BODY MASS INDEX AND PHYSICAL FUNCTIONING IN OLDER ADULTS

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BODY MASS INDEX AND PHYSICAL FUNCTIONING IN OLDER ADULTS

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THESIS ABSTRACT

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Several researchers have reported that elevated body mass index (BMI) increases the risk of poor physical functioning. In most studies, physical functioning has been measured using self-reported questionnaires. For this study, we explored the relationship between BMI and two objective measures of physical functioning, gait speed and peak knee extensor power. We analyzed data from the population-based NCHS' National Health and Nutrition Examination Survey (NHANES 1999-2002). Gait speed was determined with a 20-foot timed walk test and peak knee extensor power was calculated as the product of isokinetic peak leg torque (peak force multiplied by arm length of dynamometer) and peak force velocity for subjects aged 60 years and older. BMI was specified as a continuous variable. The relationship between BMI and gait speed differed by race/ethnicity (P = 0.044) and the relationship between BMI and peak knee extensor power differed by gender (P = 0.002). Among non-Hispanic whites, the association

between BMI and gait speed was the strongest ($P < 0.001$). With every unit increase in BMI (kg/m^2), gait speed decreased by 0.011 meters/second. Among non-Hispanic blacks, with every unit increase in BMI (kg/m^2), gait speed decreased by 0.006 meters/second ($P = 0.001$). Among Hispanics, no linear relationship was found ($P = 0.435$). Regarding leg power, with every unit increase in BMI (kg/m^2), leg power increased by 1.09 watts ($P < 0.001$) for women and by 1.86 watts ($P < 0.001$) for men. With the growth of the older population, our results may facilitate the planning of public health interventions directed toward the most vulnerable groups.

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CHAPTER 1 INTRODUCTION

As the average life expectancy and number of older adults continue to rise in the United States, more people will experience chronic disability. It has been estimated that, from 1985 to 2050, the number of functionally limited older adults will approximately triple. Currently, 36% of community-dwelling older adults report some type of limitation in activity, and 11% report limitation in a major activity (1).

Physical functioning in older adults can be described as a combination of the "overall impact of medical conditions, lifestyles, and age-related physiologic changes in the context of the environment and social support system" (2). Poor physical functioning is usually associated with loss of independence, increased caregiver burden, and greater financial expenditures (2, 3). Also, poor physical functioning can predict disability, institutionalization, and mortality (4). Therefore, identifying preventable causes of lowered physical functioning is a high priority for health policymakers and researchers.

Many researchers have reported that excess body weight increases the risk for functional disability and mobility limitations (1, 5, 6, 7, 8, 9). These changes in physical functioning, even relatively modest ones, decrease independence and quality of life in old age (2, 3, 10, 11). However, many of these studies are based on traditional self-reported measures such as the Katz Activities of Daily Living Scale (12), the Rosow-Breslau Scale

(13) or the Nagi scales (14), which largely assess ability to complete complex activities (e.g., putting on a blouse). More recently developed performance measures include assessments of the basic building blocks of functional ability such as balance, strength, and coordination. These measures may be more appropriate because they are more objective and allow for variability in the effort needed to perform different tasks (15).

Results from researchers indicate that gait speed is a sensitive test for detecting mobility impairment and a strong predictor of adverse events, even in highly functional older adults (16, 17). Additionally, Tinetti and colleagues have reported that both upper and lower extremity function each have an independent impact on functional outcomes (18); lower extremity functional limitations were stronger determinants of subsequent disability as compared to upper extremity functional limitations (19). Muscle power has been identified as a more influential proximal determinant of physical performance and might be an important determinant of physical functioning in older adults (20, 21). In addition, knee extensors are the key muscle group for ambulation and balance (22). Thus, peak muscle power has been considered to be important in the functional independence of older adults and has attracted significant research interest (23). However, very few papers have reported the relationship between body mass index (BMI) and knee extensor power for older adults. This study sought to further examine the relationship between BMI and physical functioning using two performance-based measurements, habitual gait speed and knee extensor power.

CHAPTER 2 REVIEW OF LITERATURE

2.1 Physical functioning

2.1.1 Definition of physical functioning

Older adults' physical functioning can be described as a combination of the "overall impact of medical conditions, lifestyles, and age-related physiologic changes in the context of the environment and social support system" (2). Physical functioning can also be conceptualized across a spectrum of increasing complexity, from a focus on specific physical movements, such as lifting and walking, to a focus on more integrated activities such as the ability to maintain occupational and social roles (24). Nagi described the pathway to diminished physical functioning as a series of four steps: the initial step in this pathway is the onset of disease states, followed by the physiological manifestation of disease in multiple systems leading to functional limitations such as difficulty walking, grasping, climbing stairs, and ultimately, the onset of disability, described as the inability to fulfill expected or societal roles (14). In the last fifteen years, researchers have realized the importance of identifying older adults who have not yet entered Nagi's pathway to disability, but who exhibit pre-clinical changes in functioning (e.g. changes in their ability to complete certain physical movements short of complete "inability"). Identification of such older adults with "pre-clinical disability" may enable the identification of interventions to modify the pathway to disability (3).

A useful model has been proposed to describe how the “building blocks” of functioning are integrated to form a hierarchy of ability (25). These building blocks include strength, balance, coordination, flexibility, and endurance. At the most basic level of integration, these elements are coordinated to execute specific physical movements such as standing, walking, and gripping. At the second level of integration, these movements are coordinated into more complex tasks such as dressing, bathing, feeding, writing, and climbing stairs. At the highest level of integration, the basic building blocks are coordinated with cognitive and affective resources to carry out functioning in occupational and social roles.

2.1.2 Measurements of physical functioning

Because the definition of physical functioning is very broad, there are many available measures for physical functioning. Traditional self-reported measures such as the Katz Activities of Daily Living Scale (12), the Rosow-Breslau Scale (13) and the Nagi Scales largely assess the ability to complete complex activities (e.g., putting on a blouse) (14). Recently developed performance measures include assessments of complex activities (e.g. walking across a room, putting on a blouse) in addition to assessments of the basic building blocks of functioning such as balance, strength, and coordination. The following discussion will describe measures of both self-reported and performance-based physical functioning.

2.1.2.1 Self-reported measures

Early research on physical functioning in old age was primarily based on such self-reported status measures as a means of measuring functioning difficulties. One of the earliest self-reported measures was developed by Katz and colleagues (12). Katz's measure was an assessment of difficulties in performing what were referred to as "Activities of Daily Living" (e.g., dressing, bathing, eating, using the toilet, transferring from bed to chair, walking across a small room). Since that initial work, assessments of functional abilities have been further refined into three general categories of activity: basic, instrumental, and advanced activities (2). Basic activities of daily living encompass those covered by the original Katz ADL items including the ability to bathe, dress, use the toilet, transfer from bed to chair, and feed oneself independently (1, 26). Instrumental Activities of Daily Living (IADL's) include using the telephone, shopping, preparing meals, housekeeping, taking medications, and handling finances (27). Advanced Activities of Daily Living are primarily assessed in clinical settings as person-specific recreational, occupational, and community participation activities. Changes in these daily habits may reflect dysfunction (28).

Self-reported measures in which subjects are asked to report their functional abilities are considered subjective in that they require subjects to either endorse or deny functional difficulties based on their own perceptions of personal "difficulty" in performing activities (29). Commonly used self-reported measures generally collect information in terms of either dichotomous (do or do not have difficulty), or a more graded continuum of reported severity ranging from little difficulty to great difficulty.

Although existing self-reported measures for basic, instrumental and advanced activities of daily living have been widely (and profitably) used in studies of functional aging (1, 29, 30), there is a growing recognition that more discriminating assessment tools may be needed, particularly tools that allow for assessment of "pre-clinical/pre-disability" changes in the ability to perform various activities, i.e. changes in ability that do not yet rise to the level of eliciting a report of "difficulty" or "inability" to perform the designated activity but that have resulted in implementation of some type of compensatory or alternative approach to performance of the activity in order to preserve performance ability. For instance, an older woman who may have installed grab bars in her home to assist in bathing and toilet use might answer negatively to standard self-reported items asking about any difficulty because with the grab bars she does not perceive that she has any difficulty. Also, if not explicitly queried about possible home modifications she may not mention the grab bars. Self-reported measures under development by Fried and colleagues explicitly target assessment of such behavioral or other modifications that subjects may have implemented to reduce or eliminate "difficulty" in performing an activity (3). These new self-reported measures ask those who do not report difficulty or inability a series of additional questions about any behavioral or other modifications they may have made that enable them to continue to successfully perform a given activity with less or no difficulty.

2.1.2.2 Performance-based measures

Although self-reported measures are valuable for identifying older adults at the moderately to severely disabled end of the spectrum (14), these measures do not discriminate well among nondisabled older adults. Also, they may not be a reliable indication of actual function and are less sensitive to change over time (31). In contrast, performance-based measures are considered objective, and therefore, less susceptible to response bias from subjects, as well as more sensitive to differences among high functioning older adults (32).In performance-based measures, subjects attempt certain tasks or movements while their ability is objectively assessed by a test administrator. These objective assessments are generally measured along a continuum in terms of speed, repetition, or capacity and are normally linked with a specific ability necessary for functioning in old age.

Performance assessments can be categorized as measuring either the upper or lower body and then further organized in terms of the specific function being assessed, such as mobility, range of motion, strength, balance, or gait speed. For the upper body, performance-based assessments include tests of manual dexterity and physical strength. In order to assess manual dexterity, tests may include signing one's name, writing a sentence, buttoning a coat or shirt, picking up a small object, using eating utensils, or transferring beans with a spoon. Standardized assessment tests of manual dexterity include the Pegboard Test, or a Williams' board with fasteners, however, unlike many performance tests, these require special equipment (33). To test manual strength, a dynamometer is used to test ‘grip strength’ (i.e., the degree to which an individual can maximally grasp by hand). Other tests have included lifting ten pounds such as in the Women’s Health and Aging Study (WHAS) (34). Additional performance-based assessments include tests of ability to perform activities such as lifting a book onto a shelf (35) or transferring 7.7 kg of laundry from a washer to a dryer (36).

Performance-based assessments for the lower body also include tests of strength, mobility, and balance (2). To assess lower body strength, chair stands are a commonly used measure because of the ease of administration as well as the sensitivity to physical function capacity (37, 38). For this task, a subject is asked to rise from a chair and then sit once, while the test administrator determines the length of time it takes the subject to complete the task. The task may then be repeated with five sequential chair stands for greater sensitivity. Measures of balance are equally simple to administer since little if any equipment is required. Normally, a series of tests with increasing demand is administered. First, a subject may be asked to simply stand with legs side by side. Depending on whether subjects are capable of completing this task, they may be asked to stand semi-tandem, then tandem with eyes open, then closed. Based on performance, the subject may then be asked to stand on one leg, with eyes open, then closed. Finally, a subject may be asked to make a 360-degree turn while the administrator times the duration of the turn.

2.1.2.2.1 Walking test

Similar to tests of balance, performance-based tests of walking may be assessed along a range of difficulty, and are primarily gauged by time and distance. At the most basic level, subjects may be asked to walk at a normal pace while a test administrator records the time to reach a certain distance, usually called “habitual gait speed” (39).

Gait speed is usually used as a surrogate measure for functional limitations (40). There are several possible explanations as to why gait speeds slow down with age. Declines of strength and aerobic capacity with age, which may be one reason for the possible reduction in gait speed. Another reason is that many neurological and musculoskeletal diseases can impair gait speed and it is thus a useful tool for measuring function (41). Potter and colleagues evaluated inpatient and outpatient individuals (mean age 78.5 years) in a geriatric hospital (42). They compared the patients’ gait speed to their independence based on the Barthel ADL Index. They noted that with an increase in gait speed there was an increase in functional independence. Since gait speed is easily measured, clinically interpretable, and potentially modifiable, it may be a useful indicator for older adults in rehabilitation and hospital settings.

Tasks may be made more difficult by speed assessments that evaluate both time and distance. For example, a subject may be asked to walk “as fast as possible” while the administrator counts steps and keeps time (43). Alternatively, time may be fixed while distance is measured; subjects may be asked to walk as far as they can in six minutes. At the highest level of difficulty, subjects may be asked to climb stairs while the number of steps and time taken are measured (38, 44). The tests described above can be considered to have low technological demand since, in general, these tests are portable, inexpensive, and can be used in community surveys. In contrast, measures with a high technological demand include those tests that require a greater amount of equipment and expense and may only be administered in laboratory settings. For example, in order to test cardio-respiratory fitness, VO2 Max may be measured while subjects walk or run on a treadmill. However, this test requires a treadmill and a spirometer to test peak flow of oxygen with a "puff-test". The advantage and rationale for high-tech tests is increased discrimination and sensitivity to physical function, as well as the potential for identifying underlying mechanisms of physical functioning (2). Other examples of high-tech tests include tests of gait strength as measured by a force plate or machines that measure balance based on center of pressure, force, and sway. These types of tests are primarily administered in laboratory settings.

2.1.2.2.2 Leg power

Muscle strength is defined as the ability of a muscle or muscle group to exert maximal force or torque at a specific velocity during a contraction (45). Muscle power (46) can be defined as the ability to produce high quantities of work (the product of force and the distance through which the force acts) quickly. Power is the product of speed (measured as velocity) multiplied by strength (measured as force).

Muscle strength and muscle power both have been shown to decline during the aging process, with power declining at a greater rate than strength (47, 48). Some studies have reported that peak muscle power is related to functional limitations, with power consistently demonstrating a stronger relationship to functional limitations than strength (20, 21). Evans hypothesized that power has a stronger relationship to functional limitations because power involves both force production and contraction velocity, and because many daily activities are both force and speed dependent (49). Leg power was chosen as a surrogate measure of physical impairment because of its previously stated relevance to more distal disablement outcomes (20, 48).

2.1.3 Consequences of low physical functioning

Change in physical functioning is a primary determinant of quality of life in old age. Low physical functioning is usually associated with loss of independence, increased caregiver burden, and greater financial expenditures (2, 3). Also, low physical functioning is a predictor for disability, institutionalization, and death (4). Therefore, identifying preventable causes of low physical functioning is a high priority for health policy makers and researchers.

2.1.4 Risk factors for low physical functioning

A combination of many factors, including demographic factors, medical conditions, and behavioral factors, is associated with poor physical functioning (29, 50). Unfortunately, many of the strongest predictors – such as age and socioeconomic status – are not directly modifiable. However, behavioral factors such as smoking, physical inactivity, excess body weight and alcohol abstinence are modifiable factors that physicians and patients could potentially do something about (29).

2.2 Body composition changes associated with aging

Aging is accompanied by progressive changes in body composition. The ratio between fat mass (FM) and fat-free mass (FFM) increases with age, even when body weight (51), physical activity (52) and body mass index (53) remain stable.

2.2.1 Obesity in older adults

Obesity, defined as an excessive accumulation of body fat, has become a significant and growing health problem globally (26). Obesity in older adults, one of the fastest growing segments of the population, has been attributed to a complex interaction between sedentary lifestyles, dietary changes, and age-related decreases in metabolic rate (54, 55, 56, 57, 58, 59, 60). Obesity is associated with coronary heart disease, type-2 diabetes, hypertension, cardiovascular disease, osteoarthritis, and certain cancers (20, 21, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70). Excess adipose tissue rather than excess body weight is viewed as the etiological factor. Adipose tissue is viewed as an endocrine organ that actively secretes or releases a wide range of potently bioactive signal molecules: leptin, resistin, plasminogen acetylator inhibitor (PAI-1), tumour necrosis factor- α (TNF-α), interleukin-6 (IL-6), acetylation-simulating protein (ASP), fatty acids, estrogen and eicosanoids, to name but a few. There are site-specific differences in the secretion of some of these molecules, which may help to explain the greater pathogenicity of intra-abdominal fat, but in general their production appears to be proportional to the total number of adipocytes and their relative fullness (53).

2.2.2 Sarcopenia

The generalized loss of muscle mass during periods of ill health or severe undernutrition has been termed “sarcopenia” (71). Normal aging is associated with a 2%-3% decline per year in muscle mass, loss of muscle protein stores, and relative increases in body fat (72, 73), even among those who continue to actively engage in training (74). Sarcopenia has been increasingly used to describe both the process of age-related muscle loss and the clinical condition of having exceptionally low levels of muscle mass (37).

Despite the existence of the term, sarcopenia, precise criteria for its determination have not been established. Until the advent of dual-energy x-ray absorptiometry (DEXA) scanning, it was difficult to reliably quantify lean mass (LM) in large population studies, so the issue of precise clinical definitions had not been paramount. Now that DEXA scanning is widely available for osteoporosis screening, the ability to determine sarcopenia at the population level is growing. A commonly used calculation for determining sarcopenia is LM divided by height squared (kg/m^2) (37). In the New Mexico Aging Process study, sex-specific cut-points for kg/m^2 were defined as values that were two standard deviations (SDs) below the mean of a healthy young adult population, similar to the method used to define osteoporosis (67).

Sarcopenia is important because a loss of more than 40% of muscle mass is associated with death. Muscle loss can contribute to diminished strength, functional limitation, and disability in older adults (52) as well as those adults with chronic inflammatory conditions (75). As a consequence of muscle loss and accompanying weakness, there can be a reduction in physical activity and aerobic capacity. This inactivity can then reduce the anabolic input into muscle, leading to diminished fitness and more inactivity with reduction in physical functioning, and, in some, disability (76).

2.2.3 Sarcopenic obesity

Sarcopenic obesity, associated with decreased muscle mass and increased subcutaneous fat, is prevalent and problematic in older adults (66). Additionally, muscle quality (strength per kilogram of muscle mass) decreases in older obese adults, resulting in lower physical function, mobility, and quality of life. This results in greater frailty than found in normal weight or underweight older adults (77).

2.2.4 Measurement of body weight status

Information concerning the association between sarcopenia and health could be derived from studies of FFM. FFM includes bones, vital organs, muscle vessels, nerves, and connective tissues. Muscle is a major constituent of FFM. FFM can be estimated by various methods, including densitometry, hydrometry, and dual x-ray absorptiometry. It can also be predicted from combinations of anthropometric and impedance data (78). There are, however, errors in the estimation and prediction of FFM. Furthermore, the proportion of FFM that is muscle varies systematically with age and gender, and also within age- and gender-specific groups. Consequently, FFM is far from an ideal index of muscle mass (62).

Total body potassium has been interpreted as an index of muscle mass, but only about 60% of the body potassium is in muscle. Measurements of body potassium and body nitrogen (measured from gamma radiation and neutron activation, respectively) have been used in combination to estimate muscle mass. This method is based on the different proportions of potassium and nitrogen in the muscle and non-muscle fractions of FFM and the assumption that these proportions are fixed in each fraction even when FFM is gained or lost (79, 80). This assumption is not correct (81, 82) and this method seriously underestimates muscle mass (83, 84, 85).

Body mass index (BMI), calculated using weight in kilograms divided by the square of height in meters, is commonly interpreted as an index of obesity and also an index of muscle mass (62). However, BMI cannot detect the increasing ratio of FM to FFM associated with age. BMI is prone to increase with age in most individuals. However, it tends to underestimate the increase in body fat and shift in distribution that accompanies aging (53). Nevertheless, BMI values can provide important information about body composition in older adults.

2.2.5 Specifications of BMI

Researchers examining the relationship between adiposity and functional status have not consistently used the same specification of BMI. Some studies used BMI as a continuous variable, which assumes a linear relationship between BMI and risk of functional impairment (38, 86, 87). Because the relationship between BMI and disability has been shown to be curvilinear, BMI is more often split into categories to enable the development of odds ratios and relative risks for functional limitations. Studies based on national survey data tend to distribute BMI into gender-specific tertiles (5), quartiles (88), or quintiles (7) or by percentiles (e.g. $<15^{th}$ or $>85^{th}$) (89). Others used arbitrary cutpoints (15, 29, 90) or those suggested by the World Health Organization (91). At least in regard to the relationship between body weight and physical functioning, varying BMI specifications may partially explain the conflicting results observed among studies (1).

According to National Heart, Lung and Blood Institute guidelines, the categories are defined as follows: underweight= BMI <18.5, normal weight= BMI 18.5 to <25, overweight= BMI 25 to <30, obesity= BMI 30 to <35 and extreme obesity= BMI ≥35 kg/m^2 (70).

2.3 Body weight, body composition and physical functioning

Poor physical functioning, measured with self-reported items, has been shown to be related to excess body weight among older persons (1, 5, 29, 30, 50, 86, 89, 91, 92, 93). Recently, performance-based testing has been used to examine the relationship between physical functioning and body weight status (6, 8, 38, 94, 95, 96). In addition, other studies have included methods other than BMI to examine the relationship between body composition and physical functioning (37, 39, 44, 76, 77, 97, 98, 99, 100, 101, 102, 103). The results from these body composition studies suggest excess fat mass and muscle mass loss may be very important factors in determining functional status. Regardless of measurement techniques, all of these studies have found that either high or low body weight was associated with poor physical functioning in older adults.

Results from studies using self-reported and performance-based testing are presented in Table 1 and are briefly reviewed in the following discussion. Also, results from studies using methods other than BMI are presented and reviewed.

2.3.1 Self-reported physical functioning

Studies based on self-reported measures and BMI have found significant association between body weight status and physical functioning (Table 1). However, differences in study design were observed with researchers variously using self-reported height and weight (91, 92), measured height and weight (1, 5, 29, 30, 50, 86, 89, 93), current BMI (1, 29, 89, 93), or history of BMI (5, 50, 86, 92, 108). Longitudinal studies (5, 50, 86, 89, 93) and cross-sectional studies (1, 29, 91) have reported similar results: higher BMI is associated with poor physical functioning in older adults.

2.3.2 Performance based testing

Objective measures of physical performance support a strong relationship between elevated BMI and physical functioning, even though there are differences in study design across these studies. Some studies had small sample size (8, 94, 95); some had large sample size (6, 38, 96); some studies are cross-sectional (6, 8, 38, 95, 96) while others are longitudinal (94). They were conducted using different populations and locations, including Japan (38), the United States (8, 94, 96), France (6) and the Netherlands (95).

2.3.3 Body composition studies

Many recent studies have focused on body compositions, since BMI cannot distinguish well between fat mass and fat-free mass. These studies used different methods to measure body composition, with some studies using dual-energy X-ray absorptiometry (DEXA) (37, 39, 77, 97, 98, 99, 100, 101), some using bioelectrical impedance (BIA) (44, 76, 102, 103) and some using both DEXA and BIA (104). Additionally, they were conducted in different countries and populations, some in the USA (37, 76, 77, 97, 99, 102, 103), some in Italy (44, 101, 104), one in France (98), one in China (100) and one in Canada (39).

Few studies based on objective measures of physical functioning are longitudinal (37, 76, 102). Studies using methods other than BMI have also employed different methods to measure physical functioning: performance-based measures (37, 39, 44, 76, 97, 98, 100, 104), self-reported measures (99, 102) and both the performance-based and self-reported measures (77, 101, 103).

Among these body composition studies, some have implicated excessive fat mass as a key factor in obesity associated functional limitations (39, 97, 99, 100, 101, 102), but the possible contributions of a relative decrement in muscle mass (37, 67, 105, 106) and the combination of excess fat mass with low muscle mass (66) have also been raised. Several studies support the hypothesis that the impairment of physical function in older adults is more strongly associated with excess body mass and relative fat mass than inadequate fat-free mass (37, 96, 99, 101, 102, 103).

2.3.5 Biological mechanisms

Researchers have found several physiological pathways for the influence of excess body weight on functioning (107). Poor physical functioning among obese individuals may be caused by development of chronic disease related to obesity, particularly cardiovascular diseases. Another pathway may involve excessive body weight contributing to the inflammation of the tissues of the joints, which makes ambulating painful and difficult. Excess body weight also increases the amount of mechanical stress placed on body joints, elevating the risk for and severity of osteoarthritis and increasing functional impairment. Furthermore, excess weight is associated with a sedentary lifestyle, which contributes to decreased muscle strength and cardiovascular fitness and may eventually result in difficulties with physical functioning such as walking or climbing a flight of stairs.

2.3.4 Gender modifications

Several studies have reported gender differences in the association between body weight and physical functioning, with some using self-reported measures (1, 61, 93, 108), some using performance-based measures (6, 44, 95, 96), and some using BIA (44) to measure body weight. One study conducted by Stafford and colleagues (93) used longitudinal data while all others used cross-sectional data. The locations where these studies were conducted included Great Britain (93), the USA (1, 96, 108), France (6), the Netherlands (95) and Italy (44).

These studies reported that women with excess body weight are more likely to have functional limitations than men. The reasons for this gender discrepancy in self-reported functional limitation remain unclear (107). The stronger relationship between obesity and functional limitations in women could partly be explained by greater BMI, higher body fat percentage, and decreased muscle mass among women. Another hypothesis could be that women may suffer more disability and are more willing to report limitations. Also, men who have obesity may not live as long to accrue appreciable disability.

Table 1. Overview of previous studies that examined the relationship between body weight status and physical functioning

Author/Date	Population		Definition & Measurement	Results
		Self-reported Physical functioning		
Coakley, 1998	Nurses' Health Study *Cross –sectional*	N=56510 women (45-71 yrs)	1. Physical functioning: physical functioning, vitality, bodily pain and role limitations 2. Body weight: Self reported current BMI	BMI had a strong inverse relationship with all four measures of functioning. In addition to increasing risk of chronic health conditions, greater adiposity is associated with lower every day physical functioning, as well as lower feelings of well-being and greater burden of pain.
Ensrud, 1994	Four clinical centers in USA *Cross-sectional*	N=9704 non-black women (65+ yrs)	1. Physical Functioning: ability to perform six physical and instrumental ADL Impaired function as difficulty performing 3 or more physical and instrumental ADL 2. Body weight: Current measured BMI Current measured waist to hip ratio	Obesity is associated with impaired function in older women.
Friedmann, 2001	Rural Pennsylvania *Cross-sectional*	N=3312 men & 3808 women (mean: 71.6 yrs)	1. Physical functioning: impairment in any ADL or IADL 2. Body weight: Current measured BMI	How BMI relates to functional limitation depends on both sex and method of categorizing BMI. Women in the highest quintile of BMI had increased risk of functional impairment. There was no relationship between BMI and

				functional limitation for men. When BMI was categorized by the NIH obesity guidelines, both men and women with BMI 40+ had significantly increased risk of functional limitation.
Galanos, 1994	NHANES1(82-84 71-79) *Longitudinal*	N=3061 men & women (65 + yrs)	1. Physical functioning: amount of difficulty in the 26 item battery 2. Body weight: Current BMI Height measured (1971-74) Weight measured (1982-84)	Risk was greater for functional impairment for subjects with a low BMI or a high BMI. The greater the extreme of BMI (either higher or lower), the greater the risk for functional impairments. The BMI is related to the functional capabilities of community-dwelling older adults.
Jensen, 2002	Geisinger Health Plan in Rural Pennsylvania *Longitudinal*	N=2634 men & women (65+ yrs) 99% non-Hispanic white	1. Physical functioning: any increase in reported limitations in ADL or IADL over the study periods 2.Body weight: Measured BMI at enrollment	Women had a higher prevalence of reported functional decline than men at the upper range of BMI categories (BMI≥40 kg/m2). Women and men exhibited increase risk for any functional decline at BMI of 35 or greater.
He, 2004	University of Michigan *Longitudinal*	N=7867 men & women (51-61 yrs)	1. Physical functioning: how difficulty to walk several blocks, walk 1 block, climb 1 flight or stairs without resting and climb several flights of stairs without resting 2.Body weight: Self reported BMI (1992-94) to	Overweight and obesity were independently associated with health decline and development of a new physical difficulty. Regular exercise significantly reduced the risk of health decline and development of a new physical

			predict outcome in 1992-1996	difficulty.
Hubert, 1993	NHANES 1(1971-75) & NHANES followup (1982-1984) *Retrospective*	N=4428 men &women (50-77 yrs)	1. Physical functioning: how much difficulty they had in doing 26 ADL 2. Body weight: BMI at age 25, 40 and baseline Self-reported weight at age 25 and 40 Measured height and weight at baseline	Results showed that elevated BMI at age 40 was contributing to greater disability.
Jenkins, 2004	AHEAD (1995-1998) *Longitudinal*	N=1418 (strength impairment), 2460(lower body mobility impairment), 2554 (upper body mobility impairment) , 3373(ADL impairment) men & women (70+yrs)	1.Physical functioning: strength, upper body mobility, lower body mobility, and ability to perform ADLs 2.Body weight: BMI Self reported height (1993) Measured weight (1995)	Overweight and obese make one more likely to experience the onset of functional impairment across various domains of impairment. Obesity has an independent effect on the onset of impairment in strength, lower body mobility, and activities of daily living.
Launer, 1994	NHANES 1 (1971-87) Prospective cohort	N=1124 white women (45+ yrs during 1971-74)	1. Mobility disability: Any difficulty in executing some activities 2. Body weight: Past measured BMI (1971-74)	High BMI is a strong predictor of long-term risk for mobility disability in older women and that this risk persists even to very old age.

			Current measured BMI (1982-84)	
Sarkisian, 2000	4 areas of USA Prospective cohort	N=6632 women (65+ yrs)	1.Physical functioning: loss of ability over the 4 year interval to perform one or more of 5 vigorous or 8 basic daily activities 2. Body weight: Measured BMI at baseline	Obesity was significant modifiable predictors of functional decline in both vigorous and basic activities.
Stafford, 1998	British civil servants based in London offices(1985-88, 89-90, 91-93) *Prospective cohort*	N= 6895 men & 3413 women (35-55yrs)	1. Physical functioning: 10-item scale from the short form 36 health survey, with a score in the lowest quartile indicating poor physical functioning 2. Body weight: Current measured BMI	Among women, current obesity, steady weight change and weight fluctuation are independently and monotonically associated with poor physical functioning, whereas a threshold effect at a BMI of 27 kg/m^2. Steady weight change and weight fluctuation had no independent effects in men.
Wannamethee, 2004	24 British towns *Cross-sectional*	N=4232 men (60-79 yrs)	1.Physical functioning: if any longstanding illness, disability or infirmity in current difficulty in performing some activities on their own ; if any problems performing usual activities and self-care 2. Body weight: Past measured BMI(1978-80) Current measured BMI (1998-2000)	In older adults men, overweight and obesity are associated with a significantly increased burden of disability. The current guidelines for overweight and obesity appear to be appropriate in older adults men.

		Performance based studies		
Apovian, 2002	Geisinger Health Plan in Pennsylvania *Cross-sectional*	N=90 women (mean 70.8 yrs)	1.Physical functioning: 18 functional tasks during a home visit 2. Body weight: Current measured BMI	Higher BMI is associated significantly with poorer upper- and lower-body function but is not associated significantly to strength or coordination
Brach, 2004	Pittsburgh,PA *Longitudinal*	N=171 women (50-65yrs)	1.Physical functioning : Functional Status Questionnaire Gait speed 2.Body weight: Measured in1982,1985 and 1999 Self reported in 1995	Overweight/obese inactive group reported more ADL difficulty and walked slower than normal weight active and normal weight inactive groups. The overweight/obese active group reported similar levels of ADL difficulty, as measured by the FSQ, and walked at a similar gait speed as the normal weight active and normal weight inactive groups.
Davis, 1998	The island of Oahu, Hawaii *Cross-sectional*	N=705 Japanese women (55-93 yrs)	1. Physical functioning: Walking speed, the get up and go test, chair stands, functional reach, and hand and foot reaction times, and 8 questions regarding ADL 2. Body weight: Current measured BMI	BMI was negatively associated with five of the seven performance tests. 1-SD increases in BMI were associated with 3 to 8% reductions in performance.
Davison, 2002	NHANES (1988-1994)	N=526women & 1391 men	1.Physical functioning: difficulty in performing at least three of five	Women in the highest quintile for percentage of body fat and women

	Cross- sectional	(70+ yrs)	functional living tasks: walking a quarter mile; walking up 10 steps without resting; carrying something as heavy as 10 pounds; stooping, crouching or kneeling; and standing up from an armless chair 2.Body weight: Current measured BMI Percentage of body fat (DEXA) Muscle mass	with a BMI of 30 or greater were two times more likely to report functional limitations than women in the comparison groups. Similar, but weaker, relationships were found among men; men in the highest quintile for body fat and men with a BMI of 35 or greater were 1.5 times more likely to report limitations
Larrieu, 2004	Three cities in France *Cross-sectional*	N=8966 men & women (65-101yrs)	1.Physical functioning: continence, basic ADL, IADL and mobility 2.Body weight: Current measured BMI	Obesity was significantly associated with disability in each domain for women. Relationships were weaker in men since BMI was only associated with mobility restriction, with a higher risk for both underweight and obese subjects.
Samson, 2000	Netherlands *Cross-sectional*	N=74 women &81 men (20-90 yrs)	1. Physical functioning: Maximum isometric knee extension, handgrip strength, explosive leg extensor power, get up and go test and the modified cooper test 2. Body weight: Current measured weight	Women showed an acceleration in the decline of isometric knee extension strength and handgrip strength. Men showed a more gradual decline over the adult age range. Differences in height and weight between healthy young and old subjects contribute to the differences in walking speed and stride length.

Body composition studies				
Bouchard, 2007	NuAge study in Canada *Cross-sectional*	N=904 men & women (67-84 yrs)	1.Physical functioning: gait speed & one leg stand test 2.Body weight: DEXA (Fat mass, Fat-free mass)	FM was significantly and inversely correlated with physical capacity, whereas FFM was not associated when controlled for other potential confounding variables.
Jankowski, 2008	A university medical center *Cross-sectional*	N=109 women & men (60+ yrs)	1.Physical functioning: continuous scale-physical functional performance test(CS-PFP) & physical function subscale of the Medical Outcome Short From-36 ($SF36_{PF}$ 2.Body weight: DEXA (Fat index Appendicular skeletal muscle mass) Current measured BMI	Adiposity was a stronger predictor of measured and self-reported physical function than was muscularity in older adults living independently. BMI, adjusted for sex, is a reasonable substitute for adiposity in the prediction of physical function.
Newman, 2003	Two U.S. communities *Longitudinal*	N=2984 women &men (70-79 yrs)	1.Physical functioning: chair stands, gait speed and standing balance 2. Body weight: DEXA (Sarcopenia 1) appendicular lean divided by height-squared 2) appendicular lean mass adjusted for height and body fat mass)	A low appendicular lean mass for height and fat mass resulted in a stronger association with lower performance scores than the method adjusting LM for height squared, and only the definition accounting for fat was associated with low function in women.
Rolland, 2004	5 French cities *Cross- sectional*	N=1454 women (70+ yrs)	1.Physical functioning: grip strength, knee and elbow extension	Unadjusted muscle strength was higher in obese than in lean women,

			2.Body weight: DEXA (Appendicular skeletal muscle mass) Current measured BMI Current measured hip circumference Current measured waist circumference Current measured calf circumference	except for handgrip strength. Adjusted muscle strength did not differ significantly between obese, normal weight and lean subjects, except for knee extension.
Sartorio, 2004	Italian *Cross-sectional*	N=1298 Men & women (18-80 yrs)	1.Physical functioning: Lower limb maximal anaerobic power, Margaria stair climbing test 2.Body weight: BIA (Fat mass Fat-free mass) Measured BMI	The lower limb maximal power output is significantly higher in obese male subjects than in female subjects, being negatively influenced by age but positively related to BMI. Female appear to be at a greater disadvantage for effect of obesity, the major motor limitations being suffered by older women with higher BMI.
Sowers, 2005	SWAN Michigan *Longitudinal*	N=712 women (34-58 yrs)	1.Physical functioning: Lower leg strength, walking velocity and double support 2.Body weight: BIA (Lean mass Fat mass) Current measured BMI Current measured waist to hip ratio	Loss of lean mass is associated with greater compromise in physical functioning. Women who lost at least 2.5kg of lean mass had slower walking velocity, less leg strength, and more time in double support.

Sternfeld, 2002	Reside in or near Sonoma, California *Cross-sectional*	N=2092 Men & women (55+ yrs)	1.Physical functioning: walking speed, grip strength, self reported functional limitations 2.Body weight: BIA (Fat mass Lean mass)	Higher fat mass was associated with slower walking speed and greater likelihood of functional limitation, while higher lean mass was generally associated with increased grip strength. A higher lean mass-to-fat mass ratio, a relative measure of body composition, was associated with faster walking speed and less limitation.
Villareal, 2004	Washington *Cross-sectional*	N=52 obese,52 nonobese frail &52 nonobese nonfrail (age matched)	1.Physical functioning: physical performance test, peak aerobic power, self reported functional status questionnaire, self reported health related quality of life questionnaire 2.Body weight: DEXA (Fat-free mass Fat-free mass percentage Muscle quality)	Compared with non-obese non-frail group, the obese and non-obese frail groups had lower and similar scores in physical performance test, peak aerobic power, and functional status questionnaire, and exhibited similar impairment in strength, walking speed, balance and health–related quality of life. Although absolute FFM was greater, the percentage body weight as FFM and muscle quality was lower in the obese group than in the other two groups.
Visser, 1998	Cardiovascular health study 4 communities in USA *Longitudinal*	N=2714 whites women&2095 men (65-100yrs)	1. Physical functioning: Self reported questionnaire on difficulty in performing 17 tasks at baseline and 3 yr follow up 2.Body weight: BIA at baseline and 3 yr follow up	A positive association was observed between fat mass and disability. Low fat-free mass was not associated with a higher prevalence of obesity. Fat mass at baseline was predictive of disability 3 years later,

			(Fat-free mass Body fat percentage)	while low fat-free mass was not.
Visser, 1998	Framingham heart study *Cross-sectional*	N=753 men &women (72-95 yrs)	1. Physical functioning: scored as self reported any versus non on a 9-item questionnaire 2. Body weight: DEXA (Skeletal muscle mass Body fat percentage Lower extremity muscle mass)	Total body and lower extremity muscle mass were not associated with disability in either men or women. However, a strong positive association between percent body fat and disability was observed.
Woo, 2007	Chinese University of Hong Kong *Cross-sectional*	N=2000 men &2000 women (65+ yrs)	1.Physical functioning: Grip strength, timed 6-m walk 2.Body weight: DEXA (Fat mass Appendicular skeletal muscle mass) Current measured BMI	Those with BMI≥30 had the worst walking performance. Fat mass, but not appendicular muscle mass was associated with walking speed after adjusting for BMI
Zamboni, 1999	General population of Verona, Italy *Cross-sectional*	N=144 women (68-75 yrs)	1.Physical functioning: Distance walked in 6 minutes, isometric knee strength and a ADL scale 2.Body weight: DEXA, BIA, (Body fat percentage Total fat-free mass Body cell mass) Current measured BMI	Nondisabled women had a significantly lower BMI and percent body fat. These women had a higher ratio of body cell mass (BCM) and total fat-free mass (FFM) than women with physical impairments.

Zoico, 2004	Verona, Italy *Cross-sectional*	N=167 women (67-78 yrs)	1. Physical functioning: self reported modified ADL Scale , dominant leg isometric strength , 2. Body weight: DEXA (Body fat percentage Total body fat Total body skeletal mass) Current measured BMI	Higher body fat and high BMI values were associated with a greater probability of functional limitation in a population of older adult women at the high end of the functional spectrum. Isometric leg strength was significantly lower in subjects with sarcopenia and sarcopenia obesity.

CHAPTER 3 BODY MASS INDEX AND PHYSICAL FUNCTIONING IN OLDER ADULTS

3.1 Abstract

Several researchers have reported that elevated body mass index (BMI) increases the risk of poor physical functioning. In most studies, physical functioning has been measured using self-reported questionnaires. For this study, we explored the relationship between BMI and two objective measures of physical functioning, gait speed and peak knee extensor power. We analyzed data from the population-based NCHS' National Health and Nutrition Examination Survey (NHANES 1999-2002). Gait speed was determined with a 20-foot timed walk test and peak knee extensor power was calculated as the product of isokinetic peak leg torque (peak force multiplied by arm length of dynamometer) and peak force velocity for subjects aged 60 years and older. BMI was specified as a continuous variable. The relationship between BMI and gait speed differed by race/ethnicity ($P = 0.044$) and the relationship between BMI and peak knee extensor power differed by gender ($P = 0.002$). Among non-Hispanic whites, the association between BMI and gait speed was the strongest ($P < 0.001$). With every unit increase in BMI (kg/m^2), gait speed decreased by 0.011 meters/second. Among non-Hispanic blacks, with every unit increase in BMI (kg/m^2), gait speed decreased by 0.006 meters/second ($P = 0.001$). Among Hispanics, no linear relationship was found ($P = 0.435$). Regarding leg power, with every unit increase in

BMI (kg/m^2), leg power increased by 1.09 watts ($P < 0.001$) for women and by 1.86 watts ($P < 0.001$) for men. With the growth of the older population, our results may facilitate the planning of public health interventions directed toward the most vulnerable groups.

3.2 Introduction

As the average life expectancy and number of older adults continue to rise in the United States, more people will experience chronic disability. It has been estimated that, from 1985 to 2050, the number of functionally limited older adults will approximately triple. Currently, 36% of community-dwelling older adults report some type of limitation in activity, and 11% report limitation in a major activity (1).

Physical functioning in older adults can be described as a combination of the "overall impact of medical conditions, lifestyles, and age-related physiologic changes in the context of the environment and social support system" (2). Poor physical functioning is usually associated with loss of independence, increased caregiver burden, and greater financial expenditures (2, 3). Also, poor physical functioning can predict disability, institutionalization, and mortality (4). Therefore, identifying preventable causes of lowered physical functioning is a high priority for health policymakers and researchers.

Many researchers have reported that excess body weight increases the risk for functional disability and mobility limitations (1, 5, 6, 7, 8, 9). These changes in physical functioning, even relatively modest ones, decrease independence and quality of life in old age (2, 3, 10, 11). However, many of these studies are based on traditional self-reported measures such as the Katz Activities of Daily Living Scale (12), the Rosow-Breslau Scale (13) or the Nagi scales (14), which largely assess ability to complete complex activities (e.g., putting on a blouse). More recently developed performance measures include assessments of the basic building blocks of functional ability such as balance, strength, and coordination. These measures may be more appropriate because they are more objective and allow for variability in the effort needed to perform different tasks (15).

Results from researchers indicate that gait speed is a sensitive test for detecting mobility impairment and a strong predictor of adverse events, even in highly functional older adults (16, 17). Additionally, Tinetti and colleagues have reported that both upper and lower extremity function each have an independent impact on functional outcomes (18); lower extremity functional limitations were stronger determinants of subsequent disability as compared to upper extremity functional limitations (19). Muscle power has been identified as a more influential proximal determinant of physical performance and might be an important determinant of physical functioning in older adults (20, 21). In addition, knee extensors are the key muscle group for ambulation and balance (22). Thus, peak muscle power has been considered to be important in the functional independence of older adults and has attracted significant research interest (23). However, very few papers have reported the relationship between body mass index (BMI) and knee extensor power for older adults. This study sought to further examine the relationship between BMI and physical functioning using two performance-based measurements, habitual gait speed and knee extensor power.

3.3 Method and procedures

3.3.1 Study Design and Subjects

The data used are from the National Health and Nutrition Examination Survey (NHANES 1999-2002). The NHANES data set, a population-based survey collected by NCHS, used a stratified, multistage, and cluster sampling design to obtain a representative sample of the non-institutionalized U.S. civilian. The NHANES consisted of a detailed home interview and a health examination conducted in a mobile examination center (MEC). Due to the lack of population-based data in the United States, the measurements of muscle strength used in our study were not available from NHANES until 1999.

Of 3,706 individuals aged 60 years and older who participated in the home interview, 3,234 attended the MEC for examination, which included an assessment of isokinetic muscle strength in the right quadriceps and a 20-foot timed walk test. We further excluded 239 persons with missing BMI data and 43 persons whose BMI was below 18.5 kg/m^2. People with BMI<18.5 kg/m^2 were excluded because the sample size for underweight individuals is too small for comparison.

We further excluded 236 persons for missing values of gait speed, leaving 2,716 individuals in the final analytic sample for gait speed. Regarding knee extensor power, 429 individuals were excluded from the muscle strength examination because of the following safety reasons: chest or abdominal surgery in the past 3 weeks; heart attack in the past 6 weeks; brain aneurysm or stroke; current neck or back pain; difficulty in bending or straightening the right knee; or right knee or right hip replacement. Additionally, because the NHANES isokinetic muscle test was conducted at a fixed angular velocity of 60 degrees/s, 823 persons with peak force velocity which varied >5 degrees/s from the chosen testing velocity were further excluded, leaving 1,700 individuals in the final analytic sample.

3.3.2 Measurement of body weight status

In NHANES 1999-2002, subjects were weighted wearing underwear, disposable paper gowns, and foam slippers, using a Toledo digital scale. Standing height was measured with a fixed stadiometer with a vertical backboard and a moveable headboard. The subjects were asked to move or remove hair ornaments, jewelry, buns, braids, or corn rolls from the top of the head in order to measure stature properly.

BMI, calculated with measured weight and height values (kilograms divided by height in square meters), was used to measure body weight status. Although it is recognized that BMI may misclassify the health risk of very active and/or lean individuals, the use of body mass index provides a meaningful clinical assessment of health risk. Due to the small sample size, those with a BMI of <18.5 were excluded. Different variable specifications were used for BMI. First, we treated BMI as a continuous variable to estimate its association with gait speed and knee extensor power. Second order interaction terms between continuous BMI and the variables (race, gender, age) were tested for both gait speed and knee extensor power. Then, BMI was analyzed as both a continuous and a categorical variable according to NIH (70). Those subjects with a BMI of 25 to <30 kg/m^2 were the reference group for the stratified modeling where BMI was categorized as: 18.5 to <25, 25.0 to <30, and ≥30 kg/m^2, as well as 18.5 to <25, 25.0 to <30, 30.0 to <35.0, and ≥35 kg/m^2.

3.3.3 Gait speed

The timed 20-foot walk test was performed at the subject's usual pace, measured using a stopwatch. Walk time was measured from the time the subject's foot first touched the floor across the start line and stopped when his or her foot touched the floor across the finish line. Subjects were excluded from testing if they needed the assistance of others to walk but were allowed to use a walker or cane if needed. Gait speed (meters/second) was calculated as walking distance (20 feet = 6.15 meters) divided by time in seconds.

3.3.4 Knee extensor power

Right knee extensor force production was assessed using a Kinetic Communicator isokinetic dynamometer (Kin-Com MP, Chattecx Corp., Chattanooga, TN, USA). Maximum voluntary concentric muscle force was measured in newtons in the right quadriceps at an angular velocity of 60 degrees/second, which has been reported as the optimum speed for measuring muscle strength. Only the right leg was measured since significant differences between right and left legs have not been observed (109). A total of six trials were performed during the strength test: three practice warm-ups and three trials for maximal voluntary effort. Highest peak force in newtons was selected from trials 4-6 (the final three trials with maximal voluntary effort). For an examinee with fewer than four trials, the highest value was selected from the completed trials. Subjects with extreme values of peak force velocity that varied more than 5 degrees/second from the 60 degrees/second specification were excluded. Additionally, the lever arm length represents the distance from ankle to knee joint. Knee extensor power was calculated as following (23):

Peak leg power (watts) = Peak torque (newton-meters) *Peak force velocity (radians/second) where peak torque is equal to peak force (newtons) * lever arm length (meters), and peak force velocity (radians/second) is equal to peak force velocity (degrees/second) * (pi/180).

pi = 3.14

3.3.5 Covariates

Age, gender, race/ethnicity, education, income and smoking status obtained from self-reported information were analyzed and included in our models. For this analysis, age was broken into three categories: 60 to <70 years old, 70 to <80 years old, and those aged ≥80 years old. Race/ethnicity information included Mexican American, other Hispanic, non-Hispanic white, non-Hispanic African American, and other race. Due to small sample sizes, Mexican Americans and other Hispanics were combined to form Hispanics and the other race category was combined with non-Hispanic whites. Thus, three categories were examined non-Hispanic white, non-Hispanic black and Hispanics.

Level of education was defined as less than a high school degree or greater than or equal to a high school degree. Poverty income ratio was used to measure the family's economic status, and was calculated as the ratio of family income to poverty thresholds based on household size. Smoking status was based on the use of cigarettes, cigars, or pipes. Subjects were asked if they had ever smoked at least 100 cigarettes, a pipe at least 20 times, or a cigar at least 20 times. Subjects who answered no to all these questions were classified as never smokers. If subjects answered yes to any of the previous questions, they were coded as former or current smokers based on if they reported current smoking. Any variables that subjects refused to answer or did not know were assigned missing values.

Most studies (6, 43) that have examined the relationship between body weight and physical functioning have included chronic conditions as covariates, such as hypertension, type-2 diabetes, coronary artery diseases, and osteoarthritis, which were not in our models because those diseases most likely represent intermediate steps in the causal pathway between obesity and physical functioning, rather than being confounding variables (110, 111).

3.3.6 Statistical analysis

Data manipulation was conducted using SAS software (version 9.1, 2005, SAS Institute Inc, Cary, NC, USA). The NHANES surveys are multistage, stratified area probability samples. According to guidelines issued by the federal government, analytic approaches based on data from a simple random sample are not appropriate (112). All descriptive and inferential statistics were estimated using STATA (version 10, 2007, Stata Corp, College Station, TX, USA) to account for sample design and sampling weights. Differences in means for continuous variables and in distributions for categorical variables were examined.

When examining BMI as a continuous variable, interaction terms of race, gender and age were tested to determine if these characteristics modified the relationships between BMI and the two separate outcomes. For gait speed, the racial interaction term was significant ($P = 0.04$), whereas for knee extensor power, only the gender interaction term was significant ($P < 0.01$). Thus we stratified the model for gait speed by race/ethnicity, and the model for knee extensor power by gender for both continuous and categorical BMI. Multiple regression models controlling for age, poverty income ratio, gender, ethnicity/race, education and smoking status were used to estimate the associations between BMI and gait speed and between BMI and knee extensor power. The multiple regression models were adjusted for sample weighting and survey design corrections. Statistical significant was chosen at $P \leq 0.05$.

This study was approved as exempt from further review by the Institutional Review Board of the Office of Human Subjects Research at Auburn University.

3.4 Results

Descriptive characteristics of the analytical sample for gait speed by racial groups are presented in Table 2. The mean gait speed of the subjects was 0.96 meters/second.

More than one half of the subjects were female (56%) and non-Hispanic white (85%). Seventy percent of subjects had an education higher than high school, 48% were non-smokers, and 15% were those aged 80 years and older. The mean poverty income ratio of the subjects was 2.79. Blacks in the study sample were more likely to be younger (57%), female (61%) and obese (44%). They tended to have a lower poverty income ratio (2.2) and a slower gait speed (0.84 meters/second). Whites seemed more likely to have an education higher than high school (75%), a higher poverty income ratio (2.9), and a lower gait speed (0.84 meters/second). Hispanics seemed more likely to be female (60%) and younger (58%).Their mean poverty income ratio was 1.63 and their mean gait speed was 0.88 meters/second.

Descriptive characteristics of the analytical sample for knee extensor power are presented in Table 3. In this sample, males were more likely to have a BMI of 25 to <30 (46%) and to have been former smokers (53%). The mean poverty income ratio for males tended to be higher (3.18) and their leg power was also higher (139.87 watts). Females were more likely to have been never smokers (59%). Both the mean leg power (111.23 watts) and the mean poverty income ratio (2.65) were low.

Results for gait speed from stratified models using continuous BMI are presented in Table 4. After controlling for age, gender, income and smoking, there was a 0.01 meters/second decrease ($P < 0.001$) and 0.01 meters/second decrease ($P = 0.001$) in gait speed for each unit increases in BMI (kg/m^2), for whites and blacks, respectively. No significant linear relationship (P = 0.435) between BMI and gait speed was found for Hispanics.

Results for gait speed from stratified models using three categorical terms for BMI are presented in Table 5. After adjustment for age, gender, income and smoking, compared to those with a BMI of 25 to <30 kg/m^2, among whites, there was a 0.08 meters/second decrease (P < 0.001) for those with a BMI of ≥30 kg/m^2, while a 0.05 meters/second increase (P = 0.010) for those with a BMI of 18.5 to <25 kg/m^2 for each unit increase in BMI (kg/m^2). No relationship between BMI and gait speed was found in blacks or Hispanics.

Results for gait speed from stratified models using four categorical terms are presented in Table 6. After adjustment for age, gender, income and smoking, compared to those with a BMI of 25 to <30 kg/m^2, among whites, there was a 0.16 meters/second decrease (P < 0.001) for those with a BMI of ≥35 kg/m^2, while a 0.05 meters/second increase for those with a BMI of 18.5 to <25 kg/m^2, for each unit increase in BMI (kg/m^2). Among blacks, there was a 0.10 meters/second decrease for those with a BMI of ≥35 kg/m^2 (P < 0.001) for each unit increase in BMI (kg/m^2), while no significant differences were found for those with a BMI of 30 to <35 kg/m^2 or those with a BMI of 18.5 to <25 kg/m^2.The sample size for Hispanics was not large enough to examine those with a BMI ≥35 kg/m^2.

Adjusted values for gait speed when three (Table 7 & Figure 1) and four (Table 8 & Figure 2) categorical BMI terms were used are presented. Compared to those with a

BMI of 25 to <30 kg/m^2 among whites, those with a BMI of ≥30 kg/m^2 (0.91 meters/second, *P* < 0.001) had a slower gait speed, while those with a BMI of 18.5 to <25 kg/m^2 (1.03 meters/second, *P* = 0.010) had a faster speed. No relationship between BMI and gait speed was found in blacks or Hispanics. Compared to those with a BMI of 25 to <30 kg/m^2, those with a BMI of ≥35 kg/m^2 (0.78 meters/second, *P* = 0.001) had a slower gait speed in blacks; those with a BMI of 30 to <35 kg/m^2 (0.95 meters/second, *P* = 0.059) did not have significantly different gait speed in whites, while those with a BMI of ≥35 kg/m^2 (0.83 meters/second, *P* < 0.001) had a slower gait speed. The sample size for Hispanics is not large enough to examine those with a BMI ≥35 kg/m^2.

Results for knee extensor power from stratified models using continuous BMI are presented in Table 9. BMI was positively associated with knee extensor power for both men and women. After adjustment for age, gender, income and smoking, there was a 1.09 watt increase for women (*P* < 0.001) and a 1.86 watt increase (*P* < 0.001) for men in knee extensor power, for each unit increase in BMI (kg/m^2).

Results for knee extensor power from stratified models using three categorical terms for BMI are presented in Table 10. After adjusting for age, education, income and race/ethnicity, compared to those with a BMI of 25 to <30 kg/m^2, for males, there was a 13.38 watt decrease (*P* = 0.002) for those with a BMI of 18.5 to <25 kg/m^2, while no significant difference was found for those with a BMI of ≥30 kg/m^2, for each unit increase in BMI (kg/m^2); for females, there was a 8.22 watt decrease for those with a

BMI of 18.5 to <25 kg/m^2 (P = 0.003), and there was a 6.73 watt increase for those with a BMI of ≥30 kg/m^2, for each unit increase in BMI (kg/m^2).

Unadjusted and adjusted values for knee extensor power when categorical BMI terms were used are presented in Table 11 (Figure 3). Males with a BMI of 18.5 to <25 kg/m^2 tended to have lower leg power (124.03 watts, P = 0.002) compared to those with a BMI of 25 to <30 kg/m^2. No significant difference was found between males with a BMI of ≥30 kg/m^2 (142.00 watts, P = 0.184) and those with a BMI of 25 to <30 kg/m^2. Females with a BMI of 18.5 to <25 kg/m^2 had significantly lower leg power (77.45 watts, P = 0.003) and those with a BMI of ≥30 kg/m^2 had significantly higher leg power (92.40 watts, P = 0.005) compared to those with a BMI of 25 to <30 kg/m^2.

3.5 Discussion

This study is the first to find a race/ethnicity difference in the relationship between BMI and gait speed. Using nationally representative data, we showed that excess body weight is significantly associated with lower gait speed in whites, while only those with a BMI of ≥ 35 kg/m^2 are significantly associated with lower gait speed in blacks. No significant association between BMI and gait speed was found in Hispanics.

Some studies have found that excess body weight is associated with lower gait speed (31, 100) and we found a similar relationship among whites. Excess body weight might be related to physical inactivity, which can result in declining strength and aerobic capacity. Excess body weight might also be associated with chronic diseases, such as coronary heart disease and diabetes (96). Excess body weight may also increase the physical demands associated with movement as well as the strain placed on joints and muscles (113, 114). All of these consequences of excess body weight may be associated with declines in balance, vision, reaction time and emotional well-being, as well as increasing pain. Conversely, functional limitations can also lead to weight gain due to physical inactivity or through alterations in nutritional habits.

Some studies have reported race/ethnic differences in the effects of BMI in black and white Americans. Despite the fact that excess body weight is more common in African Americans than in Caucasian Americans, the effect of excess body weight on health outcomes appears different for whites and blacks. Calle and colleagues reported that nonsmoking Caucasian men and women with no history of disease at the highest level of BMI were at significantly greater risk of mortality than their average weight counterparts (115). A similar association was not detected among African-Americans. Some studies have reported the association of BMI with mortality was attenuated in blacks when compared with whites although it was not statistically significant (116). Others have shown that a relationship between BMI and mortality does exist in blacks; however, the BMI associated with the lowest mortality is slightly higher in blacks (117, 118). There was also one study that reported excess body weight was associated with a greater rate of nursing home admission in whites, whereas no such relationship was found in blacks (111). Possible explanations for the observed difference among race/ethnic groups may include differences in the percentage of fat mass or fat distributions for the same BMI (53). Some studies have reported that BMI in blacks is higher than in whites for equal levels of body fat (53, 118). Another study reported that waist circumference values that corresponded to both overweight and obesity were substantially lower in Blacks and Hispanics (119). Additionally, greater visceral adipose tissue has been demonstrated in whites compared with blacks despite greater total fat in black women, which may be linked with a more atherogenic plasma lipid profile and greater insulin resistance (120, 121). Additionally, some studies have found that African Americans have greater intramuscular adipose tissue even after adjustment for differences in total adiposity, skeletal muscle mass, and other potential covariates (122, 123, 124). Other possible explanations may be attributed to lifestyle behaviors and economic resources (125).

Researchers have reported gender differences in the association between excess body weight and physical functioning (1, 6, 44, 61, 93, 95, 96, 108). Most of these studies suggest that women may be more vulnerable than men to the effect of excess body weight. Jensen and Friedmann showed that women had a higher prevalence of self-reported functional decline than men at a BMI of $\geq$40 kg/m^2 (108). Friedmann showed that women in the highest quintile of BMI had an increased risk for reporting functional limitation, whereas there was no relationship between BMI and functional limitation for men (1). Davison also reported that links between functional limitations, percent of body fat, and BMI were more apparent in women than men (96). Functional limitations in this study were defined as difficulty in performing three of five functional living tasks such as walking a quarter mile, walking up 10 steps without resting, carrying something as heavy as 10 pounds, stooping, crouching or kneeling, and standing up from an armless chair.

Only one other study to our knowledge has focused on lower limb power measured by a stair climbing test. The subjects were invited to climb up an ordinary staircase at the highest possible speed, one step at a time, according to the subject's capabilities. The staircase consisted of 13 steps of 15.3 cm each, thus covering a total vertical distance of 1.99 m. The vertical component of speed was calculated from the vertical dimensions of the steps. The average mechanical power was calculated as the product of body weight, gravitational acceleration, and the vertical component of speed. Result from this study indicated older women with a BMI >40 kg/m^2 appear to exhibit motor limitations determined by maximum anaerobic power per unit body weight (44). Greater BMI was associated with a progressive increase in lower limb power among men, while a less definite increase was observed among women. However, this study assessed an Italian population of obese subjects with a wide range of ages (18-80 years old) and elevated BMI values (30.1-67.7 kg/m^2).

Our results suggest that women with excess body weight may have stronger leg power than their normal weight counterparts. BMI values do not distinguish between fat and fat-free mass and thus a greater BMI may indicate greater fat-free mass, and a greater fat-free mass is associated with increased muscle strength and power (114). Among men, we found a BMI $\geq$ 30 kg/m^2 was not associated with higher knee extensor power. Thus the training stimulus created by excess body weight may be relevant for women but not for men at high BMI values.

Power is only one of the "building blocks" in the overall spectrum of physical functioning (24). The numerous consequences of excess body weight may be varied in terms of their health impact. Some have suggested that excess weight may have a protective effect among women, especially with respect to maintaining bone health and preventing more serious injuries from falls (126, 127). However, we did find decreased gait speed with increasing BMI in both older men and women. Although peak leg power is an important contributor to mobility and functioning in older adults, gait speed is considered a "functional limitation", which integrates and involves multiple features of lower body physical functioning (10, 20, 21). Excess body weight may have other negative consequences, such as poor balance and increased foot pressure, which may lead to overall decline in physical functioning. Therefore, higher knee extensor power might not compensate for the overall effects of excess body weight.

Our study presents some limitations. First, we used BMI as a measurement of excess body weight, even though it has been reported that BMI cannot discriminate between muscle and fat tissues, especially in older individuals. Older adults also tend to experience a shift of fat from peripheral to central sites with a concomitant increase in waist-to-hip ratio but no increase in BMI, which may therefore underestimate the risk for adverse health outcome (115, 128). Second, our cross-sectional study does not allow investigation of the causal relationship between BMI and gait speed or knee extensor power. Third, few performance-based measures were available from the NHANES survey. For example, hand-grip strength has also been shown to be predictive of major health-related events in older persons (61, 129). Fourth, because we are examining non-institutionalized older individuals, we may have a selection bias because excess body weight has been linked to earlier nursing facility admission, particularly among whites (111). This may lead to underestimation of the observed correlations between fat-free mass and poor physical functioning previously reported by Buchner and colleagues (41). Finally, some studies have mentioned that the gait speed test may not have sufficiently stressed persons with lower physiologic reserves, and the additional effort needed for rapid walking may have allowed finer differences in fitness and functionality to emerge (31).

Despite these limitations, our study had some unique advantages. First, we used nationally representative data composed of men and women older than 60 years old, which provided precisely measured weight and height data. Additionally, this nationally representative data provided racial/ethnic information allowing us to examine racial/ethnic differences, whereas, many studies only included predominately Caucasian subject groups (39, 44, 93) or a single race (100) in their studies. In addition, we used valid, reliable, and objective measures of physical functioning instead of self-reported questionnaires. Gait speed was used as our measure of functional limitations because of its predictive relationship to subsequent adverse outcomes including mobility (16), comorbidity (17) and disability (10). In addition, leg power represents a more dynamic measurement of muscle function, and has been found to decline to an even greater degree than strength with age and chronic disease (20, 21, 130). Finally, we did not control for physical activity level and chronic conditions as in other studies, which we considered as intermediate pathways rather than confounders. Taken together, we considered all of these factors to strengthen our results.

Although the prevalence of disability among older adults have declined in recent decades, there is concern that rising prevalence of excess body weight in the United States could reverse the decline in disability among older adults (131). Interventions should be implemented to prevent the increasing prevalence of disability due to excessive body weight. More research is needed to understand differences in factors related to physical functioning among race/ethnic groups, as well as between genders.

3.6 Conclusion

After controlling for age, gender, income, education and smoking status, the effect of excess body weight on gait speed differed by race/ethnicity, and the effect of excess body weight on knee extensor power differed by gender. The association between excess body weight and gait speed is evident among whites, but is only evident for those with extremely elevated body weight among blacks. Also, the association between excess body weight and knee extensor power is stronger in females than males. Future studies using longitudinal data are needed to establish the causal relationship between excess body weight and poor physical functioning. With the growth of the older population, our results may facilitate the planning of public health interventions directed toward the most vulnerable groups.

Table 2. Descriptive characteristics by race/ethnicity[a] when gait speed is the outcome

	White (n=1613)	Black (n=448)	Hispanic (n=655)	Total (n=2716)
Percent[b]				
Age, years[c]				
60 to <70	48	57	58	50
70 to <80	35	32	34	35
≥80	16	11	8	15
Gender[c]				
Female	55	61	60	56
Male	45	39	40	44
Education[c]				
<High school	25	57	62	30
≥High school	75	43	38	70
Smoking status				
Never	48	51	55	48
Former	38	33	29	37
Current	14	16	17	15
Body mass index (kg/m^2)[c]				
18.5 to <25	30	21	26	29
25 to <30	39	36	46	39
≥30	32	44	29	32
Body mass index (kg/m^2)[c]				
18.5 to <25	30	21	26	29
25 to <30	39	36	46	39
30 to <35	21	20	19	21
≥35	11	23	9	12
Mean (standard error)				
Body mass index (kg/m^2)[c]	28.23 (0.16)	30.21 (0.42)	28.12 (0.39)	28.37 (0.13)
Poverty Income Ratio (PIR)[cd]	2.94 (0.11)	2.17 (0.08)	1.63 (0.15)	2.79 (0.09)
Gait speed (meters/second)[c]	0.98 (0.01)	0.84 (0.02)	0.88 (0.02)	0.96 (0.01)

Means and standard errors are presented for continuous variables (gait speed, income) and proportions for categorical variables (age, male, education, smoking status). For continuous variables, the *P* value is for the test of difference in means of the variable of interest. For categorical variables, the *P* value is for the chi square test of association.

[a]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[b]Population Percentages: columns may not add up to 100% because of rounding.

[c]Statistical significance at $P \leq 0.05$.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 3. **Descriptive characteristics by gender when knee extensor power is the outcome**

	Male (n=915)	**Female (n=785)**	**Total (n=1700)**
Percent[a]			
Age, years			
60 to<70	52	57	54
70 to <80	34	33	34
≥80	14	10	12
Ethnicity[b]			
White	84	87	86
Black	8	6	7
Hispanics	8	6	7
Education[c]			
<High school	23	55	28
≥High school	77	45	72
Smoking status[c]			
Never	59	30	47
Former	29	53	39
Current	12	18	14
Body mass index (kg/m^2)[c]			
18.5 to <25	33	25	29
25 to <30	35	46	41
≥30	31	29	30
Mean (standard error)			
Body mass index	28.05 (0.16)	28.03 (0.22)	28.04 (0.15)
Poverty income ratio[cd]	3.18 (0.10)	2.65 (0.12)	2.91 (0.11)
Leg power (watt)[c]	139.87 (1.91)	84.21 (1.30)	111.23 (1.54)

Means and standard errors are presented for continuous variables (gait speed, income) and proportions for categorical variables (age, male, education, smoking status). For continuous variables, the *P* value is for the test of difference in means of the variable of interest. For categorical variables, the *P* value is for the chi square test of association.

[a]Population Percentages: columns may not add up to 100% because of rounding.

[b]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[c]Statistical significance at $P \leq 0.05$.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 4. Gait speed stratified by race/ethnicity[a] in the 1999-2002 NHANES survey (Coefficients for all variables included in model: Continuous BMI)

Characteristic	Gait speed (meters/second)					
	White		Black		Hispanic	
Levels	Coefficient	*P*-value	Coefficient	*P*-value	Coefficient	*P*-value
Intercept	1.21	<0.001	1.07	<0.001	0.85	<0.001
Body mass index (kg/m^2)	-0.01	<0.001	-0.01	0.001	-0.00	0.435
Age						
60 to <70[b]	NA[c]	NA	NA	NA	NA	NA
70 to <80	-0.08	<0.001	-0.13	0.001	-0.06	0.083
≥80	-0.27	<0.001	-0.28	<0.001	-0.12	0.013
Gender						
Female[b]	NA	NA	NA	NA	NA	NA
Male	0.04	0.012	0.02	0.492	0.05	0.026
Education						
<High school[b]	NA	NA	NA	NA	NA	NA
≥High school	0.06	0.002	0.06	0.006	0.06	0.179
Smoking status						
Never[b]	NA	NA	NA	NA	NA	NA
Former	-0.01	0.533	-0.06	0.023	0.04	0.257
Current	-0.05	0.050	-0.04	0.210	0.03	0.211
Income						
PIR[d]	0.04	<0.001	0.01	0.231	0.05	0.001
R-squared	0.31	<0.001	0.21	<0.001	0.17	<0.001

[a]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[b]Reference category.

[c]Not applicable.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 5. Gait speed stratified by race/ethnicity[a] in the 1999-2002 NHANES survey (Coefficients for all variables included in mode: 3 categorical BMI terms)

Characteristic	Gait speed (meters/second)					
	White		Black		Hispanic	
Levels	Coefficient	*P*-value	Coefficient	*P*-value	Coefficient	*P*-value
Intercept	0.90	<0.001	0.90	<0.001	0.78	<0.001
Body mass index (kg/m^2)						
18.5 to <25	0.05	0.010	-0.02	0.674	-0.02	0.627
25 to <30[b]	NA[c]	NA	NA	NA	NA	NA
≥30	-0.08	<0.001	-0.04	0.070	-0.03	0.415
Age						
60 to <70[b]	NA	NA	NA	NA	NA	NA
70 to <80	-0.08	<0.001	-0.12	0.001	-0.05	0.104
≥80	-0.26	<0.001	-0.26	<0.001	-0.12	0.012
Gender						
Female[b]	NA	NA	NA	NA	NA	NA
Male	0.04	0.008	0.03	0.300	0.05	0.022
Education						
<High school[b]	NA	NA	NA	NA	NA	NA
≥High school	0.06	0.004	0.06	0.007	0.06	0.162
Smoking status						
Never[b]	NA	NA	NA	NA	NA	NA
Former	-0.01	0.307	-0.06	0.028	0.04	0.253
Current	-0.05	0.030	-0.02	0.465	0.03	0.218
Income						
PIR[d]	0.04	<0.001	0.01	0.229	0.05	0.001
R-squared	0.29	<0.001	0.19	<0.001	0.17	<0.001

[a]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[b]Reference category.

[c]Not applicable.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 6. Gait speed stratified by race/ethnicity[a] in the 1999-2002 NHANES survey (Coefficients for all variables included in model: 4 categorical BMI terms)

Characteristic	Gait speed (meters/second)			
Levels	**White**		**Black**	
	Coefficient	***P*-value**	**Coefficient**	***P*-value**
Intercept	0.90	<0.001	0.91	<0.001
Body mass index (kg/m^2)				
18.5 to <25	0.05	0.012	-0.01	0.702
25 to <30[b]	NA[c]	NA	NA	NA
30 to <35	-0.03	0.059	0.02	0.542
≥35	-0.16	<0.001	-0.10	0.001
Age				
60 to <70[b]	NA	NA	NA	NA
70 to <80	-0.08	<0.001	-0.13	0.001
≥80	-0.26	<0.001	-0.27	<0.001
Gender				
Female[b]	NA	NA	NA	NA
Male	0.03	0.023	0.02	0.370
Education				
<High school[b]	NA	NA	NA	NA
≥High school	0.06	0.003	0.06	0.019
Smoking status				
Never[b]	NA	NA	NA	NA
Former	-0.01	0.583	-0.07	0.013
Current	-0.04	0.054	-0.03	0.310
Income				
PIR[d]	0.04	<0.001	0.01	0.265
R-squared	0.31	<0.001	0.22	<0.001

[a]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[b]Reference category.

[c]Not applicable.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 7. Unadjusted and adjusted values (standard error) for gait speed stratified by race/ethnicity[a] (3 BMI categories)

BMI categories (kg/m^2)	Unadjusted[b] Race/ethnicity			Adjusted[c] Race/ethnicity		
	White (meters/second)	**Black (meters/second)**	**Hispanic (meters/second)**	**White (meters/second)**	**Black (meters/second)**	**Hispanic (meters/second)**
18.5 to <25	1.01 (0.02)	0.82 (0.04)	0.85 (0.03)	1.03 (0.02)[e]	0.87 (0.04)	0.94 (0.03)
25 to <30[d]	0.99 (0.01)	0.87 (0.02)	0.91 (0.02)	0.98 (0.01)	0.88 (0.02)	0.96 (0.02)
≥30	0.94 (0.01)[e]	0.83 (0.02)	0.87 (0.04)	0.91 (0.01)[e]	0.84 (0.02)	0.93 (0.03)

[a]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

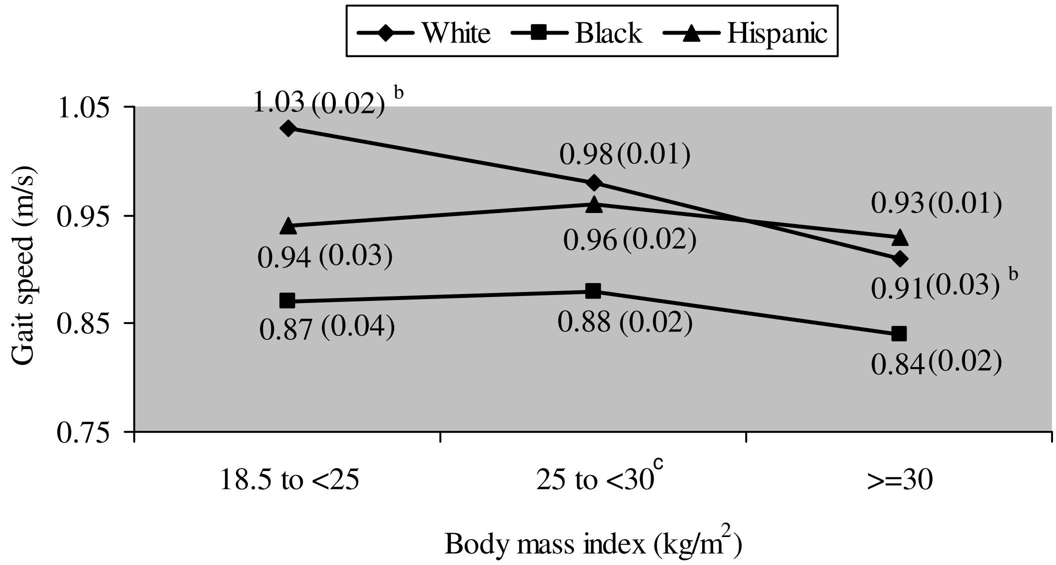
[b]Predictions based on multiple linear regression with no adjusted variables.

[c]Predictions based on multiple linear regression including age, gender, income, smoking status and education.

[d]Reference group.

[e]Statistical significance at $P \leq 0.05$.

Figure 1. Adjusted[a] values for gait speed stratified by race/ethnicity (3 BMI categories)



[a]Control for: age, gender, education, income and smoking status

[b]Significant difference at $P \leq 0.05$

[c]Reference group

Table 8. Unadjusted and adjusted values (standard error) for gait speed stratified by race/ethnicity[a] (4 BMI categories)

BMI categories (kg/m^2)	**Unadjusted[b]**		**Adjusted[c]**	
	Race/ethnicity		**Race/ethnicity**	
	White (meters/second)	**Black (meters/second)**	**White (meters/second)**	**Black (meters/second)**
18.5 to <25	1.01 (0.02)	0.82 (0.04)	1.03 (0.02)[e]	0.86 (0.04)
25 to <30[d]	0.99 (0.01)	0.87 (0.02)	0.98 (0.01)	0.88 (0.02)
30 to <35	0.98 (0.02)	0.89 (0.02)	0.95 (0.01)	0.90 (0.03)
≥35	0.86 (0.02)[e]	0.78 (0.03)[e]	0.83 (0.02)[e]	0.78 (0.03)[e]

[a]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

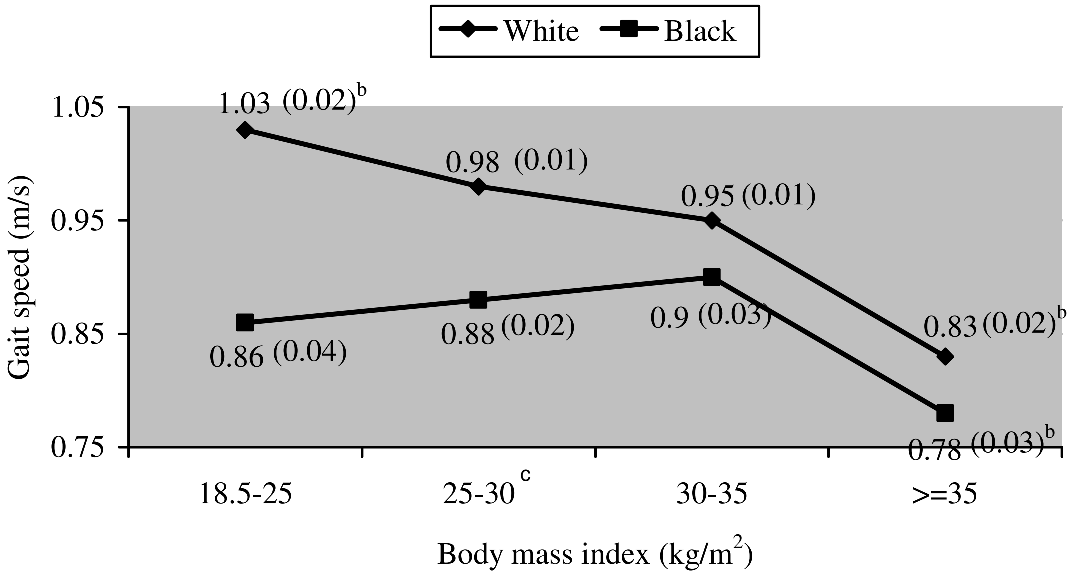
[b]Predictions based on multiple linear regression with no adjusted variables.

[c]Predictions based on multiple linear regression including age, gender, income, smoking status and education.

[d]Reference group.

[e]Statistical significance at $P \leq 0.05$.

Figure 2. Adjusted[a] values for gait speed stratified by race/ethnicity (4 BMI categories)



[a]Control for: age, gender, education, income and smoking status

[b]Significant difference at $P \leq 0.05$

[c]Reference group

Table 9. Knee extensor power stratified by gender in the 1999-2002 NHANES survey (Coefficients for all variables included in model: continuous BMI)

Characteristic	Knee extensor power (watt)			
	Male		**Female**	
Levels	**Coefficient**	***P*-value**	**Coefficient**	***P*-value**
Intercept	75.29	<0.001	54.78	<0.001
Body mass index (kg/m^2)	1.86	<0.001	1.09	<0.001
Age				
60 to <70[a]	NA[b]	NA	NA	NA
70 to <80	-20.81	<0.001	-8.61	<0.001
≥80	-40.69	<0.001	-19.47	<0.001
Ethnicity[c]				
White[a]	NA	NA	NA	NA
Black	11.08	0.014	14.05	<0.001
Hispanics	-3.53	0.474	-2.15	0.477
Education				
<High school[a]	NA	NA	NA	NA
≥High school	8.68	0.014	-0.49	0.826
Smoking status				
Never[a]	NA	NA	NA	NA
Former	1.67	0.399	-0.10	0.968
Current	-5.42	0.163	-1.14	0.664
Income				
PIR[d]	4.65	<0.001	1.55	0.011
R-squared	0.33	<0.001	0.24	<0.001

[a]Reference category.

[b]Not applicable.

[c]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 10. Knee extensor power stratified by gender in the 1999-2002 NHANES survey (Coefficients for all variables included in model: 3 categorical BMI)

Characteristic	Knee extensor power (watt)			
	Male		Female	
Levels	Coefficient	*P*-value	Coefficient	*P*-value
Intercept	128.93	<0.001	86.41	<0.001
Body mass index (kg/m^2)				
18.5 to <25	-13.38	0.002	-8.22	0.003
25 to <30[a]	NA[b]	NA	NA	NA
≥30	4.58	0.184	6.73	0.005
Age				
60 to <70[a]	NA	NA	NA	NA
70 to <80	-21.84	<0.001	-9.42	<0.001
≥80	-41.71	<0.001	-19.53	<0.001
Ethnicity[c]				
White[a]	NA	NA	NA	NA
Black	11.12	0.011	14.04	<0.001
Hispanics	-4.32	0.392	-2.32	0.455
Education				
<High school[a]	NA	NA	NA	NA
≥High school	9.19	0.013	0.59	0.785
Smoking status				
Never[a]	NA	NA	NA	NA
Former	2.51	0.253	0.73	0.786
Current	-5.37	0.150	-1.00	0.708
Income				
PIR[d]	4.67	<0.001	1.47	0.016
R-squared	0.32	<0.001	0.24	<0.001

[a]Reference category.

[b]Not applicable.

[c]Due to small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race (including multiracial) category was combined with non-Hispanic whites.

[d]Poverty Income Ratio (PIR) is calculated as the ratio of family income to poverty thresholds based on household size.

Table 11. Unadjusted and adjusted values (standard error) for knee extensor power stratified by gender (3 BMI categories)

BMI categories (kg/m^2)	Unadjusted[a] Gender		Adjusted[b] Gender	
	Male (watt)	**Female (watt)**	**Male (watt)**	**Female (watt)**
18.5 to <25	125.05 (2.16)[d]	74.45 (1.83)[d]	124.03.98 (2.73)[d]	77.45 (1.86)[d]
25 to <30[c]	139.24 (2.62)	84.61 (2.09)	137.41 (2.55)	85.67 (1.84)
≥30	153.49 (3.13)[d]	94.28 (1.49)[d]	142.00 (2.50)	92.40 (1.50)[d]

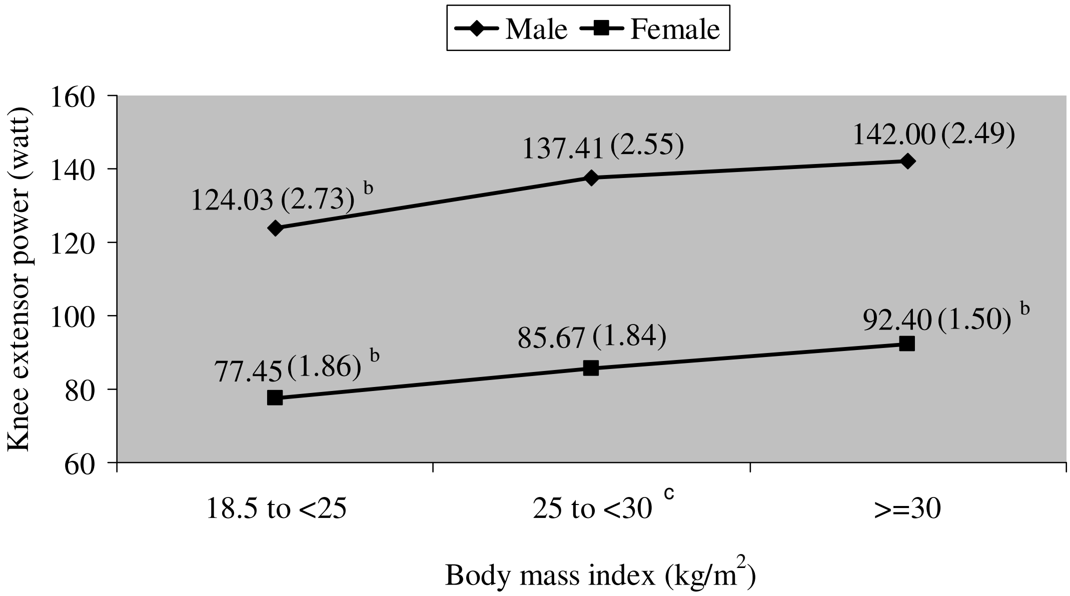
[a]Predictions based on multiple linear regression with no adjusted variables.

[b]Predictions based on multiple linear regression including age, race/ethnicity, income, smoking status and education.

[c]Reference group.

[d]Statistical significance at $P \leq 0.05$.

Figure 3. Adjusted[a] values for knee extensor power stratified by gender (3 BMI categories)



[a]Control for: age, race/ethnicity, education, income and smoking status

[b]Significant difference at $P \leq 0.05$

[c]Reference group

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