES	
Table 1	22
Table 2	23
Table 3	24
Table 4	25
Table 5	26
Table 6	27
FIGURE CAPTIONS	28
FIGURES	
Figure 1	29
Figure 2	30
APPENDIX A: PROPOSAL INFORMATION	31
Statement of the problem	32
Experimental hypotheses	32
Delimitations	33
Limitations	33
Operational definitions	33

APPENDIX B: LITERATURE REVIEW	35
Loss of muscle mass, strength, and power with age	36
The relationship of muscle mass, strength, and power to functional ability	40
Sex and racial differences in muscle mass, strength, and power	43
Assessment of power and movement velocity	50
Summary	55
APPENDIX C: FORMS AND FIGURE	56
Informed consent	57
1RM testing form	60
Power testing form	61
Sample figure of MatLab power curve	62
REFERENCES	63

## LIST OF TABLES

Table 1. Physical characteristics grouped by sex and race	22
Table 2. Sex differences in 1RM knee extension strength, power, movement velocity, and muscle volume of the knee extensors	23
Table 3. Racial differences in 1RM knee extension strength, power, movement velocity, and muscle volume of the knee extensors	24
Table 4. Race and sex differences in power and velocity at absolute loads	25
Table 5. Sex and race differences in tests of functional ability	26
Table 6. Relationships of strength, peak power, and movement velocity to measures of functional ability	27

## LIST OF FIGURES

Figure 1. Sex differences in MQ and PV/MV	29
Figure 2. Race differences in MQ and PV/MV	30

## LIST OF ABBREVIATIONS

MQ	muscle quality
MPQ	muscle power quality
MV	muscle volume
FFM	fat-free mass
DXA	dual energy x-ray absorptiometry
PP	peak power
PV	peak velocity
PV/MV	movement velocity quality
CSA	cross-sectional area
Nm	Newton meter
Rad·s <sup>-1</sup>	radians per second
BMI	body mass index
1RM	one-repetition maximum

## INTRODUCTION

Age-related declines in muscle mass and strength, a condition known as sarcopenia, as well as interventions designed for the prevention and treatment of sarcopenia, have been widely investigated in recent years (35, 83). Sarcopenia is associated with deteriorations in health status and the performance of activities of daily living, and a rise in health care costs (31, 39, 56, 75) through increased risk of falls (49, 50), hip fractures (3), and losses in functional ability (14, 36). Lindle et al. (48) have shown significant declines in muscular strength beginning as early as the forties, while other studies have demonstrated accelerated strength losses after the age of 50 (1, 46, 60). One underlying cause of strength losses with age appears to be declines in muscle mass, especially in the lower extremities (27, 48, 80, 98). However, age-related deterioration of neuromuscular function and reductions in the proportion and size of type II muscle fibers have also been reported (16, 46). Past investigations have established that the loss in muscle mass (39, 100) and muscle strength (36, 44, 49, 77, 84, 98) are strongly correlated with reduced functional capacity in the elderly. Although significant age-related functional declines can be attributed to losses in strength, muscular power, the product of force and velocity, appears to be more closely related to functional ability (8-10, 76, 88). It may also be possible that velocity alone influences the relationships observed between power and function (35). However, there is little information available on this or on the associations of peak muscle power, movement velocity and functional ability. In this regard, recent studies have reported greater age-associated losses in muscular power than strength (9, 10, 60, 88). Some investigators have cited deficits in the velocity of movement as the primary cause of age related-power losses (15, 20, 97). Pearson et al.

(72) reported similar age-related losses in velocity between aged elite masters weightlifters and age-matched controls, despite large differences in strength and power. Differences in methodologies and sample populations may explain some of the conflicting results in studies dealing with predictors of functional ability. To our knowledge, no reports have examined the relationship of peak movement velocity, independent of power and force, with functional abilities.

Another important factor to consider when evaluating relationships between muscle power, movement velocity and functional ability is muscle mass. Several investigators have reported strong correlations between age-related losses in strength and muscle mass (57, 80), but the sarcopenic effect on power is not well understood. While some studies have found no correlation between power and muscle CSA (23, 72), others have provided significant relationships between muscle CSA and its influence on muscular power (21, 38). One possible explanation for the discrepancies observed in these and other studies, is the use of girth measurements to estimate muscle mass, which can be affected by other anthropometric factors, such as subcutaneous fat. Cadaver studies have shown that the use of computed tomography (CT) to assess muscle volume can provide an accurate and reliable assessment of muscle mass or volume (33, 63).

Previous studies in our lab have shown the importance of analyzing strength per unit of muscle volume, or muscle quality (MQ) in assessing age- and gender-related differences in muscle function (51, 93). MQ is believed to be a better indicator of muscle function than strength alone because it takes into account the intrinsic characteristics of the musculature (45). To our knowledge, no other investigators have reported the

expression of muscle power or movement velocity in the same way, i.e., per unit volume of muscle.

In an attempt to identify subpopulations that have greater functional risks, many studies have assessed sex-differences in the age-related decline in power. Although men are thought to lose a larger percentage of their power output than women per year (88), women have significantly lower power, even when normalized for overall body mass (5, 7, 15, 45). This lower power in women is thought to contribute to their higher rates of disability than men (76). There is a substantial amount of information available concerning maximal force (strength) differences between sexes (1, 12, 17, 27, 34, 48, 84, 88), but little information is available on the velocity component of power. In addition, because strength differences narrow when normalized for muscle mass (15, 27), it may be of interest to determine sex differences in power when normalized per unit of muscle.

To our knowledge, only three studies have reported peak velocity as it relates to power output in women (15, 20, 52). Only one of these studies (15) has compared their findings to men of similar age, and this study observed lower peak power values in women that were attributed to deficits in velocity. Each of these studies found that velocity influences power more than strength, but the data may be skewed due to the use of a very old population (15) and the use of a standing force jump plate (15, 20). Jumping requires a large amount of strength and coordination, as well as power, and will constitute a higher percentage of strength in the elderly. At these near-maximal forces, velocity would likely have been compensated based on the force/velocity curve, and may reflect the very low velocities reported in these studies. There is a need to determine sex-

differences in power and velocity by keeping force constant relative to strength, which has not been reported.

Although limited, some information does exist on sex-differences in power, but to our knowledge there are no reports on racial differences in power. In this regard, power may be an important link to understanding racial differences in age-related deficits in muscle function. Recent studies have shown that on average African Americans have greater muscle mass than Caucasians (2, 100). Surprisingly, the larger muscle mass in African Americans has not correlated with greater strength in specific muscle groups. For example, Rantanen et al. (79) reported no difference in knee extension strength between Caucasians and African Americans, while Newman et al. (66) concluded that African Americans had greater muscular strength, but poorer muscle quality than Caucasians of a similar age. Even more perplexing are conflicting results from studies on racial differences in functional performance. Some investigations have shown that Caucasians, especially women, are at greater risk for falls than are African Americans (19, 32). Conversely, Means et al. (59) concluded that African American women had poorer balance and mobility than Caucasian women and Visser et al. (100) reported worse lower extremity performance in African Americans. Although there are methodological differences in the previously mentioned studies, it is clear that racial differences in aged muscle is not well understood. Because peak power and movement velocity are associated with the ability to perform functional tasks related to activities of daily living, and because there are racial differences in functional ability among the elderly, determining racial differences in these two components may have important implications.

Therefore, the purpose of this study is to and to examine possible sex and racial differences that may exist among strength, power, and movement velocity and how these variables are related to functional ability in an older population.

## METHODS

*Subjects.* Seventy-nine healthy men (N = 30) and women (N = 49) between 50 and 85 years of age volunteered to participate in the study. Racial identification was classified by self-report of the subject. All subjects underwent a phone-screening interview, received medical clearance from their primary care physician and completed a detailed medical history prior to participating in the study. Subjects qualified if they were not participating in regular vigorous physical activity ( $\geq 1$ x/wk) and had been sedentary for at least six months. All subjects were nonsmokers, free of significant cardiovascular, metabolic, or musculoskeletal disorders that would affect their ability to safely perform heavy resistance exercise. After all methods and procedures were explained, subjects read and signed a written consent form, which was approved by the Institutional Review Board of the University of Maryland, College Park.

*Body composition assessment.* Body weight was determined to the nearest 0.1 kg with subjects dressed in medical scrubs, and height was measured to the nearest 0.1 cm using a stadiometer (Harpenden, Holtain, Wales, UK). BMI was calculated as weight (kg) divided by height (m) squared. Body composition was estimated by dual energy x-ray absorptiometry (DXA) using the fan-beam technology (model QDR 4500A, Hologic, Waltham, MA). A standardized procedure for patient positioning and utilization of the QDR software was used to ensure consistency from scan to scan. Total body mass, fat-free mass (FFM), and % fat were analyzed using Hologic's version 8.21 software for

tissue area assessment. Total body FFM was defined as lean soft tissue mass plus total body bone mineral content (BMC). The coefficients of variation for all DXA measures of body composition were calculated from repeated scans of 10 subjects who were scanned three consecutive times on the same visit with repositioning. DXA scan coefficient of variation for assessing tissue measures was 0.6 % for FFM and 1.0 % for percent fat. The scanner was calibrated daily against a spine calibration block and step phantom block supplied by the manufacturer. In addition, a whole body phantom was scanned weekly to assess any machine drift over time.

To quantify muscle volume, computed tomography (CT) imaging was performed (GE Lightspeed Qxi, General Electric, Milwaukee). Axial slices of both thighs were obtained starting at the most distal point of the ischial tuberosity down to the most proximal part of the patella while the subjects were in a supine position. Slice thickness was fixed at 10 mm, with 40 mm separating each slice based on the work from our lab by Tracy et al. (94). Two technicians performed analyses of all images for each subject using MIPAV software (NIH, Bethesda, MD). Briefly, for each axial slice, the cross-sectional area (CSA) of the quadriceps muscle group was manually outlined as a region of interest. The quadriceps CSA was manually outlined in every 10 mm axial image from the superior border of the patella to a point where the quadriceps muscle group is no longer reliably distinguishable from the adductor and hip flexor groups. The sartorius muscle was not included in the CSA because it does not contribute to knee extension. Investigators were blinded to subject identification, sex, and race. Repeated measurement coefficient of variation was calculated for each of two investigators based on repeated measures of selected axial slices of each person on two separate days.

Average intra-investigator CV was 1.7% and 2.3% for investigator one and two, respectively. The average inter-investigator CV was < 4.3%. Final muscle volume was calculated using the truncated cone formula as reported by Tracy et al. (94).

*One repetition maximum (1 RM) strength test.* The 1RM strength test was assessed unilaterally in the knee extensors and was defined as the highest resistance that can be used to complete one repetition of exercise successfully. Three low resistance training sessions were conducted prior to the 1RM strength testing, so that subjects would be familiar with the equipment and proper exercise techniques. On a separate visit following the two familiarization training sessions, knee extensor 1RM strength of both legs was assessed on the pneumatic knee extension apparatus (Keiser A-300 Leg Extension machine). Prior to the start of testing, the seat was adjusted so that the axis of rotation of the knee extension apparatus was in line with the medial condyle of the tibia, and subjects were positioned with a pelvis strap (seat belt) to minimize the involvement of other muscle groups. After ~ 60 s of rest upon a successful completion of a repetition, subsequent trials were performed at progressively higher resistance levels to minimize the total number of trials required before the true one repetition maximum value was obtained. Vocal encouragement was given to all subjects in an attempt to maximize effort. Termination criteria for the 1 RM test were as follows: 1) perceived exertion of 20 on the RPE scale, 2) inability to perform a repetition through the full range of motion, or 3) reporting >3 on the pain/discomfort scale (more than moderate, but less than severe pain). All testing procedures were standardized based on specific seat adjustments and body position during testing.

*Muscle power and movement velocity.* Determination of peak knee extensor power and angular velocity was performed on a customized Keiser pneumatic resistance knee extension (K410) machine (Keiser Sports/Health Equip. Co., Inc., Fresno, CA) custom-equipped for muscle power assessment. The K410 machine is instrumented with load cell force transducers and position sensors to detect rotary motion at the joint. The K410 hardware is connected to a PC and uses an industrial data collection expansion card to digitize data at  $400 \text{ times} \cdot \text{s}^{-1}$  from the force and position sensors. This speed is configured and set by the K410 software. The actual velocity assessment is derived from a crystal oscillator on the data collection board. Power was calculated as the product of torque and angular velocity about the knee and reported in watts. Torque was calculated by multiplying the force exerted by the distance from the knee joint to the force sensor (0.5 m) and reported in N-m. Angular velocity was reported as  $\text{rad} \cdot \text{s}^{-1}$ .

Subjects were instructed to perform a knee extension with each leg unilaterally at a resistance of  $\sim 30\%$  of their measured 1 RM at  $\sim 50\%$  of their maximal velocity. Following a 30 s rest period, subjects performed three power tests on each leg alternating between right and left at 50%, 60%, and 70% of their 1 RM, with a 30 s rest period between each of the three trials and 2 min rest between each increase in resistance. Previous studies using similar methods and populations have reported that peak power occurs at  $\sim 60\% - 70\%$  of 1 RM (9, 24), therefore, 50%, 60%, and 70% of 1 RM loads were used in this study to cover all the ranges that peak power is likely to be observed. The tester offered standardized oral encouragement to subjects to extend their knee as quickly and forcefully as possible during each trial. To establish a more stable assessment, all power tests were repeated 48-72 h after the initial test. Data points

collected for each repetition were analyzed to determine peak power and velocity after testing. The data were first passed through a zero-phase forward and reverse digital filter designed using MatLab software version 6.0.5 (MathWorks Inc., Natick, MA) to remove sensor noise. A low-pass, 10<sup>th</sup> order Butterworth filter with a cut-off frequency of 10 Hz was used. Because the resulting velocity and power curves were unimodal, a simple point-to-point search of the velocity and power data were conducted to determine the peak (see Appendix C, figure 1). The highest power achieved throughout all trials of all loads was reported as the peak power, and the corresponding movement velocity at peak power was used as the velocity measure. For both 1RM and power testing, only data for the subject's self reported dominant leg was used for analysis. For each test, the force reading was calibrated by hanging a known weight from the load cell, and angular distance was calibrated by manually moving the machine arm through the entire range of motion. Prior to testing, a pilot study was conducted to assure machine reliability. Testing reliability was established using the test-retest method on 10 subjects, allowing 48 hours between tests. The Pearson correlation coefficient between tests for the right and left leg was 0.973 and 0.972, respectively.

*Functional Ability Tests.* A subset of individuals over the age of 65 (n = 40) completed functional ability testing using five assessments of activities of daily living (ADL). Each test was chosen based on performance relationships to strength and power (9, 10, 76). During all tests, subjects wore a safety harness and were followed by a spotter in order to prevent falls. Each test was timed with a stopwatch and reported to the nearest 0.1 second. For tests in which the subjects were seated, a straight-backed, armless, plastic molded chair approximately 45 cm high at the front edge was used for

each test. The back of the chair was placed against a wall for steadying support. Each test was initiated at the command of “go” by the tester. The tests included, 1) usual and rapid pace timed gait, 2) five chair stands, 3) 8-foot up-and-go, and 4) stair climb as described below.

1) Timed Gait, Usual and Rapid Pace - Subjects were instructed to stand behind a line on the floor and at the command of the tester, walk at a usual pace across a second line 6 meters away. Two trials were performed and the fastest of the two trials and the least number of steps taken to walk the 6 meters was reported. During the rapid pace timed gait, the same procedures were followed, except subjects were instructed to walk as quickly as possible while still maintaining safety.

2) Timed 5-Chair Stands - Subjects were instructed to sit halfway forward in the chair with their feet resting on the floor no wider than shoulder width apart and arms crossed over the chest. At the command of the tester, subjects were instructed to stand up straight and immediately sit down five times consecutively as fast as possible while maintaining both feet on the floor at all times and proper balance. The timer was stopped when the subject successfully completed the fifth stand. Subjects who temporarily lost balance or needed to use their arms for assistance were given a second trial. Prior to the test, subjects were asked to perform one practice stand slowly to ensure proper technique.

3) 8-Foot-Up-and-Go - The 8-foot up-and-go test followed the protocol described by Rikli and Jones (81). The subjects assumed a similar position as the chair stands, except the hands were placed on the thighs, one foot was positioned slightly in front of the other foot and the torso slightly leaning forward. On the signal from the tester the subjects rose from the chair, walking as quickly as possible around a cone that was placed

8 feet away, and returned to the seated position in the chair. Two trials were given, and the faster of the two times was used for analyses.

4). Stair Climb – For the final measurement, subjects were asked to climb one flight of stairs (9 steps). The starting area was marked as the distance of one stair back from the first step. On the command of the tester the subject was required to climb the steps as quickly and safely as possible until both feet reached the top step. Subjects were asked to refrain from using the hand-rail if possible, unless it was necessary for safety. A single trial was given if the subject completed the climb without error. Prior to the timed trial, a slow practice trial of three steps was performed to ensure the subject was fit to perform the test.

*Statistical Analysis.* All statistical analyses were conducted using SAS software (SAS version 8.2, SAS Institute Inc., Cary NC). To determine variables which may be significantly related to the dependent measures, linear regression was used, with the level of significance set at  $P < 0.05$ . Potential confounding variables included age, height, weight, BMI, percent fat, fat free mass, and medication use. The use of medications was classified into the following categories: diuretics, ACE inhibitors, hormone replacement therapies (HRT), and anti-inflammatory/pain reducers. These categories were selected because of their potential for having physiological effects on muscle mass. Once the confounding variables were identified, analysis of covariance (ANCOVA) was performed to determine between-group differences for each dependent variable. To determine the relationships of strength, power, and movement velocity to measures of functional ability, Pearson product correlations were performed. For each analysis, the assumptions of the model were checked, and necessary transformations were applied to the data in cases

where these assumptions were not met. Values are expressed as means  $\pm$  standard error, and the significance was set at 0.05.

## RESULTS

*Physical Characteristics.* Subject characteristics grouped by sex and race are summarized in Table 1. There was no significant difference in age between sexes. Men had significantly greater height and weight than women (both  $P < 0.001$ ), but there was no difference in BMI. Men also had greater FFM than women ( $P < 0.001$ ), and significantly lower percent body fat ( $P < 0.001$ ). There were no significant differences between African Americans and Caucasians for any physical characteristics, except age, where African Americans were significantly younger than Caucasians ( $P < 0.001$ ). Within these groups, 40% of the Caucasians were men and 60% were women, whereas, 32% of the African Americans were men and 68% were women. There were six subjects who were not included in the racial analysis because they were not categorized as either Caucasian or African American.

*Sex Differences.* Differences in knee extensor 1RM strength, peak power (PP), movement velocity (PV), and muscle volume (MV) between sexes are presented in Table 2. The results in this table indicate that men were 24% stronger ( $P < 0.01$ ), exhibited 26% higher PP ( $P < 0.01$ ), had 14% faster PV ( $P < 0.001$ ), and 55% larger MV than women ( $P < 0.001$ ). Diuretic use in women was the only medication category found to be significantly related to muscle volume and was included as a confounding variable. A separate analysis was run without the women who were on diuretics and the results indicated that exclusion of those subjects did not significantly affect the difference between the groups. Men had a significantly greater power at 50% and 60% of 1RM ( $P <$

0.01), but there was no significant difference observed at 70% of 1RM (table 4). When PP was normalized for MV (MPQ), the difference narrowed, but men still showed 14% greater PP than women ( $P < 0.001$ ). Figure 1 demonstrates that MQ in men was also 9% higher than women ( $P < 0.05$ ). Although PV was significantly greater for men at peak ( $P < 0.05$ ), when normalized for MV (PV/MV, movement velocity quality), women exhibited a 38% faster movement velocity than men (Figure 1;  $P < 0.001$ ). Results for sex differences in tests of functional ability (FA) in a subset of individuals over age 65 are presented in Table 5. Sex comparisons revealed no significant differences in function except for the stair climb, where the men's times were 22% faster than women ( $P < 0.01$ ).

*Racial Differences.* Table 3 illustrates racial differences in knee extensor 1RM strength, PP, PV, and MV. There was no significant difference in 1RM strength between races. There were no significant differences observed among racial groups for absolute PP (table 3), 50%, and 60% (table 4) of 1RM, but, African Americans exhibited significantly greater power at 70% of 1RM ( $P < 0.05$ ). African Americans had 20% greater MV ( $P < 0.001$ ), but their MQ values (Figure 2) were 11% less than Caucasians ( $P < 0.01$ ). Adjustment for MV did not show any significant difference between racial groups for PP. There was no difference between groups for absolute PV, however, as shown by Figure 2, when movement velocity was normalized per unit of MV, Caucasians had 17% greater movement velocity quality ( $P < 0.05$ ). Results for race differences in tests of functional ability (FA) in a subset of individuals over age 65 are presented in Table 5. Race comparisons revealed times 19% and 16% faster for Caucasians in rapid

pace timed gait and 8-foot up-and-go, respectively ( $P < 0.05$ ). There were no other race differences observed for any other functional ability variable.

*Combined group correlations.* The relationships of strength, power, and movement velocity to functional ability are presented in Table 6. The strongest correlations observed were between 1RM and stair climb time ( $r = -0.5$ ;  $P < 0.05$ ), MQ and 5-chair stand time ( $r = -0.49$ ;  $P < 0.05$ ), MQ and 8-ft up-and-go ( $r = -0.49$ ;  $P < 0.05$ ), MQ and stair climb ( $r = -0.5$ ;  $P < 0.05$ ), MPQ and usual pace ( $r = -0.5$ ;  $P < 0.05$ ).

## DISCUSSION

The findings in this study add new perspectives to our understanding of sex and race differences in strength, power, and movement velocity in middle-aged and older adults. In this regard, a new finding is that women exhibit significantly faster knee extension movement velocity per volume of muscle than men. As expected, men have significantly greater knee extension strength and power than women of similar age, but this difference narrows when normalized for muscle volume and expressed as muscle power quality. Moreover, when assessed at higher relative loads (70% of 1 RM), sex differences in peak muscle power disappear. Therefore, when describing the force-velocity-power relationship, the sex of the person may be an important consideration.

This study was also the first to report racial differences among these variables. In this regard, although African Americans show significantly greater power at higher relative loads (70%) than Caucasians, no differences were observed between races for overall peak power and movement velocity. Moreover, when these values were normalized for muscle volume, this difference disappeared for peak power and favored Caucasians for movement velocity, suggesting that the greater muscle mass in African

Americans was not accompanied by concomitantly faster movement velocities compared to Caucasians. This finding is in agreement with the original hypothesis, but the finding of no difference in strength or peak power between races was unexpected and did not support our hypothesis.

Previous studies that have examined sex differences in power have concluded that men have greater absolute power than women (5, 45, 88). This conclusion appears logical because on average men have greater absolute strength and muscle mass than women. However, it has been argued that fair comparisons of muscle function between sexes should express values relative to the size of the muscle mass involved in the movement. Sex differences in absolute muscle strength reflect differences in muscle quantity rather than architectural characteristics or metabolic function of the muscles in use (58). Previous studies that have attempted to control for body size differences between men and women have normalized leg extension power for total body mass and found that women still have significantly less power than men (5, 88). Caserotti et al. (15) found similar results, but when power was normalized for lean body mass estimated by bioimpedance, the difference between men and women disappeared. In contrast, we observed that although the difference narrowed when expressed as muscle power quality by normalizing for the volume of the contracted muscle, men were still significantly more powerful than women. To our knowledge, the current investigation is the first to examine this comparison between sexes when normalizing for the entire muscle involved in producing the movement (i.e., knee extension).

Previous investigations have attempted to explain this reduced power output in women by citing deficits in movement velocity as the primary factor. For example,

Caserotti et al. (15) concluded that men and women showed similar force values at peak power, but that women had less power due to reduced movement velocity. In addition, DeVito et al. (20) reported that reductions in velocity most influenced the loss of power in women age 50-75. Our findings are in agreement with these previous results, in that men exhibited greater absolute movement velocity. However, when considering the volume of the muscle in use, our study revealed that women had considerably greater velocity at peak power, suggesting that deficits in strength are more related to the lower peak power outputs observed in women. One possible explanation for this finding is presented by Krivickas et al. (43). They measured the maximum shortening velocity of muscle fibers in older men and women and found that men had greater age-associated losses in velocity of type II fibers, while women showed no change in velocity of type II fibers when compared to younger women, suggesting a preferential sparing of the velocity of type II fibers in older women. Similarly, Trappe et al. (95, 96) reported that, at baseline, there were significant gender differences in single muscle fiber contractile properties. In this study, myosin heavy chain (MHC) I fibers of older women contracted 38% faster than older men, and MHC IIa fibers contracted 69% faster in women. These findings offer further insight into sex differences in movement velocity, illustrating that other mechanisms other than muscle mass, such as neuromuscular function and fiber type distribution may be influential.

From the results of this investigation and others, it is important to establish which factors influence the underlying differences in functional ability observed between sexes. The finding that women showed slower stair climb times is consistent with previous studies that have reported better lower extremity performance (99) and functional

mobility (84) in men than women of similar age. However, although there was a trend for men to perform better in all measures of functional ability, stair climb time was the only to show a significant difference between sexes. This observation is probably due to small sample sizes and low statistical power, therefore lessening the possibility to detect a true difference in the ability to perform the various tasks. When examining the relationships of muscle volume, strength, power, and movement velocity to tests of function, significant correlations were found, but were much lower than expected. It was initially hypothesized that peak power and strength would be more associated with higher force tasks, while movement velocity would strongly correlate with tasks of lower force requirement. However, strength and muscle quality only explained 25% of the variance in stair climb time, while movement velocity did not show a significant correlation with any measure of functional ability. However, small sample sizes may have masked any existing significant relationship. Therefore, future studies should aim to determine sex differences in functional ability and which variables of muscle function (i.e., strength, power, or velocity) most influence these deficits.

Differences in the assessment of peak power and velocity may also explain discrepancies in the values reported for power and velocity in this study and others. In this context, the two most common methods reported to assess power output have been the foot plate/flywheel rig (5, 10, 72, 88, 89) and the standing jump force plate (15, 20, 22). Although some of the studies using the foot plate/flywheel rig have reported peak power measurements, they are actually measuring the total area under the power curve. This measurement mixes slower velocities at the beginning of the movement to overcome the inertial phase of the movement, as well as near the end of the range of movement

where co-contraction of antagonist muscle groups also result in slower velocities. These velocities are averaged in with the faster velocities that occur in the middle of the range of motion. An example of how this difference in testing can affect results comes from Macaluso et al. (55) who found that the increased co-contraction of the knee flexors in older women compared to younger women may at least partially explain lower knee extension average torque seen in older women. Thus, it is conceivable that this phenomenon could explain discrepancies in the literature on sex differences in strength, power, and movement velocity. Assessing power at its peak in the range of motion eliminates the lower torque and velocities at the beginning and near the end of the range of motion and therefore may provide a more accurate description of true power differences between men and women.

Another disadvantage of the flywheel rig is that it requires overcoming a fixed inertia for both young and older subjects, with the older subjects being forced to use a greater percentage of their maximal force capability. This ultimately affects the optimal velocity necessary to achieve peak power. The standing force jump plate is also based on similar assumptions, which means that older individuals, particularly women, in some cases need to overcome near maximal forces to produce the desired movement. Therefore, movement velocity is likely compromised, and the movement does not favor the optimal force-velocity relationship (54).

To our knowledge, no other investigation has reported the product of peak torque and peak velocity (peak power) from maximal knee extension exercise. Recent studies have used similar equipment to that used in this investigation (i.e., Keiser pneumatic resistance equipment) with a computer interface and various loads relative to each

subject's maximum force production (9, 25, 53). However, these studies are still reporting the average, not peak power during the exertion. Our measure of peak power may be more functionally relevant to events such as catching oneself from a fall or quickly correcting a loss of balance, because these actions would likely be limited by the ability to instantaneously maximize both muscle strength and the speed of movement (30, 71, 85, 101).

Currently, there are very few studies that have examined differences in muscle function characteristics between races. Our finding that African Americans had greater knee extensor muscle volume than Caucasians is similar to reports by Newman et al.(66) and Visser et al. (100). The former reported greater lower extremity lean mass in African Americans as assessed by DEXA, while the latter used computed tomography to report larger CSA of thigh muscles. Aloia et al. (2) also reported greater whole body muscle mass in African-Americans estimated from total body potassium. However, the present study is the only report we are aware of that has used direct measurements of muscle volume for normalizing muscle function to allow valid comparisons between racial groups. Unlike the consensus reached for racial differences in muscle mass, reports on strength between races remains inconclusive. For example, Newman et al. (66) showed greater knee extension strength in African Americans using an isokinetic dynamometer whereas, Rantanen et al. (79) reported no significant differences in knee extension strength between races, but the validation of the instrument used to assess strength in their study is unclear. In contrast with all of the previous studies, Means et al. (59) reported lower strength values in African American women over the age of 65 compared to Caucasian women of similar age. However, in their study, strength was assessed

manually by a physical therapist and therefore did not measure the maximal force production of the subject. The differences in strength assessment may be the cause for conflicting results among our study and others. For example, when strength was expressed per unit of muscle (i.e., muscle quality), our results support the findings of Newman et al. (66), who reported lower specific tension in the lower extremities of African-American men and women. To our knowledge, no study has reported racial differences in peak power and movement velocity.

Although we did not find race differences in peak power or its corresponding movement velocity, our finding that Caucasians exhibit greater movement velocity when normalized for muscle volume may have implications for differences in functional abilities between races. The findings that African Americans exhibited slower rapid pace and 8ft up-and-go times support the observation of lower movement velocity quality in African Americans, as these tasks require less force and greater velocity production. Although these findings are similar to other studies that have reported worse functional performance in African Americans (59, 67, 100), there are conflicting reports on which racial group is at highest risk for losses in independence (19, 32). It is likely that differences in muscle volume, strength, power and movement velocity between races influence functional abilities in performing activities of daily living, but this relationship has not been investigated. Therefore, further research is needed on racial differences in functional ability, with an emphasis on determining the extent to which they can be explained by differences in muscle volume, strength, power, and movement velocity.

A major limitation to this study is the cross-sectional design, which does not allow for conclusions on causal relationships. Secondly, the sample size of African

Americans for examining racial differences was quite small. Post hoc analysis revealed that MV, PP at 70% 1RM, PV, and movement velocity quality (PV/MV) were the only variables to reach the 0.8 level of statistical power. Thus, it is possible that there may be differences between races among the other variables that were not observed due to insufficient statistical power.

In conclusion, these results indicate that men exhibit greater strength and peak power per unit of muscle than women, but women have greater movement velocity per unit of muscle than men. African Americans have greater muscle volume than Caucasians, but exhibit lower strength and movement velocity per unit of muscle, which may be related to poorer performance on tests of functional ability. African Americans possess greater power than Caucasians when tested at high loads. Future research should aim to further examine how these variables act to influence sex and race differences in functional ability with aging.

**Table 1. Physical characteristics grouped by sex and race**

	Men	Women	African Americans	Caucasians
N	30	49	28	45
Age, yr	63 ± 1	63 ± 1	59 ± 1	66 ± 1 <sup>†</sup>
Height, cm	173.8 ± 1.3	161.8 ± 1.0*	166.6 ± 0.9	167.1 ± 1.6
Weight, kg	91.3 ± 2.7	75.5 ± 2.2*	83.8 ± 2.8	80.1 ± 2.7
BMI, kg/cm <sup>2</sup>	30.1 ± 0.8	29.0 ± 0.8	30.2 ± 0.9	28.5 ± 0.8
FFM, kg	64.6 ± 1.8	45.5 ± 1.0*	54.3 ± 2.2	52.0 ± 1.9
BF, %	29.0 ± 1.0	39.0 ± 1.0*	35.2 ± 1.4	34.8 ± 1.2

Values are means ± SE.

N = number of subjects; FFM = fat free mass; BF = percent body fat; BMI = body mass index.

One man and two women did not have data for Weight, FFM, BF, BMI due to missing DXA scans.

One Caucasian and one African American did not have data for weight, FFM, BF, BMI due to missing DXA scans.

\* Significantly different from men ( $P < 0.001$ )

<sup>†</sup> Significantly different from Caucasians ( $P < 0.001$ )

**Table 2. Sex differences in 1RM knee extension strength, power, movement velocity, and muscle volume of the knee extensors**

	Men	Women
	N = 30	N = 49
1 RM, kg	43 ± 2*	25 ± 1
PP, watts (Nm·rad·s <sup>-1</sup> )	1410 ± 70*	785 ± 38
PV, rad·s <sup>-1</sup>	5.8 ± 0.1*	5.1 ± 0.1
MV, cm <sup>3</sup>	1857 ± 72*	1195 ± 41
MPQ, watts/cm <sup>3</sup> (x 10 <sup>-1</sup> )	7.6 ± 0.2*	6.6 ± 0.2

Values reported are overall group means ± SE, but p-values are based on least-square means, considering the significant co-variates.

N = number of participants; 1RM = one-repetition maximum; PP = peak power;

PV = velocity of peak power; MV = muscle volume; MPQ = muscle power quality.

One man and two women were missing from MV measures due to errors in CT scans.

\* Significantly greater than women ( $P < 0.05$ ).

**Table 3. Racial differences in 1RM knee extension, strength, power, movement velocity, and muscle volume of the knee extensors**

	African-Americans	Caucasians
	N = 28	N = 45
1 RM, kg	30 ± 2	34 ± 2
PP, watts (Nm·rad·s <sup>-1</sup> )	1176 ± 81	941 ± 64
PV, rad·s <sup>-1</sup>	5.5 ± 0.2	5.3 ± 0.1
MV, cm <sup>3</sup>	1627 ± 89*	1355 ± 66
MPQ, watts/cm <sup>3</sup> (x 10 <sup>-1</sup> )	7.0 ± 0.2	6.9 ± 0.2

Values reported are overall group means ± SE, but p-values are based on least-square means, considering the significant co-variates.

N = number of participants; 1RM = one-repetition maximum; PP = peak power

PV= velocity of peak power; MV = muscle volume; MPQ = muscle power quality.

Three Caucasians were missing from MV measures due to errors in CT scans.

\* Significantly greater from Caucasians ( $P < 0.05$ ).

**Table 4. Race and sex differences in power and velocity at relative loads**

	Men	Women	African Americans	Caucasians
N	30	49	28	45
P50%, watts (Nm·rad·s <sup>-1</sup> )	1363 ± 67*	760 ± 35	1117 ± 76	927 ± 63
P60%, watts (Nm·rad·s <sup>-1</sup> )	1383 ± 73*	760 ± 38	1152 ± 82	916 ± 65
P70%, watts (Nm·rad·s <sup>-1</sup> )	1343 ± 74	734 ± 38	1125 ± 84 <sup>†</sup>	868 ± 62
V50%, rad·s <sup>-1</sup>	6.2 ± 0.2*	5.3 ± 0.1	6.0 ± 0.2	5.5 ± 0.1
V60%, rad·s <sup>-1</sup>	5.5 ± 0.2*	4.8 ± 0.1	5.5 ± 0.2 <sup>†</sup>	4.8 ± 0.1
V70%, rad·s <sup>-1</sup>	4.7 ± 0.2*	4.2 ± 0.1	4.8 ± 0.2 <sup>†</sup>	4.1 ± 0.1

Values reported are overall group means ± SE, but p-values are based on least-square means, considering the significant co-variates.

N = number of participants; P% = power at percentage of 1RM; V% = velocity at percentage of 1RM.

\*Significantly different from women ( $P < 0.05$ )

<sup>†</sup>Significantly different from Caucasians ( $P < 0.05$ )

**Table 5. Sex and race differences in tests of functional ability**

	Usual Pace	Rapid Pace	5-Chair Stands	8-ft up-and-go	Stair Climb
Men (N = 11)	5.3 ± 0.2	3.6 ± 0.2	7.5 ± 0.8	5.1 ± 0.2	3.6 ± 0.2
Women (N = 17)	5.2 ± 0.3	3.8 ± 0.1	8.8 ± 0.5	6.1 ± 0.2	4.5 ± 0.2*
African Americans (N = 5)	5.6 ± 0.2	4.1 ± 0.3	8.5 ± 0.7	6.4 ± 0.4	4.2 ± 0.4
Caucasians (N = 22)	5.2 ± 0.2	3.6 ± 0.1 <sup>†</sup>	8.2 ± 0.5	5.5 ± 0.2 <sup>†</sup>	4.2 ± 0.2

Values are means ± SE. All values are reported as seconds to the nearest 0.1.

N = number of participants.

One woman was not included in 5-chair stands due to missing data.

One Caucasian was not included in 5-chair stands due to missing data.

\* Significantly different than men (P < 0.01).

<sup>†</sup> Significantly different than African Americans (P < 0.05).

**Table 6. Relationships of strength, peak power, movement velocity to measures of functional ability.**

	Usual Pace	Rapid Pace	5-Chair Stands	8-ft up-and-go	Stair Climb
1RM	-0.25 (.06)	-0.38 (.14)	-0.27 (.073)	-0.41 (.17)	-0.50 (.25)
PP	-0.33 (.11)	-0.16 (.03)	-0.15 (.02)	-0.23 (.05)	-0.44 (.19)
PV	-0.36 (.13)	-0.10 (.01)	-0.07 (.01)	-0.25 (.06)	-0.24 (.06)
MQ	-0.43 (.18)	-0.41 (.16)	-0.49 (.24)	-0.49 (.24)	-0.50 (.25)
MPQ	-0.50 (.25)	-0.18 (.03)	-0.30 (.09)	-0.33 (.11)	-0.44 (.19)
PV/MV	-0.19 (.04)	0.05 (.003)	-0.15 (.02)	-0.10 (.01)	0.16 (.03)

Values are correlation coefficient ( $R^2$ ).

1RM = one-repetition maximum; PP = peak power; PV = velocity of peak power;

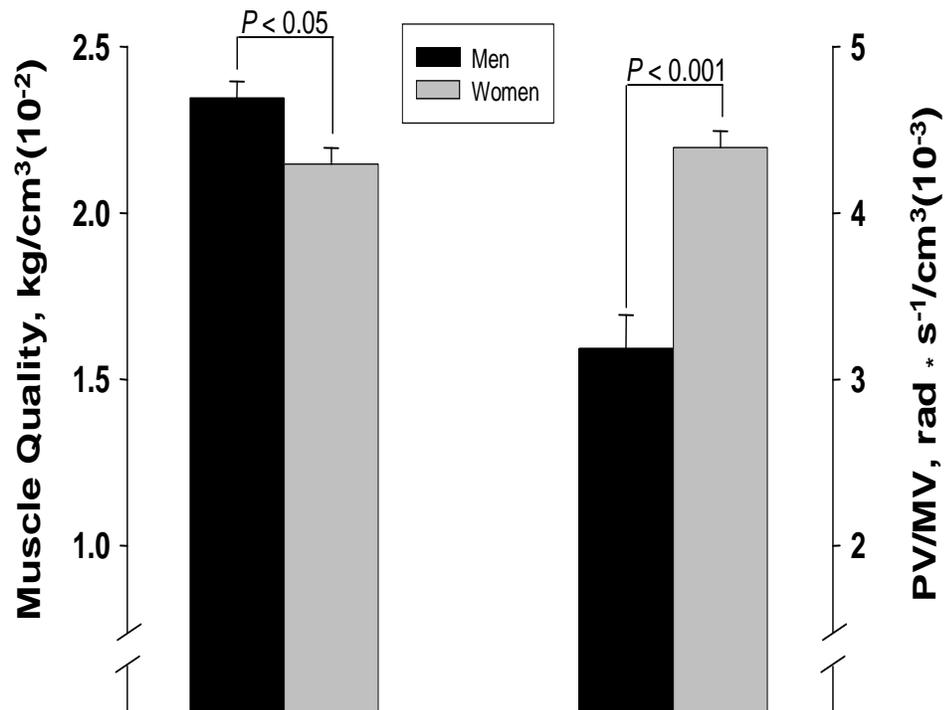
MV = muscle volume; MQ = muscle quality; MPQ = muscle power quality

## FIGURE CAPTIONS

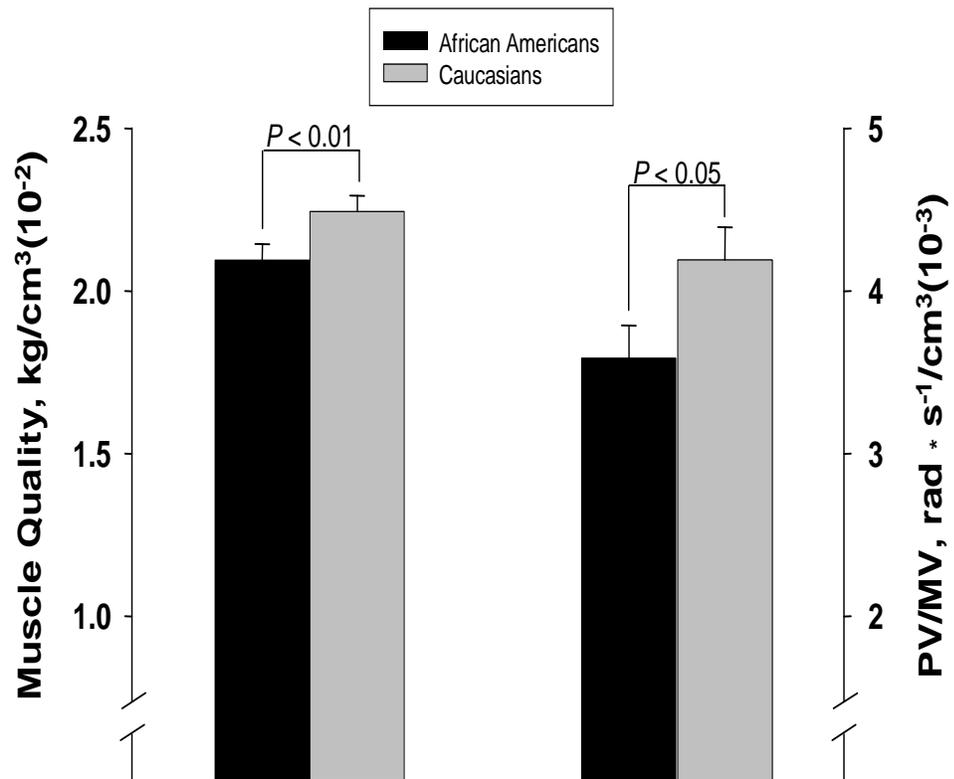
Fig.1. Differences in muscle quality (MQ) and movement velocity quality (PV/MV) between sexes. Men exhibited significantly greater MQ than women ( $P < 0.05$ ). PV/MV was significantly greater in women than in men ( $P < 0.001$ ).

Fig 2. Differences in muscle quality (MQ) and movement velocity quality (PV/MV) between races. African-Americans showed significantly lower MQ ( $P < 0.01$ ) and PV/MV ( $P < 0.05$ ) than Caucasians.

Figure 1. Sex differences in MQ and PV/MV



**Figure 2. Race differences in MQ and PV/MV**



## **APPENDIX A: PROPOSAL INFORMATION**

**Statement of the problem**

**Experimental hypotheses**

**Delimitations**

**Limitations**

**Operational definitions**

## APPENDIX A

### PROPOSAL INFORMATION

#### **Statement of the problem**

The purpose of this study is to determine the influence of race and sex differences on the relationship of strength, peak muscle power, movement velocity, and functional ability in middle-aged and older adults (age range 50-85). To achieve this purpose, peak power of the knee extensors will be assessed at three different percentages of 1RM strength levels. The peak power and corresponding velocity will be correlated with functional ability tests simulating activities of daily living (ADL). Peak Power and velocity measures will be expressed with and without being normalized for quadriceps muscle volume (MV).

#### **Experimental hypotheses**

1. Men will have a significantly greater absolute peak power than women, but the difference will narrow when adjusted for MV.
2. African-Americans will have greater strength and MM than Caucasians, but will not have a significantly greater MQ than Caucasians
3. African-Americans will show greater peak power than Caucasians due to greater strength and muscle mass.
4. Peak power and strength will be more associated with higher force functional tests (5 Chair stands, 8-foot up-and-go, stair climb) than will movement velocity
5. Movement velocity will be more associated with low force functional tasks (usual and rapid gait).

### **Delimitations**

1. The scope of this study will be limited to 30 men and 49 women (45 Caucasian, 28 African-American) between the ages of 50 and 85 who were volunteer participants in the GUSTO Study at the University of Maryland.
2. Participation in the study was limited to sedentary, non-smokers who were free of obvious signs of any musculoskeletal or cardiovascular disease.

### **Limitations**

1. The participants were volunteers recruited according to demographics and were not randomly selected from the entire population.
2. Participants were verbally encouraged to perform maximal exertions on all measures, therefore maximal effort is assumed but not verified.
3. Conclusions made from comparing African-American subjects may lack statistical power due to a small sample size.
4. The age group of the participants in this study were rather heterogeneous (50-84 yrs).
5. It was assumed that participants were inactive prior to the study.

### **Operational definitions**

1. Antagonist: Muscles that oppose a particular movement in order to slow or stop the movement
2. Concentric: the phase of muscle action during which the muscles are shortening while generating force throughout a range of motion. Presently termed “shortening phase” of muscle contraction.

3. Extension: A movement that increases the angle between the bones of the limb at the joint.
4. Force/Velocity Curve: The curve explaining the inverse relationship between muscular force production and movement velocity
5. Inertia: A force that must be overcome in order to start a movement
6. Muscular Power: the product of torque and angular velocity during a single repetition of movement
7. Sarcopenia: Age-associated loss of skeletal muscle resulting in reduction of muscle mass and strength

## **APPENDIX B: LITERATURE REVIEW**

**Loss of muscle mass, strength, and power with age**  
**The relationship of muscle mass, strength, and power to functional ability**  
**Sex and racial differences in muscle mass, strength, and power**  
**Assessment of muscle power and movement velocity**  
**Summary**

## APPENDIX B

### LITERATURE REVIEW

#### Loss of muscle mass, strength, and power with age

Age-associated changes in skeletal muscle mass and function, known as sarcopenia, have been widely investigated. Sarcopenia, from Greek meaning poverty of flesh, is the wasting of skeletal muscle with increasing age, and has been linked to deficits in strength, power, and functional ability in older adults. Although differing in design and methodology, numerous studies have reported lower amounts of muscle mass in older individuals (26-28, 34, 40, 46, 69, 102). Although there are conflicting reports on the average age at which the loss of muscle begins, it appears that the most significant changes occur after the age of fifty. Janssen et al. (40) reported a reduction in relative skeletal muscle mass starting in the third decade, but that a noticeable decrease in absolute muscle mass was not observed until the end of the fifth decade. Also, Larsson et al. (46) reported the largest decrease in the area of type II muscle fibers between 40-49 and 50-59 age groups. Although these and other cross-sectional studies have been effective in illustrating muscle mass changes between age groups, longitudinal studies have provided even more accurate conclusions on changes in skeletal muscle as an individual ages. A study by Frontera et al. (26) examined muscle size and function in nine older men (age  $65.4 \pm 4.2$ y) and were reevaluated after 12 years. With the use of computerized tomography they observed reductions in the CSA of the thigh muscles (14.7%), the quadriceps femoris muscle (16.1%), and flexor muscles (14.9%). This is similar to a study by Hughes et al. (34), who reported muscle mass losses of ~13% per

decade when men between the ages of 46-78 were reevaluated after an average of 9.7 years.

Age related losses in muscle mass have also been associated with decreased force production in older individuals. Several studies have shown a strong correlation between losses in muscle mass and strength with aging. Larsson et al. (46) reported the strength declines they observed correlated significantly with the selective atrophy of type II muscle fibers ( $r = 0.54$ ,  $P < 0.001$ ), and quadriceps size and strength were correlated in 70-year-old men and women ( $r = 0.77$ ,  $P < 0.03$  and  $r = 0.66$ ,  $P < 0.001$ ) in separate studies by Young et al. (102, 103). However, Reed et al. (80) reported a relatively weak correlation between mid thigh muscle area and strength ( $r = 0.29$ ) and suggest that even though the two are related, measures of body mass should not be used to predict muscle strength. In this regard, numerous investigations have examined the extent of strength losses in older individuals (1, 11, 12, 26, 27, 34, 46, 48, 64, 65, 69, 74, 99, 102). Similar to losses in muscle mass, strength is thought to begin to decrease after the age of 50, as reported by Larsson et al. (46). Although this appears to be the consensus, some studies have reported strength losses even earlier. Lindle et al (48) showed losses in knee extension concentric peak torque as early as the forties, while Borges (12) reported significantly lower isokinetic knee extension torque between 20 and 30 years of age in men and 40 to 50 years of age in women. Cross-sectional studies have shown that, on average, strength in older adults (60-86 years) is anywhere between 22-54% less than their younger counterparts (64, 69, 74, 102, 103). Similar to investigations on muscle mass, a longitudinal design provides a more precise measurement of changes in strength with aging. Bassey et al. (6) examined handgrip strength in men and women over age 65

and found that after four years, handgrip strength had declined between 12-19% and the changes were significantly related to age. A study by Frontera et al. (26) examined strength of the knee and elbow extensors in older men (age  $65.4 \pm 4.2$ y) and tested them again after 12 years. They found that both muscle groups showed losses ranging from 20-30% at all velocities tested. Another study by Hughes et al. (34) reported losses of 14% per decade in the knee extensors and 16% per decade in the knee flexors. They also noted that, particularly in men, the longitudinal rates of decline in strength were ~60% greater than estimates from a cross-sectional study of the same population. Therefore, although each of previously mentioned studies has been effective in reporting muscle mass and strength losses with age, it appears that the longitudinal design is more sensitive in detecting changes in this population.

In an attempt to better quantify changes in skeletal muscle function with aging, recent investigations have adjusted strength measures for individual variations in muscle mass (1, 27, 48, 51, 61, 102, 103). This variable has been commonly referred to as muscle quality (MQ) or specific tension, and believed to be a better indicator of muscle function than strength alone because it takes into account the intrinsic characteristics of the musculature (51). With regards to examining changes in MQ with age, there have been relatively few studies, all of which are of cross-sectional design. The longitudinal studies in this area have concentrated more on interventions to improve MQ, rather than changes over time. Nevertheless, the existing literature does provide useful insight on muscle function with aging. Although some of these studies are consistent in their conclusions, there are some who have reported conflicting results. Studies by Lindle et al (48), Young et al (103), and Lynch et al (51) have all reported a age-related decline in

MQ, although the type of contraction may influence the results. In the Young et al. study (103), there was a 19% loss of MQ between 20- and 70-year-olds, which is similar to the 25% loss reported in the Lynch (51) investigation. However, in the Lynch et al. investigation, they also reported a 40% loss during concentric contractions. In contrast to these reports, Frontera et al (27) reported no difference in isokinetic torque when expressed per kilogram of muscle mass. However, this study used urinary creatinine excretion to estimate muscle mass, which may measure muscle properties different than that of CSA or measures of fat-free mass (61). Therefore, it appears that when using MQ to assess age –related differences in muscle function the type of contraction and method of estimating muscle mass are important considerations.

In addition to assessing changes in strength with age, researchers recently have shown interest in muscular power, which is the combination of strength and movement velocity. One reason for the new interest in this variable is a study by Skelton et al (88), who reported that leg extensor muscular power was more sensitive to aging (loss of 3.5%/yr) than was strength alone (loss of 1-2%/yr). Despite its cross-sectional design, this was the first study to report this phenomenon and has influenced further research. Although utilizing a different muscle group, this finding was confirmed by Metter et al. (60). In this study, power was tested every two years in subjects aged 20-80 years, showing a decline after the age of 40 and a 10% larger decrease than strength. Despite differences in testing methodologies, recent investigations have all confirmed that age has an important influence on power (22, 37, 38, 45, 53, 97). However, other factors other than losses in muscle mass and strength contribute to this phenomenon. In a study by Ferretti et al. (22), power measures were normalized for CSA of the thigh muscles,

however, there was still a significant difference in power (~17%) between 20-30 year-olds and adults over 50. This finding indicates that although losses muscle mass are related to power, they cannot fully explain deficits in power in older adults. Lanza et al. (45) reported a significant age-by speed interaction, where older subjects showed further impaired power at higher speeds. This indicates the need to further investigate movement velocity and its contribution to power losses in the elderly. Macaluso et al. (53) also found that the increased co-contraction of the knee flexors in older women compared to younger women may at least partially explain lower power values in older adults. Therefore, future research should include these considerations in order to make accurate conclusions on losses in muscle power with aging.

### **The relationship of muscle mass, strength, and power to functional ability**

The loss in muscle mass, strength, and power with aging is clinically significant because it is associated with losses in functional ability. Although less studied than strength or power, a few studies have established a relationship between reduced muscle mass and impaired function (39, 67, 82, 98, 100). In a study assessing sarcopenia in older adults, Janssen et al. (39) found that the likelihood of functional impairment and disability was 2-3 times greater in men and women with a skeletal muscle mass index (skeletal muscle mass/body mass  $\times$  100) below two standard deviations of values in young adults. Using a less precise technique, Rolland et al. (82) reported that small calf-circumference was associated with disability and self-reported physical function in a sample of 70-year old women. Also, Visser et al. (100) reported that reduced mid thigh muscle area was associated with poorer lower extremity performance, regardless of sex or race. The relationship among losses in muscle mass and function is probably less

studied, primarily due to the higher expense and limited access of obtaining accurate measurements of muscle mass.

The feasibility and ease of obtaining accurate strength measurements has allowed for numerous investigations to establish relationships between muscle strength and functional ability. Several studies have reported that reduced muscular strength in the elderly is closely associated with simulated daily tasks such as maximal walking speed and step tests (4, 91), timed gait (44, 68, 98) ADL dependence (77), and chair stand (98, 100). Brown et al (13) reported that when isometric hip extension, knee extension, and ankle plantar flexion strength were combined and normalized for body weight, a significant relationship was found for five chair-stand time. Associations of strength and other functions other than those that mimic activities of daily living have also been discovered. For example, decreased strength has been correlated with dysfunction in manual dexterity and locomotion (36), falls (49, 50), and trips (70). Conversely, a study by Danneskiold-Samsøe et al. (17) found very little correlation between functional tests and isokinetic contractions of the knee and ankle at varying speeds. The only significant relationship was knee extension strength at 60 deg/s. Recent studies have also sought to compare the influence of muscle mass and muscle strength on function. Visser et al. (98), for example, found that both leg muscle mass and grip strength were significantly related to lower extremity performance, although, after adjustment for behavioral, physiological, and psychological factors, the association with muscle mass disappeared. However, it is unclear why handgrip strength was chosen as an indicator of muscle strength, when some measure of leg strength would have been more appropriate. Nevertheless, this result is similar to another study by Visser et al. (99) comparing the

relationships of maximal isokinetic torque of the leg extensors and leg muscle mass to repeated timed chair stands. Again, deficits in both variables were found to be associated with poorer chair stand performance, but when modeled simultaneously, only leg extension torque was independently associated with performance. Both of these studies show that low muscle strength is a stronger predictor of decreased functional ability in older adults than are losses in muscle mass.

Recently, investigations have focused on the relationship of impaired functional ability to reduced muscle power in older age. Similar to strength measures, the power output of various muscle groups have been associated with activities of daily living tests, such as stair-climb time (5, 9, 10, 91), chair-stand time (5, 9, 88, 91), and walking speed (5, 9, 76). Moreover, Skelton et al. (89) found a strong relationship between power and falls, where women with a history of falls were 24% less powerful than those with no reported falls. Izquierdo et al. (37) indicated that deficits in the velocity component of power may be a possible cause of falls by inhibiting response time and impairing speed of postural adjustments. Since it has been previously established that muscle strength is more influential in functional ability than muscle mass, recent investigations have examined whether reduced muscle power may show an even greater association to losses in function. Bean et al.(9) reported that, although leg power and strength were highly correlated, leg power explained 8% more of the variance in measures of functional performance. Even when using different instrumentation for measuring power, Bean et al. (10) again determined that leg power consistently explained more of the variance than strength in the functional performance variables of habitual gait speed, balance, chair rise time, and stair climb time in subjects over the age of 65. Foldvari et al. (25) also reported

that leg power had a stronger univariate correlation with self-reported functional status than did strength. Conversely, Lauretani et al. (47) found that leg extension power was no better than knee extension torque or handgrip strength in the early identification of poor mobility. However, in this study, muscle power values were normalized for body weight, while strength values were not, which may have affected the results.

Although power appears to be more closely associated with functional ability, interventions should be designed to improve muscle mass and strength, as well as power, in order to prevent functional dependence in older adults. Also, future investigations should further investigate movement velocity, the other component of power, and its influences on functional ability in older adults.

### **Sex and racial differences in muscle mass, strength, and power**

The existing literature on muscle mass, strength, and power has also focused on differences between men and women and how the variations in these variables may affect functional ability later in life. In this regard, it is well established that, even in the elderly, men have larger muscle mass and area than women (17, 27, 36, 42, 98, 99). A study by Janssen et al. (40) using magnetic resonance imaging to determine skeletal muscle mass in men and women between the ages of 18-88 found that men had significantly more absolute muscle mass (33.0 vs. 21.0 kg) as well as muscle relative to body mass (38.4% vs. 30.6%). An even more detailed picture of sex differences in muscle mass and area was illustrated by Miller et al. (62) with the use of needle biopsies and computerized tomography. Here, the women were observed to have 45, 41, 30, and 25% smaller CSA for the biceps brachii, total elbow flexors, vastus lateralis, and total

knee extensors, respectively. Also, men had significantly larger type I and II fiber areas and mean fiber areas.

The significance of the lower amount of muscle mass is the higher rates of sarcopenia seen in older women. Janssen et al. (39) reported that the prevalence of class I and class II sarcopenia was significantly greater in older women than older men, and was also associated with a greater likelihood of functional impairment and disability. With this in mind, some researchers have sought to examine sex differences in the rates of decline in muscle mass with aging. One such study by Hughes et al (34) measured muscle mass in 120 men and women initially 46-78 years old and then reexamined them ~10 years later. Although both groups lost considerable amounts of muscle over the period, the percent changes were significantly greater in men ( $-12.9 \pm 15.5\%$ ) than in women ( $-5.3 \pm 18.2\%$ ). This finding is similar to in a study by Lindle et al. (48) of men and women aged 20-93 years. They found that in men, total body FFM was significantly lower in the two oldest age groups compared to the youngest group, however in women there was no significant difference between age groups. Conversely, Frontera et al. (27) showed that muscle mass in women in three age groups from youngest to oldest was 66, 63, and 59% that of the men. This finding suggests that the rate of decline in muscle mass may be faster in women. The different findings in these studies may reflect differences in research design and testing methodology, and need to be investigated further.

Research on strength differences between sexes has yielded results similar to those on muscle mass. The existing literature is unanimous in concluding that, on average, men exhibit greater absolute strength than women of similar age (12, 17, 27, 36,

42, 48, 57, 62, 68, 88, 99). For example, Lindle et al. (48) reported that peak torque values for men were significantly higher than women across all ages, velocities, and types of muscle action tested. Several studies have also been in agreement that absolute strength in women is ~ 43- 68% that of men of similar age (27, 62, 88). Only one study (17) reported no sex difference in the ankle dorsal and plantar flexors between sexes, although men were found to be significantly stronger in all other muscle groups tested. Although it is clear that men are stronger than women, there are conflicting reports on sex differences in the changes in strength with aging. Akima et al. (1) reported that percentage decline in knee extension and flexion torque was higher in men than women (12% and 8%; 11% and 8%, respectively). A longitudinal study by Hughes et al. (34) demonstrated that women showed slower rates of decline in the elbow flexors and extensors than men, but there was no difference in losses of knee extension and flexion after a 10 year follow-up. Contradictory to these reports is Borges (12) who reported that the decrease in isokinetic knee extension torque from the ages of 20 to 70 was greater in women (69%) than in men (63%). Similarly, Bassey et al. (6) reported that in subjects over the age of 65, grip strength had declined by 19% in women and only 12% in men after a 4 year follow-up. Clearly, more longitudinal studies are needed to understand changes in strength between sexes.

In order to accurately draw conclusions on sex differences in strength, the individual differences in muscle mass must be taken into account. It has been argued that sex differences in absolute muscle strength reflect differences in muscle quantity rather than architectural characteristics or metabolic function of the muscles in use (58). Therefore, past investigations have used indexes of muscle strength referred to as specific

strength or muscle quality to make more accurate descriptions of differences in muscle strength between sexes. A study by Maughan et al. (57) reported that although men had significantly greater absolute strength values, when strength was adjusted for CSA of knee extensor muscles, the difference between groups was no longer statistically significant. This is similar to the findings of Lindle et al. (48) who reported that the gender difference diminished from 37% to 9% when concentric peak torque was expressed relative to thigh nonosseous FFM. Frontera et al. (27) also described that absolute strength in women ranged from 42.2 to 62.8% that of men, but when expressed per kg of muscle mass, the sex differences were smaller and/or not present. Only one study (42) indicated that specific strength tended to be higher in young and older men, however, this finding did not reach statistical significance ( $P < 0.08$ ). Therefore, it appears when strength is normalized per unit of muscle and expressed as specific strength or muscle quality, sex differences in strength are no longer apparent. Also of interest are findings that suggest muscle quality is preserved longer in women during aging than in men. A study by Akima et al. (1) that examined muscle function in 164 men and women aged 20-84 found that the force/CSA of the knee extensors exhibited a significant decrease with age in men, but not in women. Although Lynch et al. (51) found that the rate of decline in leg muscle quality was the same between sexes, the age-associated decrease in arm muscle quality was steeper in men. Although these findings would suggest lower muscle function in older men, they may only be influenced by the overall higher values in men, as they do not correspond to sex differences observed in functional ability.

Although investigations have concluded that women do not show significantly lower muscle quality than men of similar age, reduced muscle mass, strength, and power in older women is thought to put them at greater risk for successfully managing simple everyday activities (15). In studies that have examined functional differences between sexes, women tend to perform worse than men on tests of functionality. For example, Kwon et al. (44) showed that women took longer and required more steps on the walk-turn-walk test and were slower in both normal and rapid gait tests. Similarly, Visser et al. (99) reported that women had poorer lower extremity performance as assessed by a timed, repeated chair-stands test. Samson et al. (84) also reported that older women performed worse on functional mobility tests. A study by Janssen et al. (39) determined that reduced muscle mass was significantly and independently associated with functional impairment and disability, and that the likelihood of impairment was greater in older women. These observed differences in tests that mimic everyday tasks may help explain higher fall rates seen among older women. A study by de Renkiere et al (19) found that older adults that reported at least one fall within a year tended to be female and have lower leg strength, poorer balance, slower 400-meter walk time and lower muscle mass. Similarly, Suzuki et al. (90) reported higher fall rates in institutionalized elderly women. A possible explanation for the higher incidence of falls in older women is provided by Wojcik et al. (101). In this study, they found that older women were less able to recover balance during a fall due to limitations in the maximum speeds at which they moved their swing foot during recovery. This finding of reduced movement speed is supported by Krivickas et al. (43) who found that older women exhibited lower absolute unloaded shortening velocity of type I and II skeletal muscle fibers. Despite the fact that women

clearly are at greater risk for functional impairment, the loss of functional ability is a concern for the entire aged population. It also appears that the factors that cause these impairments may be sex-specific, and need to be verified in future studies in order to design interventions to improve function in the elderly

Although sex differences among these variables have commonly been examined, there is very little existing literature on muscle mass, strength, and power between racial groups. For the purpose of this review, only comparisons between African Americans and Caucasians will be reported. In this regard, some studies have examined differences in muscle mass between races. Studies by Newman et al.(66, 67) reported greater lower extremity lean mass and appendicular lean mass divided by height, respectively, in African-Americans as assessed by DXA. Also, Visser et al (100) used computed tomography to report larger CSA of the midthigh in African Americans, while Aloia et al. (2) also observed greater whole body muscle mass in African-Americans estimated from total body potassium. Similarly, Gallagher et al. (28) found greater appendicular muscle mass and total body potassium in African Americans after adjustment for height, stature, and age. Although few studies are available and some have used different methodologies, all are in agreement that, on average, African Americans have greater muscle mass than Caucasians.

These documented differences have led investigators to examine if the larger muscle mass in African Americans corresponds to increased force production capabilities. However, unlike muscle mass, studies on strength between races have not been in agreement. Using isokinetic dynamometry, Newman et al. (66) reported greater muscle strength in African Americans. However, using a similar method, Ostchega et al.

(68) observed no difference in concentric peak torque between races. Rantanen et al. (79) also reported no differences in strength among races. However, in this study the force was recorded as the greatest force the tester had to apply to break the subject's isometric contraction, and the validity of this measurement is unknown. Even more unexpected is a study by Means et al (59), which found that African American women had less muscle strength than their Caucasian counterparts, although the validity of the strength measurement in this study is questionable. They used a physical therapist to manually test muscle strength, and is therefore not a reliable index of maximal voluntary force production. Due to the small amount of available literature and wide variety of testing procedures, strength differences between African Americans and Caucasians remains inconclusive.

Only one study has considered both of the previously discussed variables and examined muscle quality between races. As noted earlier, Newman et al. (66) reported greater muscle mass and strength in African Americans. However, when the ratio of muscle strength to muscle mass was examined, leg muscle quality tended to be lower in African Americans than Caucasians. This unique discovery demonstrates that racial differences in muscle function are multi-dimensional, and needs to be pursued further. In this regard, there is no existing literature that has focused on racial differences in the combination of muscular strength and movement velocity, or muscle power. Clearly, all of these variables and their relationships with each other must be examined in order to fully understand racial differences in muscle function.

The importance of understanding racial differences in muscle mass, strength, and power is that it relates to differences in functional performance among these groups.

Although there appears to be racial differences in functional abilities with aging, the current literature is conflicting. When examining falls in an elderly population both de Rekeneire et al. (19) and Hanlon et al (32) concluded that elderly Caucasians, particularly women, were at a greater risk than African Americans. Also, in the de Rekeneire study (19) risk of falls was associated with poorer performance on functional tasks such as 6- and 400- meter walk time, standing and walking balance, and inability to perform five chair stands. Contradictory to these reports are others that have shown African Americans to perform worse on measures of functional performance. Means et al. (59) demonstrated that older African American women exhibited poorer balance, mobility, and obstacle course performance than Caucasian women. Also, Visser et al (100) reported that African Americans showed poorer lower extremity performance on a battery of tests that included the 6-meter walk and five chair stands. Newman et al. (67) also noted that African American women were more likely to have lower physical function, despite the fact that less likely to be classified as sarcopenic in comparison to their Caucasian counterparts. The conflicting reports in all of the previously described studies indicates that in order to truly understand racial differences, muscle mass, strength, power, and their relationships to functional ability must be determined.

### **Assessment of muscle power and movement velocity**

Results that have been previously reported in the literature have likely been influenced by differences in methodologies, which may help explain discrepancies with regards to age- and gender- associated differences in muscular power and movement velocity.

One of the most commonly used methods of assessing power and movement velocity has been the flywheel, or “Nottingham” rig. The feasibility and reliability of this instrument was first reported by Bassey et al in 1990 (7), and has been replicated in numerous other investigations since then (5, 10, 72, 88, 89). This apparatus is designed to measure leg extensor power and consists of a footplate connected through a lever and chain to a flywheel. Briefly, subjects are asked to apply maximal force to push the footplate away, accelerating the flywheel from rest. Velocity of the flywheel is estimated by interruption of an infra-red opto-switch to the nearest millisecond. Average power is calculated using this estimated velocity and constants for, moment of inertia, angular distance (rads), average force of the return spring, pedal movement (meters), and frictional loss (7). Although this method has been reported to be a reliable measurement of muscular power, it is not valid by itself for assessing power differences between age groups and/or sexes. This is because it requires each subject to overcome the same fixed inertia and does not account for individual variations in strength. Therefore, when assessing power differences between young and old subjects, the older and presumably weaker subjects are forced to use a greater percentage of strength, and thus working in a less favorable portion of the force-velocity curve. The same argument can be made for assessing power differences between sexes, where on average, women have less absolute strength than men and would be using a larger percentage of their maximum force-generating capacity.

The second most commonly used method for measurement of power and velocity is the standing force jump plate. This method, first described by Davies and Rennie (1968), requires a vertical jump on a force platform and has been widely used to measure

explosive or instantaneous power in a wide range of populations (15, 18, 21, 22, 37, 76, 78, 87). Power output during the jump is calculated by multiplying the vertical velocity of displacement of the body's center of gravity and the vertical force measured by the platform. Also taken into account in this equation is the vertical acceleration imposed by muscle contraction, body mass of the subject, and acceleration of gravity (18). Although this method does have the ability to extract a maximal force and maximal velocity to determine the maximal power attained during each repetition, it has some limitations that must be accounted for. First, when examining explosive power in older adults, actions such as jumping may be accompanied by an increased risk of injury during the test. Thus, safety may be a concern for testing older adults. With respect to age, it has a similar disadvantage as the flywheel rig in that the validity of making age comparisons has been questioned (54). Jumping requires a large amount of force production and in the elderly would require a greater percentage of strength than in younger people, thus compromising movement velocity. A study by Rantanen and Avela attempted to account for the safety issue by using a sledge ergometer and had subjects extend their legs powerfully, "as if trying to jump" (76). However, the mass of the chair attached to the ergometer added an extra 27.7 kg, which would require the older subjects to use an even larger percentage of strength to produce the desired movement. A few studies using the vertical jump plate have also reported "peak" power in older adults (15, 20, 22). However, because of the considerations previously described, these measurements should not be reported as peak power. These older subjects are likely not working in the optimal range of force and velocity needed to attain peak power output. What is actually being measured in these studies are the maximal power values achieved during the movement.

It is reasonable to assume that these subjects could attain higher power values if they were working in a portion of the force-velocity curve that is more favorable for optimizing peak power.

A less common method currently for assessing power output, but more common in earlier investigations, is isokinetic dynamometry. Previous studies have used this equipment to test knee extension power at various speeds in an attempt to determine peak power (29, 86). Gauchard et al. used isokinetic testing to measure power in adults over the age of 60 (29). However, they tested knee extensor power only at 90 deg/s, which is too slow for most people to achieve the optimal velocity component of power. Other studies (45, 86) have used higher velocities (up to 400 deg/s), but this speed may be above optimal for some and below optimal for others. Perrine et al. (73) estimated that unloaded movement of the human limbs could reach 832 deg/s. Thus, one problem with the use of isokinetic testing to assess muscle power is that a specific velocity is imposed on everyone being tested, but the optimal velocity for eliciting maximal (peak) power is likely different among individuals. Other studies have also used this equipment to measure the maximal isometric strength and then use the “isotonic” mode to optimize the load during the contraction (53). This allows for the measurement of maximal movement velocity during the movement. However, the sampling rate of isokinetic equipment is typically 100Hz, which may be too short to capture the true peak achieved, but could provide an accurate measure of average power throughout the range of motion. Further research would be needed to validate the use of isokinetic dynamometers in assessing peak power output.

A more recent method for examining power output uses pneumatic (compressed air) resistance equipment interfaced to a computer. The advantage of this equipment is that the velocity component is controlled by the subject. This allows for the optimal velocity for peak power production to be attained, which may not have occurred with the use of the equipment previously discussed. The pneumatic resistance also provides the ability to control for individual differences by optimizing the load relative to the subjects' one repetition maximum (1RM) (2, 9, 25, 41, 86, 92). Therefore, by testing at numerous percentages of one's 1RM, it may be possible to optimize the strength component of power as well, thus providing the most accurate representation of muscular power to date. Also, these isotonic contractions are believed to closely resemble normal muscular contraction where the muscle is maximally loaded at one point in the range of motion, and therefore may be a more functionally relevant measure of power. During a repetition, the computer software calculates work and power by sampling the pressure at the air cylinder 400 times per second and records distance traveled by the piston shaft. In order to account for slower speeds encountered due to inertial forces needed to overcome forces at the beginning of the movement and the co-contraction of the antagonist muscles the end of the movement, these studies excluded the first and last 5% of the motion. However, some of these studies report this measurement as "peak" power (2, 9, 25). In reality, these investigations are reporting the highest average power observed during the test. A true peak power would likely reflect the point in the range of motion where optimal force and optimal velocity occur simultaneously, which has yet to be reported.

## **Summary**

It is clear that with aging, there are significant losses in muscle mass, strength, and power. Deficits in each of these variables have been linked to impaired functional ability in the elderly, and it appears that losses in muscular power may be the most influential. However, the importance of each in contributing to functional dependence may be sex- and/or race-specific and have important implications for designing interventions to counteract losses in functional ability. In this regard, older women have been shown to possess less muscle mass, strength, and power than older men, all of which contribute to poorer functional performance and higher risk of falls. However, when considering the amount of muscle mass, strength differences between the sexes narrow and are non-significant. This indicates a need to normalize all measures of muscle function for individual differences in muscle mass and suggests that other non-muscular factors may contribute to the disability process. Although less studied, there are also differences in muscle mass and strength between races. African Americans typically have greater muscle mass, but results on race differences in strength, muscle quality, and functional ability remain controversial. Currently, there is no existing literature on race differences in power and movement velocity. Future studies in this area may assist to solidify our understanding of racial differences in muscle function. Finally, findings regarding age, sex, and race differences in power and its relationship to function may also be greatly influenced by testing methodology, and must be considered in order to make accurate conclusions.

## **APPENDIX C: FORMS AND FIGURE**

**Informed consent**

**1RM testing form**

**Power testing form**

**Sample figure of MatLab power curve**

## APPENDIX C

### FORMS AND FIGURE

#### Informed consent

#### CONSENT TO PARTICIPATE IN A RESEARCH PROJECT

**Project Title:** Effects of Gene Variations on Age- and Strength Training-Induced Changes in Muscular Strength, Body Composition, Blood Pressure, Glucose Metabolism, and Lipoprotein-lipid Profiles

I state that I am over 18 years of age, in good physical health, and have elected to participate in a program of research being conducted by Dr. Ben Hurley in the Department of Kinesiology at the University of Maryland, College Park, MD 20742.

I understand that the primary purpose of this study is to assess the role that genetics may play in causing losses of muscular strength and muscle mass with age and gains in strength and muscle mass as a result of strength training. I understand that another purpose of the study will be to assess the influence of genes on changes in body composition, blood pressure, blood sugar metabolism, blood fats muscle power, and performance of common physical tasks with age and strength training.

I understand that the procedures involve three phases. During the first phase, I will undergo testing, which will include a blood draw to analyze my DNA (genetic material), blood sugar and fats, and other blood proteins. My blood pressure, body composition, bone mineral density, leg muscle volume, muscle strength, muscle power, and ability to complete selected tasks similar to common activities of daily living will also be assessed during this first phase. The second phase of the study involves my participation in a strength training program three times a week for approximately six months. The third and final phase will be a repeat of all previously taken measures, except analysis of my DNA, which will not need to be repeated. Some of the tests will be repeated both after ~ 10 weeks of training and again after the entire training program. These repeat tests will include blood pressure, strength, power, muscle volume and body composition. Other tests will be repeated only after the entire training program.

I understand that the blood draw will require providing about 2 to 3 tablespoons of blood. I understand that there is a risk of bruising, pain and, in rare cases, infection or fainting as a result of blood sampling. However, these risks to me will be minimized by allowing only qualified people to draw my blood. A portion of this blood sample will be sent to the University of Pittsburgh to analyze my DNA. I understand that the remainder will be stored at the University of Maryland for later analysis of my blood sugar, the hormone that regulates my blood sugar (insulin), blood fats, and other blood proteins. I understand that a portion of this sample may also be used for potential future studies, but only as such studies examine strength, body composition (i.e., fat, muscle & bone), metabolism of blood sugar, and blood pressure. I understand that I may contact the principal investigator at any future point in time to request that any stored blood sample be destroyed immediately.

I understand that while I am lying on a padded table, my leg muscle and fat mass will be measured by computed tomography (CT). The CT scan will be performed at the Washington Adventist Hospital. My percent body fat and bone mineral density measurements will be performed at the United States Department of Agriculture in Beltsville, Maryland by dual-energy x-ray absorptiometry (DXA). This will require my lying still on a padded exam table wearing metal-free clothing for about 10 minutes at a time, totaling less than 30 total minutes for the entire procedure.

I understand that there will be a total radiation dose of approximately 1 Rem to the whole body (effective dose equivalent) from each CT scan. This amount is well below the maximal annual radiation dose (5 Rems) allowed for exposure in the workplace. The body composition and bone density testing completed by DXA involves a small radiation exposure. The radiation exposure I will receive from DXA is equal to an exposure of less than 50 millirems to the whole body. Naturally occurring radiation (cosmic radiation, radon, etc.) produces whole body radiation of about 300 millirems per year. Therefore, the total dose of radiation exposure due to the DXA measurement is minimal and the combined dose of DXA and CT is considered low. The major risk from high radiation exposure is passing on damaged genes (genetic mutations) to offspring. Consequently, this risk is typically of less concern to those who are beyond childbearing age.

I understand that strength and power assessments will be performed on machines that measure how much force and how fast I can exert force through a typical range of knee extension motion. Strength testing will also be performed on the same exercise machines used for training by measuring the maximal amount of force that I can move through the full range of an exercise. During each strength training session I will be asked to exercise on machines which offer resistance against extending and flexing my arms, legs, and trunk region for approximately 40 minutes or less a day, three times a week for up to six months. I understand that I may experience some temporary muscle soreness as a result of the testing sessions. There is also a risk of muscle or skeletal injury from strength and power testing, as well as from strength training. The investigators of this study will use procedures designed to minimize this risk.

I understand that I will be asked to complete some tasks to measure my ability to carry out normal daily activities. These tasks include rising from a chair, short brisk walks and climbing a flight of stairs. Any risk of injury during the completion of these tasks will be minimized by having all sessions supervised by an exercise physiologist qualified to direct this type of testing and wearing a safety harness during the short brisk walks and climbing a flight of stairs.

I understand that it is also possible that heart or blood vessel problems could arise during my participation in the testing or training involved in this study. Although unusual, it is possible that these problems could lead to a heart attack or even death. Therefore, prior evaluation and permission from my physician will be required to participate in this study. I also understand that it is possible that these risks will not be eliminated completely, even with a medical evaluation prior to participation in the study. However, we believe the risk of harm from study participation is small and that the benefits of the study will likely outweigh any probable risks.

I understand that this study is not designed to help me personally, but may help the investigators better understand who is likely to be most and least susceptible to losing

strength, power, and muscle mass with advanced age and who is most and least likely to benefit from strength training.

I understand that my decision of whether or not to participate in this study is voluntary. I understand that I am free to ask questions about this study before I decide whether or not to participate in this study. I understand that if I consent to participate in the study, I am free to withdraw from participation at any time without penalty or coercion, or without any requirement that I provide an explanation to anyone of my decision to withdraw. In addition, I understand that refusal to participate will not involve a penalty or loss of benefit to which a volunteer would ordinarily be entitled at that time. I understand that all information collected in this study is confidential. For my participation in the study I will receive information after the study is completed about my blood pressure, blood test results, bone mineral density, body composition, and functional ability, free of charge. However, I understand that I will not receive any financial compensation in exchange for my participation in this study.

In the event of physical injury resulting from participation in this study, upon my consent, emergency treatment will be available at the medical center of Washington Adventist Hospital with the understanding that any injury that requires medical attention becomes my financial responsibility. I understand that the University of Maryland at College Park will not provide any medical or hospitalization insurance coverage for participants in this research study, nor will they provide compensation for any injury sustained as a result of this research study, except as required by law.

I understand that I can discuss this research study at any time with the principal investigator, Dr. Ben Hurley at (301) 405-2486 or with the study coordinator, Matt Delmonico, at (301) 405-2569.

I have read and understand the above information and have been given an adequate opportunity to ask the investigators any questions I have about the study. My questions, if any, have been answered by the investigators to my satisfaction. By my signature I am indicating my decision to consent to participate voluntarily in this study.

Principal investigator: Ben Hurley, Ph.D., Dept of Kinesiology, HLHP Building,  
University of Maryland, College Park, MD 20742-2611, Ph: (301) 405-2486.

Printed Name of Subject \_\_\_\_\_

Signature of Subject \_\_\_\_\_ Date \_\_\_\_\_

Contact information of Institutional Review Board: If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, MD 20742; e-mail, [irb@deans.umd.edu](mailto:irb@deans.umd.edu); telephone, 301-405-4212

**1RM testing form**

**University of Maryland / National Institute on Aging  
GUSTO**

**Symptom-limited Baseline Knee Extension 1-RM**

Arms across chest	_____
Seat Belt	_____
Remember to breathe	_____

Examiners Name \_\_\_\_\_  
Name \_\_\_\_\_ Date \_\_\_\_\_

Time \_\_\_\_\_ Location \_\_\_\_\_

**Body weight** \_\_\_\_\_ **Age** \_\_\_\_\_ **Predicted 1-RM** \_\_\_\_\_

Seat \_\_\_\_\_ Leg \_\_\_\_\_ Blood Pressure \_\_\_\_\_ **Right leg / Left leg**

	Resistance	P/D scale	RPE scale
<b><u>Rest</u></b>	_____	_____	_____
Set 1	_____	_____	_____
Set 2	_____	_____	_____
Set 3	_____	_____	_____
Set 4	_____	_____	_____
Set 5	_____	_____	_____
Set 6	_____	_____	_____
Set 7	_____	_____	_____
Set 8	_____	_____	_____
Set 9	_____	_____	_____
Set 10	_____	_____	_____
Set 11	_____	_____	_____
Set 12	_____	_____	_____

Most severe P/D: \_\_\_\_\_ Subject's initials: \_\_\_\_\_

Post BP \_\_\_\_\_ 3 min. post BP \_\_\_\_\_ **Valid** **Invalid**

If invalid, please explain: \_\_\_\_\_  
\_\_\_\_\_

**Power testing form**

Name \_\_\_\_\_ Date \_\_\_\_\_  
 Tester \_\_\_\_\_ Time \_\_\_\_\_

**Baseline: Power Test #1**

Resting BP: \_\_\_/\_\_\_mmHg

Seat Position: \_\_\_\_\_ 1-RM R: \_\_\_\_\_ Dominant Leg: R L Order of Testing: \_\_\_R \_\_\_L  
 1-RM L: \_\_\_\_\_

30% I-RM R \_\_\_\_\_ Practice P/D: \_\_\_\_\_ 30% I-RM L \_\_\_\_\_ Practice P/D: \_\_\_\_\_

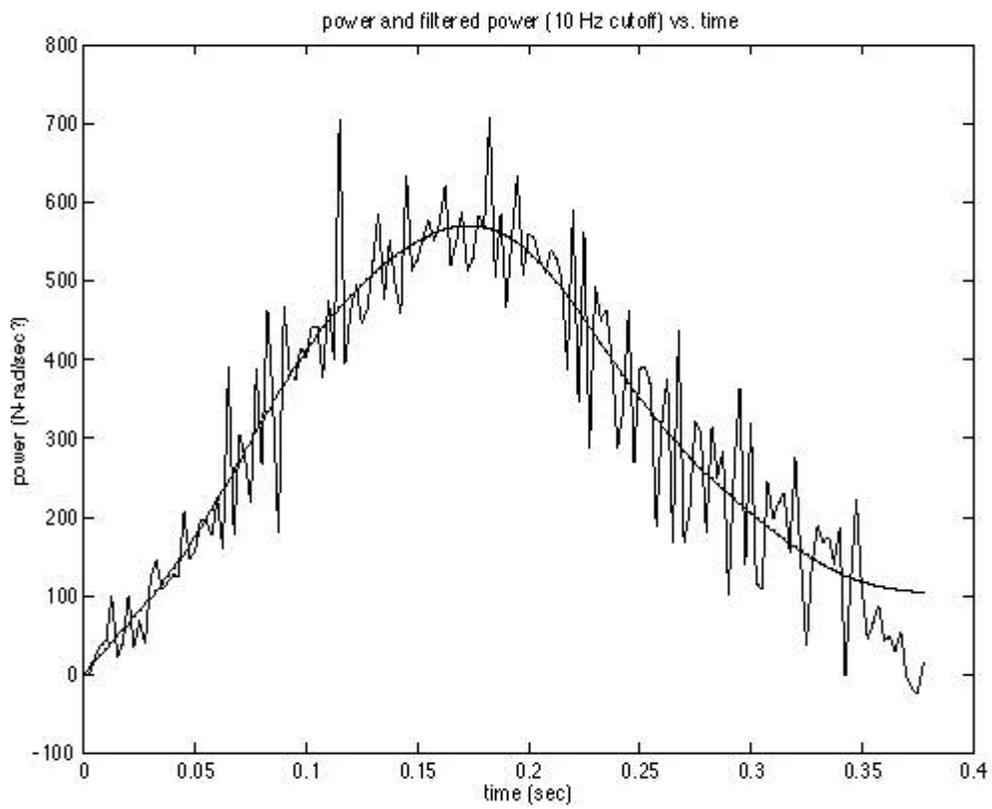
% 1- RM	Right Resistance	Test #	P/D & Locatio n (0-6)	Imme d dissi p (Y/N)	Left Resistance	Test #	P/D & Location (0-6)	Imme d dissip (Y/N)	File Name Initials number P1 %1- RM.txt
50									<b>1P</b> <b>_506070</b> <b>scan.txt</b> <b>1P</b> <b>_506070</b> <b>graf.txt</b>
50									
50									
60									
60									
60									
70									
70									
70									

Immediate BP: \_\_\_/\_\_\_mmHg      Constant Reminders: Back against seat  
 Look straight ahead  
 3 min BP: \_\_\_/\_\_\_mmHg                      Breathe Normally

General Comments: \_\_\_\_\_  
 \_\_\_\_\_

Test	Comment

### Sample figure of MatLab power curve



## References

1. Akima H, Kano Y, Enomoto Y, Ishizu M, Okada M, Oishi Y, Katsuta S and Kuno S. Muscle function in 164 men and women aged 20--84 yr. *Med Sci Sports Exerc* 33: 220-226, 2001.
2. Aloia JF, Vaswani A, Feuerman M, Mikhail M and Ma R. Differences in skeletal and muscle mass with aging in black and white women. *Am J Physiol Endocrinol Metab* 278: E1153-E1157, 2000.
3. Aniansson A, Zetterberg C, Hadberg M and Henriksson K. Impaired muscle function with aging. A background factor in the incidence of fractures of the proximal end of the femur. *Clinical Orthopedic Related Resistant* 191: 193-200, 1984.
4. Avlund K, Schroll M, Davidsen M, Lovborg B and Rantanen T. Maximal isometric muscle strength and functional ability in daily activities among 75-year-old men and women. *Scand J Med Sci Sports* 4: 32-40, 1994.
5. Bassey EJ, Fiatarone MA, O'Niell EF, Kelly M, Evans WJ and Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci (Lond)* 82: 321-327, 1992.
6. Bassey EJ and Harries UJ. Normal values for handgrip strength in 920 men and women aged over 65 years, and longitudinal changes over 4 years in 620 survivors. *Clin Sci (Lond)* 84: 331-337, 1993.
7. Bassey EJ and Short AH. A new method for measuring power output in a single leg extension: feasibility, reliability and validity. *Eur J Appl Physiol* 60: 385-390, 1990.
8. Bassey E, Fiatarone M, O'Neil E, Kelly M, Evans W and Lipsitz L. Leg extensor power and functional performance in very old men and women. *Clinical Science* 82: 321-327, 1992.
9. Bean JF, Kiely DK, Herman S, Leveille SG, Mizer K, Frontera WR and Fielding RA. The relationship between leg power and physical performance in mobility-limited older people. *J Am Geriatr Soc* 50: 461-467, 2002.
10. Bean JF, Leveille SG, Kiely DK, Bandinelli S, Guralnik JM and Ferrucci L. A comparison of leg power and leg strength within the InCHIANTI study: Which influences mobility more? *J Gerontol A Biol Sci Med Sci* 58A: 728-733, 2003.
11. Bembien MG, Massey BH, Bembien DA, Misner JE and Boileau RA. Isometric muscle force production as a function of age in healthy 20- to 74-yr-old men. *Med Sci Sports Exerc* 23: 1302-1310, 1991.

12. Borges O. Isometric and isokinetic knee extension and flexion torque in men and women aged 20-70. *Scand J Rehabil Med* 21: 45-53, 1989.
13. Brown M, Sinacore DR and Host HH. The relationship of strength to function in the older adult. *J Gerontol A Biol Sci Med Sci* 50 Spec No: 55-59, 1995.
14. Buchner D and de Lateur BJ. The importance of skeletal muscle strength to physical function in older adults. *Ann Behav Med* 13: 91-98, 1991.
15. Caserotti P, Aagaard P, Simonsen EB and Puggard L. Contraction-specific differences in maximal muscle power during stretch-shortening cycle movements in elderly males and females. *Eur J Appl Physiol* 84: 206-212, 2001.
16. Clarkson PM, Kroll W and Melchionda AM. Age, isometric strength, rate of tension development and fiber type composition. *J Gerontol* 36: 648-653, 1981.
17. Danneskiold-Samsøe B, Kofod V, Munter J, Grimby G, Schnohr P and Jensen G. Muscle strength and functional capacity in 78-81-year-old men and women. *Eur J Appl Physiol Occup Physiol* 52: 310-314, 1984.
18. Davies CT and Rennie R. Human power output. *Nature* 217: 770-771, 1968.
19. de Rekeneire N, Visser M, Peila R, Nevitt MC, Cauley JA, Tylavsky FA, Simonsick EM and Harris TB. Is a Fall Just a Fall: Correlates of Falling in Healthy Older Persons. The Health, Aging and Body Composition Study. *J Am Geriatr Soc* 51: 841-846, 2003.
20. De Vito G, Bernardi M, Forte R, Pulejo C, Macaluso A and Figura F. Determinants of maximal instantaneous muscle power in women aged 50-75 years. *Eur J Appl Physiol* 78: 59-64, 1998.
21. Ferretti G, Berg HE, Minetti AE, Moia C, Rampichini S and Narici MV. Maximal instantaneous muscular power after prolonged bed rest in humans. *J Appl Physiol* 90: 431-435, 2001.
22. Ferretti G, Narici MV, Binzoni T, Gariod L, Le Bas JF, Reutenauer H and Cerretelli P. Determinants of peak muscle power: effects of age and physical conditioning. *Eur J Appl Physiol Occup Physiol* 68: 111-115, 1994.
23. Ferretti G, Narici MV, Binzoni T, Gariod L, Le Bas JF, Reutenauer H and Cerretelli P. Determinants of peak muscle power: effects of age and physical conditioning. *Eur J Appl Physiol Occup Physiol* 68: 111-115, 1994.
24. Fielding RA, LeBrasseur NK, Cuoco A, Bean J, Mizer K and Fiatarone Singh MA. High-velocity resistance training increases skeletal muscle peak power in older women. *J Am Geriatr Soc* 50: 655-662, 2002.

25. Foldvari M, Clark M, Laviolette LC, Bernstein MA, Kaliton D, Castaneda C, Pu CT, Hausdorff JM, Fielding RA and Fiatarone MA. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol A Biol Sci Med Sci* 55A: M192-M199, 2000.
26. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ and Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol* 88: 1321-1326, 2000.
27. Frontera WR, Hughes VA, Lutz KJ and Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol* 71: 644-650, 1991.
28. Gallagher D, Visser M, De Meersman RE, Sepulveda D, Baumgartner RN, Pierson RN, Harris T and Heymsfield SB. Appendicular skeletal muscle mass: effects of age, gender, and ethnicity. *J Appl Physiol* 83: 229-239, 1997.
29. Gauchard GC, Tessier A, Jeandel C and Perrin PP. Improved muscle strength and power in elderly exercising regularly. *Int J Sports Med* 24: 71-74, 2003.
30. Grabiner MD, Koh TJ, Lundin TM and Jahnigen DW. Kinematics of recovery from a stumble. *J Gerontol* 48: M97-102, 1993.
31. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME and Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N Engl J Med* 332: 556-561, 1995.
32. Hanlon JT, Landerman LR, Fillenbaum GG and Studenski S. Falls in African American and White Community-Dwelling Elderly Residents. *J Gerontol A Biol Sci Med Sci* 57: M473-M478, 2002.
33. Hudash G, Albright JP, McAuley E, Martin RK and Fulton M. Cross-sectional thigh components: computerized tomographic assessment. *Med Sci Sports Exerc* 17: 417-421, 1985.
34. Hughes VA, Frontera WR, Wood M, Evans WJ, Dallal GE, Roubenoff R and Singh MAF. Longitudinal Muscle Strength Changes in Older Adults: Influence of Muscle Mass, Physical Activity, and Health. *J Gerontol A Biol Sci Med Sci* 56: B209-B217, 2001.
35. Hurley BF and Roth SM. Strength Training in the Elderly, Effects on Risk Factors for Age-Related Diseases. *Sports Med* 30: 249-268, 2000.
36. Hyatt R, Whitelaw M, Bhat A, Scott S and Maxwell J. Association of muscle strength with functional status of elderly people. *Age Ageing* 19: 330-336, 1990.

37. Izquierdo M, Aguado X, Gonzalez R, Lopez JL and Hakkinen K. Maximal and explosive force production capacity and balance performance in men of different ages. *Eur J Appl Physiol Occup Physiol* 79: 260-267, 1999.
38. Izquierdo M, Ibanez J, Gorostiaga E, Garrues M, Zuniga AAA, Larrion JL and Hakkinen K. Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiol Scand* 167: 57-68, 1999.
39. Janssen I, Heymsfield SB and Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc* 50: 889-896, 2002.
40. Janssen I, Heymsfield SB, Wang ZM and Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol* 89: 81-88, 2000.
41. Jozsi AC, Campbell WW, Joseph L, Davey SL and Evans WJ. Changes in power with resistance training in older and younger men and women. *J Gerontol A Biol Sci Med Sci* 54: M591-M596, 1999.
42. Kent-Braun JA and Ng AV. Specific strength and voluntary muscle activation in young and elderly women and men. *J Appl Physiol* 87: 22-29, 1999.
43. Krivickas LSM, Suh DM, Wilkins JB, Hughes VAM, Roubenoff RMM and Frontera WRMP. Age- and Gender-Related Differences in Maximum Shortening Velocity of Skeletal Muscle Fibers. *Am J Phys Med Rehabil* 80: 447-455, 2001.
44. Kwon IS, Oldaker S, Schrage M, Talbot LA, Fozard JL and Metter EJ. Relationship Between Muscle Strength and the Time Taken to Complete a Standardized Walk-Turn-Walk Test. *J Gerontol A Biol Sci Med Sci* 56: B398-B404, 2001.
45. Lanza IR, Towse TF, Caldwell GE, Wigmore DM and Kent-Braun JA. Effects of age on human muscle torque, velocity, and power in two muscle groups. *J Appl Physiol* 95: 2361-2369, 2003.
46. Larsson L, Grimby G and Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol* 46: 451-456, 1979.
47. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, Corsi AM, Rantanen T, Guralnik JM and Ferrucci L. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol* 95: 1851-1860, 2003.
48. Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, Roy TA and Hurley BF. Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. *J Appl Physiol* 83: 1581-1587, 1997.

49. Lipsitz L, Nakajima I, Gagnon M, Hirayama T, Connelly C and Izumo H. Muscle strength and fall rates among residents of Japanese and American nursing homes: an International Cross-Cultural Study. *J Am Geriatr Soc* 42: 953-959, 1994.
50. Lord SR, Clark RD and Webster IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc* 39: 1194-1200, 1991.
51. Lynch NA, Metter EJ, Lindle RS, Fozard JL, Tobin JD, Roy TA, Fleg JL and Hurley BF. Muscle quality. I. Age-associated differences between arm and leg muscle groups. *J Appl Physiol* 86: 188-194, 1999.
52. Macaluso A and De Vito G. Comparison between young and older women in explosive power output and its determinants during a single leg-press action after optimisation of load. *Eur J Appl Physiol* 90: 458-463, 2003.
53. Macaluso A and De Vito G. Comparison between young and older women in explosive power output and its determinants during a single leg-press action after optimisation of load. *Eur J Appl Physiol* 90: 458-463, 2003.
54. Macaluso A and De Vito G. Muscle strength, power and adaptations to resistance training in older people. *Eur J Appl Physiol* 91: 450-472, 2004.
55. Macaluso A, Nimmo MA, Foster JE, Cockburn M, McMillan NC and De Vito G. Contractile muscle volume and agonist-antagonist coactivation account for differences in torque between young and older women. *Muscle Nerve* 25: 858-863, 2002.
56. Marcell TJ. Sarcopenia: causes, consequences, and preventions. *J Gerontol A Biol Sci Med Sci* 58: M911-M916, 2003.
57. Maughan RJ, Watson JS and Weir J. Strength and cross-sectional area of human skeletal muscle. *J Physiol* 338: 37-49, 1983.
58. McArdle WD, Katch F.I. and Katch V.L. *Exercise physiology: energy, nutrition, and human performance*. Lippincott, Williams and Wilkins, 2001.
59. Means KM, O'Sullivan PS and Rodell DE. Balance, mobility, and falls among elderly African American women. *Am J Phys Med Rehabil* 79: 30-39, 2000.
60. Metter EJ, Conwit R, Tobin J and Fozard JL. Age-associated loss of power and strength in the upper extremities in women and men. *J Gerontol A Biol Sci Med Sci* 52: B267-B276, 1997.
61. Metter EJ, Lynch N, Conwit R, Lindle R, Tobin J and Hurley B. Muscle quality and age: cross-sectional and longitudinal comparisons. *J Gerontol A Biol Sci Med Sci* 54: B207-B218, 1999.

62. Miller AE, MacDougall JD, Tarnopolsky MA and Sale DG. Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol Occup Physiol* 66: 254-262, 1993.
63. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D and Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. *J Appl Physiol* 85: 115-122, 1998.
64. Murray MP, Duthie EH, Jr., Gambert SR, Sepic SB and Mollinger LA. Age-related differences in knee muscle strength in normal women. *J Gerontol* 40: 275-280, 1985.
65. Murray MP, Gardner GM, Mollinger LA and Sepic SB. Strength of isometric and isokinetic contractions: knee muscles of men aged 20 to 86. *Phys Ther* 60: 412-419, 1980.
66. Newman AB, Haggerty CL, Goodpaster B, Harris T, Kritchevsky S, Nevitt M, Miles TP and Visser M. Strength and muscle quality in a well-functioning cohort of older adults: The health, aging and body composition study. *J Am Geriatr Soc* 51: 323-330, 2003.
67. Newman AB, Kupelian V, Visser M, Simonsick E, Goodpaster B, Nevitt M, Kritchevsky SB, Tylavsky FA, Rubin SM and Harris TB. Sarcopenia: Alternative Definitions and Associations with Lower Extremity Function. *J Am Geriatr Soc* 51: 1602-1609, 2003.
68. Ostchega Y, Dillon CF, Lindle R, Carroll M and Hurley BF. Isokinetic leg muscle strength in older americans and its relationship to a standardized walk test: data from the national health and nutrition examination survey 1999-2000. *J Am Geriatr Soc* 52: 977-982, 2004.
69. Overend TJ, Cunningham DA, Kramer JF, Lefcoe MS and Paterson DH. Knee extensor and knee flexor strength: cross-sectional area ratios in young and elderly men. *J Gerontol* 47: M204-M210, 1992.
70. Pavol MJ, Owings TM, Foley KT and Grabiner MD. Mechanisms leading to a fall from an induced trip in healthy older adults. *J Gerontol A Biol Sci Med Sci* 56: M428-M437, 2001.
71. Pavol MJ, Runtz EF, Edwards BJ and Pai YC. Age influences the outcome of a slipping perturbation during initial but not repeated exposures. *J Gerontol A Biol Sci Med Sci* 57: M496-M503, 2002.
72. Pearson SJ, Young A, Macaluso A, Devito G, Nimmo MA, Cobbold M and Harridge SDR. Muscle function in elite master weightlifters. *Med Sci Sports Exerc* 34: 1199-1206, 2002.

73. Perrine JJ. The biophysics of maximal power outputs: methods and problems of measurement. In: Human Muscle Power, edited by Jones N.L., McCartney N. and McComas A.J. Champagne, IL: Human Kinetics, 1986, p. 15-25.
74. Porter MM, Myint A, Kramer JF and Vandervoort AA. Concentric and eccentric knee extension strength in older and younger men and women. *Can J Appl Physiol* 20: 429-439, 1995.
75. Rantanen T. Muscle strength, disability and mortality. *Scand J Med Sci Sports* 13: 3-8, 2003.
76. Rantanen T and Avela J. Leg extension power and walking speed in very old people living independently. *J Gerontol A Biol Sci Med Sci* 52A: M225-M231, 1997.
77. Rantanen T, Avlund K, Suominen H, Schroll M, Frandin K and Pertti E. Muscle strength as a predictor of onset of ADL dependence in people aged 75 years. *Aging Clin Exp Res* 14: 10-15, 2002.
78. Rantanen T, Guralnik JM, Ferrucci L, Leveille S and Fried LP. Coinpairments: Strength and balance as predictors of severe walking disability. *J Gerontol A Biol Sci Med Sci* 54: M172-M176, 1999.
79. Rantanen T, Guralnik JM, Leveille S, Izmirlian G, Hirsch R, Simonsick E, Ling S and Fried LP. Racial differences in muscle strength in disabled older women. *J Gerontol A Biol Sci Med Sci* 53A: B355-361, 1998.
80. Reed R, Pearlmutter L, Yochum K, Meredith K and Mooradian A. The relationship between muscle mass and muscle strength in the elderly. *J Am Geriatr Soc* 39: 555-561, 1991.
81. Rikli R and Jones C. *Senior Fitness Testing Manual*. Human Kinetics, 2001.
82. Rolland Y, Lauwers-Cances V, Cournot M, Nourhashemi F, Reynish W, Riviere D, Vellas B and Grandjean H. Sarcopenia, calf circumference, and physical function of elderly women: a cross-sectional study. *J Am Geriatr Soc* 51: 1120-1124, 2003.
83. Roth SM, Ferrell RF and Hurley BF. Strength training for the prevention and treatment of sarcopenia. *J Nutr Health Aging* 4: 143-155, 2000.
84. Samson M, Meeuwssen I, Crowe A, Dessens J, Duursma S and Verhaar H. Relationships between physical performance measures, age, height and body weight in healthy adults. *Age Ageing* 29: 235-242, 2000.
85. Schultz AB, Ashton-Miller JA and Alexander NB. What leads to age and gender differences in balance maintenance and recovery? *Muscle Nerve Suppl* 5: S60-S64, 1997.

86. Signorile JF, Carmel MP, Czaja SJ, Asfour SS, Morgan RO, Khalil TM, Ma F and Roos BA. Differential increases in average isokinetic power by specific muscle groups of older women due to variations in training and testing. *J Gerontol A Biol Sci Med Sci* 57: M683-M690, 2002.
87. Sipila S, Koskinen SO, Taaffe DR, Takala TE, Cheng S, Rantanen T, Toivanen J and Suominen H. Determinants of lower-body muscle power in early postmenopausal women. *J Am Geriatr Soc* 52: 939-944, 2004.
88. Skelton DA, Greig CA, Davies JM and Young A. Strength, power and related functional ability of healthy people aged 65-89 years. *Age Ageing* 23: 371-377, 1994.
89. Skelton DA, Kennedy J and Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. *Age Ageing* 31: 119-125, 2002.
90. Suzuki M, Okamura T, Shimazu Y, Takahashi H, Eguchi K, Kano K and Tsuchiya S. [A study of falls experienced by institutionalized elderly]. *Nippon Koshu Eisei Zasshi* 39: 927-940, 1992.
91. Suzuki T, Bean JF and Fielding RA. Muscle Power of the Ankle Flexors Predicts Functional Performance in Community-Dwelling Older Women. *Journal of the American Geriatrics Society* 49: 1161-1167, 2001.
92. Thomas M, Fiatarone MA and Fielding RA. Leg power in young women: relationship to body composition, strength, and function. *Med Sci Sports Exerc* 28: 1321-1326, 1996.
93. Tracy BL, Ivey FM, Hurlbut D, Martel GF, Lemmer JT, Siegel EL, Metter EJ, Fozard JL, Fleg JL and Hurley BF. Muscle quality. II. Effects Of strength training in 65- to 75-yr-old men and women. *J Appl Physiol* 86: 195-201, 1999.
94. Tracy BL, Ivey FM, Jeffrey ME, Fleg JL, Siegel EL and Hurley BF. A more efficient magnetic resonance imaging-based strategy for measuring quadriceps muscle volume. *Med Sci Sports Exerc* 35: 425-433, 2003.
95. Trappe S, Godard M, Gallagher P, Carroll C, Rowden G and Porter D. Resistance training improves single muscle fiber contractile function in older women. *Am J Physiol Cell Physiol* 281: C398-C406, 2001.
96. Trappe S, Williamson D, Godard M, Porter D, Rowden G and Costill D. Effect of resistance training on single muscle fiber contractile function in older men. *Journal of Applied Physiology* 89: 143-152, 2000.
97. Valour D, Ochala J, Ballay Y and Pousson M. The influence of ageing on the force-velocity-power characteristics of human elbow flexor muscles. *Exp Gerontol* 38: 387-395, 2003.

98. Visser M, Deeg DJ, Lips P, Harris TB and Bouter LM. Skeletal muscle mass and muscle strength in relation to lower-extremity performance in older men and women. *J Am Geriatr Soc* 48: 381-386, 2000.
99. Visser M, Newman AB, NEVITT MC, Kritchevski SB, STAMM EB, Goodpaster BH and Harris TB. Reexamining the Sarcopenia Hypothesis: Muscle Mass versus Muscle Strength. *Ann NY Acad Sci* 904: 456-461, 2000.
100. Visser M, Kritchevsky SB, Goodpaster BH, Newman AB, Nevitt M, Stamm E and Harris TB. Leg Muscle Mass and Composition in Relation to Lower Extremity Performance in Men and Women Aged 70 to 79: The Health, Aging and Body Composition Study. *J Am Geriatr Soc* 50: 897-904, 2002.
101. Wojcik LA, Thelen DG, Schultz AB, Ashton-Miller JA and Alexander NB. Age and gender differences in single-step recovery from a forward fall. *J Gerontol A Biol Sci Med Sci* 54: M44-M50, 1999.
102. Young A, Stokes M and Crowe M. Size and strength of the quadriceps muscles of old and young women. *Eur J Clin Invest* 14: 282-287, 1984.
103. Young A, Stokes M and Crowe M. The size and strength of the quadriceps muscles of old and young men. *Clin Physiol* 5: 145-154, 1985.