Associations Between Nutritional Status, Physical Performance, and Disability Among Older Americans

by

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Abstract

Impaired functional status with aging is a major concern of the older population, limiting their daily activities, predisposing them to falls and increasing their mortality and morbidity risk. This condition also increases the admissions to nursing homes and caregiver burden. The purpose of this dissertation is to provide a better understanding of the relationship between nutritional risk factors, physical performance and disability among older Americans. This dissertation consists of three studies which used data from the National Health and Nutrition Examination Surveys (NHANES). The first study examined the association between overall diet quality, as measured by the United States Department of Agriculture's (USDA) Healthy Eating Index-2005 (HEI-2005), and physical performance, as measured by gait speed and knee extensor power, among adults ≥ 50 y. Older adults with higher HEI-2005 scores had a faster gait speed compared to those with the lowest HEI-2005 score (1.03 and 1.04 m/s in quartiles three and four, respectively, vs. 1.00 m/s in quartile one; both $p < 0.05$). For knee extensor power, those with the highest HEI-2005 scores had greater knee extensor power compared to those with the lowest HEI-2005 scores (1.60 W/kg in quartile four vs. 1.50 W/kg in quartile one; $p = 0.03$). The second study examined the association between overall diet quality, measured by HEI-2005, and self-reported disability among adults aged 60 and older. Self-reported measures of disability included activities of daily living (ADLs), instrumental activities of daily living (IADLs), leisure and social activities (LSAs), lower extremity mobility (LEM), and general physical activities (GPAs). Older adults with higher HEI-2005 scores were less likely to experience LEM disability (p for trend < 0.001) and GPAs disability (p for trend < 0.001). Compared to older adults whose HEI-2005 scores were in the lowest quartile, the likelihood of both LEM and GPA disability were significantly lower in individuals whose scores were in quartiles two, three, and four. Compared to those who had HEI-2005 scores in the lowest quartile, the odds of IADLs disability were significantly lower in older adults whose scores were in quartile two and three. The third study examined the association between food insecurity and physical performance including gait speed and knee extensor power, among adults aged 50 and older. Responses to the US Household Food Security Survey Module (HFSSM) were used to assign participants to study food security categories. The association between food insecurity and gait speed varied by smoking status ($p = 0.005$). For non-smokers, those who were marginally food secure (0.91 m/s, $p = 0.016$) and food insecure (0.94 m/s, $p = 0.004$) had significantly slower gait speeds than food secure participants (1.04 m/s). No statistically significant associations were observed for both current and former smokers. Similar findings were observed for knee extensor power. These results suggest the ensuing proper nutritional status and being nonsmokers are vital to maintain the functional status among older adults. More studies are needed to understand the complex factors that influence the nutritional and functional status of older adults to reduce healthcare costs and enhance quality of life.

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List of Abbreviations

AADLs	Advanced Activities of Daily Living
ADLs	Activities of Daily Living
BMI	Body Mass Index
CDC	Center for Disease Control
CRP	C-reactive protein
CPS	Center for Population Survey
DGA	Dietary Guidelines for Americans
GPAs	General Physical Activities
HEI-2005	Healthy Eating Index-2005
HFSSM	Household Food Security Survey Module
IADLs	Instrumental Activities of Daily Living
LEM	Lower Extremity Mobility
LSAs	Leisure and Social Activies
LSRO	Life Science Research Office
m	meter
N	Newton
NHANES	National Health and Nutrition Examination Survey
NCHS	National Center for Health Statistics

s	second
SE	Standard error
SoFAAS	Calories from Solid Fats, Alcoholic Beverages, and Added Sugars.
USDA	United States Department of Agriculture
W	Watts
y	Year

Chapter 1 General Introduction

According to the Surgeon General's Call to Action in 2005, 54 million people living in the United States have some disability (US Department of Health and Human Services 2005). The chance of developing a disability increases with age, from less than 10% for people aged 15 y and younger to almost 75% for people aged 80 y and older (US Department of Health and Human Services 2005). As the number of older adults and average life expectancy continues to rise, the prevalence of poor functional status is expected to increase and cause an increasing burden to the health care systems (Guralnik et al., 1996).

Functional status has been used frequently as an outcome measure for epidemiological and clinical research on older adults, because it accounts for the effects of a variety of diseases and the natural functional decline that occurs with aging. It 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" (Reuben et al., 2004). Measures of functional status have been considered to be predictors of various adverse health outcomes including loss of independence, increased mortality, and greater financial expenditures (Fried et al., 2000; Inouye et al., 1998; Reuben et al., 2004). Identifying preventable causes of impaired functional status is a high priority for health policymakers and researchers.

Risk factors for impaired functional status among older adults have been examined in both cross-sectional and longitudinal studies using both self-reported and performance-based measures. Results from these studies indicated that modifiable factors such as diet and smoking are associated with impaired functional status (Milaneschi et al., 2010; Nelson et al., 1994; Rampuri et al., 2007).

Many studies examining the relationship between diet and functional status of individuals have focused on single nutrients or food groups (Casari et al., 2004; Houston et al., 2005; Ortega et al., 1996; Sharkey et al., 2003; Tomey et al., 2008). Because people consume a combination of foods, it is difficult to attribute the effects of a single nutrient or food to health outcomes (Hu 2002). Recent studies examining diet have shifted from focusing on single nutrients to addressing overall diet quality. Dietary indexes, based on recommendations from various organizations, have been constructed to aid in identifying diet quality, patterns, and variety (Weinstein et al., 2004). The Healthy Eating Index-2005 (HEI-2005), developed by the United States Department of Agriculture (USDA), is a measure of overall diet quality that assesses adherence to the 2005 Dietary Guidelines for Americans (DGA) (Guenther et al., 2007).

HEI-2005 includes the assessment of energy-dense, nutrients-poor foods and ingredients (Guenther et al., 2007). This index emphasizes dietary recommendations that are not being met in the US. One previous study reported that an earlier version of the HEI (HEI-1995) was associated with self-reported mobility limitations among older adults aged between 70 to 79 years (Koster et al., 2007). However, physical performance and other self-reported disability measures were not examined in this study. To our knowledge, very few studies have examined the association between overall diet quality, as measured by HEI-2005 scores, physical performance, and self-reported disability assessed by multiple domains among older adults.

Another important factor in understanding and assessing nutritional problems is the measurement of food insecurity (Anderson 1990; Reuben et al., 1995). Food insecurity, a complex multidimensional phenomenon, is defined as ‘limited or uncertain availability of nutritionally adequate and safe foods, or limited, or uncertain ability to acquire acceptable foods in socially acceptable ways” (Anderson 1990). Food insecurity has been associated with variety of adverse health outcomes including diabetes (Seligman et al., 2010), metabolic syndrome (Parker et al., 2010), obesity (Kim 2007; Lyons et al., 2008; Seligman et al., 2007; Tayie et al., 2009;), depression (Kim 2007), poor cognitive function (Gao et al., 2009) and poor self-reported health status (Pheley et al., 2002; Stuff et al., 2004). In one study that examined the association between food insecurity and physical performance among older adults aged 65 and older, participants living in food insufficient households had a lower gait speed than those living in food sufficient households (Klesges et al., 2001). However, this study used a single-item measure to measure food insecurity, which was considered to be relatively insensitive (Frongillo et al., 1997). The development of the United States Household Food Security Survey Module (HFSSM) provides an effective standard tool for measuring food security status (Bickel et al., 2000). However, few studies have examined the influences of food insecurity as measured by this scale on functional status among older adults. The purpose of this dissertation was to examine the association between the complex risk factors such as diet quality, food security status, and important outcomes including physical performance and disability among older Americans.

Chapter 2 Literature Review

2.1 Functional status in older adults

2.1.1 Definition of functional status

Researchers, policy makers and health care providers are all concerned with maintaining older adults' independence and quality of life, which is far beyond the concept of extending the life and compressing the morbidity (Kaplan 1991). Earlier studies have focused solely on health outcomes for prolonging life rather than functional status among older adults (Nagi 1976). However, older adults perceive quality of life to be influenced more by their functional status than by disease conditions and symptomology (Guralnik et al., 1989).

Generally speaking, functional status is a measure of the ability of an individual to carry out activities that are related to daily functioning (Kaplan 1993). Functional status is considered a measure of overall health status, which incorporates medical conditions, lifestyles, and age-related physiologic changes in the context of a person's environment and social support system (Reuben et al., 2004). This multidimensional construct allows measurement of function that transcends the presence of symptoms or specific conditions. In recent decades, functional status has become a common outcome measure for epidemiology and clinical research on older adults because it indicates the impact of disease, impairments, and other risk factors on an individual's function. In addition, measures of functional status can also be used to characterize the health status of individuals and populations, and are powerful predictors of various adverse outcomes, including loss of independence, increased caregiver burden, increased mortality and greater financial expenditures (Reuben et al., 2003; Reuben et al., 2004). Functional decline has been suggested to represent "preclinical disability", which should be detected earlier (Fried et al., 2000). Studies have found interventions implemented earlier are more effective than later (Fried et al., 2000). Due to the public health burden associated with functional decline among older adults, it is imperative to identify risk factors for impaired functional status and implement strategies to prevent or delay the onset of disability (Guralnik et al., 1996).

According to the original definition by Nagi, functional decline was described as a series of four stages (Nagi 1976). The initial stage was the onset of one or more disease states, followed by the physiological manifestation of these diseases in multiple systems in stage two, leading to functional limitations in stage three, and ultimately, the onset of disability in stage four (Figure 2.1). There is an increase in researchers who have realized the importance of identifying older adults who exhibit pre-clinical changes in functioning, but have not yet entered this pathway to disability. Identification of these older adults with "pre-clinical disability" may enable the earlier implementation of interventions to modify the pathway to disability (Fried et al., 2003).

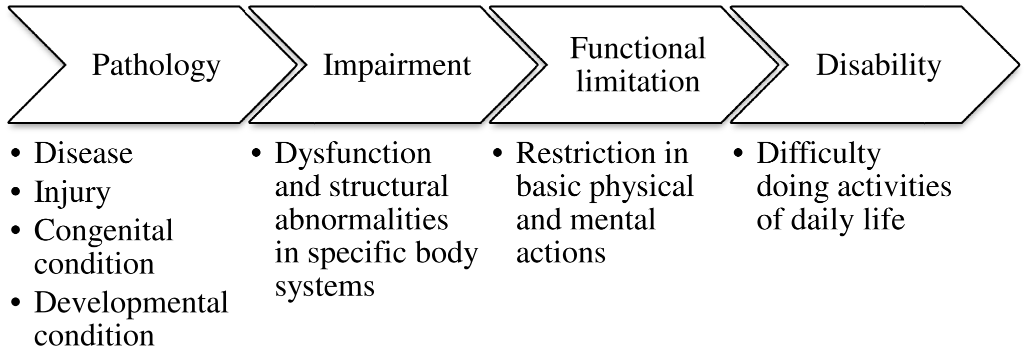

Figure 2.1 Nagi's theoretical pathway to disability (Guralnik & Ferrucci 2003).

Functional status can be studied at the molecular, cellular and organ level (Halter et al., 2001). To further aid the diagnosis of functional decline in the clinical setting, current interest focused on the levels of the organism and its interaction with society. From this perspective, functional status can be conceptualized across a hierarchy of increasing complexity, from basic components (e.g., paid or volunteer work) to specific physical movements (e.g., lifting, walking), and even to more integrated activities (e.g., occupational and social roles)(Guralnik & Ferrucci, 2003). Halter and Reuben proposed another useful model to conceptualize function decline (Halter & Reuben, 2001). That model describes the building blocks of functioning are integrated to form a hierarchy of ability (Reuben 2003). These building blocks, including strength, balance, coordination, flexibility, and endurance, are coordinated to execute specific physical movements, such as walking, standing and sitting up. Then these movements are coordinated into more complex tasks, such as dressing, bathing and feeding. At the highest level of the coordination, these basic building blocks are coordinated with emotional and cognitive sources to carry out those social and occupational roles (Figure 2.2). The concept of functional status has evolved from one that focuses on diseases to one that incorporates more physical measurements.

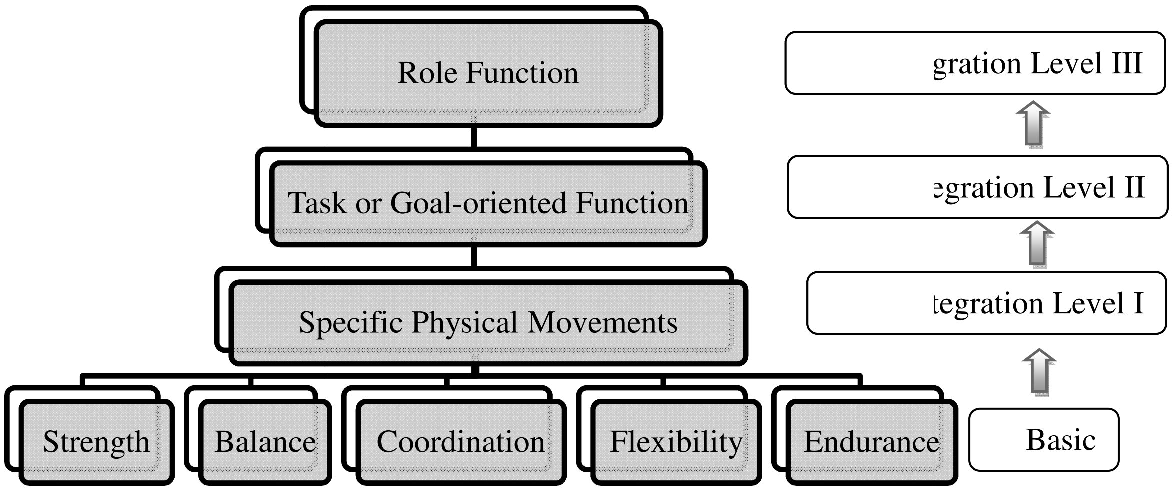

Figure 2.2 A framework for the hierarchy of physical functional status (Reuben 2003).

2.1.2 Prevalence of disability or pre-disability in older adults

Older adults, aged 65 y and older, currently represent 12.5% of the US population, and are projected to increase to 20% of the population by 2030. This represents the number of older adults growing from 35 million to 72 million (Federal Interagency Forum 2004; He et al 2005). By 2050, 12% of the population, or one in eight Americans, will be 75 y and older (National Center for Health Statistics, 2005).

According to the 2005 Surgeon General's Call to Action, disability is defined as a feature of the body, mind, or senses that can affect a person's daily life (Surgeon General's Call 2005). Over 54 million- or 1 in 5 people of the overall population living in the United States have at least one disability. The chance of having a disability increases with age, from less than 10% for people 15 y of age or younger, to almost 75% for people 80 and older. Although the prevalence of disability in the United States declined from 1982 to 2004 (Manton 2006), the absolute number of disabled older Americans is projected to increase as the population ages over the next two decades (US Census Bureau).

2.1.3 Assessments/measurements of functional status

There are an abundance of functional status measures available for use. These measures range from self-reported questionnaires to performance-based measurements of specific tasks to vigorous laboratory measures. There are advantages and disadvantages to each of the measurements. Self-reported and performance-based measures of functional status will be discussed and compared in the next section of this literature review.

2.1.3.1 Self -reported measures of functional status

Early studies on functional status in old age were primarily based on self-reported measures. Self-reported measures are considered subjective and require participants to report their functional abilities based on their perceptions of ability to complete activities. Participants can provide answers in terms of either dichotomous, as yes/no responses, or along a graded continuum of reported severity ranging from little to great difficulty.

One of the first self-report measures, developed by Katz and colleagues (Kats et al., 1963), assessed the difficulties in performing what were referred to as "Activities of Daily Living" (e.g., dressing, bathing, eating, toileting, transferring from bed to chair, walking across a small room). Functional status has also been refined to three general categories of activity (i.e., basic, instrumental, or advanced activities; Reuben, 2003). Basic activities of daily living encompass those covered by the original Katz ADL items including the ability to bathe, dress, toilet, transfer from bed to chair, and feed one's self independently. Instrumental Activities of Daily Living (IADL's) include using the telephone, shopping, preparing meals, housekeeping, taking medications, and handling finances (Lawton & Brody, 1969). Advanced activities of daily living (AADLs) are primarily assessed in clinical settings as person-specific recreational, occupational, and community participation; changes in these daily habits may reflect dysfunction (Reuben, 1990).

Table 2.1 Kats' self-reported scales of functional status

ADLs	IADLs	AADLs
Bathe	Telephone	Recreational participation
Dress	Shopping	Occupational participation
Toilet	Prepare meals	Community participation
Transfer from bed to chair	Housekeeping	
Feed oneself independently	Take medicines	
	Handle finances	

Although self-reported measures have been widely used in aging studies, these tools do not assess the pre-disability changes in the ability to perform various activities. For example, people may not perceive that they have any difficulties if they can complete activities with the implementation of some type of compensatory or alternative approach. Therefore, modified self-reported measure developed by Fried and colleagues may satisfy this need by adding the questions of additional behavioral or other modifications that participants' may have implemented to reduce or eliminate difficulty in performing an activity, especially for those who do not report any difficulty or inability (Fried et al.,2000).

2.1.3.2 Performance-based measures of functional status

Functional status is usually considered as a continuum ranging from high functioning to severely disability. Self-reported measures are valuable to identify those at the moderately to severely disabled end of the spectrum (

Figure 2.3). These subjective measures do not discriminate well among non-disabled older adults. In contrast, performance-based measures distinguish outcomes in high functioning older adults, especially in those who self-reported no functional problems (Guralnik et al. 1995; Penninx et al., 2000). In addition, performance-based measures are considered objective and less susceptible to response bias from participants (Reuben 2004).

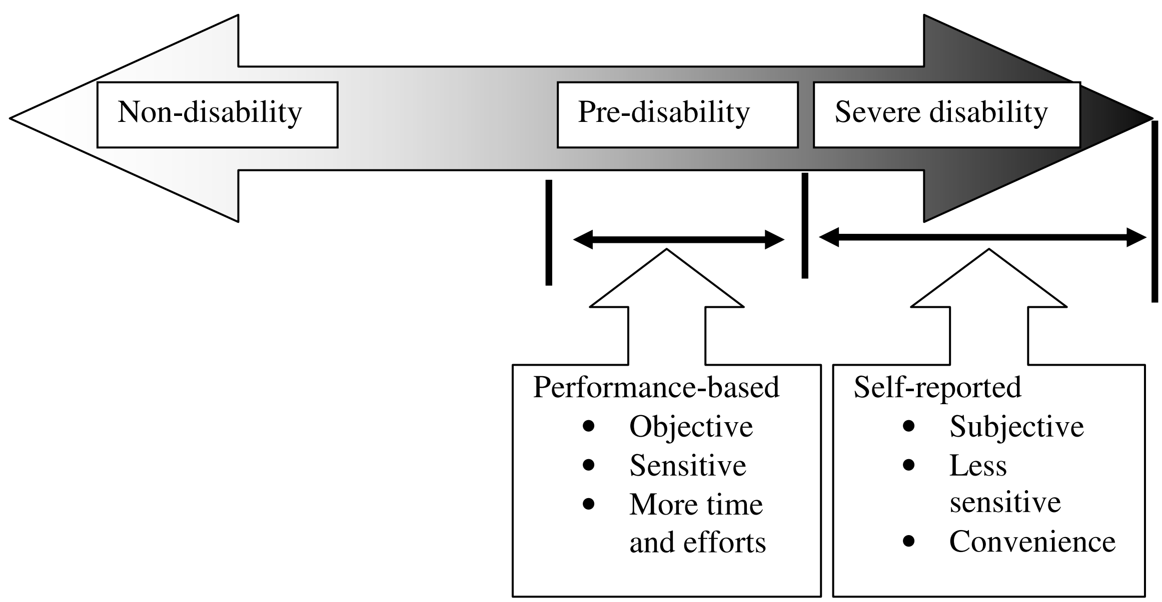

Figure 2.3 Disability spectrum and the comparison of performance-based and

self-reported measures of functional status.

In performance-based measures, participants are asked to perform certain tasks or movements, and their ability to perform the movements is objectively assessed by a test administrator. Performance-based measurements are categorized into upper and lower body tests. Measurements for upper body include tests of manual dexterity, manual strength, lifting ten pounds and range of motion in the shoulder. Tests for manual dexterity 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. Tests for manual strength such as grip strength usually need a dynamometer.

Studies have shown that lower body function deteriorates more rapidly with age than upper body function (Aoyagi & Shephard 1992). Thus, tests of lower body function represent a more important and sensitive measure to detect the functional decline among older adults (Foldvari et al., 2000). Measurements for lower body function include tests of strength, mobility and balance (Suthers & Seeman, 2004). Chair stands are a commonly used measure of lower body strength. For this task, participants are asked to rise from one chair and then sit once, and the length of time it takes the participants to complete is reported by a test administrator. For greater sensitivity, participants are asked to repeat the task five times. Another simple assessment to measure lower body functioning is measures of balance. No equipment is required for this assessment. Participants are asked to simply stand with legs side by side. If they can complete this task, they are asked to stand semi-tandem, then tandem with eyes open, then closed. Based on the performance, participants also may be further asked to stand on one leg, with eyes open then shut. If participants can complete the above tasks well, they may be asked to make a 360-degree turn. The length of time it takes to complete these tasks are recorded by a test administer.

Similarly, tests of walking are based on measures of time and distance. First, participants are asked to walk at his/her usual speed while the length of the task is timed by a test administrator. Participants also can be asked to walk as fast as possible while the time is recorded. Also, time may be fixed, while distance is measured. To add difficulty to the mobility test, participants can be asked to walk at a longer distance/time or climb stairs while number of steps taken and time are measured. These more challenging tests are considered to reduce potential ceiling effects especially in high-functioning older adults (Gill 2010). Among all of these walking tests, gait speed is the most commonly used one because it is simple, inexpensive and informative. Especially for older adults, a slow gait speed is associated with cardiovascular disease, disability, mortality and longevity (Guralnik et al., 2000; Newman et al, 2006; Ostir et al, 2007; Rolland et al., 2006; Studenski et al., 2011; Woo et al., 1999). A previous study reported that in a battery of three tests including standing balance, chair rises, and gait speed over 8 feet, the gait speed test was most closely related to future disability among nondisabled older people (Guralnik et al., 2000).

Gait speed has been recommended as a potential useful clinical indicator of well-being among older adults (Hall 2006). Some researchers have suggested that gait speed can be tested in the full spectrum of the older population as a "geriatric vital sign" (Montero-Odasso et al., 2004; Studenski et al., 2003). Walking requires energy, movement control, and support and places demands on multiple organ systems, including heart, lungs, circulatory, nervous, and musculoskeletal systems (Van Kan et al., 2009).

Slowing gait may reflect both damaged systems and a high-energy cost of walking. Gait speed could be considered a simple and accessible summary indicator of vitality because it integrates known and undetected disturbances in multiple organ systems (Studenski et al., 2011). In addition, decreasing mobility may also induce a vicious cycle of reduced physical activity and deconditioning that has a direct effect on health and survival (Cesari et al., 2009). Lack of physical activity, smoking, obesity and diet are modifiable risk factors that have been associated with poor walking speed (Alipanah et al., 2009; Forrest et al., 2006; Simonsick et al., 2005; Stenholm et al., 2007).

Gait speed over a short distance such as 4 or 6 meters has the potential to be implemented in practice, using a stop watch and a 4/6-m course. From a standing start, individuals are instructed to walk at their usual pace, as if they were walking down the street, and given no further encouragement or instructions. Cut points of gait speed were also available to help interpretations. Several authors have proposed that gait speeds faster than 1.0 m/s suggest healthier aging while gait speeds slower than 0.6 m/s increase the likelihood of poor health and function (Cesari et al., 2005; Studenski et al., 2003). Others propose one cutoff around 0.8 m/s (Van Kan et al., 2009). A recent study examining gait speed and survival in older adults reported that a gait speed faster than 1.0 m/s suggests better than average life expectancy and above 1.2 m/s suggests exceptional life expectancy (Studenski et al., 2011). In addition, gait speed is responsive to clinically meaningful changes, with 0.05 m/s denoting a small meaningful change and 0.1 m/s denoting a substantial meaningful change (Perera et al., 2003).

Two other popular performance-based measures of functional status are muscle strength and muscle power. Muscle strength is defined as the ability of a muscle or muscle group to exert maximal force or torque at a specified velocity during a contraction (Kraemer & Newton 2000). Muscle power is characterized by the product of force production and the velocity at which the force is produced (Kraemer & Newton 2000). Muscle strength and power both have been shown to decline with advancing age, with power declining at a greater rate than strength (Bassey & Short, 1990; Bassey et al., 1992; Earles et al., 1997; Foldvari et al., 2000; Lexell et al., 1988; Skelton et al., 1994). Bosco and Komi (1980) assessed explosive power in a maximal vertical jump from a force plate. They reported that healthy older adults in their early 70s produced an average power output of 70 to 75% less than healthy people in their early 20s. However, the decrease in average force was only about 50%, demonstrating the preferential loss of power with age. Another two studies that evaluated leg extension power in older adults found that the older adults had about 20% of the power found in nonathletic young adults (Bassey et al., 1992; Bassey et al., 1990). These losses in power far exceed what has been reported for declines in strength with age (Foldvari et al., 2000). Similarly, a cross-sectional study has shown that losses in handgrip and quadricep strength average 1.5% per y, while the decline of peak leg extensor power is about 3.5% per y (Skelton et al., 1994). These large losses in power with age suggest a dominant role of muscle power in relation to impaired functional status during aging.

Evans hypothesized that power has a stronger relationship to functional limitations because power involves both force production and contraction velocity (Evans 2000). Along with decreases in muscle strength with advancing age, the other component of power, the velocity with which muscle force can be generated, declines in old age as well (DeVito et al., 1998). The velocity component of power makes muscle power dependent on fast fibers. Selective fast fibers were shown to be lost in healthy adults aged 80 and older (Grimby et al., 1982). In addition, many daily activities such as walking, climbing stairs, or simply standing from a seated position are both force and velocity dependent (Aniansson et al., 1980; Hyatt et al., 1990; Jette & Branch 1981; Lundgren-Lindquist et al., 1983).

Studies have reported that peak muscle power consistently demonstrate a stronger relationship to functional limitations than strength (Bassey et al., 1992; Bean et al., 2003). Foldvari and colleagues (2000) reported that peak leg power had the strongest univariate correlation to self-reported functional status of the other physiologic factors includingVO2 peak, maximal treadmill time, muscle strength and muscle endurance among sedentary older community-dwelling women. One recent study also reported that peak muscle power had a stronger relationship to functional limitations (such as walking, stair climbing, getting dressed, running, pouring water, or opening a door) compared to power at a low intensity (Puthoff & Nielsen, 2007). The explanation may be because these activities may not be low intensity activity for all people. Cress and Meyer (2003) presented the idea that over time, older adults lose their physiological reserve and may need to apply a larger percentage of their maximal performance to daily activities. Those older adults with impaired functional status may depend more on power production at higher relative intensities for daily activities than younger adults. Therefore, during walking and other activities, the largest amount of power that can be produced may be more important than the power production at a predetermined relative intensity for older adults.

Because the amount of strength or power needed to perform functional activities, such as walking or getting out of a chair, is related to movement and control of the whole body, strength and power data were normalized to body mass for analysis. This method of analysis, suggested by earlier studies, provides a more normal distribution for strength and power values. It also provides a means for making intersubject comparisons (Brown et al., 1995; Buchner et al., 1996; Jette et al., 1998; Skelton et al., 1994).

2.1.3.3 Comparisons between self-reported and performance-based measures of functional status

Comparisons between self-reported and performance-based measures shown in Figure 2.3 have long been reported (Hoeymans et al., 1996; Sayers et al., 2004). Performance-based measures should be used with caution especially in older adults due to possibilities of falls and injuries. Another problem with using these tasks is that many of them have a "ceiling" or "floor" effect. That is, depending on the subject's ability to perform the given task, the subject may or may be too weak or frail to be able to perform the task. Performance-based measures, as an objective marker of functioning, can be more sensitive than self-reported measures, particularly for people with some degree of cognitive impairment (Melzer et al., 2005). In addition, significant challenges in the use of self-reported measures include choice of items and reliability. Although performance-based measures have many advantages and are closely associated with self report measures, performance based measurements can serve as complementary assessments to participants' self-reported perception of difficulty, not as substitutes of self report measures. Participants define their functional status as disability only when environmental demands exceed intrinsic capabilities (Fried, 2003). They may perform poorly on tests of functioning in a laboratory setting. However, that situation may change if they can optimize their environment and compensate for performance deficits with other abilities. Performance-based measures cannot be regarded as the only benchmark also because people can perform better on tests than in everyday life. Older adults may ignore pain in order to do well in the test situation.

Therefore, performance testing in the laboratory and self-reported real world functional independence measures are two related, but different constructs (Fried 2001; Reuben, 2003). Combining self-report and performance-based data can be useful to capture a broader spectrum of functioning in a single index. Adding self-reported data provides insight into how an individual is doing in his or her own environment, which is important for providing supportive services and accommodations (Reuben et al., 2004).

2.1.4 Risk factors of impaired functional status

Although impaired functional status is considered a natural process during aging, there is now increasing evidence of considerable heterogeneity in levels of functioning at all ages, which is instrumental in laying the grounds for preventive approaches (Kaplan 1993). Understanding the factors contributing to functional disability in older adults has important clinical and public health implications. Studies have confirmed associations between a wide variety of biological, psychological, social risk factors, health status, and demographic risk factors and the impaired functional status (Kaplan 1993; Stuck et al., 1999). These risk factors include alcohol, medications, body weight status, physical activity, self-reported health, smoking, vision, chronic diseases and demographic factors. Unfortunately, many of the strongest predictors, such as age and socioeconomic status, are not directly modifiable. However, behavioral factors such as smoking, physical inactivity, overweight/obesity, and alcohol abstinence are modifiable factors that physicians and patients could potentially do something about (Ensrud et al., 1994). With a growing older population, there is an increasing need to identify the potentially modifiable risk factors for the onset of disability.

Smoking is one of the major preventable risk factors of impaired functional status. Smoking is associated with many adverse health outcomes including cancer, vascular diseases, respiratory diseases, and osteoporosis (Kapoor & Jones 2005). Each of these conditions is in turn associated with impaired functional status. Smoking has also been associated with poor physical performance including slow timed rise, timed walk tests, as well as decreased grip strength among older women (Rapuri et al. 2007). Smoking may affect physical performance through its effect on vitamin D metabolism. Improvements in vitamin D status have been reported to improve physical performance in older adults (Houston 2007). A recent study also reported that smoking impairs muscle protein synthesis and increases the expression of genes associated with impaired muscle maintenance (Petersen et al., 2007). In addition, smoking potentially generates oxidative stress and reduces levels of antioxidants that are important in preventing functional decline among older adults (Skycher et al., 1988). Smoking is also associated with insulin resistance and increased adipocytokines, which are potential cardiovascular risk factors, with also a close relationship with functional decline (Van Gaal 2006). Additionally, smoking is a powerful inflammatory stimulus causing the influx and activation of inflammatory cells (Walters et al., 2005). This chronic inflammation may have a pathophysiological role in impaired functional status (Morley et al., 2004). Older adults with higher circulating levels of C-reactive protein (CRP) and interleukin-6 (IL-6) exhibit poor physical performance and muscle weakness (Cesari et al., 2004). Higher circulating levels of IL-6 and CRP also predict the onset of disability (Ferrucci et al., 1999). Additionally, neurovascular and peripheral vascular effects of smoking may partially explain the poor physical performance (Nelson 1994). Women who smoked had a higher relative risk for ischemic and hemorrhagic stroke (Colditz et al., 1989; Kawachi et al., 1993). Smoking is also a risk factor for atherosclerosis in the major arteries of the lower extremities (Criqui et al., 1989; Fowkes 1988; Kannel & McGee, 1985). Exercise tolerance and ability to walk on level ground are severely reduced in individuals with lower extremity arterial disease (Vogt et al., 1993).

2.2 Diet quality and functional status

2.2.1 Diet quality

Epidemiologic studies of diet and chronic disease have tended to focus on the relationship between single-nutrient consumption and disease risk. Previous research has linked the consumption of vitamins, minerals, fats, saturated fat, protein, or alcohol to the risk of coronary heart disease or cancer (Garland et al., 1999; Holmes et al., 1999; Hu et al., 1999; Corrao et al., 2000). However, people usually consume combination of foods, not just a single food or nutrient. In addition, most foods contain many nutrients, and different nutrients may interact with each other, complicating the association between single dietary factors and disease (Kant et al., 1996). To address this issue, researchers are now considering the complexity of dietary behaviors. Two methods are commonly used in the study of diet quality and health. First, data driven analyses such as factor analysis and cluster analysis may be used to identify the common dietary patterns and then relate these patterns to the health outcome. Using this approach, a diet with a high intake of red meat, processed meat, and refined carbohydrates has been associated with higher cardiovascular risk compared to a diet with a high intake of fruits, vegetables, and whole grains (Fung et al., 2001; Hu et al., 2000). In addition, a higher intake of fruits, vegetables, and whole grains was recently confirmed to be associated with smaller gains in body mass index (BMI) and waist circumference (Newby et al., 2003), and a dietary meat pattern was positively associated with BMI in a multiethnic group of women (Maskarine et al., 2000). The second approach to assessing an individual's diet is to score it with a set of criteria to produce a composite index of diet quality. Examples include the Diet Quality Index (DQI) (Haines et al., 1999; Patterson et al., 1994), the Diet Diversity Score (Kant et al., 1995), and the Healthy Eating Index (HEI) (Kennedy et al., 1995; McCullough et al., 2000a). These indexes are generally based on dietary recommendations designed to reduce the risk of chronic disease and reflect dietary quality, patterns, and variety (Weinstein et al., 2004).

The HEI, one of those dietary indexes validated most extensively, was developed to assess the adherence to the key diet-related recommendations of the Dietary Guidelines for Americans (DGA), which is the basis of nutrition policy for the US government and the foundation of all federal nutrition guidance (Guenther 2007). The original HEI was based on the 1990 DGA, which has been updated every 5 y; the latest update (HEI-2005) was publicized in 2005 (USDA 2005). The US Departments of Agriculture and of Health and Human Services issue dietary recommendations to help Americans maintain a healthy weight, reduce risk of chronic diseases and promote overall health (USDA 2005).

The sixth version of the DGA, released early in 2005, is a departure from previous editions in that it emphasizes nutrient density, recommends a minimum amount of whole grain, recommends a limited intake of *trans* fats, recommends the intake of a greater variety of fruit and vegetables, and includes the new concept of "discretionary" calories.

The most recent updated HEI scores (HEI-2005) was designed to assess how well American diets conform to the 2005 DGA. It incorporates nutrient requirements and dietary guidelines into one single, summary measure. The HEI-2005 is comprised of 12 nutrient- and food-based components. The first six components, including total fruits (includes 100% juice), whole fruit (forms other than juice), total vegetables, dark green and orange vegetables and legumes, total grains and whole grains (which must include the entire grain kernel, bran, germ, and endosperm), are each awarded 0 to 5 points. The next five components, including milk (includes all milk products, such as fluid milk, yogurt, and cheese, and soy beverages), meat and beans, oils (includes nonhydrogenated vegetable oils and oils in fish, nuts and seeds), saturated fat and sodium, are each awarded 0 to 10 points. The last component reflects calories from solid fat, alcohol, and added sugars (SoFAAS) and is allocated 0 to 20 points. For food groups and oils, intakes at the level of standard or better are assigned the maximum number of total points allotted. No intake is assigned zero. Scores for food groups and oils are prorated linearly between zero and the standard. For saturated fat and sodium, a value at approximately the 85^{th} percentile of the population distribution was selected to assign the minimum value zero and the maximum value 10. The two components get a score of 8 for the intake that reflect the 2005 DGA, <10% of calories from saturated fat and 1.1 grams of sodium per 1000 kcal, respectively. Scores were prorated linearly between 0 to 8 and 8 to 10 points 98 and 10 points represented acceptable and optimal levels, respectively). For calories from SoFAAS, 0 is assigned to intakes of 50% of calories or more and 20 is assigned to intakes of 20% of calories or less. The amounts in between are prorated linearly. Scores for the 12 components were summed to give a total HEI-2005 score ranging from 0 to 100, with a higher score indicative of a healthful diet. Information about the HEI-2005 and its scoring system is reviewed elsewhere (Guenther 2007). Because of its composite nature, this index score may capture the multidimensional character of the diet better than any single nutrient (Hann 2001), thus addressing the complexity of dietary behaviors and serving as a potentially useful tool for epidemiological research.

HEI was intended as a basis for nutrition education and health promotion activities and as the primary tool for monitoring changes in consumption patterns and dietary quality of Americans over time (Kenndy et al., 1995). Since its release, the HEI has had a wide range of applications.

Results from studies examining the relationship between HEI or HEI-2005 and health outcomes were presented in Table 2.2 and are briefly reviewed hereafter. Studies have reported that lower HEI scores, indicating a less health promoting diet, are associated with a greater risk of obesity, arthritis, depression, cancer, and death (Drewnowski et al., 2009; Guo et al., 2004; Kant et al., 2005; Kuczmarski e tal, 2010). However, two large-scale cohort studies found that HEI scores were only weakly associated with a lower risk of cardiovascular disease in men and were not associated with reduced chronic disease risk in women (McCullough 2000a; McCullough 2000b). The inconsistency in the association between diet quality and health outcomes may be due to the variability in the outcome measures and diet quality studied, as well as different covariates included in the analyses.

2.2.2 The relationship between diet quality and functional status

Rosenberg and Miller have proposed that the most practical outcome of research on the relationship of diet and nutrition to aging would be a better understanding of how nutrition-related behaviors can help maintain an optimal functional status (Rosenberg & Miller 1992). Results from studies examining the relationship between diet quality and functional status were presented in Table 2.3 and reviewed in the following two paragraphs. Few studies published have described the associations between overall diet quality and functional status. Two longitudinal studies examining the association between food groups and functional status reported that lower fruits and vegetable consumption is associated with poor lower extremity physical performance, ADL, IADL and greater self reported functional limitations in older adults (Houston et al., 2005; Tomey et al., 2008). Fruit and vegetables are important sources of vitamins, minerals, fiber and antioxidants (USDA 2008; Weisburger 2000). Inverse associations have been reported between increased fruit and vegetables consumption and metabolic syndrome, cardiovascular diseases, and decreased serum C-reactive protein (CRP) concentrations (Esmaillzadeh et al., 2006). The mechanisms behind the protective effects of consuming fruit and vegetables remain unclear, but it is hypothesized that increased intake of antioxidants plays a role (Lister et al., 2007).

It has been suggested that DNA damage, one of the most sensitive biological markers of oxidative stress, might be caused by an imbalance between the excessive generation of free radicals and the deficient action of the antioxidant system (Mendoza-

Nunez et al., 2001). Antioxidants may help diminish free radical damage that contributes to inflammation associated with chronic disease and functional decline and may reduce the accumulation of oxidative damage in tissues. Therefore, the onset of functional decline associated with aging may be slowed.

Most studies have examined the association between the plasma concentration or dietary intake of nutrients and functional status. Cross sectional studies reported plasma antioxidant concentrations are associated with higher physical performance (Cesari et al 2004), and better self reported functioning (Ortega et al 1996; Snowdon et al 1996;). Longitudinal studies supported this association and reported that low serum or plasma carotenoids concentrations were associated with low walking speed, greater decline of walking speed, high risk of developing poor hip, knee and grip muscle strength during the follow-up years (Alipanah et al., 2009; Lauretani et al., 2008; Semba et al., 2006). These studies supported the beneficial effects of fruits and vegetables, the most important natural sources of antioxidants. Researchers also reported that low serum vitamin D concentrations may be related to muscle weakness and poor physical performance (Bischoff-Ferrari et al., 2004; Dhesi et al., 2002; Gerdhem et al., 2005; Houston et al., 2007; Mowe et al., 1999; Pfeifer eta l., 2005; Visser et al., 2003; Zamboni et al., 2002). However, results of this association are inconsistent, with some reporting gender difference (Zamboni et al.,2002) or some reporting no association (Verreault et al., 2002). One longitudinal study also reported that women with higher dietary cholesterol, fat and saturated fat intakes were more likely to report more functional limitations (Tomey et al., 2008)

Some studies found an inverse association between higher scores on nutritional risk-screening tools and self report functional status measures (Boult 1999; Bryant 2002; Jensen 1997). Higher nutrition risk scores were also associated with increased incidence of disability at 12- and 22-month follow-ups (Boult 1999; Bryant 2002). One study also reported that older men and women with a higher summary score, which included items on food choices and meal patterns, were more likely to have better ADL scores than were their counterparts with lower summary scores (Duffy & MacDonald, 1990). In a cross-sectional study, nutrition risk factors (medication, alone, oral, prepare, shop, money and illness) were directly and indirectly associated with indicators of nutritional risk (meals, serving and weight) and increased severity of disability (Sharkey 2002).

Table 2.2 Overview of studies examining the relationship between the Health Eating Index (HEI)* and health outcomes**

Author/Date	Study design	Population	Exposure variable	Health outcomes	Covariates	Results
Guo et al., 2004	NHANES III Cross-sectional	*n* = 10,930 Age: 20-75 y Nationally representative sample	24-hour recall; Three diet categories: Good(≥81); Needs improvement (51-80); Poor (≤50)	BMI	Age, sex, race/ethnicity, household income, education, physical activity, smoking status and alcohol use	A low HEI score was associated with overweight and obesity. There was a graded increase in the odds ratio of obesity across the HEI category after adjusting for covariates.
Gao et al., 2008	Multi-Ethnic Study of Atherosclerosis (MESA) Longitudinal analysis 6 US sites	*n* = 6,236 Age: 45-84 y White, African American, Hispanic, and Chinese participants	FFQ: included typical Hispanic and Chinese food and was modified from the validated Insulin Resistance Atherosclerosis Study; HEI-2005 HEI-1990	BMI; Waist circumference; Categorical obesity status	Socio-demographic variables, total calorie intake, recreational physical activity, smoking status, alcohol use	There was an inverse association between quintiles of both HEIs and each anthropometric measure. Among whites only, both HEIs were significant

						predictors of BMI and WC. The odds of being obese rather than normal weight were inversely related to HEI scores primarily in whites.
Tande et al., 2009	NHANES III Cross sectional	*n* = 15,658 Age: ≥ 20 y Nationally representative sample	24-hour recall; Total HEI score: continuous HEI component scores: continuous	Abdominal obesity: WC ≥102 cm for men; WC≥ 88 cm for women	Age, sex, race/ethnicity, residence location, education, income, smoking, activity, marital status, energy intake and alcohol intake	The odds of abdominal obesity was lower with increasing total HEI score. For each point increase for fruit score, abdominal obesity risk decreased by 2.6% for women. Abdominal obesity decreased for men with each point increase in saturated fat

						and variety scores, by 3.1% and 4.0% respectively.
Hann et al., 2001	University of Michigan Hospitals' Breast Care Center Case-control	*n* = 340 women (172 women with newly diagnosed cancer, 149 cancer-free control subjects, 19 women at high risk of breast cancer) Age: 21-80 y	3-d food records Total HEI scores: four groups <65, 65-74, 75-84, ≥85 HEI scores for each component: Three groups <5, 5-8, >8	Circulating plasma biomarkers	Vitamin supplement use, age, case or control status, energy intake	Higher HEI scores were associated with higher plasma concentrations of alpha-carotene, beta-carotene, beta-cryptoxanthin, lutein, and vitamin C after age and vitamin supplement use were controlled for.
Kant & Graubard, 2005	NHANES III Cross sectional	*n* = 8,719 Age: ≥20 y Nationally representative sample	24 hour dietary recall Total HEI score: Continuous Quartiles	Biomarkers of risk of cardiovascular disease and dietary exposure	Gender, age, race, smoking, education, physical activity, BMI, alcohol, hours of fasting, supplement use in the past month before phlebotomy, and supplement use in the past month	HEI was a strong independent positive predictor of serum concentrations of vit C, E, folate, and all carotenoids, except

						lycopene, and was negative predictor of BMI, serum homosysteine, C-reactive protein, plasma glucose, and hemoglobin A1C.
Weinstein et al., 2004	NHANES III Cross sectional	*n* = 16,467 Age: ≥ 17 y Nationally representative sample	24-hour recall Continuous and Five HEI categories: ≤50, 51-60, 61-70, 71-80, and >80	Blood nutrient concentrations	Age, race/ethnicity, gender, census region, poverty income ratio, pregnancy, body mass index, energy intake, alcohol intake, smoking, and vitamin or mineral supplement sue	HEI score was positively correlated with serum and red blood cell folate, serum vitamins C and E, and all serum carotenoids except lycopene. These blood nutrient concentrations were 21% to 175% higher for participants in the highest HEI score group

						compared with those in the lowest group.
Grimstvedt et al., 2010	Local community in Arizona Cross sectional	*n* = 108 women Age: ≥55 y	7 day food records HEI-2005	Rheumatoid arthritis	Correlation without controlling for confounders	Healthy participants had higher mean HEI-2005 scores for whole fruit, total fruit, whole grains, oil and total HEI score than the rheumatoid arthritis group. Participants with rheumatoid arthritis reported lower mean intakes of carbohydrate, fibre and vitamin C.
Kucamarski et al., 2010	Healthy Aging in Neighborhoods of Diversity across the Life Span (HANDLS)	*n* = 1,118 Age: 30-64 y African Americans and whites	Average of two 24 hour dietary recalls	The Center for Epidemiologic Studies Depression (CES-D) scale: linear regression	Race, sex, age, education, income and food-assistance program participation	HEI-2005 was inversely and significantly associated with reported symptoms of depression.

	study City of Baltimore, MD Cross sectional			analysis with no CES-D cut-off point and logistic regression analysis with a CES-D cur-off point of 16		
McCullough et al., 2000a	The Nurses' Health Study US Longitudinal	*n* = 67,272 female nurses Age: 30-55 y	Semiquantitative FFQ; The calculations for HEI-f components were consistent with HEI except variety score. Participants were grouped into 11 equal quantiles according to the number of unique foods consumed per month and the groups were assigned scores of 0-10. HEI-f:quintiles	Combined major chronic disease, defined as CVD, cancer, or death not resulting from trauma, whichever came first. CVD and cancer were also examined as separate outcomes.	Age, exogenous hormone use and menopausal status, cigarette smoking, BMI, and multivitamin and vit E supplement, physical activity, total energy intake, alcohol consumption and a baseline diagnosis of hypercholoesterolemia or hypertension	The HEI score was not associated with risk of overall major chronic disease in women, comparing the highest with the lowest quintile of HEI score. Being in the highest HEI quintile was associated with a 14% reduction in cardiovascular disease risk and was not associated with lower cancer risk.

McCullough et al., 2000b	Health Professional Follow-up Study (HFPS) US Longitudinal	*n* = 38,622 male professionals without major diseases Age: 40-75 y	Semiquantitative FFQ; The calculations for HEI-f components were consistent with HEI except variety score. Participants were grouped into 11 equal quantiles according to the number of unique foods consumed per month and the groups were assigned scores of 0-10. HEI-f:quintiles	Combined major chronic disease, defined as CVD, cancer, or death not resulting from trauma, whichever came first. CVD and cancer were also examined as separate outcomes.	Age, exogenous hormone use and menopausal status, cigarette smoking, BMI, and multivitamin and vit E supplement, physical activity, total energy intake, alcohol consumption and a baseline diagnosis of hypercholoesterolemia or hypertension	The HEI was weakly inversely associated with risk of major chronic disease comparing highest with lowest quintile of the HEI. The HEI was associated with moderately lower risk of cardiovascular disease but was not associated with lower cancer risk.
Nunn et al, 2008	NHANES III Cross-sectional	*n* = 3,912 Age: 2-5 y	24-hour recall Total HEI score: Continuous Tertile	Early childhood caries (ECC): Simple ECC Severe ECC Maxillary ECC	Age, race/ethnicity. Education, poverty income ratio, recent dental visit, eats breakfast every day, stopped bottle feeding by 12 months, infant feeding (breast only, bottle only, or breast and bottle)	HEI is a predictor of the prevalence of severe ECC, independent of race/ethnicity and socio-economic status.

Drewnowski et al., 2009	Supplementation en Vitamins et Mineraux Antioxydants (SU.VI.MAX) France national wide Cross-sectional	*n* = 2,200 men (age: 41-61 y) and 2,881 women (age: 35-61 y)	Subjects recorded all dietary consumption over a 24 –hour period every other month for two years Total HEI score: Five groups <56, 56-60, 61-65, 66-70, >70	BMI Blood pressure Plasma lipids	Age, energy, alcohol, tobacco use and BMI	Higher HEI scores were modestly associated with lower BMI and with lower blood pressure for men but not for women. HEI scores was not associated with plasma lipids measures.
Shah et al., 2010	Urban counties of Texas Cross sectional	*n* = 125 Age: 18-40 y African-American, white, or Hispanic women at 1 to 4 months postpartum; Annual household income <185% federal poverty level	24-hour recall Total HEI-2005 scores: Continuous Tertiles	Body fat percent; Waist circumferences; Lipid profiles	Energy intake and BMI; Models with HDL and triglycerides were further controlled for lactation status	The HEI 2005 scores inversely predicted BMI and low density lipoprotein and total cholesterol and positively predicted high density lipoprotein cholesterol

Footnote * Healthy Eating Index (HEI) includes the revised HEI-2005 and the earlier HEI measure.

Footnote ** Health Outcomes include anthropometric measures, biomarkers such as circulating plasma concentrations, and coronary vascular disease (CVD), cancer and death.

Table 2.3 Overview of studies examining the relationship between diet and functional status

Author/Date	Study design	Population	Exposure variable	Outcome variable	Covariates	Results
Duffy et al., 1990	Sample through investigator-made contacts with staff who manage senior housing units, retirement, senior citizen, and nutrition centers. Southeast Texas Cross sectional	Age: 65-99 y *n* = 179	Nutritional items dealing with food choices and meal patterns: Health-Promoting Lifestyle Profile (HPLP)	ADLs		Older men and women with “better” nutrition practices, as ascertained by using a summary score that included questions on food choices and meal patterns, were more likely to have better ADL scores than were their counterparts with “worse” nutrition practices.
Jensen et al., 1997	A regional nutrition screening program by the Geisinger Health Care System	Age: > 60 y *n* = 5,373	Self administered questionnaire adapted from the Nutrition Screening Initiative (NSI)*	ADLs/IADLs	Age, gender, BMI, annual income, albumin, uses ≥ 3 prescription drugs, feels depressed,	Poor eating habits were associated with functional limitation.

	Northeatern and central Pennsylvania Cross-sectional					
Ortega et al., 1996	Spain Cross-sectional	Age: 65-89 y *n* =177	Dietary folate intake: weighed food record for seven consecutive days and a food frequency intake questionnaire; serum and erythrocyte folate concentrations and serum cyanocobalamin	1.Katz's scale of ADLs 2.Scale of self-maintaining and IADLs 3.Mental capacity: Pfeiffer's mental status questionnaire; Folstein's Mini-Mental State Test 4.Affective capacity: Geriatric depression scale	Gender, socioeconomic status and educational background	IADL was significantly better when folate intake and serum or erythrocyte folate concentrations were adequate. Subjects with adequate Mini-Mental State Exam results had serum and erythrocyte folate concentrations significantly higher than those with less adequate results.
Sharkey, 2002	Wake County home-delivered meals program Wake county, NC Cross-sectional	Age: ≥60 y *n* = 1,010	1.Nutritional risk factors (draw from Nutrition Screening Initiative	ADLs	None. Structural equation modeling	Specific nutritional risk factors were directly and indirectly associated

			(NSI)*): medication, alone, oral, prepare, shop, money, illness 2.Indicators of nutritional risk: meals, serving, weight			with indicators of nutritional risk and increased severity of disability.
Cesari et al., 2004	Invecchiare in Chianti (InCHIANTI) study Florence, Italy Cross-sectional	Age: ≥65 y *n* = 986 Italians	Daily dietary intakes of vit C, vit E, beta-carotene, and retinol: The European Prospective Investigation into Cancer and Nutrition (EPIC) FFQ questionnaire; Plasma vit E concentrations	1.Physical performance score: walking speed, ability to rise from a chair, and standing balance 2.Knee extension strength	Age, sex, site, smoking habit, education, Mini-Mental State Examination score, plasma lipid concentrations, comorbidity, BMI, the number of medications taken by participants at the baseline assessment, physical activity, total daily dietary energy intake	Plasma antioxidant concentrations correlate positively with physical performance and strength. Higher dietary intakes of most antioxidants, especially vit C, appear to be associated with higher muscular strength in older adults.
Sharkey et al., 2003	Nutrition and Function Study (NAFS) North Carolina	Age: ≥60 y *n* = 321	A summary musculoskeletal nutrient score including	Lower extremity physical performance:	Demographic and health information	Lowest SMN intake was significantly associated

	Cross-sectional		calcium, vitamin D, magnesium, and phosphorus Intakes (SMN): three 24-h recalls	static/dynamic balance, gait speed, repeated chair stands		with increasing worse levels of lower extremity physical performance.
Snowdon et al., 1996	The Nun Study: Roman Catholic sisters in the school sisters of Notre Dame religious congregation Cross sectional	Age: 77-98 y *n* = 88 women	Blood antioxidant concentration: carotenoids and alpha tocopherol	Walking, dressing, and feeding	Age, Mental function, Years of attained education and, triceps skinfold and BMI	Dependence in self-care had a strong negative association with lycopene, but was not clearly related to other carotenoids or alpha tocopherol.
Zamboni et al., 2002	Verona Cross-sectional	Age: 68-75 y *n* = 175 women; 94 men Able to walk for at least 0.5 mile without difficulty and free of cognitive impairment	Vitamin D status: 25(OH)D	1.6-minute walking test: distance walked by each subject at normal speed was determined 2.Isometric strength 3.Self reported: ADLs, IADLs, three Rosow-Breslau	BMI, albumin, appendicular FFM and season	In community-dwelling older women, 25(OH)D is related to muscular function and reported physical function. No relationship between muscular

				physical function items		strength, physical function, or reported disability and 25(OH)D was found in men.
Bartali et al., 2008	Invecchiare in Chianti (InCHIANTI) Tuscany, Italy Longitudinal	Age: ≥65 y *n* = 698	Serum folate, vitamine B6 and B12; Plasma vitamin E (α-tocopherol), 25-Hydroxyvitamin D, iron	Summary score from 3 objective tests (each scored from 0 to 4, with a value of 0 indicating the inability to complete the test, and 4 the highest level of performance): 4-meter walking speed, repeated chair rises, and standing balance in 3 progressively more challenging position for 10 seconds each: feet in side-by-side, semi	Age, gender, educational achievement, marital status, household composition, smoking, physical activity level, chronic conditions, BMI, and Center for Epidemiological Studies-Depression Scale, and Mini-Mental State Examination scores	Only a low concentration of vitamin E was significantly associated with subsequent decline in physical function.

				tandem, and full-tandem positions.		
Boult et al., 1999	Community-dwelling Medicare beneficiaries Urban-suburban Midwestern community Longitudinal	Age: ≥70 y *n* = 251	Nutrition Screening Initiative (NSI) DETERMINE Checklist*: 10 item weighted self-administered questionnaire	Physical Functioning Dimension of the Sickness Impact Profile: a telephone interview	Baseline functional status, depressive symptoms, and general health	Subjects with baseline Checklist scores of four or higher were significantly more likely than those with lower scores to have functional disability or high levels of depressive symptoms a year later.
Bryant et al., 2002	San Luis Valley Health and Aging study (SLVHAS) Southern Colorado Longitudinal	Age: ≥60 y *n* = 751 rural Hispanic and non-Hispanic white elders with not dependence in basic and instrumental activities of daily living (ADLs and	Nutritional risk score: developed by investigators; similar to Nutrition Screening Initiative (NSI)*	ADLs and IADLs questions from the 1984 National Health Interview Supplement on Aging	Age, sex, ethnicity, years of education, cognition, the number of reported disease conditions	The nutritional risk factor multiplied the likelihood of incident dependence.

		IADLs) at baseline				
Houston et al., 2005	Atherosclerosis Risk in Communities (ARIC) study 4 communities in United States: Forsyth County, NC; Jackson, MS; the northwestern suburbs of Minneapolis; and Washington County, MD. Longitudinal	Baseline age: 45-64 y *n* = 9,404 African Americans and whites	Dairy, fruit and vegetable intakes obtained at baseline by using a food frequency questionnaire	Lower-extremity function (walking one-quarter of a mile; walking up 10 steps without resting; stooping, crouching, or kneeling; lifting or carrying something as heavy as 10 pounds; and standing up from an armless straight chair), ADLs, and IADLs	Baseline age, energy intake, smoking status, education, BMI and field center	Baseline fruit, vegetables, dairy intakes tended to be inversely associated with impaired lower extremity function, ADLs, and IADLs 9 years later, particularly in African American women.
Koster et al., 2007	Health, Aging and Body Composition (Health ABC) study Pittsburg, PA Longitudinal	Age: 70-79 y *n* = 2,694	HEI: food frequency questionnaire	Reported difficulty walking 1/4 mile or climbing 10 steps during two consecutive semiannual	Age, sex, race (black or white), study site (Memphis or Pittsburgh), marital status (never married, previously married, or married), and educational level (_12 years, 12 years, or _12	Non-obese people with lower HEI-90 scores (an earlier version of the HEI) had a higher risk for incident

				assessments over 6.5 years	years). Different health-related variables were included	mobility limitations over 6.5 y.
Sonn et al., 1998	Intervention of Elderly people in Goteborg Goteborg, Sweden Longitudinal	Age: 70-76 y *n* = 97	Diet History: questionnaire based method aimed at evaluating total intake of food, energy, and nutrients	ADLs: assessed according to four well-defined instrumental activities (IADLs, cleaning, shopping, transportation, and cooking) and five personal daily life activities (PADLs, bathing, dressing, going to the toilet, transfer and feeding) combined into a cumulative scale, "The Staircase of ADL"		Significant relationship between food and nutrient intake and functional ability was not found.
Stafford et al., 1998	UK Whitehall II study	Non-industrial	Eating habits: coded from 0	Short-form 36 general health	Age, employment grade. Menopausal	Eating habits was

	London Follow up	civil servants Age: 35-55 y at baseline 39-63 y at follow up *n* = 5,763 men; 2,586 women The mean length of follow up was 5.3 y, with a range of 3.7 to 7.6 y.	(unhealthy diet) to 3 (healthy diet). A healthy diet consisted of whole meal, granary or wheat meal bread, skimmed or semi-skimmed milk, and fresh fruits or vegetables at least once daily. An unhealthy diet consisted of other types of bread and milk and less frequent consumption of fresh fruits or vegetables.	survey (SF-36)	status (women only)	independently associated with poor physical functioning in women.
Tomey et al., 2008	Study of Women's Health Across the Nation (SWAN) Nine states in US Longitudinal	Age: 42-52 y *n* = 2,160 women	Diet quality index: food frequency questionnaire	10-question subscale of the Medical Outcomes Study Short Form 36 (SF36): Self report	Race/ethnicity, economic stress, self reposted presence or absence of four baseline health conditions, baseline total tobacco smoke exposure, depressive symptom questionnaire score,	Women in the highest quartile of cholesterol intake had 40% greater odds of being more limited versus those in the lowest

					trouble sleeping, menopausal status, and study site	quartile. Women in the highest quartile of fat and saturated fat intakes were more likely to be more limited versus those in the lowest quartile. Lower fruit, vegetables, and fiber intakes were related to reporting greater functional limitations
Alipanah et al., 2009	Women's Health and Aging Study I (WHAS I) Baltimore Longitudinal	Age: ≥65 y *n* = 687 moderately to severely disabled women	1.Total serum carotinoid concentrations 2.Serum selenium	Gait speed over 4- meter course	Age, BMI, and chronic diseases	Low total serum carotenoids were associated with low walking speed and greater decline of walking speed during the

						three years of follow up. Low serum selenium was associated with low walking speed over three years of follow up but not with the rate of change of walking speed.
Houston et al., 2007	InCHIANTI study Two towns in the Chianti geographic area of Italy Prospective	Age: 65-102 y *n* =1,022	Vit D (serum 25OHD)	Short physical performance battery and handgrip strength	Sociodemographic variables, behavioral characteristics, BMI, season, cognition, health conditions, creatinine, hemoglobin, and albumin	Vit D status was inversely associated with poor physical performance.
Lauretani et al., 2007	InCHIANTI Study A population based study in Tuscany Italy Longitudinal	Age: ≥ 65 y *n* = 891	Plasma selenium	Muscle strength: hip flexion, grip and knee extension	Age, gender, BMI, education, total energy intake	Low plasma selenium is independently associated with poor skeletal muscle strength in community-dwelling older adults in

						Tuscany.
Lauretani et al., 2008	InCHIANTI Study A population based study in Tuscany Italy Longitudinal	Age: ≥ 65 y n = 1,055	Total plasma carotenoids	Short Physical Performance Battery: 4-meter walking speed, repeated chair rises and standing balance in progressively more challenging positions; isometric muscle strength	Age, gender, baseline muscle strength	Subjects in the lowest versus the highest quartile of total plasma caroteniods at enrollment were at higher risk of developing poor hip, knee and grip muscle strength at the 6 year follow-up visit
Semba et al., 2006	Women's Health and Aging Study I Baltimore, Maryland Longitudinal	Age: ≥65 y n = 554 women without severe walking disability	Serum carotenoids levels	Incidence of severe walking disability (inability to walk or walking speed < 0.4 m/s) assessed every 6 months over 3 years	Age, race, BMI	Women in the lowest quartile of total carotenoids were more likely to develop severe walking disability compared with women in the three upper quartiles
Verreault et al.,	Women's	Age: ≥65 y	Serum 25(OH)D	1.Lower	Age, race, education,	This study

2002	Health and Aging Study (WHAS) Medicare beneficiaries in Baltimore, Maryland. Prospective cohort study	at baseline *n* = 628 women Every 6 months for 3 years	and parathyroid hormone (PTH)	extremity strength: maximum isometric strength of knee extensor and hip flexor muscles 2.Grip strength 3.Walking speed: usual pace over a 4-meter course 3.Repeated chair stands 4.Reported disabilities	BMI, baseline performance, chronic conditions	failed to find an association between low serum vitamin D levels and subsequent loss in muscle strength or decline in performance in mobility and upper extremity functioning. However, they observed a nonsignificant trend toward faster decline over time in hip flexor strength, knee extensor strength, and walking speed with higher baseline PTH.

*Nutrition screening initiative: a simple screening tool that may be self administered or graded by any health care professional or family member to identify non institutionalized older persons at risk for low nutrient intake and health problems.

2.3 Food insecurity and functional status

2.3.1 Food insecurity

2.3.1.1 Definition of food insecurity

The concept of food insecurity was used in poor nations to define the instability of national food supplies and then expanded to include the insecurity of food situations within families (Habicht et al., 2004). In the United States, the standard definition of food insecurity is that "food insecurity existed whenever the limited or uncertain availability of nutritionally adequate and safe foods, or limited, or uncertain ability to acquire acceptable foods in socially acceptable ways." (Life Science Research Office 1990). This definition also includes the concepts of access, availability, and safety of food in addition to the social meaning of food-acquisition methods. The contrary situation, food security was defined as existing when all people have "access at all times to enough food for an active, healthy life; and includes at a minimum, the ready availability of nutritionally adequate and safe foods and assured ability to acquire acceptable foods in socially acceptable ways." At the 1996 World Food Summit, food security is defined as existing when all people, "at all times, have physical economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." (World Food Summit, 1996). Food security is understood by the following three aspects (WHO 2011):

- food availability: sufficient quantities of food available on a consistent basis;
- food access: having sufficient resources to obtain appropriate foods for a nutritious diet;

- food use: appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation.

Food insufficiency, the same concept as food insecurity, was used in an earlier national survey. It was measured by a single question that assessed the quantity of food available at the household level, but not the quality, uncertainty, or psychological components as measured by the Food Security Scale (Alaimo et al., 1998).

2.3.1.2 Prevalence of food insecurity

The food and nutrition assistance programs of the USDA were developed to increase food security by proving low-income households access to food, a healthful diet, and nutrition education. However, the prevalence of food insecurity in the US has been rising since 1999 (Hall 2005; Nord et al., 2010). Since 1995, USDA has monitored the prevalence and severity of food insecurity through an annual, nationally representative survey conducted by the US census Bureau as a supplement to the monthly Current Population Survey. This survey, sponsored by USDA and USDA's Economic Research Services (ERS), compiles and analyzes the responses. According to the latest household food insecurity report, at the national level, 14.7 % of households (17.4 million households) were not able to secure their food consumption at certain points of 2009, with a third of food-insecure households (6.8 million households) had very low food security (Nord et al., 2010). The prevalence rates of food insecurity and very low food security were essentially unchanged from 14.6 % and 5.6 %, respectively, in 2008, and remained at the highest recorded levels since 1995, when the first national food security survey was conducted (Nord et al., 2010). Across the 2001-2007 period, nearly 5.7 %

(over 2.7 million older adults) of older Americans (aged $\geq$ 60 y) are classified as food insecure. There is a discernable upward trend in the prevalence of older Americans experiencing food insecurity, rising from 5.3% in 2001 to 5.8% in 2007 (Ziliak & Gundersen, 2009).

The prevalence of food insecurity is higher in Black households (24.9 %) and Hispanic Households (26.9 %) than in households of other racial groups. Food insecurity is also more prevalent among households with family incomes below the federal poverty line (43.0 %). In 2009, food insecurity was more than four times as prevalent in households with annual incomes below 185 percent of the poverty line as it was in households with incomes above that range.

2.3.1.3 Measurements of food insecurity

Food security is an essential, universal dimension of household and personal well-being (Bickel et al., 2000). The deprivation of basic need represented by food insecurity and hunger are undesirable in their own right and also are possible precursors to nutritional, health, and developmental problems. Monitoring food security can help to identify and understand this basic aspect of well-being of the population and to identify population subgroups or regions with unusually severe conditions.

Although food insecurity stem from constrained financial resources, traditional income and poverty measurements cannot capture the whole concept of food security. It has been reported that many low-income households appear to be food secure, whereas a small percentage of non-poor households appear insecure (Bickel et al., 2000). The reasons may include changes in circumstances, variations in household decisions about how to handle competing demands for limited resources, and geographic patterns of relative costs and availability of food and other basic necessities, such as housing.

The Food Security Survey Module (FSSM), developed by the USDA, is currently utilized to provide independent, more specific information on food security than can be inferred from economic data alone in the US. It has been validated previously (Bickel et al., 2000). This module is used in numerous surveys, including the National Health and Nutritional Examination Surveys (NHANES) and Current Population Survey (CPS) (a national level reports of food insecurity) (Bickel et al., 2000; Bureau of the Census for the Bureau of Labor; CDC 2005; US Census Bureau).

Based on the findings from previous research, ten questions (or eighteen questions if there are children in the household) are included in this module. Participants are generally asked about the following kinds of household conditions, events, behaviors, and subjective reactions during the previous 12 months (Bickel et al., 2000):

- Anxiety the household experienced over the lack of resources to meet basic food needs;
- The experience of running out of food, without money to obtain more;
- Perception of inadequacy in quality or quantity of the diet,
- Adjustments to normal food use, substituting fewer and cheaper foods than usual;
- Instances of reduced food intake by adults in the household, or consequences of reduced intake such as the physical sensations of hunger or loss of weight; and

- Instances of reduced food intake, or consequences of reduced intake, for children in the household.

All of these food security questions have two characteristics in common. Each question asks if the reported condition occurs due to the financial limitations by including phrases such as “because we couldn’t afford that” or “because there wasn’t enough money for food”. Based on the number of positive responses to these questions, this current measure of food security status lies on a continuum extending food security at one end to severe food insecurity at the end, with the continuum being divided into the three or four categories. Before 2006, this module included four main categories to define different severity of household food security: food security, food insecurity without hunger, and food insecurity with hunger. According to the 2006 revisions, food security has been further divided into high food security and marginal food security categories. Food insecurity without hunger and food insecurity with hunger has been replaced by the term low food security and very low food security respectively. Sometimes, it is preferable that the two categories including low food security and very low food security are combined into one group named food insecurity. A comparison of old and new classifications and definitions is shown in Table 2.4.

Table 2.4 Definitions of food security categories according to the USDA household Food Security Survey Module

Old classification (before 2006)	New classification (According to 2006 classifications)		
		No. of food-insecure conditions reported	Definitions
Food security	Fully food security	0	Household with no problems accessing adequate food
	Marginal food security	1-2	Households with problems, at times, of accessing adequate food, but no or little changes in quality, variety, or quantity of food intake
Food insecurity without hunger	Low food security	3-5	Household with reduced quality or variety of diets, but showing no or little changes in quantity of food intake; no substantial disruption in normal eating patterns
Food insecurity with hunger	Very low food security	6-10	Households with disrupted eating patterns and reduced food intake at times during the year

Source: USDA 2006

Participants who report three or more food-insecure conditions are also usually classified as food insecure, which includes the two categories previously mentioned: low food secure and very low food secure. At the least severe level of food insecurity, people are worrying about getting enough food; at the most severe level, people are skipping or cutting back on meals or losing weight because of lack of food (Nord et al., 2010). The questions which comprise the food security scale, shown in Appendix 1, specify that any behavior or condition must be due to a lack of economic or other resources to obtain food. The scale, therefore, is not affected by insecurity and hunger due to voluntary dieting or fasting or being too busy to eat or other reasons.

2.3.1.4 Food insecurity and health outcomes

Although each episode of food insecurity is generally short in duration, the dietary changes associated with food insecurity may persist over extended periods because food-insecure households often experience repeated food budget shortages. Households reported being food insecure at some time during the year were food insecure for about 7 months during the year (Nord et al., 2010). Food insecurity has been associated with a lack of home availability of nutritious, decreased dietary variety and increased consumption of energy-dense foods including refined grains, added sugars, and added saturated/trans fats (Seligman et al., 2009). Those who live in food-insecure households consume fewer weekly serving of fruits, vegetables, and dairy and lower levels of micronutrients, including the B complex vitamins, magnesium, iron, zinc, and calcium (Dixon et al., 2001; Lee et al., 2001; Tarasuk et al., 1999). These dietary patterns are linked to the development of adverse health outcomes including inflammation, obesity, metabolic syndrome, hypertension, hyperlipidemia, diabetes and so on (Mendoza et al., 2006; Mendoza et al., 2007; Nettleton et al., 2006; Seligman et al., 2009; Vozoris et al., 2003). Studies report that food insecurity is associated with poor dietary intake (Lee et al., 2001), obesity (Kim 2007; Lyons et al., 2008; Seligman et al., 2007; Tayie et al., 2009;), chronic diseases (Parker et al.,. 2010; Seligman et al., 2009; Terrel et al.,2009), depression (Kim 2007), poor cognitive function (Gap et al., 2009), and poor self-reported health status (Pheley et al., 2002; Stuff et al., 2004).

Results from studies examining the relationship between food insecurity and health outcomes were presented in Table 2.5 and briefly reviewed in the following discussion. Few studies have examined the health consequences of food insecurity among older adults. The experience of food insecurity for older populations may be different from that of other age groups. Compared to the general population, older adults had poorer health status and larger accumulated life experience, which may affect their perceptions of their food insecurity status (Lee et al., 2001). Previous research has shown that past experience such as food deprivation during the Great Depression greatly affects older adults' perception of food insecurity (Wolfe et al., 1996; Quandt et al., 2001), which is likely to affect how they respond to food insecurity questions (Wolfe et al., 1996). In addition, normal and pathological changes that occur with aging can decrease food intake and impair nutrition absorption and use (Zizza, 2007). Food insecurity may cause other physical, emotional, and economic burdens in older adults who already use more healthcare and other services than the general population (Lee et al., 2001).

2.3.2 The relationship between food security and functional status

Only three cross-sectional studies appear to have examined the relationship between food security and functional status. A site-specific study reported that food insecure older adults were more likely to have lower global quality of life, assessed by the means of an 11-point uniscale (Vailas et al., 1998). This study assessed food insecurity using 7 questions with response options ranging from always true to never on a 5 point scale. Pheley et al. reported that food insecurity, measured by US HFSSM, was a significant independent predictor of functional health and well-being as assessed by the Medical Outcome Study Short Form-36 (SF-36) (Pheley et al., 2002). Another study found that household food insecurity, measure by the US HFSSM, is associated with poorer self-reported health status of adults among a rural sample in the Lower Mississippi Delta area (Stuff et al., 2004). All three studies are site-specific studies and based on self-reported measures of functional status.

The association between food insecurity and impaired functional status may be attributed to several factors, among which is poor dietary intake. People living in food insecure households tend to have increased consumptions of energy dense and nutrient poor foods, as well as decreased consumption of energy poor and nutrient dense foods. In addition, food insecurity is also associated with low diet variety. Previous studies suggested that people living in food insecure households may have a preference for buying low-cost foods such as refined grains, added sugars, and/or fats, which are energy dense and nutrient poor. This dietary pattern may result in reduced consumption of healthier but more expensive foods, such as lean meats, fish, fresh vegetables, and fruits.

Although literature about the association of food insecurity and functional status has been limited, such a linkage can be expected since other studies support the relationships between food insecurity and various health conditions (Figure 2.4).

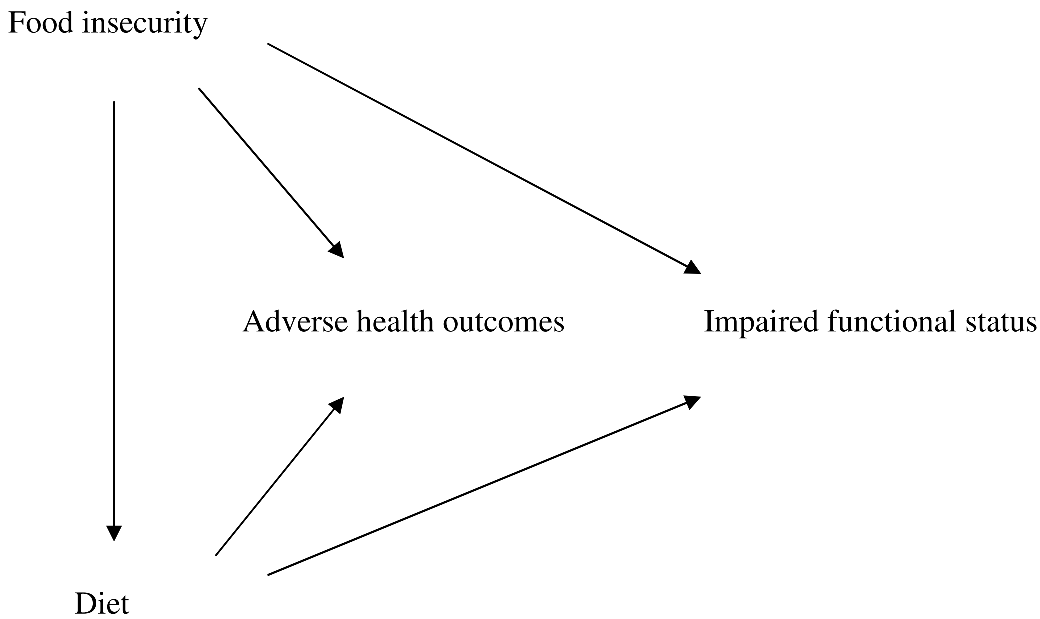

Figure 2.4 A theoretical model to explain the association between food insecurity and impaired functional status

Table 2.5 Overview of studies examining the relationship between food insecurity and health outcomes in adults

Author/Date	Study design	Population	Exposure variable	Outcome variable	Covariates	Results
Gao et al., 2009	Boston, MA Cross-sectional	Age: 45-75 y *n* = 1,358 Puerto Ricans	Food insecurity: assessed by the Food Security Survey Module Three categories: food secure, low food insecure, very low food secure	Mini-Mental State Examination (MMSE)	Age, gender, education, BMI, poverty, smoking, alcohol use, presence of hypertension or diabetes, plasma homocystein concentration, acculturation score	Food insecurity was inversely associated with global cognitive performance, as assessed by the MMSE score.
Klesges et al., 2001	Women's Health and Aging Study 1992-1995 Baltimore, MD Cross-sectional	Age: ≥65 y *n* = 1,001	Food sufficiency: assessed by a single item which is similar to measures used in USDA surveys of food insecurity	Mental health and cognitive functioning: Mini-Mental State Examination; Disability and performance:15 activities clustered in 4 domains, gait speed and grip strength; Health status anthropometrics: biomedical markers (iron, albumin and total cholesterol)	Age, education, marital status and number of household members Effect modifier: race/ethnicity.	Greater likelihood of financial difficulty acquiring food was associated with slower gait speed and difficulty with ADLs among White women, not among non-White women.
Kim & Frongillo,	Health and Retirement	Age: 51-61 y (HRS)	Food insecurity: U.S. Household Food	BMI; self reported height and weight;	Age, gender, ethnicity, marital	Food insecurity was positively

2007	Study 1996-2002 (HRS) and Asset and Health Dynamics Among the Oldest Old 1995-2002 (AHEAD) Longitudinal	≥70 y (AHEAD) *n* = 12,652 (HRS) *n* = 7,447 (AHEAD)	Security Survey Module (HFSSM)	Depression: 8-item version of the Center for Epidemiologic Studies-Depression (CES-D) scale	status, education, smoking status, income, physical functioning, health conditions, and social interaction	related to weight and depression among older adults.
Lee & Frongillo, 2001	NHANES 1988-1994 Nutrition Survey of the Elderly in New York State (NSENY, 1994) Cross-sectional	Age: 60-90 y *n* = 6,596	Food insufficiency questions in the NHANES and the three food insecurity items in the NSENY	Nutrient intake: a 24-h recall; skinfold thickness; self-reported health status; nutritional risk: scale adopted from the ten-item Nutritional Screening Initiative checklist (NSIC)	Physical functioning including ADL and IADL; chronic disease; age; race/ethnicity; marital status; education; social support or social isolation; location; poverty index ratio; food assistance program participation; gender; dietary change due to health problem; use of vitamin/mineral supplementation.	Food insecure older persons had significantly lower intakes of energy, protein, carbohydrate, saturated fat, niacin, riboflavin, vitamin B-6 and B-12, magnesium, iron and zinc, as well as lower skinfold thickness. In addition, food insecure elderly persons were more likely to report fair/poor

						health status and had higher nutritional risk.
Lyons et al., 2008	Canadian Community Health Survey (CCHS): 2000-2001; 2004 Cross-sectional	Age: ≥12 y *n* = 16,527 Canadians	Three different models of food insecurity: Dimensional model of food insecurity; Levels model of food insecurity: Food Security Module (food secure; food insecure without hunger; food insecure with mild hunger; food insecure with severe hunger); Overall food insecurity model	Obesity: both self-reported and measured height and weight data to calculate BMI	Income, educational level, ethnicity, area of residence	Associations between obesity and food insecurity are more pronounced when self-reported data on height and weight are used than then measured height and weight data are used
Paker et al., 2010	NHANES 1999-2006 Cross-sectional	Age: ≥12 y *n* =9,251 US civilian population	Food insecurity: assessed by the Food Security Survey Module	Metabolic syndrome: use of criteria set forth by the National Cholesterol Education Program Adult Treatment Panel III (ATP III)	Age, gender, race/ethnicity, household income, education, smoking status	Members of households with marginal and very low food security are at increased risk of Metabolic Syndrome.
Pheley et al., 2002	Athen, Ohio, and the surrounding counties	Age: ≥ 20 y *n* = 1,006	Food insecurity: US Core Module (1999) Four categories: food secure, food insecure without hunger, food	Functional health and well-being: Medical Outcome Study Short Form-36 (SF-36)	Age, race, marital status, employment status, acknowledge of	Food insecurity was a significant independent predictor of

			insecure with moderate hunger, food insecure with hunger		a regular primary care physician, health insurance status, Medicaid recipient, and clinic-community participant	responses for each SF-36 scale.
Seligman et al., 2007	NHANES 1999-2002 Cross-sectional	Age: >20 y *n* = 4,423 US civilian population	Food insecurity: assessed by the Food Security Survey Module 3 categories: food security (0 affirmative responses); mild food insecurity (1-5 affirmative responses); severe food insecurity (6-10 affirmative responses)	BMI: measured height and measured weight Waist circumference; self reported diagnosis of diabetes	Age, race/ethnicity, parity (women only), household income, family history of diabetes in a sibling or parent, educational attainment, and level of physical activity. Models are stratified by gender.	Participants with severe food insecurity were more likely to have diabetes than those without food insecurity. This association persisted after further adjusting for body mass index.
Seligman et al., 2009	NHANES 1999-2004 Cross - sectional	Age: 18-65 y *n* =5,094 US civilian population	Food insecurity: assessed by the Food Security Survey Module	Self-reported or laboratory/examination evidence of diet-sensitive chronic disease including hypertension, hyperlipidemia, and diabetes	Age, gender, race, education attainment, and income	Food security was associated with self-reported hypertension and hyperlipidemia, but not

						diabetes. Food insecurity was associated with laboratory or examination evidence of hypertension.
Stuff et al., 2004	Food of Our Delta (FOODS 2000) Lower Mississippi Delta area Cross-sectional	Age: ≥18 y *n* = 1,488	Food security: U.S. Food Security Survey Module Three categories; food secure; food insecure without hunger; food insecure with hunger	Overall physical and mental health status: Short Form 12-item Health Survey (SF-12)	Household income, age, ethnicity	Household food insecurity is associated with poorer self-reported health status of adults in this rural, high-risk sample in the Lower Mississippi Delta.
Tayie & Zizza 2009	NHANES 1999-2002 Cross-sectional	Age: 18-50 y *n* = 2,695	Food insecurity: assessed by the Food Security Survey Module Four categories: fully food secure, marginal food secure, food insecure without hunger, food insecure with hunger	Serum triglycerides (TRG), total cholesterol, high-density lipoprotein cholesterol (HDL-c) and low-density lipoprotein cholesterol (LDL-c)	Age, education, income, physical activity, race/ethnicity and smoking status	Food insecurity did not associate with dyslipidemia among men. Compare with fully food secure, women with marginally food secure were more likely to have abnormal levels

						of LDL-c and TRG/HDL-C ratio. Women who were food insecure without hunger were more likely to have abnormal levels of TRG.
Tayie & Zizza., 2009	NHANES 1999-2002 Cross-sectional	Age: 18-50 y *n* = 4,026	Food insecurity: assessed by the Food Security Survey Module Four categories: fully food secure, marginal food secure, food insecure without hunger, food insecure with hunger	Body fat percentage, BMI, weight	Age, education, race/ethnicity, income and smoking status	Food insecurity is associated with shorter height and lower body fat percentage and BMI in men. Marginal food security is associated with shorter height in women.
Terrell et al., 2009	NHANES 1999-2004 Cross-sectional	Age: 45 y on average *n* = 15,199	Food insecurity: assessed by the Food Security Survey Module Two categories: food secure; food insecure	Diabetes mellitus, hypertension, and chronic kidney disease	Age, gender, race/ethnicity, comorbid conditions, poverty, education, insurance and employment	Food insecurity is associated with a higher likelihood of having diabetes mellitus. No association was found between food insecurity and

						hypertension and chronic kidney disease.
Vailas et al., 1998	Pepin County, Wisconsin Cross-sectional	Age: ≥60 y *n* = 155	Food insecurity: 7 questions with response options ranging from always true to never on a 5 point scale.	Global quality of life: means of an 11-point uniscale	None	Food insecurity was negatively associated with quality of life.

Chapter 3 Association between Overall Diet Quality and Physical Performance: Results from National Health and Nutritional Examination Survey (NHANES) 1999-2002

3.1 Abstract

Background: Although nutritional status is one of the major determinants of healthy aging, little is known regarding the relationship between overall diet quality and physical performance among older adults. We examined the association between overall diet quality, as measured by the USDA's Healthy Eating Index-2005 (HEI-2005), and physical performance, as measured by gait speed and knee extensor power, among adults $\geq$ 50 y.

Method: The study used data from the 1999-2002 National Health and Nutrition Examination Survey (NHANES). Multiple linear regression models were used to examine the associations between HEI-2005 scores and physical performance. Age, gender, race/ethnicity, education and smoking status were controlled for in all multiple regression models.

Results: Older adults with higher HEI-2005 scores had a faster gait speed compared to those with the lowest HEI-2005 score (1.03 and 1.04 m/s in quartiles three and four, respectively, vs. 1.00 m/s in quartile one; both $p < 0.05$). For knee extensor power, those with the highest HEI-2005 scores had greater knee extensor power compared to those with the lowest HEI-2005 scores (1.60 vs. 1.50 W/kg in quartile four vs. quartile one; $p = 0.03$).

Conclusion: Adherence to overall dietary recommendations is associated with better physical performance among older adults.

3.2 Introduction

As the number of older adults and average life expectancy continue to rise, many people will experience functional impairments, an integrated marker of health status during the aging process (Guralnik et al., 1996). Nutritional status is one of the major determinants of functional status with aging (Alipanah et al., 2009; Cesari et al., 2004; Houston et al., 2005; Lauretani et al., 2007;Lauretani et al., 2008;Milaneschi et al., 2010; Ortega et al., 1996; Semba et al., 2007; Sharkey et al., 2003; Sharkey et al., 2004; Snowdon et al., 1996; Tomey et al., 2008；Verreault et al., 2002; Zamboni et al., 2002). Much of the current research examining the association between diet and functional status are limited by area specific populations (Alipanah et al., 2009; Cesari et al., 2004; Houston et al., 2005; Lauretani et al., 2007;Lauretani et al., 2008;Milaneschi et al., 2010; Ortega et al., 1996; Semba et al., 2007; Sharkey et al., 2003; Sharkey et al., 2004; Snowdon et al., 1996; Tomey et al., 2008；Verreault et al., 2002; Zamboni et al., 2002), female only participants (Semba et al., 2007; Snowdon et al., 1996; Tomey et al., 2008；Verreault et al., 2002; Zamboni et al., 2002), small sample size (Alipanah et al., 2009; Lauretani et al., 2007；Ortega et al., 1996; Semba et al., 2007; Sharkey et al., 2003; Snowdon et al., 1996; Verreault et al., 2002; Zamboni et al., 2002) and self-reported measures of functional status (Houston et al., 2005; Ortega et al., 1996;Sharkey et al., 2004; Snowdon et al., 1996; Tomey et al., 2008). Performance-based measures have been suggested to improve the evaluation of functional status in older adults because they are objective, allow for variability in the effort needed to perform different tasks, and can better discriminate functional levels in well functioning older adults (Curb et al., 2006).

Moreover, most of those studies focused on only single nutrients or individual food groups (Alipanah et al., 2009; Cesari et al., 2004; Houston et al., 2005; Ortega et al., 1996; Snowdon et al., 1996; Lauretani et al., 2007; Lauretani et al., 2008; Semba et al., 2007; Verreault et al., 2002; Zamboni et al., 2002). Because of the complexity of dietary intake as well as the possible interaction of different nutrients, it is often difficult to attribute the effects of a single dietary component on health outcomes (Hu 2002). An overall healthy diet may play a critical role in the prevention of functional impairements among older adults. The Healthy Eating Index-2005 (HEI-2005), developed by the United States Department of Agriculture (USDA), provides a picture of overall diet quality. Considering the role of diet in the prevention of impaired muscular function, osteoporosis, and oxidative damage associated with aging and chronic disease (Cesari et al., 2004; Lampe 1999; Snowdon et al., 1996; Zamboni et al., 2002), it is reasonable to hypothesize that a better overall diet quality may play a role in preventing or delaying age-related functional decline.

To our knowledge, the association between overall diet quality and physical performance in older adults has not been studied. Therefore, the purpose of this study was to examine the association between overall diet quality as measured by HEI-2005 scores and physical performance in a nationally representative sample of men and women. The associations between each of the individual HEI-2005 components and physical performance were also examined in this study.

3.3 Methods

3.3.1 Study design and participants

The National Health and Nutrition Examination Survey (NHANES), conducted by the National Center for Health Statistics (NCHS), consists of a detailed in-person home interview and a health examination conducted in a mobile examination center (MEC). MECs consist of travel trailers with necessary equipment for health examinations, and they are staffed by trained medical personnel including physicians, medical/health technicians, and dietary/health interviewers. In-home interview results include data about demographic, socioeconomic, dietary, and health-related information. Health examinations at the MECs include information collected by performing medical and dental exams, physiological and anthropometric measurements, laboratory tests, and 24-hour dietary recall interviews.

The NHANES has a complex, multistage, probability sampling design that consists of four stages. In stage one, counties were randomly selected as primary sampling units (PSUs). In stage two, the PSUs are divided into segments (city blocks or their equivalent). In stage three, a sample is randomly drawn from households within each segment. Finally in stage four, individuals within households were selected. Every year, NHANES survey examines about 5,000 individuals from counties located across the country. Since 1999, data have been collected continuously every year and released in 2-year data segments. Information collected from 1999 to 2002 was used in this study because data on performance-based physical function measures were not collected in subsequent surveys.

Of 4,983 individuals aged 50 years and older who completed both the in-person home interview and physical examination in the MEC, 402 participants were excluded with missing confounding variables (age, gender, education and smoking status) and 685 participants were excluded for missing HEI-2005 data. After excluding incomplete data for gait speed (*n* = 342), the final sample size is 3,554 for gait speed. Regarding knee extensor power, 495 participants were excluded from the muscle strength examination because of chest or abdominal surgery in the previous 3 weeks; heart attack in the previous 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 testing was conducted at a fixed angular velocity of 60 degrees/s, 1,081 participants with peak force velocity that varied > 5 degrees/s from the chosen testing velocity were also excluded. Another seven participants were excluded because data on body weight were unavailable. Thus, the final analytic sample for knee extensor power was 2.313. This study was approved as exempt by the Institutional Review Board of the Office of Human Subjects Research at Auburn University.

3.3.2 Diet quality

Dietary data were collected using a 24-hour recall that employed the USDA Automated-Multiple Pass Method (AMPM). The AMPM included multiple passes through the 24 hours of the previous day, during which respondents received cues to help them remember and describe foods and the amounts of food they consumed (Moshfegh et al., 2008).

The HEI-2005, a composite score assessing an individual's adherence to the 2005 *Dietary Guidelines for Americans* (DGA), was used to measure an individual's overall diet quality. The HEI-2005 is comprised of 12 nutrient- and food-based components. The first six components, including total fruits, whole fruit, total vegetables, dark green and orange vegetables and legumes, total grains and whole grains, are each awarded 0 to 5 points. The next five components, including milk, meat and beans, oils, saturated fat and sugar, are each awarded 0 to 10 points. The last component reflects calories from solid fat, alcohol, and added sugars (SoFAAS) and is allocated 0 to 20 points. Scores for the 12 components were summed to give a total HEI-2005 score ranging from 0 to 100, with a higher score indicative of a healthful diet. Information about the HEI-2005 and its scoring system is reviewed elsewhere (Guenther et al., 2007).

For the purpose of this analysis, HEI-2005 scores were categorized into quartiles to express the diet quality, the first quartile representing the lowest quality and the fourth quartile representing the highest quality. The lowest quartile of HEI-2005 scores was chosen as the reference group. Each of the HEI-2005 component scores was analyzed as an indicator variable (those who met their recommendations vs. all others).

3.3.3 Physical performance

Performance-based measures included gait speed and knee extensor power. Gait speed is a validated measure of function and disability in community dwelling older adults (Brach et al., 2007). In NHANES 1999-2002, the timed 20-foot walk test, performed at the participant's usual pace, was measured using a hand-held stopwatch. Participants were allowed to use a walker or cane if needed, but individuals were excluded from testing if they needed the assistance of another individual to walk. A 20-

foot walking test track was set up along the corridor of the MEC. Strips on the floor indicate the start and stop for the measured walk. Walk time was measured from the time the participant's first foot touches the floor across the start line and stopped when his/her foot touches the floor across the finish line. Gait speed (m/s) was calculated as the walking distance (20 feet = 6.15 m) divided by the time required to complete the task (in seconds).

Muscle power is an established indicator of functional status in older adults (Bean et al., 2003). In NHANES 1999-2002, right knee extensor force production was measured using a Kinetic Communicator isokinetic dynamometer (Kin-Com MP, Chattecx Corp., Chattanooga, TN, USA). The participant was asked to sit on the dynamometer chair with the back supported and to keep hands in the lap during the examination. A stabilizing strap was attached across the chest and the pelvis to help stabilize the participant in the chair. A thigh strap and a shin pad were attached after the participant was positioned in the dynamometer chair. A goniometer (an instrument used to measure joint angles) was used to measure the angle of the knee joint when the participant was positioned in the dynamometer chair. The start and stop angles of the isokinetic quadriceps strength test were set at 90 degrees and 150 degrees, respectively. The participant was asked to push the shin pad forward through full range of motion of the right leg. Maximal voluntary concentric muscle force was measured in N in the right quadriceps muscle at an angular velocity of 60 degrees/s. Only the right leg was measured since no significant differences have been observed between right and left legs (Lindle et al., 1997). 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 N was selected from trials 4-6. For those participants with fewer than four trials, the highest value was selected from the completed trials. Although the Kin Com dynamometer can test various speeds in major muscle groups, 60 degrees per second was chosen for this examination because it is clinically relevant and it is reported in the literature as the optimum speed for measuring muscle strength (Muscle Strength Procedure Manual 2000). Knee extensor power was calculated as follows (Kuo et al., 2006):

Peak leg power (W) = Peak torque (Newton-m) * Peak force velocity (Radians/s), where peak torque is equal to peak force (Newton) * lever arm length (m), and peak force velocity (Radians/s) is equal to peak force velocity (degree/s) * (π/180), where $\pi = 3.14$. The lever arm length is the distance from the participant's ankle to their knee joint. As power requirements for functional tasks vary by body size, knee extensor power values were standardized by dividing by body weight in kilograms (W/kg) (Davis & Dalsky 1997). Body weight with minimal clothing was measured on a digital electronic scale.

3.3.4 Confounding variables

Confounding variables included age, gender, race/ethnicity, education, and smoking status. For this analysis, age was considered as a continuous variable. Three race/ethnicity categories were examined: non-Hispanic white, non-Hispanic black, and Hispanics. Level of education was defined as < a high school degree or ≥ a high school degree. Smoking status was determined by the reported use of cigarettes, cigars, or pipes and participants were classified as never, former or current smokers.

3.3.5 Statistical analyses

The NHANES surveys are multistage, stratified area probability samples. According to guidelines issued by the federal government, analytic approaches of data from a simple random sample are not appropriate for data analysis (CDC 2006). 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. Trend associations between confounding factors and quartiles of HEI-2005 scores were tested by using chi-square tests for categorical variables and linear regression analysis for continuous variables. Multiple linear regression models were used to estimate the associations between quartiles of HEI-2005 scores and physical performance including gait speed and knee extensor power. The median value for each HEI-2005 quartile was used as a continuous variable to test the trend association. The relationship between the 12 individual HEI-2005 components and physical performance was also examined using multiple regression models. Age, gender, race/ethnicity, education and smoking status were controlled for in all multiple regression models. Statistical significance was assigned at $p < 0.05$ (two sided).

3.4 Results

3.4.1 Descriptive characteristics of the sample

Descriptive characteristics of the analytic sample for gait speed by quartile of HEI-2005 scores are presented in Table 3.1. The mean gait speed of the participants was 1.02 m/s. More than one half of the participants were non-Hispanic white (83%), female (59%) and had an education ≥ high school (74%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older, better educated and more likely to meet individual HEI-2005 component recommendations (except for sodium). We also found that the completion or non-completion of 20-foot walk test ($p = 0.62$) and muscle power test ($p = 0.10$) did not predict HEI-2005 scores.

Descriptive characteristics of the analytic sample for knee extensor power by quartile of HEI-2005 scores are presented in Table 3.2. The mean knee extensor power of the participants was 1.54 W/kg. More than one half of the participants were non-Hispanic white (83%), female (55%) and had an education ≥ high school (77%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older, better educated and more likely to meet individual HEI-2005 component recommendations (except for sodium). We also found that the completion or non-completion of muscle strength test ($p = 0.10$) did not predict HEI-2005 scores.

3.4.2 Total HEI-2005 scores and self-reported disability

After adjusting for confounders, total HEI-2005 scores were positively associated with both gait speed (p for trend = 0.004) and knee extensor power (p for trend = 0.005) (Table 3.3). Older adults with HEI-2005 scores in quartiles three ($p = 0.028$) and four ($p = 0.008$) had a faster gait speed compared to those with HEI-2005 scores in the lowest quartile. For knee extensor power, those with HEI-2005 scores in quartile four had a greater knee extensor power compared to those with HEI-2005 scores in the lowest quartile ($p = 0.004$). Additional analyses including BMI as a confounder did not change the direction of the association between total HEI-2005 scores and physical performance.

3.4.3 Individual HEI-2005 component scores and physical performance

Individual HEI-2005 component scores were also associated with performance-based measures. Those who met the recommendations for HEI-2005 total fruit and whole fruit, dark green and orange vegetables and legumes and oils had a faster gait speed compared to those who did not (Table 3.4). However, those who met the recommendations for HEI-2005 meat and beans and sodium had a slower gait speed compared to those who did not. Those who met the recommendations for HEI-2005 total fruit and whole fruit had greater knee extensor power. No inverse relationship between individual HEI-2005 components and knee extensor power was observed.

3.5 Discussion

To our knowledge, this is the first study to observe that overall diet quality, as measured by HEI-2005 scores, was positively associated with physical performance, as measured by gait speed and knee extensor power, among a nationally representative sample of US men and women. Similar to our results, a previous longitudinal study reported that people with lower HEI-1995 scores (an earlier version of the HEI) had a higher risk for incident self-reported mobility limitations (Koster et al., 2007). Using a representative sample of older Italians, Cesari and colleagues reported higher dietary antioxidants intake was associated with higher knee extension strength (Cesari et al., 2004). Another study examining specific nutrients and physical performance found that a low summary musculoskeletal nutrient intake including calcium, vitamin D, magnesium, and phosphorus intakes was associated with increasing worse levels of lower extremity physical performance, including balance, gait speed and repeated chair stands (Sharkey et al., 2003).

The component scores used to calculate the total HEI score offer an opportunity to study important components of dietary intake and their relationships to physical performance measures. Our study found higher HEI-2005 scores for total fruit, whole fruit and dark green and orange vegetables and legumes were associated with a faster gait speed. In addition, higher HEI-2005 scores for total fruit and whole fruit were associated with greater knee extension power. The mechanisms behind the protective effects of consuming fruit and vegetables remain unclear, but it is hypothesized that antioxidants found in these foods play a role (Lampe 1999). Fruits and vegetables are important sources of antioxidants, vitamins, minerals, and fiber (Weisburger 2000). Cross-sectional and longitudinal studies have both reported relationships between low serum or plasma carotenoids concentrations and lower gait speed, greater decline of gait speed, greater risk of developing poor hip, knee and grip muscle strength (Alipanah et al., 2009; Lauretani et al., 2008; Semba 2007). These studies support the beneficial effects of fruits and vegetables, the most important natural sources of antioxidants, to minimize physical limitations. Antioxidants, including the carotenoids, vitamin C, vitamin E and other polyphenols, may help prevent free radical damage that contributes to inflammation associated with chronic disease and functional decline (Cesari et al., 2004; Snowdon et al., 1996; Lampe 1999). Two longitudinal studies examining the association between food groups and functional status reported that lower fruit and vegetable consumption is associated with greater self-reported functional limitations in older adults (Houston et al., 2005; Tomey et al., 2008).

Besides antioxidants, researchers also reported that other nutrients play a role in functional status. One longitudinal study reported that women with diets higher in cholesterol, total fat and saturated fat intake reported more functional limitations (Tomey et al., 2008). We also found those who met the oil recommendations had a faster gait speed compared to those who did not.

An unexpected finding was that the sodium component was inversely associated with gait speed. The complexity of assessing overall quality is illustrated by these results. Sodium is widely distributed in foods, as it occurs naturally and is also added in the processing and preparation of many foods. Guenther has reported that higher grains, total vegetables, and the meat and beans component scores correspond with, higher sodium intake and, consequently, lower sodium component scores (Guenther 2007). According to our results, those with higher HEI-2005 scores were more likely to meet those component recommendations except for sodium component (Table 3.1 & Table 3.2).

Diagnosed and undetected cardiovascular disease that involve dysfunction of one or more underlying biologic, neurologic, or psychological systems have also been associated with poor physical performance (Tomey et al., 2008). It is well established that the risk of chronic diseases, including heart disease, arthritis, and obesity can be lowered by diets that include an abundance of fruits, vegetables, whole grains, nuts, n-3 fatty acids, and antioxidants as well as low levels of refined carbohydrates and saturated fats (Hu & Willett 2002；Stafford et al., 1998). The HEI-2005 score encompasses these dietary characteristics; therefore, it is a useful tool to predict functional status among older adults.

In an earlier study, others examined the magnitude of clinically meaningful differences in gait speed among older adults (Perara et al., 2006). They concluded that the criterion for a small meaningful difference in gait speed was equal to 0.05 m/s while 0.10 m/s represented a substantial meaningful difference. Our study found a small meaningful difference in gait speed between those individuals that met the recommendations for dark green and orange vegetables and legumes.

Our study is limited by its cross-sectional design, which cannot provide evidence of a causal relationship between HEI-2005 and functional status. In addition, the NHANES study does not include institutionalized individuals who probably have a lower diet quality and a higher prevalence of poor functional status than community-dwelling older adults. The mean gait speed for participants in our study was a little higher than 1.0 m/s, which is a clinically useful value to identify people who are at high risk of developing health-related adverse events (Cesari et al., 2005). In addition, the HEI-2005 scores in this study were based on a single 24-hour dietary recall data which may be subject to under- or over-reporting, depending on the population (Thompson & Subar 2008). The AMPM method has been shown to underestimate energy intakes by 11% in a population of normal, overweight, and obese persons (Moshfegh et al., 2008).

Despite these limitations, this study has some advantages. First, our study employed the rigorous data collection procedures used in the NHANES with the ability to generate a nationally representative estimate. In addition, diet quality was measured by HEI-2005 scores that reliably capture key recommendations in the 2005 DGA (USDA 2005). Using HEI-2005 scores to measure diet quality is also useful for comparisons across different study populations. It has been noted that studies using data-driven analyses to examine dietary behavior within a population may not be replicable in other populations (Miller et al., 2010). In addition, we used valid, reliable, and objective performance-based measures instead of self-reported measures (Bean et al., 2003；Brach et al., 2007).

In summary, the results of the present study add to the growing body of literature that demonstrates that diet quality is associated with functional status in older adults. Future studies to examine the prospective association of diet quality and functional status should provide greater insight into this relationship. In particular, it is important to understand how poor diet quality leads to poor functional status, and how poor functional status can itself lead to poor dietary intake. Future work that evaluates longitudinally whether the consumption of a healthy diet contributes to other markers of health status, including health care utilization, is warranted. Such investigation may provide greater evidence in support of nutritional interventions targeting community dwelling older adults (Kamp et al., 2010). As policies and programs are increasingly being targeted at maintaining older adults' residence in the community, such work is compelling. Improving diet quality may be key as a cost saving measure in maintaining the functional status of older adults and must be an important focus of public health efforts as the size of this population continues to increase.

Table 3.1 Descriptive characteristics of analytic sample for gait speed among participants aged 50 and older by quartiles of HEI-2005 scores (*n* = 3,554)

	Quartiles of HEI-2005					
	Q1 (*n* = 889)	Q2 (*n* = 888)	Q3 (*n* = 889)	Q4 (*n* = 888)	Total (*n* = 3,554)	*p*-value*
Median HEI (Range)	37.4 (15.0-44.2)	50.0 (44.2-55.1)	60.1 (55.1-65.5)	71.9 (65.5-94.0)	55.1 (15.0-94.0)	
Age (y), Mean (SE)	61.5 (0.3)	63.6 (0.3)	64.7 (0.4)	65.2 (0.5)	63.7 (0.2)	<0.001
Male (%)	50	44	37	34	41	<0.001
Race/ethnicity (%)†						0.001
Non-hispanic white	80	81	84	85	83	
Non-hispanic black	12	9	7	6	9	
Hispanic	8	10	9	9	9	
≥ High school education (%)	69	70	75	81	74	<0.001
Smoke (%)						<0.001
Never	36	42	46	57	45	
Former	30	33	40	35	34	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 889)	(*n* = 888)	(*n* = 889)	(*n* = 888)	(*n* = 3,554)	*p*-value*
Current	34	25	14	8	21	
HEI-2005, Mean (SE)	36.7 (0.3)	50.6 (0.2)	60.6 (0.2)	73.5 (0.4)	54.8 (0.6)	<0.001
Meeting recommendations (%)						
Total fruit	10	25	38	66	34	<0.001
Whole fruit	11	29	50	75	41	<0.001
Total vegetables	20	30	39	46	33	<0.001
Dark green and orange vegetables and legumes	5	10	16	27	14	<0.001
Total grains	43	50	57	62	53	<0.001
Whole grains	2	4	8	19	8	<0.001
Milk	13	18	17	24	18	<0.001
Meat and beans	47	53	58	67	56	<0.001
Oils	7	22	29	41	24	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 889)	(*n* = 888)	(*n* = 889)	(*n* = 888)	(*n* = 3,554)	*p*-value*
Saturated fat	8	13	17	31	17	<0.001
Sodium	3	2	2	3	3	0.343
SoFAAS‡	0	2	12	42	14	<0.001
Gait speed (m/s), Mean (SE)	1.01 (0.01)	1.02 (0.01)	1.02 (0.01)	1.03 (0.01)	1.02 (0.01)	0.164

* For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the *p* value is for the chi-square test of association.

†Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic whites.

SoFAAS: Calories from Solid Fats, Alcoholic beverages, and Added Sugars.

Table 3.2 Descriptive characteristics of analytic sample for knee extensor power among participants aged 50 and older by quartiles of HEI-2005 scores (n = 2,313)

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 579)	(n = 578)	(n = 578)	(n = 578)	(n = 2,313)	p-value*
Median HEI (Range)	36.9 (15.1-43.5)	49.7 (43.5-55.0)	59.9 (55.0-65.3)	71.4 (65.3-94.0)	55.1 (15.1-94.0)	
Age (y), Mean (SE)	60.1 (0.4)	62.5 (0.4)	63.0 (0.6)	63.6 (0.7)	62.3 (0.2)	<0.001
Male (%)	52	49	38	37	45	<0.001
Race/ethnicity (%)†						0.079
Non-hispanic white	82	82	83	85	83	
Non-hispanic black	10	9	7	5	8	
Hispanic	7	9	10	10	9	
≥ High school education (%)	72	72	78	85	77	<0.001
Smoking status (%)						<0.001
Never	37	39	45	56	44	
Former	30	35	41	37	35	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 579)	(*n* = 578)	(*n* = 578)	(*n* = 578)	(*n* = 2,313)	*p*-value*
Current	33	26	15	7	21	
HEI-2005, Mean (SE)	36.7 (0.3)	50.6 (0.2)	60.6 (0.2)	73.5 (0.4)	54.8 (0.6)	<0.001
Meeting recommendations (%)						
Total fruit	11	26	36	69	34	<0.001
Whole fruit	12	30	47	76	40	<0.001
Total vegetables	20	29	38	44	32	<0.001
Dark green and orange vegetables and legumes	4	10	14	26	13	<0.001
Total grains	42	46	55	64	51	<0.001
Whole grains	2	4	8	18	8	<0.001
Milk	11	17	15	26	17	<0.001
Meat and beans	48	53	60	66	56	<0.001
Oils	7	22	31	40	24	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 579)	(*n* = 578)	(*n* = 578)	(*n* = 578)	(*n* = 2,313)	*p*-value*
Saturated fat	8	12	15	34	17	<0.001
Sodium	2	3	2	4	3	0.282
SoFAAS	0	2	12	40	13	<0.001
Knee extensor power (W/kg), Mean (SE)	1.57 (0.02)	1.55 (0.02)	1.49 (0.02)	1.54 (0.03)	1.54 (0.01)	0.126

* For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the *p* value is for the chi-square test of association.

† Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic whites.

SoFAAS: Calories from Solid Fats, Alcoholic beverages, and Added Sugars.

Table 3.3 Predicted values (LS means (SE)) for physical performance among those aged 50 and older by quartiles of HEI-2005 scores

	Quartiles of HEI-2005 scores				
	Q1[*]	Q2	Q3	Q4	*p* for trend[†]
	Mean (SE)				
Gait speed, m/s (n = 3,554)	1.00 (0.01)	1.02 (0.01)	1.03 (0.01)[‡]	1.04 (0.01)[§]	0.004
Knee extensor power, W/kg (n = 2,313)	1.50 (0.02)	1.54 (0.01)	1.54 (0.02)	1.60 (0.02)[§]	0.005

Notes: All linear regression models were adjusted for age, gender, race/ethnicity, education and smoking status.

[*]The first quartile of HEI-2005 scores was the reference group.

[†]Test for trend over the quartiles of HEI-2005 when the median value per quartile was used.

[‡]Statistical significance at $p < 0.05$ compared with the first quartile of HEI-2005 scores.

[§]Statistical significance at $p < 0.01$ compared with the first quartile of HEI-2005 scores.

Table 3.4 Predicted values (LS means (SE)) for physical performance among those aged 50 and older by meeting vs not meeting each HEI component

HEI-2005 components	Gait speed (m/s) (*n* = 3,554) Meeting the HEI component recommendation	Not meeting the HEI component recommendation	*p*-value	Knee extensor power (W/kg) (*n* = 2,313) Meeting the HEI component recommendation	Not meeting the HEI component recommendation	*p*-value
Total fruit	1.04(0.01)	1.01(0.01)	0.04	1.58(0.02)	1.53(0.01)	0.02
Whole Fruit	1.04(0.01)	1.02(0.01)	0.04	1.58(0.02)	1.52(0.01)	0.005
Total vegetables	1.02(0.01)	1.02(0.01)	0.85	1.54(0.02)	1.55(0.01)	0.85
Dark green and orange vegetables and legumes	1.06(0.01)	1.01(0.01)	<0.001	1.59(0.03)	1.54(0.01)	0.09
Total grains	1.02(0.01)	1.03(0.01)	0.38	1.53(0.01)	1.56(0.02)	0.11
Whole grains	1.01(0.02)	1.02(0.01)	0.52	1.54(0.04)	1.54(0.01)	0.94
Milk	1.02(0.01)	1.02(0.01)	0.86	1.55(0.02)	1.54(0.01)	0.63

	Gait speed (m/s) (n = 3,554)			Knee extensor power (W/kg) (n = 2,313)		
	Meeting the HEI component recommendation	Not meeting the HEI component recommendation	p-value	Meeting the HEI component recommendation	Not meeting the HEI component recommendation	p-value
Meat and beans	1.01(0.01)	1.04(0.01)	<0.001	1.54(0.02)	1.55(0.01)	0.71
Oils	1.04(0.01)	1.02(0.01)	0.03	1.57(0.02)	1.53(0.01)	0.18
Saturated fat	1.04(0.01)	1.02(0.004)	0.13	1.57(0.02)	1.54(0.01)	0.28
Sodium	0.97(0.02)	1.02(0.01)	0.02	1.66(0.06)	1.54(0.01)	0.06
SoFAAS	1.02(0.01)	1.02(0.01)	0.66	1.57(0.03)	1.54(0.01)	0.31

Notes: All linear regression models were adjusted for age, gender, race/ethnicity, education and smoking status.

SoFAAS: Calories from Solid Fats, Alcoholic beverages, and Added Sugars.

Chapter 4 Association between Overall Diet Quality and Self-reported Disability among Older Americans: Results from National Health and Nutritional Examination Survey (NHANES) 1999-2004

4.1 Abstract

Background: Nutritional status is vital to older adults' physical health and may prevent the onset of disability. The purpose of this study was to examine the association between overall diet quality and self-reported disability among a nationally representative sample of Americans aged 60 and older.

Methods: Cross-sectional data obtained from the 1999-2004 National Health and Nutrition Examination Survey (NHANES) were used. Overall diet quality was assessed using the Unite States Department of Agriculture's (USDA) Healthy Eating Index-2005 (HEI-2005). Self-reported measures of disability included activities of daily living (ADLs), instrumental activities of daily living (IADLs), leisure and social activities (LSAs), lower extremity mobility (LEM), and general physical activities (GPAs). Multiple logistic models were used to examine the association between HEI-2005 scores and self-reported measures of disability.

Results: Older adults with higher HEI-2005 scores were less likely to experience LEM (p for trend < 0.001) and GPAs (p for trend < 0.001) disability. Compared to older adults

whose HEI-2005 scores were in the lowest quartile, the likelihood of both LEM and GPA disability were significantly lower in individuals whose scores were in quartiles two, three, and four. Compared to those who had HEI-2005 scores in the lowest quartile, the odds of IADLs disability were significantly lower in older adults whose scores were in quartile two and three.

Conclusion: Older adults who do not adhere to the 2005 *Dietary Guidelines for Americans* (DGA) report disability more frequently than those who do adhere to the guidelines.

4.2 Introduction

According to the Surgeon General's Call to Action in 2005, 54 million people living in the United States have some disability. The chance of developing a disability increases with age, from less than 10% for people aged 15 and younger to almost 75% for people aged 80 and older (USDHHS 2005). Diet is an important modifiable factor contributing to functional disability, particularly in older adults (Milaneschi et al., 2010; Sharkey et al., 2003). Several studies examining the relationship between diet and functional status of individuals have focused on single nutrients or food groups (Cesari et al., 2004; Houston et al., 2005; Sharkey et al., 2003; Tomey et al., 2008). Because people consume a combination of foods, it is difficult to attribute the effects of a single nutrient or food to health outcomes (Hu 2002). Thus, studies examining the relationship between diet and health have increasingly witnessed a shift in focus from single nutrients to overall dietary quality. Dietary indexes, based on recommendations from various organizations, have been constructed to aid in identifying dietary quality, patterns, and variety (Weinstein et al., 2004).

The Healthy Eating Index-2005 (HEI-2005), developed by the United States Department of Agriculture (USDA), is a measure of overall dietary quality that assesses adherence to the 2005 *Dietary Guidelines for Americans* (DGA) (Guenther et al., 2007). HEI-2005 emphasizes dietary recommendations that are not currently being met in the US. This dietary index differs from an earlier version, HEI-1995, because it incorporates an assessment of foods and nutrients on a density basis (amounts per 1,000 calories). It also includes new food groups: whole fruit, dark green and orange vegetables and legumes, whole grains and oils. Lastly, it incorporates a discretionary component, the calories from solid fat, alcohol and added sugar (SoFAAS). One previous study reported that an earlier version of the HEI (HEI-1995) was associated with mobility limitations that were assessed with two items on a questionnaire among older adults aged between 70 to 79 years (Koster et al., 2007). However, other disability domains were not examined in this study.

We are not aware of any other studies that have examined the association between overall dietary quality, as measured by HEI-2005 scores, and self-reported disability assessed by multiple domains among older adults. Therefore, the purpose of this study was to examine the association between HEI-2005 scores and self-reported disability in a nationally representative sample of older adults.

4.3 Methods

4.3.1 Study design and participants

The present study used data from the National Health and Nutrition Examination Survey (NHANES) for the survey periods of 1999-2000 (n = 9,965), 2001-2002 (n = 11,039), and 2003-2004 (n = 10,122). These publicly available survey data files are conducted by the National Center for Health Statistics (NCHS). The response rates for the household interview and health examination, respectively, were 82% and 76% for 1999-2000, 84% and 80% for 2001-2002, and 79% and 76% for 2003-2004. The NHANES surveys are multistage, stratified area probability samples. Data were obtained from a subset of the US civilian non-institutionalized population during both a detailed in-person home interview and a health examination conducted in a mobile examination center (MEC) (http://www.cdc.gov/NCHS/nhanes/nhanes19992000/exam99_00.htm).

Of 4,984 participants aged 60 and older, data from 454 participants were excluded because of missing covariates (age, gender, race/ethnicity, education and smoking status) and data from 547 participants were excluded because of missing dietary information. After excluding missing data for activities of daily living (ADLs) (n = 2), instrumental activities of daily living (IADLs) (n = 118), leisure and social activities (LSAs) (n = 47), lower extremity mobility (LEM) (n = 460), and general physical activities (GPAs) (n = 471), the final sample size was 3,983 for ADLs, 3,865 for IADLs, 3,936 for LSA, 3,523 for LEM, and 3,512 for GPA. This study was approved as exempt by the Institutional Review Board of the Office of Human Subjects Research at Auburn University.

4.3.2 Dietary assessment

One 24-hour dietary recall that employed the USDA Automated-Multiple Pass Method (AMPM) was used to collect the dietary data. The AMPM included multiple passes through the 24 hours of the previous day, during which respondents received cues to help them remember and describe foods and the amounts of foods they consumed (Moshfegh et al., 2008).

The HEI-2005, a composite score assessing an individual's adherence to the 2005 DGA, was used to measure overall diet quality (Guenther et al., 2007). The HEI-2005 is comprised of 12 nutrient- and food-based components. The first six components, including total fruit, whole fruit, total vegetables, dark green and orange vegetables and legumes, total grains, and whole grains, are each given a score of 0 to 5 points. The next five components including milk, meat and beans, oils, saturated fat, and sugar are each given 0 to 10 points. The last component that reflects calories from solid fat, alcohol, and added sugars (SoFAAS) is given 0 to 20 points. The sum of the scores for the 12 components is the total HEI-2005 score, which ranges from 0 to 100, with a higher score indicatives of a more healthful diet. Information about the HEI-2005 and its scoring system is reviewed elsewhere (Guenther et al., 2007).

For the purpose of this analysis, HEI-2005 scores were categorized into quartiles to express the diet quality: the first quartile represents the lowest quality and the fourth quartile represents the highest quality. The lowest quartile of HEI-2005 scores was chosen as the reference group. Each of the HEI-2005 component scores was analyzed as an indicator variable (individuals who met their dietary recommendations vs. all others).

4.3.3 Disability

As in previous studies, 19 questions assess five major domains of disability: Activities of Daily Livings (ADLs), Instrumental Activities of Daily Livings (IADLs), Leisure and Social Activities (LSAs), Lower Extremity Mobility (LEM), and General Physical Activities (GPAs) (

Table 4.1). Each question assessed the difficulty an individual had in performing a task without the aid of any equipment. For each item, participants were allowed to select from among four levels of difficulty: “no difficulty,” “some difficulty,” “much difficulty,” and “unable to do.” The items examined included locomotion and transfers, household productivity, social integration, and manipulation of surroundings. Four activities were classified as ADLs: dressing oneself; walking between rooms on the same floor; getting in and out of bed; and using a fork, knife, and drinking from a cup. Three activities were used to classify IADLs: managing money; doing household chores; and preparing meals. LSAs also consisted of three activities: going out to movies and events; attending social events; and performing leisure activities at home, and LEM consisted of two activities: walking a quarter mile and walking up 10 steps. GPAs consisted of seven activities: stooping, crouching, kneeling; lifting or carrying; standing up from an armless chair; standing for long periods; sitting for long periods; reaching up over head; and grasping/holding small objects. These self-reported disability measurements have been validated (Rosow & Breslau 1966). Impaired functional status was defined as any difficulty in performing one or more of the activities within a given domain.

Table 4.1 Self-reported functional status

Domains	Components
Activities of Daily Living (ADLs)	Eating difficulty: using fork and knife, and drinking from cup
	Dressing yourself difficulty
	Walking between rooms on same floor difficulty
	Getting in and out of bed difficulty
Instrumental Activities of Daily Living (IADLs)	Managing money difficulty
	Housework difficulty
	Preparing meals difficulty

Leisure and Social Activities (LSAs)	Going out to movies and events difficulty
	Attending social events difficulty
Lower Extremity Mobility (LEM)	Walking for a quarter mile difficulty
	Walking up 10 steps difficulty
General Physical Activities (GPAs)	Stooping, crouching, kneeling difficulty
	Lifting or carrying difficulty
	Standing up from armless chair difficulty
	Standing for long periods difficulty
	Sitting for long periods difficulty
	Reaching up over head difficulty
	Grasping/holding small objects difficulty

4.3.4 Data analyses

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. Six-year examination sample weights were derived using an approach described in the NHANES analytic guidelines to account for the unequal probabilities of selection, person-level non-response, and a post-stratification adjustment to the estimated U.S. population (CDC).

Associations between confounding factors and quartiles of HEI-2005 scores were tested with Chi-square tests for categorical variables and linear regression analysis for continuous variables. Multiple logistic regression models were used to estimate the associations between quartiles of HEI-2005 scores and self-reported disability. Tests for linear trends across quartiles of HEI-2005 were conducted using the median value in each HEI-2005 category as a continuous variable in the logistic regression models. The relationship between the 12 individual HEI-2005 components and functional status was also examined using multiple logistic regression models. Age, gender, race/ethnicity, education, and smoking status were controlled for in all logistic regression models. For this analysis, age was considered to be a continuous variable. Three race/ethnicity categories were examined: non-Hispanic white, non-Hispanic black, and Hispanic. Level of education was defined as < a high school degree or ≥ a high school degree. Smoking status was determined by the self-reported use of cigarettes, cigars, or pipes, and participants were classified as never, former or current smokers. Statistical significance was assigned at $p < 0.05$ (two sided).

4.4 Results

4.4.1 Descriptive characteristics of the sample

Descriptive characteristics of the analytic sample for ADLs by quartile of HEI-2005 scores are presented in Table 4.2. Twenty three percent of the participants reported the ADLs disability. More than one half of the participants were non-Hispanic white (83%), female (62%), and had an education ≥ high school (70%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older and better educated.

Descriptive characteristics of the analytic sample for IADLs by quartile of HEI-2005 scores are presented in Table 4.3. Thirty percent of the participants reported the IADLs disability. More than one half of the participants were non-Hispanic white (83%), female (63%), and had an education ≥ high school (70%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older and better educated.

Descriptive characteristics of the analytic sample for LSAs by quartile of HEI-2005 scores are presented in Table 4.4. Twenty two percent of the participants reported LSAs disability. More than one half of the participants were non-Hispanic white (83%), female (62%), and had an education ≥ high school (70%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older and better educated.

Descriptive characteristics of the analytic sample for LEM by quartile of HEI-2005 scores are presented in Table 4.5. Thirty three percent of the participants reported LEM disability. More than one half of the participants were non-Hispanic white (84%), female (62%), and had an education ≥ high school (71%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older and better educated. Those individuals with HEI-2005 scores in the two highest quartiles were less likely to report LEM disability.

Descriptive characteristics of the analytic sample for GPAs by quartile of HEI-2005 scores are presented in Table 4.6. Fifty nine percent of the participants reported the GPAs disability. More than one half of the participants were non-Hispanic white (83%), female (61%), and had an education ≥ high school (69%). Those with HEI-2005 scores in quartile 4 tended to be female, never smokers, older and better educated. Those individuals with HEI-2005 scores in the two highest quartiles were less likely to report GPAs disability.

4.4.2 Total HEI-2005 scores and self-reported disability

Table 4.7 shows the results for the association between total HEI-2005 scores and self-reported disability by quartiles of HEI-2005 scores. After adjusting for confounding factors, no statistically significant associations were found between HEI-2005 scores and two disability domains including ADLs and LSAs. Compared to older adults with HEI-2005 scores in the lowest quartile, the odds of IADLs disability were significantly lower for those whose HEI-2005 scores were in quartile two and three (*p* for trend = 0.068). Older adults with higher HEI-2005 scores were less likely to experience impaired LEM (*p* for trend < 0.001) and GPAs (*p* for trend < 0.001). Compared to those individuals with HEI-2005 scores in the lowest quartile, the likelihood of both LEM and GPAs disability were significantly lower for those with scores in quartiles two, three, and four. Those with HEI-2005 scores in the highest quartile had approximately 50% lower odds of impaired LEM and GPAs.

4.4.3 Individual HEI-2005 component scores and self-reported disability

Table 4.8 shows the results for the association between individual HEI-2005 component scores and self-reported disability by HEI-2005 score quartiles. Some of individual HEI-2005 component scores were statistically associated with self-reported disability. The odds of IADLs disability were significantly lower for individuals who met the recommendations for HEI-2005 dark green and orange vegetables and legumes scores compared to those who did not meet those recommendations. The likelihood of IADLs, LEM, and GPAs disability was significantly lower for older adults who met the recommendations for HEI-2005 total fruit and whole fruit scores. The likelihood of GPAs disability was significantly lower for those who met the HEI-2005 SoFAAS recommendations than for those individuals who did not.

4.5 Discussion

This study is among the first to document an inverse association between overall dietary quality, measured by HEI-2005 scores, and self-reported disability among a nationally representative sample of older adults in the US. There are few studies examining overall diet quality and disability among older adults. Results of one longitudinal study are consistent with our findings. In the Health, Aging and Body Composition (Health ABC) study, researchers reported that older adults with lower HEI-1995 scores (an earlier version of the HEI) had a higher risk for incident mobility limitations (equivalent to LEM in the current study), defined as reported difficulty walking a quarter mile or climbing 10 steps (Koster et al., 2007).

Two other studies examined the association between the consumption of food groups and functional status (Houston et al., 2005; Tomey et al., 2008). In the Study of Women's Health Across the Nation (SWAN), middle-aged women with lower baseline fruit and vegetable intakes were more likely to report subsequent functional limitations as assessed 4 years later using the Medical Outcomes Study Short-Form 36 (Tomey et al., 2008). In the Atherosclerosis Risk in Communities (ARIC) Study, researchers reported that lower fruit and vegetable consumption was associated with poorer lower extremity function, ADLs, and IADLs among middle-aged and older black and white participants (Houston et al., 2005). Likewise, we found that meeting the HEI-2005 recommendations for total fruit and whole fruit consumption was associated with a lower likelihood of reporting disability in IADLs, LEM, and GPAs. Also, meeting the HEI-2005 recommendations for consumption of dark green and orange vegetables and legumes was associated with a lower likelihood of IADLs disability.

The protective effects of consuming fruit and vegetables may be explained by the antioxidants found in these foods (Lister et al., 2007; Mendoza-Nunez et al., 2001). Antioxidants, including the carotenoids, vitamin C, vitamin E and other polyphenols, may help prevent free radical damage that contributes to inflammation associated with chronic diseases and subsequent functional decline (Cesari et al., 2004; Snowdon et al., 1996). Both cross-sectional and longitudinal studies have reported low serum or plasma carotenoid concentrations were associated with poor physical performance including gait speed and muscle strength (Alipanah et al., 2009; Lauretani et al., 2008; Lauretani et al., 2008; Semba et al., 2007). Consumption of fruits and vegetables, the most important natural sources of antioxidants, may be important dietary components that function to minimize physical limitations. One longitudinal study also reported that women with higher dietary cholesterol, total fat, and saturated fat intakes reported more functional limitations than those who did not (Tomey et al., 2008). Similarly, we found that individuals who did not meet the HEI-2005 recommendations for SoFAAS had a higher likelihood of LEM disability.

It is important to note that the use of a cross-sectional design did not allow us to provide evidence of a causal relationship between HEI-2005 and disability. Further, the NHANES study does not include institutionalized individuals who probably have a higher prevalence of disability than community-dwelling older adults. Therefore, the lack of significant associations found between HEI-2005 scores and self-reported disability for ADLs and LSAs may be explained because these measures are not sensitive enough to discriminate among high functioning community-dwelling individuals. Finally, the HEI-2005 scores in this study were based on a single 24-hour dietary recall instrument, which may be subject to under- or over-reporting, depending on the population (Thompson & Subar 2008). The AMPM method has been shown to underestimate energy intakes by 11% in a population of normal, overweight, and obese persons (Moshfegh et al., 2008).

Despite these limitations, this study has a number of strengths. Functional status was evaluated using self-reported measures that included five different domains. This comprehensive assessment allowed us to explore the association between diet quality and functional ability in different physical, social and psychological contexts. In addition, the NHANES data were rigorously collected and allow us to examine a nationally representative sample population. Further, diet quality was measured using HEI-2005 scores that reliably simultaneously capture key recommendations in the 2005 DGA (USDA 2005). The HEI-2005 incorporates several 2005 DGA recommendations which allows us to begin to address the complexity of diet behaviors. Using HEI-2005 scores to measure diet quality is also useful for comparisons across different study populations. Studies using data-driven analyses to examine dietary behaviors within a population may not be replicated in other populations (Miller et al., 2010). Finally, the individual HEI-

2005 component scores used to calculate the total HEI score offer an opportunity to study important components of dietary intake and their relationships to disability.

In summary, the results demonstrate that adherence to the 2005 DGA was associated with lower disability in physical, social, and psychological domains among older adults who participated in the study. Future studies to examine the prospective association of HEI scores and disability should provide greater insight into this relationship. This study will help others to shape more effective policy interventions to promote healthy diets and prevent functional decline in older adults. Public health goals related to reducing healthcare costs and enhancing quality of life in the older adult population are dependent on ensuring proper nutritional status and maintaining functional abilities. The development of targeted interventions for reaching these goals will only be met through improving our understanding of the complex factors influencing the relationship of nutrition and functional status. The Dietary Guidelines for Americans are the most authoritative dietary recommendations provided to the US population. Understanding the health benefits of following the guidelines is essential for setting up effective behavioral interventions.

Table 4.2 Descriptive characteristics for ADLs among participants aged 60 and older by quartiles of HEI-2005 scores (n = 3,981)

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 996)	(n = 995)	(n = 995)	(n = 995)	(n = 3,981)	p-value*
HEI-2005 score, Median (Range)	38.2 (15.1-45.0)	50.7 (45.1-55.4)	60.3 (55.4-65.8)	72.2 (65.8-93.1)	55.1 (15.1-93.1)	
Age (y), Mean (SE)	69.5 (0.4)	70.4 (0.3)	70.3 (0.3)	71.1 (0.3)	70.3 (0.2)	0.001
Male (%)	45	40	36	31	38	<0.001
Race/ethnicity (%)†						0.001
Non-hispanic white	82	82	83	86	83	
Non-hispanic black	12	9	8	6	9	
Hispanic	7	9	8	8	8	
≥ High school education (%)	63	66	70	79	70	<0.001
Smoking status (%)						<0.001
Never	37	46	51	55	47	
Former	37	37	39	37	37	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 996)	(*n* = 995)	(*n* = 995)	(*n* = 995)	(*n* = 3,981)	*p*-value*
Current	26	17	11	8	15	
Meeting recommendations (%)						
Total fruit	10	27	39	68	36	<0.001
Whole fruit	15	32	52	75	44	<0.001
Total vegetables	20	32	38	48	35	<0.001
Dark green and orange vegetables and legumes	5	10	14	27	14	<0.001
Total grains	45	53	62	63	56	<0.001
Whole grains	4	4	9	20	9	<0.001
Milk	15	18	16	24	18	<0.001
Meat and beans	45	53	59	62	55	<0.001
Oils	7	21	28	39	24	<0.001
Saturated fat	8	14	16	30	17	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 996)	(*n* = 995)	(*n* = 995)	(*n* = 995)	(*n* = 3,981)	*p*-value*
Sodium	2	2	1	2	2	0.872
SoFAAS	1	4	11	41	14	<0.001
ADLs disability	25	23	22	23	23	0.697

* For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the p value is for the chi square test of association.

† Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic white.

Table 4.3 Descriptive characteristics for IADLs among participants aged 60 and older by quartiles of HEI-2005 scores (n = 3,865)

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 967)	(n = 966)	(n = 966)	(n = 966)	(n = 3,865)	p-value[*]
HEI-2005 score, Median (Range)	38.3 (15.1-45.2)	50.7 (45.2-55.4)	60.3 (55.6-65.8)	72.2 (65.9-93.1)	55.1 (15.1-93.1)	
Age (y), Mean (SE)	69.5 (0.4)	70.3 (0.3)	70.3 (0.3)	71.0 (0.3)	70.3 (0.2)	0.003
Male (%)	45	39	35	31	37	<0.001
Race/ethnicity (%)[†]						<0.001
Non-hispanic white	82	82	84	86	83	
Non-hispanic black	11	9	8	6	9	
Hispanic	7	9	8	8	8	
≥ High school education (%)	63	66	70	79	70	<0.001
Smoking status (%)						<0.001
Never	37	46	51	55	47	
Former	37	37	39	37	37	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 967)	(n = 966)	(n = 966)	(n = 966)	(n = 3,865)	p-value*
Current	26	18	11	8	15	
Meeting recommendations (%)						
Total fruit	10	27	39	68	36	<0.001
Whole fruit	15	32	52	75	44	<0.001
Total vegetables	20	32	38	48	35	<0.001
Dark green and orange vegetables and legumes	5	10	14	26	14	<0.001
Total grains	45	53	61	63	56	<0.001
Whole grains	4	4	9	20	9	<0.001
Milk	15	17	16	24	18	0.002
Meat and beans	45	52	59	62	55	<0.001
Oils	7	21	27	39	24	<0.001
Saturated fat	7	14	15	31	17	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 967)	(*n* = 966)	(*n* = 966)	(*n* = 966)	(*n* = 3,865)	*p*-value*
Sodium	2	2	1	2	2	0.876
SoFAAS	1	4	11	41	14	<0.001
IADLs disability (%)	34	29	28	29	30	0.073

* For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the p value is for the chi square test of association.

† Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic white.

Table 4.4 Descriptive characteristics for LSAs among participants aged 60 and older by quartiles of HEI-2005 scores (n = 3,981)

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 984)	(n = 984)	(n = 984)	(n = 984)	(n = 3,936)	p-value*
HEI-2005 score, Median (Range)	38.2 (15.1-45.2)	50.7 (45.2-55.4)	60.3 (55.4-65.8)	72.2 (65.9-93.1)	55.1 (15.1-93.1)	
Age (y), Mean (SE)	69.5 (0.4)	70.4 (0.3)	70.4 (0.3)	71.0 (0.3)	70.3 (0.2)	0.001
Male (%)	45	39	35	31	38	<0.001
Race/ethnicity (%)[†]						<0.001
Non-hispanic white	82	82	83	86	83	
Non-hispanic black	12	9	8	6	9	
Hispanic	7	9	8	8	8	
≥ High school education (%)	64	66	70	79	70	<0.001
Smoking status (%)						<0.001
Never	37	46	51	55	47	
Former	37	37	38	37	37	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 984)	(*n* = 984)	(*n* = 984)	(*n* = 984)	(*n* = 3,936)	*p*-value*
Current	26	17	10	8	15	
Meeting recommendations (%)						
Total fruit	10	27	39	68	36	<0.001
Whole fruit	16	32	52	75	44	<0.001
Total vegetables	20	32	38	48	35	<0.001
Dark green and orange vegetables and legumes	5	10	14	27	14	<0.001
Total grains	45	53	62	63	56	<0.001
Whole grains	4	4	9	20	9	<0.001
Milk	15	18	16	24	18	0.002
Meat and beans	45	53	59	62	55	<0.001
Oils	7	21	27	39	24	<0.001
Saturated fat	7	14	16	31	17	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 984)	(*n* = 984)	(*n* = 984)	(*n* = 984)	(*n* = 3,936)	*p*-value*
Sodium	2	2	1	2	2	0.879
SoFAAS	1	4	11	41	14	<0.001
LSAs disability (%)	25	20	22	21	22	0.247

* For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the p value is for the chi square test of association.

† Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic white.

Table 4.5 Descriptive characteristics for LEM among participants aged 60 and older by quartiles of HEI-2005 scores (n = 3,523)

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 881)	(n = 881)	(n = 881)	(n = 881)	(n = 3,523)	p-value*
HEI-2005 score, Median (Range)	38.5 (15.1-45.5)	50.9 (45.5-55.9)	60.6 (56.1-66.0)	72.6 (66.0-93.1)	55.1 (15.1-93.1)	
Age (y), Mean (SE)	69.5 (0.4)	70.1 (0.3)	70.1 (0.3)	70.9 (0.3)	70.2 (0.2)	0.009
Male (%)	45	41	36	32	38	<0.001
Race/ethnicity (%)[†]						0.001
Non-hispanic white	83	83	84	86	84	
Non-hispanic black	11	9	7	6	8	
Hispanic	6	9	9	8	8	
≥ High school education (%)	66	67	71	81	71	<0.001
Smoking status (%)						<0.001
Never	38	46	50	57	48	
Former	37	37	40	36	38	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 881)	(*n* = 881)	(*n* = 881)	(*n* = 881)	(*n* = 3,523)	*p*-value*
Current	25	17	10	8	15	
Meeting recommendations (%)						
Total fruit	11	26	39	70	37	<0.001
Whole fruit	17	32	53	76	45	<0.001
Total vegetables	22	31	39	48	35	<0.001
Dark green and orange vegetables and legumes	5	10	14	27	14	<0.001
Total grains	45	53	61	63	55	<0.001
Whole grains	4	4	9	20	9	<0.001
Milk	14	19	16	24	18	0.003
Meat and beans	45	53	58	63	55	<0.001
Oils	7	21	28	39	24	<0.001
Saturated fat	7	14	15	31	17	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 881)	(*n* = 881)	(*n* = 881)	(*n* = 881)	(*n* = 3,523)	*p*-value*
Sodium	2	2	1	1	1	0.931
SoFAAS	0	3	11	41	14	<0.001
LEM disability (%)	39	32	34	28	33	<0.001

* For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the p value is for the chi square test of association.

† Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic white.

Table 4.6 Descriptive characteristics for GPAs among participants aged 60 and older by quartiles of HEI-2005 scores (n = 3,512)

	Quartiles of HEI-2005					
	Q1 (n = 878)	Q2 (n = 878)	Q3 (n = 878)	Q4 (n = 878)	Total (n = 3,512)	p-value*
HEI-2005 score, Median (Range)	38.2 (15.1-45.0)	50.6 (45.1-55.3)	60.0 (55.3-65.5)	72.2 (65.5-93.1)	55.1 (15.1-93.1)	
Age (y), Mean (SE)	69.5 (0.4)	70.2 (0.3)	70.1 (0.3)	70.7 (0.3)	70.2 (0.2)	0.064
Male (%)	46	40	36	32	39	<0.001
Race/ethnicity (%)†						0.001
Non-hispanic white	81	82	84	85	83	
Non-hispanic black	12	9	8	6	9	
Hispanic	7	9	8	9	8	
≥ High school education (%)	63	66	70	79	69	<0.001
Smoking status (%)						<0.001
Never	38	44	50	56	47	
Former	36	38	39	36	37	

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(n = 878)	(n = 878)	(n = 878)	(n = 878)	(n = 3,512)	p-value*
Current	26	18	11	7	16	
Meeting recommendations (%)						
Total fruit	10	27	38	69	37	<0.001
Whole fruit	14	32	51	75	43	<0.001
Total vegetables	20	32	38	47	34	<0.001
Dark green and orange vegetables and legumes	5	10	13	27	14	<0.001
Total grains	47	54	62	64	57	<0.001
Whole grains	4	4	9	20	9	<0.001
Milk	14	18	16	24	18	0.002
Meat and beans	45	54	59	62	55	<0.001
Oils	7	21	27	39	24	<0.001
Saturated fat	8	14	15	30	17	<0.001

	Quartiles of HEI-2005					
	Q1	Q2	Q3	Q4	Total	
	(*n* = 878)	(*n* = 878)	(*n* = 878)	(*n* = 878)	(*n* = 3,512)	*p*-value*
Sodium	1	2	1	2	2	0.600
SoFAAS	1	4	11	41	14	<0.001
GPAs disability (%)	67	57	57	55	59	<0.001

[*] For continuous variables, the *p* value is for the test of difference in means of the variables of interest. For categorical variables, the p value is for the chi square test of association.

[†] Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic white.

Table 4.7 Adjusted odds ratios (ORs) and 95% Confidence Intervals (CIs) of self-reported disability among participants aged 60 and older by quartiles of HEI-2005 scores

	Q1	Q2	Q3	Q4	
Self-reported disability		OR (95% CI)	OR (95% CI)	OR (95% CI)	*p* for trend*
ADLs (*n* = 3,981)	1.00	0.88 (0.66 to 1.18)	0.88 (0.64 to 1.21)	0.92 (0.70 to 1.22)	0.561
IADLs (*n* = 3,865)	1.00	0.75 (0.57 to 1.00)	0.71 (0.54 to 0.94)	0.78 (0.59 to 1.02)	0.068
LSAs (*n* = 3,936)	1.00	0.74 (0.53 to 1.02)	0.84 (0.63 to 1.14)	0.82 (0.58 to 1.16)	0.354
LEM (*n* = 3,523)	1.00	0.71(0.54 to 0.94)	0.78 (0.61 to 1.00)	0.56 (0.44 to 0.73)	<0.001
GPAs (*n* =3,512)	1.00	0.58(0.43 to 0.77)	0.60(0.46 to 0.78)	0.53(0.42 to 0.69)	<0.001

Notes： All logistic regression models were adjusted for age, gender, race/ethnicity, education, and smoking status.

* Test for trend over the quartiles of HEI-2005 using the median HEI-2005 score in each quartile.

ADLs, activities of daily living; IADLs, instrumental activities of daily living; LSAs, leisure and social activities; LEM, lower-extremity mobility; GPAs, general physical activities.

Table 4.8 Adjusted odds ratios (ORs) and 95% Confidence Intervals (CIs) of self-reported disability among those aged 60 and older meeting individual HEI-2005 component recommendations

	Self-reported disability				
	ADLs (n = 3,981)	IADLs (n = 3,865)	LSAs (n = 3,936)	LEM (n = 3,523)	GPAs (n =3,512)
Individual HEI-2005 components	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Total fruit	1.02(0.83 to 1.24)	0.81(0.67 to 0.97)	0.89(0.74 to 1.07)	0.71(0.59 to 0.86)	0.79(0.65 to 0.96)
Whole Fruit	0.91(0.75 to 1.11)	0.72(0.60 to 0.86)	0.82(0.67 to 1.01)	0.65(0.54 to 0.79)	0.74(0.61 to 0.91)
Total vegetables	0.92(0.79 to 1.08)	0.90(0.74 to 1.09)	0.89(0.72 to 1.11)	0.96(0.80 to 1.14)	0.99(0.81 to 1.22)
Dark green and orange vegetables and legumes	0.82(0.63 to 1.07)	0.70(0.55 to 0.89)	0.77(0.58 to 1.04)	0.80(0.62 to 1.03)	0.89(0.71 to 1.11)
Total grains	0.96(0.79 to 1.17)	0.97(0.83 to 1.14)	1.01(0.97 to 1.30)	0.94(0.78 to 1.12)	0.98(0.81 to 1.18)
Whole grains	0.99(0.73 to 1.36)	1.11(0.80 to 1.54)	1.19(0.85 to 1.65)	0.92(0.67 to 1.27)	1.13(0.83 to 1.55)
Milk	1.00(0.79 to 1.28)	1.11(0.88 to 1.41)	0.97(0.72 to 1.30)	1.05(0.84 to 1.30)	1.05(0.79 to 1.40)
Meat and beans	0.94(0.77 to 1.16)	1.00(0.81 to 1.22)	0.97(0.77 to 1.23)	1.03(0.83 to 1.27)	0.98(0.86 to 1.11)

	Self-reported disability				
	ADLs	IADLs	LSAs	LEM	GPAs
	(*n* = 3,981)	(*n* = 3,865)	(*n* = 3,936)	(*n* = 3,523)	(*n* =3,512)
Individual HEI-2005 components	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Oils	1.08(0.84 to 1.39)	1.04(0.80 to 1.36)	0.85(0.69 to 1.04)	0.96(0.75 to 1.22)	0.94(0.77 to 1.16)
Saturated fat	0.90(0.69 to 1.18)	0.89(0.68 to 1.17)	0.80(0.62 to 1.04)	0.79(0.61 to 1.03)	0.89(0.70 to 1.13)
Sodium	1.06(0.55 to 2.05)	1.10(0.61 to 1.97)	0.74(0.38 to 1.44)	0.76(0.39 to 1.46)	0.88(0.51 to 1.53)
SoFAAS	1.06(0.81 to 1.39)	1.14(0.88 to 1.49)	1.15(0.88 to 1.51)	0.81(0.66 to 1.01)	0.81(0.66 to 0.98)

Notes：All logistic regression models were adjusted for age, gender, race/ethnicity, education, and smoking status. Referent group includes those who did not meet the recommendation for that individual HEI-2005 component.

ADLs, activities of daily living; IADLs, instrumental activities of daily living; LSAs, leisure and social activities; LEM, lower-extremity mobility; GPAs, general physical activities; SoFAAS, Calories from Solid Fats, Alcoholic beverages, and Added Sugars.

Chapter 5 Smoking Modifies the Association between Food Insecurity and Physical Performance: Results from National Health and Nutritional Examination Survey (NHANES) 1999-2002

5.1 Abstract

Background: Few studies have examined the association between food insecurity and physical performance among older adults. To our knowledge, the effect modification of smoking status has never been examined in previous studies of food insecurity and physical performance. The purpose of this study was to examine the association between food security status and physical performance among a nationally representative sample of men and women.

Methods: This study used data from the 1999-2002 National Health and Nutrition Examination Survey (NHANES). Responses to the United States (US) Household Food Security Survey Module (HFSSM) were used to assign participants to study categories. Physical performance measures included gait speed over 20-foot and knee extensor power. Multiple linear regression models controlling for age, gender, race/ethnicity, education, and income were used.

Results: The association between food insecurity and gait speed varied by smoking status (p = 0.005). For non-smokers, those who were marginally food secure (0.91 m/s, p =

0.016) and food insecure (0.94 m/s, $p = 0.004$) had significantly slower gait speeds than food secure participants (1.04 m/s). Similar findings were found for knee extensor power. An association between food insecurity and either physical performance was not detected among smokers.

Conclusion: Given the magnitude of the effects of smoking on physical performance, smoking appears to obscure the relationship between food insecurity and physical performance.

5.2 Introduction

Food insecurity is defined as limited or uncertain availability of nutritionally adequate and safe foods, or limited, or uncertain ability to acquire acceptable foods in socially acceptable ways (LSRO 1998). Data from the 2009 Current Population Survey (CPS) Food Security Supplement showed that 14.5 % of adults (33 million) were in the food insecure category while 5.4 % (12 million) of them were in the very low food security category (Nord et al., 2010). Food insecurity is more prevalent in some subgroups including low income population and smokers (Armour et al., 2008; Nord et al., 2010).

Food insecurity has been associated with variety of adverse health outcomes (Gao et al., 2009; Kim 2007; Lee et al., 2001; Lyons et al., 2008; Parker et al.,. 2010; Pheley et al., 2002; Seligman et al., 2007; Seligman et al., 2009; Stuff et al., 2004; Tayie et al., 2009; Terrel et al.,2009). Physical performance has been used frequently as health outcome measures for epidemiological research on older adults. It accounts for the effects of a variety of diseases as well as the natural functional decline that occurs with aging. Physical performance measures have been shown to be predictors of adverse outcomes including loss of independence, increased mortality, and greater financial expenditures (Reuben et al., 2004). Klesges and colleagues reported that older adults who experienced food insufficiency had a lower gait speed than food sufficient counterparts (Klesges et al., 2001). However, this study used a single-item measure of food security status, which does not express the full range of the severity of food insecurity (Frongillo et al., 1997). The United States (US) Household Food Security Survey Module (HFSSM) is a standardized tool for measuring the degree of severity of food insecurity experienced by household members (Bickel et al., 2000). Few studies have examined the influences of food insecurity as measured by this scale on physical performance among older adults.

Smoking is an important modifiable risk factor of poor physical performance (Nelson et al., 1994; Rapuri et al., 2007). Smoking may be associated with poor physical performance through its influence on DNA damage, inflammation and oxidative stress (USDHHS 2010). Besides the chronic effects, the acute effects of smoking in physical performance include muscle fatigue, less endurance, higher resting heart rates and lower maximum heart rates, possibly due to the reduced oxygen delivery to muscle cells (Morse et al., 2007; Wust et al., 2008; Cooper et al., 1968). Given the magnitude of the effect of smoking on physical performance, we hypothesized that smoking may obscure the relationship between food insecurity and physical performance. To our knowledge, the effect modification of smoking status has never been examined in previous studies of food insecurity and physical performance (Nelson et al., 1994; Rapuri et al., 2007). Accordingly, the purpose of this study was to examine whether the association between food insecurity measured by HFSSM and physical performance varied by smoking status in a nationally representative sample of men and women.

5.3 Methods

5.3.1 Study design and participants

Cross-sectional data from the National Health and Nutritional Examination Survey (NHANES) was used. NHANES, conducted by the National Center for Health Statistics (NCHS), is a nationally representative survey of the non-institutionalized population of the United States. Stratified, multistage probability cluster sampling methods were used to assess the health and nutritional status of adults and children in the United States. The NHANES consisted of a detailed home interview and a health examination conducted in a mobile examination center (MEC). Information collected from 1999 to 2002 was used because data on physical performance measures were not collected in subsequent surveys. Details of the NHANES design, sampling procedures, and evaluation protocols are available on the Center for Disease Control (CDC) website (http://www.cdc.gov/nchs/tutorials/Nhanes/index_current.htm).

The study sample included 4,983 participants ≥ 50 years of age. Individuals were excluded from the study if data on the confounding variables (age, gender, education, race/ethnicity and poverty income ratio (PIR)) (*n* = 712), the effect modifier (smoking status) (*n* = 322) and the independent variable (food security measures) (*n* = 97) were missing. Additionally, participants with no associated data for gait speed (*n* = 708) were excluded from the analysis, resulting in final sample sizes of 3,144 for gait speed. Regarding knee extensor power, 438 participants were excluded from the muscle strength examination because of chest or abdominal survey in the previous 3 weeks; heart attack in the previous 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 testing was conducted at a fixed angular velocity of 60 degrees/s, 1,367 people with peak force velocity that varied > 5 degrees/s from the chosen testing velocity were also excluded. Another five participants were excluded because data for body weight were unavailable. Thus, data obtained from 2,042 participants were included in the final analytic sample for knee extensor power.

This study was approved as exempt by the Institutional Review Board of Auburn University.

5.3.2 Food security measures

Food security status over the prior 12 month was evaluated using the US HFSSM developed by the USDA (Bickel et al., 2000). The HFSSM was validated previously (Bickel et al., 2000). Based on the affirmative responses to 10-item adult food security scale, food security status were categorized into four categories: fully food secure (0 affirmative response); marginally food secure (1-2 affirmative responses); low food secure (3-7 affirmative responses); and very low food secure (8-10 affirmative responses). Because there were few observations in the low food secure and very low food secure categories, these two categories were combined to yield the food insecure group. Households with income ≥ federal poverty line were automatically classified by NCHS as highly food secure. The ten-item adult food security scale was used to ensure the same measure for every individual across the households. Food insecurity may affect household members differently, and adults are more severely affected than young children (Nord et al., 2010).

5.3.3 Physical performance measures

Physical performance measures included gait speed and knee extensor power. Gait speed is a commonly used performance-based measure to detect mobility impairment in clinical research and practice and is a strong predictor of adverse health events (Studenski et al., 2011). In NHANES 1999-2002, the time to complete a 20-foot walk test, performed at the participants' usual pace, was measured using a hand-held stopwatch. Participants were allowed to use a walker or cane if needed, but they were excluded from testing if they needed the assistance of another person to walk. Gait speed (m/s) was calculated as the walking distance (20 feet = 6.15 m) divided by the time required to complete the task (in seconds).

Knee extensors are the key muscle group for ambulation and balance, and peak muscle power is important for the functional independence of older adults (Bean et al., 2003; Kuo et al., 2006; Ostchega et al., 2004). In NHANES 1999-2002, right knee extensor force production was measured using a Kinetic Communicator isokinetic dynamometer (Kin-Com MP, Chattecx Corp., Chattanooga, TN, USA). Knee extensor power was calculated as follows (Kuo et al., 2006): Peak leg power (W) = Peak torque (N-m) * Peak force velocity (Radians/s), where peak torque is equal to peak force (N) * lever arm length (m), and peak force velocity (Radians/s) is equal to peak force velocity (degree/s) * (π/180), where $\pi = 3.14$. The lever arm length was the distance from the participants' ankle to their knee joint. Knee extensor power values were divided by body weight in kilograms (W/kg), as power requirements for functional tasks vary by body size (Davis et al., 1997). In NHANES 1999-2002, participants were weighed wearing underwear, disposable paper gowns, and foam slippers, using a Toledo digital scale. The procedure manual, which contains details about the measurement of weight, is available on the CDC web site (http://www.cdc.gov/nchs/tutorials/Nhanes/index_current.htm).

5.3.4 Smoking status

Smoking status was determined by the self-reported use of cigarettes, cigars, or pipes. Participants were asked if they had ever smoked at least 100 cigarettes, a pipe at least 20 times, or a cigar at least 20 times. Participants who answered no to these questions were classified as non-smokers. If participants answered yes to any of these questions, they were classified as former or current smokers. Current smokers were those who had smoked during their lifetime and reported smoking either every day or some days at the time of interview. Former smokers were those who reported smoking during their lifetime and currently did not smoke.

5.3.5 Confounding variables

Age, gender, race/ethnicity, education, and income obtained from self-reported information were analyzed and included in our models. Age was included as a continuous variable. Race/ethnicity information included Mexican American, other Hispanic, non-Hispanic white, non-Hispanic African American, and other race. Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form Hispanics, and the other race was combined with non-Hispanic whites. Thus, three race/ethnicity categories were examined: non-Hispanic white, non-Hispanic black, and Hispanic. Level of education was defined as less than a high school degree or greater than or equal to a high school degree. PIR was used to measure the family's economic status, which was included as a continuous variable, and calculated as the ratio of family income to poverty thresholds based on household size.

5.3.6 Statistical Analyses

STATA (version 10, 2007, Stata Corp, College Station, TX, USA) was used to estimate all descriptive and inferential statistics accounting for sample design and sampling weights. Differences for variables across categories were tested using the design-based F statistic.

During the regression analysis, second order interactions terms of food security status and smoking status were tested to determine if smoking status modified the associations between food insecurity and physical performance. The interaction of food security status and smoking status was statistically significant for gait speed (p = 0.005). Thus, the model for gait speed is stratified by smoking status. The interaction of food security status and smoking status was not statistically significant for knee extensor power (p = 0.421). The model for knee extensor power was still stratified by smoking status to further explore the differences among smoking status groups. Multiple linear regression models controlling for age, gender, education, race/ethnicity, and PIR were used to estimate the associations between food security status and physical performance including gait speed and knee extensor power. In addition to the stratified analysis, models in which the category of fully food-secure non-smokers was a common referent for gait speed and knee extensor power were examined. To reduce the possibility of residual confounding of income, an additional analysis was conducted to restrict the data to those participants with a PIR ≤ 1.85. Additionally, a sensitivity analysis was used to combine former and current smokers into "ever-smokers". Statistical significance was tested at $p < 0.05$ (two-sided).

5.4 Results

5.4.1 Descriptive characteristics of the sample

Descriptive characteristics of the study sample for gait speed by smoking status are shown in Table 5.1. More than one half of the participants were female, non-Hispanic whites, fully food secure, and had an education greater than or equal to high school. Current smokers tended to be male, younger, and food insecure. They also had a lower PIR and a higher knee extensor power. Former smokers were more likely to be fully food secure with a higher PIR. Non-smokers tended to be female, and older than the other groups in the study population.

Descriptive characteristics of the study sample for knee extensor power by smoking status are shown in

Table 5.2. More than one half of the participants were female, non-Hispanic whites, fully food secure, and had an education greater than or equal to high school. Current smokers tended to be male, younger, and food insecure. They also had a lower PIR and a higher knee extensor power. Former smokers were more likely to be fully food secure with a higher PIR. Non-smokers tended to be female, and older than the other groups in the study population.

5.4.2 Unadjusted and adjusted values for physical performance stratified by smoking status (non-smokers, former smoker, and current smokers)

Unadjusted and adjusted values for gait speed are presented in Table 5.3. After adjusting for confounding variables, marginally food-secure (0.91 m/s, p = 0.016) and food-insecure (0.94 m/s, p = 0.004) non-smokers had a lower gait speed as compared to fully food-secure non-smokers. No relationship between food insecurity and gait speed was found among former smokers and current smokers.

Unadjusted and adjusted values for knee extensor power are presented in Table 5.4. After adjusting for confounding variables, food-insecure nonsmokers had a significantly lower leg power (1.41 W/kg, p = 0.025) compared to fully food-secure non-smokers. No significant difference was found between marginally food-secure non-smokers and fully food-secure non-smokers. Similar to the findings with gait speed, there were no statistically significant associations between food insecurity and knee extensor power among former and current smokers.

5.4.3 Adjusted values for physical performance stratified by smoking status (non-smokers, former smoker, and current smokers) with common referent analyses

Adjusted values for gait speed with common referent analyses are presented in Table 5.5. When compared to fully food-secure non-smokers, the gait speed for fully-food secure former smokers, fully food-secure current smokers, marginally food-secure non-smokers, and food-insecure non-smokers was slower. Adjusted values for knee extensor power with common referent analyses are presented in Table 5.6. Compared to fully food-secure non-smokers, food-insecure non-smokers had a greater knee extensor power.

5.4.4 Unadjusted and adjusted values for physical performance stratified by smoking status (non-smokers, former smoker, and current smokers) among those with PIR ≤ 1.85

We also examined the relationship between food insecurity and physical performance among those with PIR ≤ 1.85. After the models were stratified for gait speed by smoking status, marginally food-secure and food-insecure non-smokers had slower gait speeds as compared to fully food-secure nonsmokers (Table 5.7). No statistically significant association between food security status and gait speed were found among former smokers and current smokers. For knee extensor power, those non-smokers who were marginally food-secure and food-insecure had lower knee extensor power as compared to fully food-secure non-smokers (Table 5.8). No statistically significant associations between food security status and knee extensor power were found among former and current smokers.

5.4.5 Unadjusted and adjusted values for physical performance stratified by smoking status (non-smokers vs ever-smokers)

We conducted a sensitivity analysis that combined current and former smokers into ever-smokers. Similar to previous findings, the second order interaction terms of food insecurity and smoking status were statistically significant for gait speed (p = 0.018) but not for knee extensor power (p = 0.207). After we stratified the models by smoking status, marginally food-secure (0.91 m/s, p = 0.016) and food-insecure (0.94 m/s, p = 0.004) non-smokers had a lower gait speed as compared to fully food-secure non-smokers (1.04 m/s) (Table 5.9). Food-insecure non-smokers (1.41 W/kg, p = 0.025) had a less knee extensor power compared to fully food-secure non-smokers (1.56 W/kg) (Table 5.10). For ever-smokers, there were no statistically significant associations between food security status and any performance-based measure.

5.5 Discussion

This study may be the first to identify a relationship between food insecurity measured by HFSSM and physical performance among a national representative sample of men and women. We found statistically significant associations between food insecurity and physical performance among non-smokers, but not among former smokers and current smokers. Furthermore, when fully food-secure non-smokers were used as the common referent group, the fully food-secure former and current smokers had slower gait speeds. Similar results were observed among those with PIR ≤ 1.85.

Klesges et al. examined food insufficiency and gait speed among older adults aged 65 and older (Klesges et al., 2001). Similar to our results, their study reported that food insufficiency as measured by a single-item question is associated with a lower gait speed among older white non-smokers from Baltimore. Others reported that food insecurity is associated with self-reported measures of functional status (Stuff et al., 2004; Pheley et al., 2002; Vailas et al., 1998). A small area specific study reported that food insecurity, as measured by 7 questions, was negatively associated with global quality of life assessed by means of an 11-point uniscale among older adults (Vailas et al., 1998). Pheley and colleagues reported that food insecurity assessed by HFSSM was a significant independent predictor for functional health and well-being assessed by Medical Outcome Study Short Form-36 (SF-36) (Pheley et al., 2002). Using the same module to measure food security status, Stuff and colleagues reported that household food insecurity was associated with poorer physical and mental health status assessed by Short Form 12-item Health Survey (SF-12) in Lower Mississippi area (Stuff et al., 2004).

Mechanisms to explain the association between food insecurity and physical performance may involve several pathways. Firstly, food insecurity has been conceptually hypothesized to affect functional well-being and quality of life directly (Campbell 1991; Brew et al., 2010). In addition, food insecurity is associated with decreased variety in the diet and increased consumption of relatively inexpensive energy-dense foods including refined grains, added sugars, and added saturated/trans fats in food-insecure households (Seligman et al., 2007). People who live in food-insecure households were found to consume fewer weekly servings of fruits, vegetables, and dairy products, and lower amounts of micronutrients including the B complex vitamins, magnesium, iron, zinc, and calcium (Tarasuk & Beaton 1999; Lee & Frongillo 2001; Dixon et al., 2001). Such dietary patterns are linked to the development of adverse health outcomes including inflammation, obesity, metabolic syndrome, hypertension, hyperlipidemia, and diabetes, with each of them is associated with functional decline (Selligman et al., 2010; Vozoris & Tarasuk 2003; Nettleton et al., 2006; Mendoza et al., 2006). Dietary changes related to food insecurity may also directly contribute to impaired functional status (Klesges et al., 2001; Vailas et al., 1998). In addition, food insecurity is often accompanied by stress, depression, fatigue, and poor self-efficacy (Seligman et al., 2010; Gao et al., 2009; Hamelin et al., 1999; Hamelin et al., 2002). Additionally, food insecurity has been associated with cardiovascular diseases which then decrease physical performance (Seligman et al., 2007; Seligman et al., 2010; Parker et al., 2010). However, the direction of the association between physical performance and food insecurity has not been demonstrated to our knowledge (Brewer et al., 2010).

We did not observe an association between food insecurity and physical performance among current smokers and former smokers. Current smoking has also been reported to be associated with poor physical performance including slow timed rise and timed walk tests as well as decreased grip strength among older women (Rapuri et al., 2007). Smoking may affect physical performance through its effect on vascular function and 1,25$(OH)_2$D metabolism. Plasma/serum vitamin D status has been reported to improve physical performance in older adults (Houston et al., 2007). A recent study also reported that smoking impairs muscle protein synthesis and increases the expression of genes associated with impaired muscle maintenance (Petersen et al., 2007). In addition, smoking potentially generates oxidative stress and reduces levels of antioxidants that are important in preventing functional decline among older adults (Stryker et al., 1988). Smoking is also associated with insulin resistance and increased adipocytokines and inflammatory markers (Van Gaal et al., 2006). All of these are potential cardiovascular risk factors, with also a close relationship with poor physical performance. Smoking has been associated with variety of adverse health outcomes including cancer, vascular diseases, respiratory diseases, and osteoporosis (USDHHS 2010). Each of these conditions is closely related to poor physical performance. Additionally, smoking may immediately affect physical performance by reduced oxygen delivery to muscle groups (Strand et al., 2010). The acute effects include muscle fatigue, less endurance, higher resting heart rates and lower maximum heart rates (Morse et al., 2007; Wust et al., 2008; Cooper et al., 1968).

Possible explanations for the observed differences for gait speed among those with different smoking status may be the differences in referent comparison groups. Differences in the referent group for current and former smokers could obscure the potential association between food insecurity and gait speed. For knee extensor power, however, the referent groups for current and former smokers were not statistically different from the values found for the referent group for non-smokers.

Divergent findings between the common referent analyses of gait speed and knee extensor power may be precipitated by a range of factors. The sample for knee extensor power included participants who did not have: 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. Hover, the gait speed testing protocol did not exclude participants with these conditions. Consequently, smokers who reported having these exclusion criteria would likely have poor physical performance and not be included in the muscle strength testing but would be included in the gait speed testing. Another possible explanation for the differences found between gait speed and knee extensor power is that gait speed is a more complex measure which integrates and involves multiple features of lower body functioning (Studenski et al., 2011), while knee extensor power is only one of the "building blocks" in the overall spectrum of functional status (Bean et al., 2003). Smoking may affect gait speed through mechanisms other than muscle power. Also, the lack of an association between smoking and knee extensor power among food secure participants could be an artifact of the normalization by body weight. Smokers may weigh less than nonsmokers (Norman 2008). Smokers who weigh less and have less muscle power may have the same power score as nonsmokers who weight more and have greater muscle power.

The study is limited by the cross-sectional nature of NHANES, which does not allow us to determine the causal relationship between food insecurity and physical performance among this older population. Other researchers have also suggested impaired functional status may physically limit people's access to nutritious food which in turn leads to food insecurity (Brewer et al., 2010; Wolfe et al., 1996). Longitudinal studies are needed to examine temporal relationships between food insecurity and physical performance. In addition, because this study examined non-institutionalized older adults, it may be subject to a selection bias because either food insecurity or smoking may be linked to early nursing care facility admission (USDHHS 2010). This may lead to an underestimation of our observed associations because these older adults with impairments severe enough to be institutionalized would not have been included in the NHANES sample. Also, the smoking status was self-reported and may be underestimated (Rapuri et al., 2007). Food security status was also self-reported because no objective measures are available. However, the life experiences of older adults may change their perceptions of food security status relative to those of younger adults (Lee & Frongillo 2001).

This study used the NHANES data set, which is a nationally representative sample of men and women. Development of the US HFSSM provides a useful standardized tool for measuring food security status and for examining the effects of food security on physical performance (Bickel et al., 2000). In addition, two physical performance measures are valid, reliable, objective, and sensitive enough to discriminate functional levels in older adults (Reuben et al., 2004).

In conclusion, food insecurity was negatively associated with physical performance among non-smokers, which supports the conceptual relationships described by Campbell (1991). No statistically significant association between food insecurity and physical performance was observed among current or former smokers. More studies are needed to investigate the potential interaction between smoking and food insecurity and their potential joint effects on functional status among older adults. Continuing efforts to improve the access of older adults to nutritious foods in a socially acceptable fashion and never smoking could promote good functional status among older adults.

Table 5.1 Descriptive characteristics of the analytic sample for gait speed among participants aged 50 and older by smoking status (*n* = 3,144)

	Smoking status				
	Nonsmokers (*n* = 1,444)	Former Smokers (*n* = 1,116)	Current Smokers (*n* = 584)	Total (*n* = 3,144)	*p*-value[*]
Age (y), Mean (SE)	64.8 (0.4)	64.7 (0.3)	59.7 (0.4)	63.7 (0.2)	<0.001
Male (%)	28	51	55	42	<0.001
Race/ethnicity (%)[†]					0.132
Non-hispanic White	82	85	82	83	
Non-hispanic black	9	6	10	8	
Hispanics	9	8	8	9	
≥High school (%)	75	76	70	74	0.029
Poverty Income Ratio (PIR), Mean (SE)[‡]	3.02 (0.09)	3.24 (0.09)	2.81 (0.13)	3.05 (0.08)	<0.001
Food security measures (%)					0.002

	Smoking status				
	Nonsmokers (*n* = 1,444)	Former Smokers (*n* = 1,116)	Current Smokers (*n* = 584)	Total (*n* = 3,144)	*p*-value*
Fully food secure	91	93	86	90	
Marginally food secure	4	4	5	4	
Food insecure	5	4	9	6	
Gait speed (m/s), Mean (SE)	1.02 (0.01)	1.02 (0.01)	1.03 (0.01)	1.02 (0.01)	0.836

*For continuous variables, the P value is for the test of difference in means of the variables of interest. For categorical variables, the P value is for the chi square test of association.

†Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic whites.

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

Table 5.2 Descriptive characteristics of the analytic sample for knee extensor power among participants aged 50 and older by smoking status (n = 2,042)

	Smoking status				
	Nonsmokers (n = 904)	Former Smokers (n = 756)	Current Smokers (n = 382)	Total (n = 2,042)	p-value*
Age (y), Mean (SE)	63.0 (0.5)	63.2 (0.3)	59.0 (0.5)	62.2 (0.3)	<0.001
Male (%)	30	55	57	45	<0.001
Race/ethnicity (%)†					0.203
Non-hispanic White	83	86	83	84	
Non-hispanic black	8	6	10	8	
Hispanics	9	8	8	8	
≥High school (%)	77	78	72	77	0.112
Poverty Income Ratio (PIR) , Mean (SE)‡	3.02 (0.09)	3.24 (0.09)	2.81 (0.13)	3.05 (0.08)	<0.001
Food security measures (%)					0.009

	Smoking status				
	Nonsmokers (n = 904)	Former Smokers (n = 756)	Current Smokers (n = 382)	Total (n = 2,042)	p-value*
Fully food secure	93	94	87	92	
Marginally food secure	2	3	5	3	
Food insecure	4	3	9	5	
Knee extensor power (W/kg), Mean (SE)	1.46 (0.03)	1.56 (0.02)	1.65 (0.04)	1.54 (0.02)	<0.001

*For continuous variables, the P value is for the test of difference in means of the variables of interest. For categorical variables, the P value is for the chi square test of association.

†Because of the small sample sizes, Mexican Americans and other Hispanics were combined to form the Hispanic category and the other race was combined with non-Hispanic whites.

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

Table 5.3 Unadjusted and adjusted values (SE) for gait speed stratified by smoking status (n = 3,144)

Food security status	Unadjusted			Adjusted*		
	Smoking status			Smoking status		
	Nonsmokers (m/s) (n = 1,444)	Former Smokers (m/s) (n = 1,116)	Current Smokers (m/s) (n = 584)	Nonsmokers (m/s) (n = 1,444)	Former Smokers (m/s) (n = 1,116)	Current Smokers (m/s) (n = 584)
Fully food secure†	1.04 (0.01)	1.03 (0.01)	1.03 (0.01)	1.04 (0.01)	1.01 (0.01)	0.99 (0.01)
Marginally food secure	0.82 (0.06) ‡	0.90 (0.05) ‡	0.95 (0.02) ‡	0.91 (0.05) ‡	0.96 (0.04)	0.99 (0.03)
Food insecure	0.85 (0.03) ‡	0.93 (0.03) ‡	1.01 (0.05)	0.94 (0.03) ‡	1.01 (0.02)	1.07 (0.05)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡ Statistical significance at $p \leq 0.05$.

Table 5.4 Unadjusted and adjusted values (SE) for knee extensor power stratified by smoking status (n = 2,042)

Food security status	Unadjusted			Adjusted*		
	Smoking status			Smoking status		
	Non-smokers (W/kg) (n = 904)	Former Smokers (W/kg) (n = 756)	Current Smokers (W/kg) (n = 382)	Non-smokers (W/kg) (n = 904)	Former Smokers (W/kg) (n = 756)	Current Smokers (W/kg) (n = 382)
Fully food secure†	1.54 (0.02)	1.56 (0.02)	1.54 (0.02)	1.56 (0.02)	1.53 (0.02)	1.54 (0.03)
Marginally food secure	1.52 (0.06)	1.57 (0.10)	1.52 (0.06)	1.46 (0.09)	1.47 (0.07)	1.56 (0.07)
Food insecure	1.39 (0.04) ‡	1.51 (0.07)	1.39 (0.04) ‡	1.41 (0.07) ‡	1.52 (0.06)	1.55 (0.06)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡ Statistical significance at $p < 0.05$.

Table 5.5 Adjusted values (SE) for gait speed with common referent analyses by smoking status (n = 3,144)

Food security status	Adjusted[*]		
	Smoking status		
	Nonsmokers (m/s) (n = 1,444)	Former Smokers (m/s) (n = 1,116)	Current Smokers (m/s) (n = 584)
Fully food secure[†]	1.04 (0.01)	1.01 (0.01)[‡]	0.98 (0.01)[‡]
Marginally food secure	0.91 (0.04)[‡]	0.96 (0.04)	0.98 (0.03)
Food insecure	0.95 (0.03)[‡]	1.01 (0.02)	1.06 (0.04)

[*]Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

[†]Referent group.

[‡] Statistical significance at $p < 0.05$.

Table 5.6 Adjusted values (SE) for knee extensor power with common referent analyses by smoking status (n = 2,042)

Food security status	Adjusted*		
	Smoking status		
	Nonsmokers (W/kg) (n = 904)	Former Smokers (W/kg) (n = 756)	Current Smokers (W/kg) (n = 382)
Fully food secure†	1.56 (0.02)	1.52 (0.02)	1.55 (0.03)
Marginally food secure	1.47 (0.08)	1.46 (0.07)	1.55 (0.07)
Food insecure	1.41 (0.07) ‡	1.53 (0.07)	1.50 (0.05)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡ Statistical significance at $p < 0.05$.

Table 5.7 Unadjusted and adjusted values (SE) for gait speed stratified by smoking status among those with PIR ≤ 1.85 (n = 1,313)

Food security status	Unadjusted			Adjusted*		
	Smoking status			Smoking status		
	Non-smokers (m/s) (n = 333)	Former Smokers (m/s) (n = 253)	Current Smokers (m/s) (n = 158)	Non-smokers (m/s) (n = 333)	Former Smokers (m/s) (n = 253)	Current Smokers (m/s) (n = 158)
Fully food secure†	0.88 (0.02)	0.87 (0.02)	0.93 (NA) ‡	0.92 (0.02)	0.89 (0.02)	0.88 (0.02)
Marginally food secure	0.77 (0.05)	0.82 (0.03)	0.90 (NA) ‡	0.78 (0.04) §	0.82 (0.04)	0.86 (0.02)
Food insecure	0.85 (0.03)	0.84 (0.03)	0.97 (NA) ‡	0.83 (0.03) §	0.84 (0.03)	0.93 (0.04)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡NA: not available because of stratum with single sampling unit.

§Statistical significance at $p \leq 0.05$.

Table 5.8 Unadjusted and adjusted values (SE) for knee extensor power stratified by smoking status among those with PIR ≤ 1.85 (n = 744)

Food security status	Unadjusted			Adjusted*		
	Smoking status			Smoking status		
	Non-smokers (W/kg) (n = 333)	Former Smokers (W/kg) (n = 253)	Current Smokers (W/kg) (n = 158)	Non-smokers (W/kg) (n = 333)	Former Smokers (W/kg) (n = 253)	Current Smokers (W/kg) (n = 158)
Fully food secure†	1.54 (NA) ‡	1.56 (NA) ‡	1.53 (NA) ‡	1.38 (0.03)	1.40 (0.04)	1.38 (0.03)
Marginally food secure	1.52 (NA) ‡	1.57 (NA) ‡	1.33 (NA) ‡	1.21 (0.07) §	1.44 (0.05)	1.24 (0.09)
Food insecure	1.39 (NA) ‡	1.51 (NA) ‡	1.48 (NA) ‡	1.24 (0.08) §	1.39 (0.07)	1.37 (0.07)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡NA: not available because of stratum with single sampling unit.

§Statistical significance at $p \leq 0.05$.

Table 5.9 Unadjusted and adjusted values (SE) for gait speed stratified by smoking status (non-smokers vs ever smokers) (n = 3,144)

Food security status	Unadjusted		Adjusted*	
	Smoking status		Smoking status	
	Nonsmokers (m/s) (n = 1,444)	Ever Smokers (m/s) (n = 1,700)	Nonsmokers (m/s) (n = 1,444)	Ever Smokers (m/s) (n = 1,700)
Fully food secure†	1.04 (0.01)	1.03 (0.01)	1.04 (0.01)	1.00 (0.01)
Marginally food secure	0.82 (0.06) ‡	0.92 (0.03) ‡	0.91 (0.05) ‡	0.97 (0.03)
Food insecure	0.85 (0.03) ‡	0.98 (0.03)	0.94 (0.03) ‡	1.04 (0.03)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡ Statistical significance at $p < 0.05$.

Table 5.10 Unadjusted and adjusted values (SE) for knee extensor power stratified by smoking status (non-smokers vs ever smokers) (n = 2,042)

Food security status	Unadjusted		Adjusted*	
	Smoking status		Smoking status	
	Non-smokers (W/kg) (n = 904)	Former Smokers (W/kg) (n = 1,138)	Nonsmokers (W/kg) (n = 904)	Former Smokers (W/kg) (n = 1,138)
Fully food secure†	1.54 (0.02)	1.60 (0.02)	1.56 (0.02)	1.53 (0.01)
Marginally food secure	1.52 (0.06)	1.57 (0.06)	1.46 (0.09)	1.50 (0.06)
Food insecure	1.39 (0.04) ‡	1.48 (0.05) ‡	1.41 (0.07) ‡	1.50 (0.05)

*Predictions based on multiple linear regressions controlling for age, gender, income, race/ethnicity, and education, and adjusted for design corrections and sample weights.

†Referent group.

‡ Statistical significance at $p < 0.05$.

Chapter 6 Overall Conclusions

6.1 Goal

The goal of this dissertation was to determine if there are associations between nutrition and functional status among a nationally representative sample of older adults. Nutritional status was examined by analysis of diet quality (the nutritional adequacy of diets) and food security status (access to nutritious food for an active and healthy life). Functional status was determined using both self-reported and performance-based measures. Self-reported measures of functional status included five different domains: ADLs, IADLs, LSAs, LEM, and GPAs. The first two domains are similar to Katz' self-reported scales for functional status, whereas LSAs, LEM, and GPAs belong to the AADLs in Katz' scales. Performance-based measures included assessment of gait speed over a distance of 20 feet and peak knee extensor power as determined by isokinetic muscle testing.

As hypothesized by Campbell (1991), food insecurity is a risk factor that can be used to predict well-being and quality of life. Chapters 3 and 4 examined the associations between overall diet quality, measured by HEI-2005 scores, and functional status as assessed by both self-reported and performance-based measures. Chapter 5 examined the association between food insecurity and physical performance, an integrated measure of health status, among older adults. Given the magnitude of the negative effect of smoking, it is hypothesized that smoking may obscure the association between food insecurity and physical performance among older adults.

6.1.1 Summary of findings

Three studies were designed to examine nutrition and functional status among older adults. Results from the chapter 3 showed that overall diet quality, as measured by HEI-2005 scores, was positively associated with physical performance, as measured by both higher gait speed and knee extensor power, among a nationally representative sample of US older adults. The chapter 5 found an inverse relationship between HEI-2005 scores and the odds of impaired LEM and GPA, and also provided additional support for the observed positive relationship between diet quality and functional status found in chapter 3. Meeting the HEI-2005 recommendations for fruits and vegetables was associated with better physical performance among participants and fewer reports of disabilities. Since HEI-2005 measures the adherence of Americans to the 2005 Dietary Guidelines, these results also support the benefits of adherence to the 2005 Dietary Guidelines in preventing functional decline among older Americans.

In addition to the examination of the nutritional adequacy of diets as a risk factor for impaired functional status among older adults, it is also examined if the sufficiency of food as directly experienced by household members is associated with impaired functional status. Chapter 5 found that smoking status modifies the association between food insecurity and physical performance. Food insecurity was negatively associated with physical performance among non-smokers. No statistically significant association between food insecurity and physical performance was observed among current or former smokers. Different from other studies, the results presented here did not find a statistically significant difference in physical performance between former and current smokers.

6.2 Significance of research

Good nutrition is one of the major determinants of the maintenance of proper functional status with aging. As the number of older adults and average life expectancy continue to rise, more people might be expected to experience impaired functional status. Previous studies examining the relationship between diet and functional status of individuals focused on single nutrients or food groups (Sharkey et al., 2003; Houston et al., 2005; Tomey et al., 2008; Cesari et al., 2004). Because people consume combinations of foods, it is difficult to attribute the effects of a single nutrient or food to any particular health outcome (Hu 2002). Few studies have examined diet quality and functional status among older adults. The results of this dissertation show that diet quality, as measured using HEI-2005 scores, is positively associated with better functional status among older Americans. As these dietary guidelines are the most authoritative dietary recommendations provided to the US population, the results of this dissertation that demonstrate the protective effects of following dietary guidelines will help health professionals to develop effective behavioral interventions to prevent functional decline among older adults. These results also show that given the magnitude of the negative effects of smoking on physical performance, smoking may obscure an association between food insecurity and physical performance among older adults. In addition, there was no apparent difference in physical performance between former and current smokers. This suggests that being a nonsmoker is vital to maintain proper functional status. Former smokers may remain a high risk subpopulation and experience accelerated functional decline due to the harmful effects of smoking. To our knowledge, this report is the first to demonstrate an effect of differences in smoking status and the relationship between food insecurity and physical performance among older adults. Health policy makers should continue efforts to improve the access of older adults to nutritious foods in a socially acceptable fashion, and educate younger people about the dangers of smoking to promote good health in older age.

6.3 Advantages and limitations

These studies are limited by their cross-sectional design, which cannot provide evidence to support causal relationships between predicted variables and functional outcomes. Impaired functional status may also lead to poor diet quality or reduced access to nutritious foods because of impairments in an individual's ability to shop, cook, or feed themselves, which may exacerbate their functional decline. In addition, survival bias is an important factor in cross-sectional studies of older adults (Kaplan et al., 1992; Lima-Costa et al., 2000a). Older adults with poor functional status may die earlier than others and thus cannot be included in the sample. This bias might dilute the strength of the associations detected, and, therefore, might tend to confirm them. Additionally, the NHANEs study population does not include institutionalized individuals who probably have a higher prevalence of disability than community-dwelling older adults. This selection bias, with an effect similar to that of survival bias, may result in an underestimate of the observed associations between food insecurity, diet quality, and functional status. In addition, the dietary data was collected by using a single 24-h dietary recall instrument, which may be subject to under- or over- reporting, depending on the population studied. Despite the valid food security measurements as determined by HFSSM, that scale cannot be used to measure other elements of the broad, conceptual definition of food security, such as food safety, nutritional quality of diets, and "social acceptability" of food sources—including the unusual and sometimes ingenious coping behaviors that food-insecure households may undertake to augment their food supply. Also, few performance-based measures were examined in the NHANES survey.

Despite these limitations, the studies reported here have some advantages. Functional status was examined using valid and reliable self-reported and performance-based measures in five different domains. This comprehensive assessment allowed exploration of the association between diet quality and functional status in different domains such as physical, social, and psychological domains, as well as in different settings such as laboratory and real-world conditions. Two valid and reliable performance-based measures, gait speed and knee extensor power, were examined. Gait speed may be considered a "vital sign" in clinical settings (Brach et al., 2007). Muscle power is important for individuals to carry out the majority of daily activities that depend on muscle strength and velocity (Bean et al., 2003). In addition, the present study employed the rigorous data collection procedures used in the NHANES, which provided the ability to generate a nationally representative sample. Further, diet quality was measured by HEI-2005 scores that are known to capture reliably key recommendations in the 2005 Dietary Guidelines for Americans. Using HEI-2005 scores to measure diet quality is also useful for making comparisons across different study populations. Previous studies that used data-driven analyses to examine dietary behavior within a population may not be replicable in other populations. Those earlier studies did not control for BMI and chronic medical conditions, which are considered as intermediate pathways rather than confounders. Here, physical activity was not considered to be a covariate. In the NHANES data set, some of the items in physical activity questionnaires like questions about the ability to walk are similar to items in functional status questionnaires. The NHANES questionnaire also collects information regarding leisure-time activities like aerobics, baseball, basketball, bicycling, and bowling. Participants with the ability to perform such voluntary activities usually exhibit relatively high functional status.

6.4 Directions for future research

Public health goals important for reducing healthcare costs and enhancing quality of life depend upon proper nutritional status so older adults can maintain their functional abilities. Targeted interventions to help achieve these public health goals will only arise through improved understanding of the complex factors that influence nutrition and functional status in older adults. Other longitudinal studies are needed to provide evidence of causal relationships between nutrition and functional status. Future studies can incorporate additional performance-based measures such as measurements of hand-grip strength, which have been shown to predict major health-related events in older adults (Rantanen et al., 1999). Further, additional studies are needed to investigate the interactions between smoking and food insecurity and the potential for combined negative effects on functional status among older adults. Future studies must address whether targeted interventions can substantially modify diet quality and food insecurity, and determine if such modifications lead to sustained, clinically important improvements in functional status. Such studies may also incorporate other dietary components like protein and water intake into the assessment of the overall diet quality for older adults.

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Appendix

Questions Used to Assess the Food Security of Households in the CPS Food Security Survey

1. "We worried whether our food would run out before we got money to buy more." Was that often, sometimes, or never true for you in the last 12 months?
2. "The food that we bought just didn't last and we didn't have money to get more." Was that often, sometimes, or never true for you in the last 12 months?
3. "We couldn't afford to eat balanced meals." Was that often, sometimes, or never true for you in the last 12 months?
4. In the last 12 months, did you or other adults in the household ever cut the size of your meals or skip meals because there wasn't enough money for food? (Yes/No)
5. (If yes to Question 4) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?
6. In the last 12 months, did you ever eat less than you felt you should because there wasn't enough money for food? (Yes/No)
7. In the last 12 months, were you ever hungry, but didn't eat, because you couldn't afford enough food? (Yes/No)

8. In the last 12 months, did you lose weight because you didn't have enough money for food? (Yes/No)

9. In the last 12 months did you or other adults in your household ever not eat for a whole day because there wasn't enough money for food? (Yes/No)

10. (If yes to Question 9) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?

(Questions 11-18 are asked only if the household included children age 0-18)

11. "We relied on only a few kinds of low-cost food to feed our children because we were running out of money to buy food." Was that often, sometimes, or never true for you in the last 12 months?

12. "We couldn't feed our children a balanced meal, because we couldn't afford that." Was that often, sometimes, or never true for you in the last 12 months?

13. "The children were not eating enough because we just couldn't afford enough food." Was that often, sometimes, or never true for you in the last 12 months?

14. In the last 12 months, did you ever cut the size of any of the children's meals because there wasn't enough money for food? (Yes/No)

15. In the last 12 months, were the children ever hungry but you just couldn't afford more food? (Yes/No)

16. In the last 12 months, did any of the children ever skip a meal because there wasn't enough money for food? (Yes/No)

17. (If yes to Question 16) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?

18. In the last 12 months did any of the children ever not eat for a whole day because there wasn't enough money for food? (Yes/No)