Spring 5-2022

The Associations of Cardiovascular Disease, Physical Activity Intensities, and Measures of Obesity on Static Balance in Middle-Aged and Older Adults

Hannah Martha Twiddy
Old Dominion University, twiddyhm@gmail.com

THE ASSOCIATIONS OF CARDIOVASCULAR DISEASE, PHYSICAL ACTIVITY INTENSITIES, AND MEASURES OF OBESITY ON STATIC BALANCE IN MIDDLE-AGED AND OLDER ADULTS

by

Hannah Martha Twiddy
B.S. May 2014, University of North Carolina Wilmington
M.S. May 2016, Old Dominion University

A Dissertation Submitted to the Faculty of Old Dominion University in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

EDUCATION – APPLIED KINESIOLOGY

OLD DOMINION UNIVERSITY

May 2022

Approved by:

Leryn J Reynolds (Director)

Patrick B Wilson (Co-Director)

David P. Swain (Member)

J. David Branch (Member)

Steven Morrison (Member)

ABSTRACT

THE ASSOCIATIONS OF CARDIOVASCULAR DISEASE, PHYSICAL ACTIVITY INTENSITIES, AND MEASURES OF OBESITY ON STATIC BALANCE IN MIDDLE-AGED AND OLDER ADULTS

Hannah Martha Twiddy
Old Dominion University, 2022
Chair: Dr. Leryn J Reynolds
Co-Chair: Dr. Patrick B. Wilson

The burden of falls is widely known in older adults, though less research has targeted middle-aged adults (40-64 years of age), particularly at the population level. The purpose of this dissertation was to explore the roles of cardiovascular disease, physical activity (PA) intensity, and body anthropometrics on balance among middle-aged adults. Study 1 sought to determine if balance was impaired in middle-aged adults with poor ankle-brachial pressure index (ABPI), a marker of cardiovascular disease. Study 2 determined the associations between PA intensity with odds of having good static balance. Study 3 explored how strongly a variety of anthropometric measures, including two novel ratios, associated with static balance. Studies utilized 1999-2002 and 2003-2004 National Health and Nutrition Examination Survey (NHANES) data. Study 1 included 1,046 middle-aged adults to examine the associations between ABPI and static balance (Romberg Test of Standing Balance) via logistic regression. This study determined middle-aged adults with at-risk ABPI had a significantly higher 3.38 (95%CI 1.66, 6.87) odds of having poor balance, indicating that balance may be an important functional assessment used in conjunction with ABPI to identify those at a higher risk of cardiovascular disease and falls. Using logistic regression, study 2 analyzed data from 1,068 middle-aged adults to examine the associations of light physical activity (LPA) and moderate-vigorous physical activity (MVPA) with static balance. No significant relationships were found between MVPA or LPA and having good static

balance in middle age. However, a sub-analysis in older adults (≥65 years) determined every 60-minute increase in LPA was significantly associated with 1.19 (95%CI: 1.09, 1.31) higher odds of good static balance after controlling for covariates, including MVPA. Study 3 included anthropometric measures of body mass index (BMI), waist circumference (WC), calf circumference (CC), thigh circumference (TC), WC/CC, WC/TC, WC/CC^2, and WC/TC^2 in 1,050 middle-aged adults. While a number of anthropometric measures were significantly associated with static balance, in both middle-aged males and females, analyses found higher WC/CC^2 and WC/TC^2 were significantly associated with decreased odds of good static balance. In both genders, area under the curve predictive ability resulted in WC/TC^2 followed by WC/CC^2 to be the highest predictors of static balance in middle-aged adults. Similarly, older-age males and females with higher WC/CC^2 and WC/TC^2 have significantly decreased odds of good static balance. Collectively, these findings demonstrate that WC/TC^2 and WC/CC^2 are good predictors of balance in middle-aged and older adults.

This dissertation is dedicated to my Grandmother Phyllis, for her passing on the perfect amount of curiosity, stubbornness, and adventure to allow me to pursue this feat. Throughout her life her drive to constantly learn and persistence to never stop is an example I will forever take with me.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the support of my parents and tribe of family, friends, mentors, and colleagues. Firstly, my upmost gratitude to Dr. Leryn Reynolds, who has pushed me throughout this process. Even prior to me becoming her doctoral student and throughout my time at ODU, she has taught me the value of good science and having the perfect amount of push to complete the task but to respect the process. Her honest feedback and knowing when to reel me in will stay with me throughout my career. Secondly, Dr. Wilson who has been a mentor to me; his ability to explain tough concepts and his writing feedback has helped me become a better writer   and stimulated my ability to look at statistics. I am also appreciative to my dissertation committee, Dr. David Swain. Dr. David Branch, and Dr. Steven Morrison who have supported this dissertation and been enthusiastic about the purpose. In addition, special thanks to Dr. Lucia Tabacu for her statistical guidance in this dissertation. I would also like to thank some ODU faculty that have been influential throughout my doctoral program; Dr. Laura Hill, Dr. Linda Bol, and Dr. Szklo-Coxe whose motivation encouraged me through teaching opportunities and grant seeking. Dr. Tom Socha who supported me in conducting a study on healthy aging on a research trip in Costa Rica; and fellow colleague, Elizabeth Mazuera whom I would have not been able to conduct interviews without. In addition, I would like to thank Sharon Pitney who believed in me from Day 1 on achieving a Fulbright Scholarship. Further, Dr. Karen Eck, Dr. Jason Lynch, and Dr. Justin Haegele whose feedback was influential. My highest gratitude to family and friends who have supported me in taking moments away for the writing of this dissertation from around the world: sailboats off the coast of Hatteras, to park benches in Chicago, and beachside in Hawaii. This would not have been possible without the support and encouragement from each and everyone.

NOMENCLATURE

ABPI	Ankle-Brachial Pressure Index
BMI	Body Mass Index
CVD	Cardiovascular Disease
RABPI	Right Ankle-Brachial Pressure Index
PA	Physical Activity
MVPA	Moderate-Vigorous Physical Activity
LPA	Light Physical Activity
TAC	Total Activity Counts
BMI	Body Mass Index
WC	Waist Circumference
CC	Calf Circumference
TC	Thigh Circumference
WC/CC	Waist -to-Calf Circumference ratio
WC/CC^2	Waist -to-squared Calf Circumference ratio
WC/TC	Waist-to-Thigh Circumference ratio
WC/TC^2	Waist-to-squared Thigh Circumference ratio

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I INTRODUCTION

Background

Advances in public health over the past century have been unprecedented; people are living longer although their quality of life is not necessarily following the same pattern of health (Jivraj, Goodman, Pongiglione, & Ploubidis, 2020). Consequently, population needs are growing towards increased care for older adults and better prevention of disease and disability for middle-aged adults (Talbot, Musiol, Witham, & Metter, 2005). Preventive measures for common ailments impacting older adult health are imperative to lessening the burden of illness, disability, and decreased quality of life and independence associated with aging. Falls are the leading cause of fatal and nonfatal injury among adults ≥65 years of age (Bergen, Stevens, & Burns, 2016; Verma et al., 2016). In a middle-aged population, approximately one in four adults reported falling at least once in a two-year period (Talbot et al., 2005). Of those who suffer a fall, >50% require hospitalization, translating into further medical complications (Park, 2018). Not only do falls pose a significant impact on health and physical function, but medical costs are estimated to be $754 million annually (Florence et al., 2018).

Fall risk is found to increase with age; in a 2014 report, 9.9% of adults aged 65-74 years reported a fall, while 11.4% of adults 75-84 years and 13.5% of adults ≥ 85 years reported falling (Bergen et al., 2016). While the burden of falls in the elderly is widely known, less population-based research has targeted adults < 65 years of age. Verma et al. (2016) estimated that 11.4% of community-dwelling adults aged 45-65 years suffered a fall over the previous year, which was linked to approximately 3.5 million fall-related injuries. Balance is a necessary component of fall risk, finding those with poor balance to have a greater risk of falls and poorer quality of life

(Moncada & Mire, 2017; Perera et al., 2018). Consequently, understanding factors that impact balance will aid in reducing the risk of falls and potentially lead to greater quality of life.

Cardiovascular disease (CVD) is common among middle-aged and older-aged adults (CDC, 2018; Yazdanyar & Newman, 2009) and is associated with a higher fall risk and risk factors leading to a fall (Jansen et al., 2016; Juraschek et al., 2018; Juraschek et al., 2019). Common cardiovascular conditions associated with falls are low blood pressure, heart failure, and cardiac arrhythmias (Jansen et al., 2016). For example, Juraschek et al. (2016) found middle-aged adults with orthostatic hypotension are at a 30% greater risk of falls. Twenty-two percent of individuals who have recently been diagnosed with CVD (heart failure, myocardial infarction, atrial fibrillation) score high on fall risk (Manemann et al., 2018).

Further, ankle-brachial pressure index (ABPI) is a non-invasive reliable predictor for identifying CVD (Ono et al., 2003). In particular, it is a valuable tool to detect early peripheral arterial disease (PAD) and is an independent marker for cardiovascular risk (Thurston & Dawson, 2019). ABPI is calculated by dividing the systolic blood pressure measured at the ankle by the systolic blood pressure measured in the brachial artery (Al-Qaisi, Nott, King, & Kaddoura, 2009). A fall in blood pressure in the artery at the ankle compared to the brachial artery would suggest stenosis between the aorta and the ankle (Al-Qaisi et al., 2009), typically located within the arteries of the leg. Studies demonstrate that an ABPI of <0.9 is indicative of PAD (Al-Qaisi et al., 2009). ABPI in older adults has been associated with poor balance (Gardner & Montgomery, 2001; Rodgers et al., 2019). Gardner and Montgomery (2001) determined that 86% of older individuals (65±10 years) with physician-diagnosed PAD and an ABPI of <0.90 have unsteadiness and stumbling while 73% report falls. However, no studies have determined whether ABPI is associated with balance in middle-aged adults (Rodgers et al., 2019). Understanding how CVD risk factors are associated to balance and fall risk in middle age is an important avenue of future research. While CVD appears to have detrimental effects on balance in the elderly, leading a physically active lifestyle plays a key role in improved balance in older adults (Bulbulian & Hargan, 2000).

Balance is a multicomponent type of fitness involving muscular action, neuromuscular control, and spatial awareness (Dunsky, 2019). Participation in regular exercise programs incorporating activities that target these actions may improve balance in young, middle, and older aged individuals. Yet one remaining question that persists is the extent to which physical activity (PA) intensity affects balance, especially alongside aging. In one population-based study of American adults aged 40 years and over, every 60-min increase in participation in light physical activity (LPA) was associated with 10% higher odds of functional balance (Loprinzi & Brosky, 2014). Further, for every 1-unit increase in daily log-transformed minutes of moderate-vigorous physical activity (MVPA), there was a 23% greater odds of having good balance (Loprinzi & Brosky, 2014). However, because this study did not conduct analyses on middle-aged and older adults separately, it is impossible to say whether PA relates to balance similarly in both groups. Notably, although both MVPA and LPA decline with aging, the drop in MVPA appears to be more precipitous (Wolff-Hughes, Fitzhugh, Bassett, & Churilla, 2015), and therefore it may not be ideal to analyze PA-balance associations across such broad age ranges. In addition, Loprinzi and Brosky (2014) did not account for the combined effects of MVPA and LPA. Individuals may have a wide range of PA levels encompassing different volumes of MVPA and LPA. Given that MVPA and LPA may both impact balance, it may be important to adjust for one another when examining how each is associated with balance. Thus, the extent to which exercise intensity impacts balance is not fully elucidated. In particular, limited studies have examined the association between PA and balance in the middle-aged population. This dissertation will, in part, determine the relationship between PA intensities and balance in a middle-aged population.

Like PA, obesity is also linked to decreased lower extremity function and fall risk in older adults (Mitchell, Lord, Harvey, & Close, 2014). In regard to the impact of obesity on static balance, obese individuals have a 18.75% failure rate on the Romberg Balance test compared to individuals with a normal BMI (9.45% failure rate) (Bermúdez-Rey, Clark, & Merfeld, 2017). Studies not only identify significant associations between high BMI and poor balance and fall risk but also body fat distribution (Bermúdez-Rey et al., 2017; Mitchell et al., 2014; Silvia G R Neri, Tiedemann, Gadelha, & Lima, 2020). Body fat accumulation in the abdominal region is related to instability in middle-aged women (Cieślińska-Świder, Furmanek, & Błaszczyk, 2017; Hita-Contreras et al., 2013; Ochi et al., 2010). Further research from Neri et al. (2020) determined women >60 years of age with higher body fat below the waist line to have a 41% increased risk of falls compared to 24% in those with higher body fat around the abdominal region. Body fat and muscle mass distribution in the middle and lower regions of the body may help identify greater fall risk.

Calf circumference (CC) reflects appendicular skeletal muscle mass and thigh circumference (TC) reflects whole body skeletal muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003). CC measures of <36 cm for males and <34 cm for women; and TC measures <49 cm in men and <44 cm in women are associated with low skeletal muscle mass (Kawakami et al., 2020; Mienche et al., 2019). These reductions in CC and TC reflective of decreased muscle mass may be indicative of poor balance. Wu et al. (2019) demonstrated in a nationally representative sample of adults ≥40 years of age that lower CC and TC is associated with having vestibular dysfunction, a significant factor in static balance control.

Specific anthropometric measures represent a greater association with skeletal muscle mass and thus could be more closely associated with balance (Wu et al., 2019; Zagyapan, Iyem, Kurkcuoglu, Pelin, & Tekindal, 2012). Further, those with a higher waist-to-calf circumference ratio (WC/CC) and waist-to-thigh circumference ratio (WC/TC) have a higher odds of having vestibular dysfunction (Wu et al., 2019). High WC/CC and WC/TC represent higher waist circumference (WC) and lower TC or CC. Anthropometric ratio data may be more beneficial by incorporating information about central adiposity and lower extremity muscle mass at the same time and result in better balance prediction compared to each on their own. For example, studies demonstrate WC/CC measures, compared to each single measure of WC or CC, are a better index for assessing the disproportionality between abdominal fat and leg muscle mass (Kim et al., 2011). A mechanism for the relationship between TC, CC, WC/CC, WC/TC and balance, is that these measures represent a measure of lean muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003), which we know to be associated with balance (Castillo-Rodríguez, Onetti-Onetti, Sousa Mendes, & Luis Chinchilla-Minguet, 2020).

While we know those with higher lower extremity circumference are found to have higher amounts of skeletal muscle mass (Wu et al., 2019), squaring these variables of the lower extremity in ratio measures may place a higher emphasis on body lean muscle mass, which is the main focus of the relationship between body anthropometric measures and balance. In adolescent males and females, Almeida et al. (2016) determined squared WC to height ratio and squared CC or squared hip circumferences are found to be strong predictive variables for %body fat. Thus, associations between balance measures could be strengthened by changing the scaling of WC/CC or WC/TC through squaring one of the lower extremity circumference values, which we know is strongly associated with skeletal muscle mass (Wu et al., 2019) and therefore balance (Castillo-Rodríguez et al., 2020). While we know body anthropometry distribution is linked to balance, no research has analyzed which measure of body adiposity is the best predictor of static balance status in a nationally representative middle-aged population.

Research has identified rising risks of cardiometabolic disease, decreased levels of PA, and obesity in the middle-aged population (Khabazkhoob, Emamian, Hashemi, Shariati, & Fotouhi, 2017; Talbot et al., 2005). Although these factors have been extensively studied in older adults in relation to balance and falls, this is not the case in the middle-aged population. Given the importance of these three factors on aspects of aging, with fall risk being a primary factor of poor health as one ages, it opens a line of research into how these factors are impacted in the middle-aged population. To our knowledge, nationally representative population-based studies in middle-aged adults are incomplete regarding the associations between 1) ABPI and balance, 2) the simultaneous associations of MVPA and LPA with balance, and 3) the body anthropometric measures most closely associated with balance. To address these gaps in the literature, this dissertation will use the National Health and Nutrition Examination Survey (NHANES), a nationally representative sample of U.S. adults, allowing for increased generalizability, which may have lacked in some previous studies.

Specific aims

<u>Study #1:</u> CVD is the leading cause of death in the United States (Heron, 2019). Ankle-brachial pressure index (ABPI) is a marker of atherosclerosis, which is a chronic vascular inflammatory disease driven by plaque accumulation within the artery wall (Al-Qaisi et al., 2009). Vascular diseases are risk factors for falls in older adults (>65 years) (Juraschek et al., 2019). However, whether vascular diseases are associated with poor balance in middle-aged adults is not well

understood. This investigation aimed to determine if balance in middle-aged adults with poor ABPI was impaired compared to those with normal ABPI.

Specific Aim #1: Determine if balance in a nationally representative sample of adults 40-64 years of age with poor ABPI was impaired compared to those with normal ABPI. We hypothesize in a nationally representative U.S. population sample, middle-aged individuals (40-64 years of age) with poor right ABPI (<0.90 ABPI) would have a poor balance score on the Romberg Test of Standing Balance.

Study #2: Increased PA levels are associated with good balance (Loprinzi & Brosky, 2014). However, the impact of LPA and MVPA on balance is not fully understood in a nationally representative sample of middle-aged adults. In addition, whether LPA or MVPA is a stronger predictor of balance in this population requires further study.

Specific Aim #2: Determine the associations of LPA and MVPA on the odds of having good static balance in a nationally representative sample of middle-aged adults 40-64 years of age. We hypothesize middle-aged individuals who habitually participate in high levels of LPA and MVPA will have better static balance, and MVPA will show a stronger association compared to LPA.

Study #3: Obesity is among the most important risk factors associated with poor balance (Bermúdez-Rey et al., 2017). Studies not only identify a significant association between high BMI with poor balance and fall risk but also body fat distribution and skeletal muscle mass (Bermúdez-Rey et al., 2017; Mitchell et al., 2014). Good balance is positively associated with skeletal muscle mass (Castillo-Rodríguez et al., 2020), of which CC and TC are predicative markers (Hodgkiss & McCarthy, 2017; Kawakami et al., 2020). Wu et al. (2019) demonstrated individuals with lower CC and TC or higher WC/CC and WC/TC to have a higher odds of having vestibular dysfunction. Further, squared measures of CC, TC, WC/CC and WC/TC may place a greater emphasis on skeletal muscle mass. Although previous studies have focused on measures of balance and lower extremity anthropometry, studies are lacking comparing multiple measures of body anthropometrics on the association with good static balance. Further, studies examining the association of these measures on static balance in middle-aged populations are scarce.

Specific Aim #3: Determine which anthropometric measure was most closely associated with good static balance in a nationally representative sample of adults 40-64 years of age. Subjects were separated into gender and age groups, and the body anthropometric measures of BMI, WC, CC, TC, WC/CC, WC/TC, WC/CC^2, and WC/TC^2 were included in the analysis to determine the odds of having good static balance. We explored which body anthropometric measures had the highest predictive power on static balance. We hypothesized WC/CC^2 and WC/TC^2 would have a stronger association with static balance than all other variables. Further, we examined how age group (middle age vs. older age) and gender impacted these associations.

Study variables

For Aim #1, the independent variable of ankle-brachial pressure index (ABPI) was a direct measure of PAD. The dependent variable was a measure of balance, taken from the four-stage Romberg Test of Standing Balance. The covariates included in this analysis were age, BMI, race/ethnicity, education, gender, and participation in muscle strengthening activity.

For Aim #2, the independent variables of daily PA were MVPA and LPA, which were taken from activity counts of worn accelerometers. For the purposes of facilitating interpretation, the LPA variable was analyzed in 60-min increments while the MVPA variable was analyzed in 10-minute increments. Age, BMI, gender, ethnicity, education, and a history of dizziness/impaired balance/previous falls served as control variables. The dependent variable of balance was taken from the four-stage Romberg Test of Standing Balance.

For Aim #3, the independent variables were BMI, WC, TC, CC, waist circumference to thigh circumference ratio (WC/TC), waist circumference to calf circumference ratio (WC/CC), waist circumference to squared thigh circumference ratio (WC/TC^2), and waist circumference to squared calf circumference ratio (WC/CC^2). The dependent variable of balance was taken from the four-stage Romberg Test of Standing Balance. The control variables included were age, race/ethnicity, education, MVPA, LPA and a history of dizziness/impaired balance/previous falls.

Limitations

1. All study data are taken from the National Health and Nutritional Examination Survey (NHANES). This is a cross-sectional design and cannot support causal or temporal inferences despite the notable statistical power associated with the data sets.
2. Although the balance score taken from the Romberg Test of Standing Balance is a common standard assessment of static balance, it does not assess dynamic balance.

Delimitations

The data set used for analysis is a nationally representative sample of middle-aged adults and older adults in the United States and thus is largely generalizable. The data collection methods are all valid and have been used extensively in related literature.

CHAPTER II LITERATURE REVIEW

Consequences of Falls

Falls are the leading cause of unintentional injury among older adults (Verma et al., 2016), and >50% of those who suffer a fall require hospitalization (Park, 2018). While the burden of falls is widely known in the elderly, less population-based research has targeted adults <65 years of age. Verma et al. (2016) estimated that 11.4% of community-dwelling adults aged 45-64 years suffered a fall over the previous year (Verma et al., 2016), and this resulted in an estimated 3.5 million fall-related injuries among this group. Consequently, identifying practical and widely available methods to assess fall risk in middle-aged adults is a priority. Agrawal et al. (2011) determined that the modified Romberg balance test is a reliable predictor of static balance and fall risk in adults. Static balance is defined as maintaining an upright position (sitting/standing) against gravitational forces (Dunleavy, Lulofs-MacPherson, & Slowik, 2019). Static balance is often measured while standing on different surfaces with eyes open or closed, such as in the Romberg Test of Standing Balance.

The Romberg Test of Standing Balance consists of 4 conditions taking into account three senses used to maintain balance. The first condition is eyes open on a firm surface, this considers vestibular, visual, and proprioceptive function or ability to maintain head position in space. The second condition is eyes closed on a firm surface and uses proprioception and vestibular function to recognize body position in space. The third condition is eyes open on a compliant surface, this measures the ability of the vision and vestibular system to monitor and adjust to changes in body position. The fourth and final condition is eyes closed on a compliant surface, which utilizes the vestibular system (Agrawal et al., 2011). Thus, failure of the Romberg Test of Standing Balance is a representation of vestibular dysfunction (Agrawal, Carey, Della Santina, Schubert, & Minor, 2009), a leading contribution to fall risk (Herdman, Blatt, Schubert, & Tusa, 2000). Specifically, Agrawal et al. (2009) determined those who failed the fourth condition of the Romberg Balance test were 6.3 times more likely to have fallen in the past year. Koo et al. (2015) found vestibular contributions to balance to increase above age 40 and significantly influence the presence of dizziness. These studies support the hypothesis that age effects on the vestibular system could be significant enough to alter balance function or vestibular thresholds in adults as young as age 40.

Balance is Impaired in the Aging Population

It is well known falls are a leading cause of disability in older adults (Nelson-Wong et al., 2012). Declines in muscle strength, coordination, and balance impair physical function, placing aging adults at a high risk of falls and thus disability (Papalia et al., 2020; Zecevic, Salmoni, Speechley, & Vandervoort, 2006). Many factors are linked to an increased risk of falls in older adults such as: increased visual impairments, decreased functional mobility and balance, previous history of falls, environmental factors, and overall weakened musculature to react to a changing stimulus (Ambrose, Paul, & Hausdorff, 2013; Bermúdez-Rey et al., 2017; Talbot et al., 2005). Balance is related to postural control, referring to the ability to maintain a posture (sitting or standing), move between postures, and not fall when reacting to an external stimulus (Pollock, Durward, Rowe, & Paul, 2000). Taken from individuals >60 years, both dynamic and static balance decline at a rate of approximately 1% each year (Takeshima et al., 2014). In an effort to determine the contribution aging has on balance, Era et al. (2006) established a reduction in balance function is observable in middle-age groups (30-59 years) but a deterioration in balance becomes significantly pronounced after age 60.

While most fall and balance related studies are focused on an older adult population, Talbot et al. (2005) was one of the first to compare falls in young, middle, and older-aged men and women.

The number of falls over a 2-year period increased alongside age: 18% in young (20-45 years), 21% in middle-aged (46-65 years), and 35% in older-aged adults (>65 years). Loss of balance within the middle-to-older-adult years is linked to a higher risk of falling, increased dependency, illness, and in some cases mortality (Howe, Rochester, Neil, Skelton, & Ballinger, 2011). The vestibular system is fundamental for balance control (Wu et al., 2019). Bermúdez Rey et al. (2017) utilized the Romberg Test of Standing Balance to examine the influence of aging on balance. The vestibular system was evaluated in test condition 4 of the Romberg Test of Standing Balance because of the contribution from the visual and kinesthetic cues reduced by closing the eyes and standing on a memory foam surface (Bermúdez-Rey et al., 2017). Failure of test condition 4 identified vestibular dysfunction and served as a measure of the vestibular contribution to balance (Bermúdez-Rey et al., 2017). Prevalence of balance failure progressed with age such that no significance was found in age groups 10-19 years, 20-29 years, or 30-39 years, although this relationship became significant after age 40. A prevalence of failure in the Romberg Test condition 4 was 9.7% in adults 40-49, which increased to 15.5% in adults 50-59, 34.7% in adults 60-69, and 60% in adults ≥70 years of age (Bermúdez-Rey et al., 2017).

Other studies also determined that balance failure rates increase markedly after age 40 (Agrawal et al., 2009; Agrawal et al., 2011; Koo et al., 2015). These studies exemplify the importance of falls and balance in the middle-aged population ≥40 years of age. In the middle-age years, adults begin decreasing PA levels and physiological changes alter postural stability leading to decreased balance (Ito et al., 2018). Gait and balance issues are cited as the most frequent cause for falls in all ages and both sexes (Talbot et al., 2005). Balance training has gained much regard as a primary intervention in the prevention of falls through fostering functional balance and postural control in an elderly population (Howe et al., 2011). Not only are balance and postural exercises beneficial in fall reduction in the elderly population, but they are also recommended for younger, healthy populations (Papalia et al., 2020). Overall total PA and exercise are known to play a major role in the prevention of falls through balance, gait function, and muscular strength (Sherrington et al., 2019). Balance is a multicomponent type of fitness involving muscular action, neuromuscular control, and spatial awareness (Dunsky, 2019). Thus, participation in regular exercise programs incorporating activities that target these actions may improve balance in young, middle, and older aged individuals. Though it is clear that dysfunction in static balance begins to decline as early as age 40, little population-based research has examined the predictors of such decline in middle-aged populations specifically.

Cardiovascular Disease is Associated with Poor Balance

Cardiovascular disease (CVD) is the leading cause of death in both men and women in the United States (Heron, 2019). The prevalence of coronary heart disease (CHD) is estimated to increase by 26% from 2010-2040 (Odden et al., 2011). The risk of developing CHD by age 40 is one in two for men and one in three for women (Lloyd-Jones, Larson, Beiser, & Levy, 1999). United States CVD healthcare costs are estimated to exceed $1.1 trillion by 2035, leading to significant economic strain (RTI International, 2017).

Ankle-brachial pressure index (ABPI) is a non-invasive reliable predictor for identifying CVD (Ono et al., 2003). In particular, it is a valuable tool to detect early PAD, and is an independent marker for cardiovascular risk (Thurston & Dawson, 2019). ABPI is calculated by dividing the systolic blood pressure measured at the ankle by the systolic blood pressure measured in the brachial artery (Al-Qaisi et al., 2009). A fall in blood pressure in the artery at the ankle compared to the brachial artery would suggest stenosis between the aorta and the ankle, particularly in the arteries of the leg. A normal ABPI ratio is at least 1.0, whereas an ABPI of

<0.9 is considered diagnostic for PAD (Al-Qaisi et al., 2009), which doubles the risk of cardiovascular mortality (McKenna, Wolfson, & Kuller, 1991). In a 15-year longitudinal study, each decrement of ABPI by 0.10 significantly increased cardiovascular mortality by 30% (Mlacak, Blinc, Pohar, & Stare, 2006). Likewise, Fowkes et al. (2008) determined an ABPI of ≤0.9 is associated with approximately twice the 10-year total mortality for CVD, suggesting a gradient risk of CVD as ABPI decreases. Even middle-aged individuals with a poor ABPI score are at an increased risk of CVD mortality (Chang et al., 2009), demonstrating that this measure has a high clinical value for determining CVD mortality. Interestingly, it appears that CVD in older individuals (>65 years) is related to not just an increased risk of mortality, but also to falling (Juraschek et al., 2019).

Multiple studies confirm that PAD in older adults is associated with poor balance and/or fall risk (Gardner & Montgomery, 2001; Matsushita et al., 2017). Gardner and Montgomery (2001) found that older individuals (65 ±10 years) with physician-diagnosed PAD and an ABPI of <0.90 have unsteadiness and stumbling, with 73% reporting falls. Additionally, Matsushita et al. (2017) determined that poor ABPI of ≤0.90 and borderline poor ABPI of 0.91-1.00, suggestive of PAD, were independently associated with poor Short Physical Performance Battery (SPPB) score compared to a normal ABPI of 1.11-1.20 in older adults aged 71-90 years. The SPPB consists of three components of physical function (chair stand, standing balance, and gait speed) and one component of upper body strength (grip strength). Specifically, Matsushita et al.(2017) found a low ABPI to have a significant relationship with lower-extremity function, walking speed, and standing balance. Further, Tanaka et al. (2016) identified those with poor ABPI (≤0.9) (and diagnosed heart failure) as having poorer standing balance. Although older adults are the most studied in terms of fall risk and poor balance, middle-aged adults also tend to have a high frequency of falls leading to significant health risk (Talbot et al., 2005). One in four middle-aged adults report a fall at least once in a 2-year period (Talbot et al., 2005). However, whether poor balance is associated with increased CVD risk as assessed by ABPI in middle-aged adults is not well understood, particularly at the population level.

Regular Physical Activity Improves Balance

A documented relationship exists between fall risk (balance) and PA levels (Loprinzi & Brosky, 2014). Participation in regular PA is known to have positive health benefits, especially in those with compromised balance and at an increased risk for falls (Bulbulian & Hargan, 2000; Osuka et al., 2015; Simonsick et al., 1993). Specifically, increasing total PA levels, accumulated over time across adulthood (43 and 53 years of age), can ensure the maintenance of physical performance later in life (Cooper, Mishra, & Kuh, 2011). Bulbulian and Hargan (2000) found older adults who were active were able to balance almost 20 seconds longer than those who were inactive during the Romberg Test of Standing Balance. Battaglia et al. (2020) determined older adults who participate in a one-hour walk, once/week, for a period of 6 months significantly supported fall risk prevention. Marques et al. (2017) reported that 32 weeks of exercise improved balance by 25% following resistance exercise and 31% following participation in aerobic exercise in older adults. From these studies, we find regular participation in PA improves balance and reduces fall risk in the older adult population.

One of the first studies to examine accelerometry-measured PA and balance from a nationally representative U.S. population sample ≥ 40years of age was Loprinzi and Brosky (2014). They found, for every 1-unit increase in log-transformed minutes of MVPA, odds of having functional balance were 23% higher (Loprinzi & Brosky, 2014). These findings align with intervention studies (Osuka et al., 2015; Pau, Leban, Collu, & Migliaccio, 2014) that show individuals >60years who participate in LPA and MVPA to have better functional balance. Blodgett et al. (2015) determined MVPA participation was independently associated with frailty in adults >50years of age. This study also identified sedentary behavior as a risk factor for frailty and adverse health outcomes in middle-to-older-aged adults (Blodgett et al., 2015).

While many studies confirm min/day of MVPA is positively associated with improved balance, fewer studies have examined this in LPA, which may be more practical for individuals who were previously sedentary, have a fear of falling, or are at a decreased physical fitness level (Jefferis et al., 2014). Osuka et al. (2015) suggested that habitual LPA is a useful indicator of lower-extremity performance and dynamic balance among older adults (60-96 years of age). It is estimated that for every 60-min increase in LPA, participants (40-85 years of age) have 10% higher odds of having functional balance (Loprinzi & Brosky, 2014). Further, longer amounts of time spent in LPA is related to better performance on measures of balance in older adults (Osuka et al., 2015). However, these results may be dependent on the type of balance measurement. Pau et al. (2014) characterized PA into light versus vigorous intensity during a 12-week intervention in adults >65 years of age and determined that reductions in postural sway can be obtained after participation in LPA. However, vigorous physical activity (VPA) was superior to LPA in gait and sit-to-stand time.

Even though multiple previous studies have examined the impact of PA intensity on balance in older adults, less research, particularly at the population level, has focused on middle-aged adults. Loprinzi and Brosky (2014) did include individuals aged 40 and over, but because they did not conduct analyses on middle-aged and older adults separately, it is impossible to say whether different PA intensities relate to balance similarly in both groups. Both MVPA and LPA decline with age, but because the drop in MVPA appears to be more precipitous (Wolff-Hughes et al., 2015), it may not be ideal to analyze PA-balance associations across such broad age ranges. Loprinzi and Brosky (2014) also did not account for the combined effects of MVPA and LPA. Individuals may have a wide range of PA levels encompassing different volumes of MVPA and LPA. Given that MVPA and LPA may both impact balance, it is important to adjust for one another when examining how each is associated with balance.

Overall, the extent to which PA intensity impacts balance is not fully elucidated. In particular, limited studies have examined the association between PA and balance in the middle-aged population. Research demonstrates the importance of participation in habitual PA in the maintenance of balance and frailty that occur with age (Loprinzi & Brosky, 2014; Riebe et al., 2015). It is known that participation in regular PA starting in young-to-middle adult years (26-45) serves as a better health protector than when begun in the older adult years (Aoyagi & Katsuta, 1990). Not only is habitual PA found to play a protective role within the aging process, but the intensity of the PA may also be a factor.

Obesity Increases the Risk for Poor Balance

In examining health factors associated with poor balance and reduced PA, obesity is among the most important (Bermúdez-Rey et al., 2017; Hassinen, Komulainen, Lakka, Väisänen, & Rauramaa, 2005; Pietiläinen et al., 2008). Maintenance of ideal body weight and fat distribution is important in the protection against disease, disability, loss of physical function, and overall health (He & Baker, 2004). Adults with severe obesity are found to have significantly impaired mobility compared to those who are in the normal or less-severe obesity category (Mitchell et al., 2014). Individuals who are within the obese BMI category (>30 kg/m^2) are at a 31% higher risk of falling and 26% less likely to have walked two or more hours within the previous week of a reported fall (Mitchell et al., 2014). Specifically, those with a normal BMI (<25 kg/m^2) have a

9.45% failure rate on the Romberg Balance test, which increases to 18.75% for those with an obese BMI (≥30 kg/ m^2) (Bermúdez-Rey et al., 2017). After adjusting for confounders such as diabetes, hypertension history, smoking, age, race/ethnicity, and gender, there was a significant 2.4-fold increase in the odds of falling if within the obese BMI category (Bermúdez-Rey et al., 2017).

Studies not only identify significant associations with poor balance and fall risk but also between body composition distribution and balance (Bermúdez-Rey et al., 2017; Mitchell et al., 2014). Higher body fat above the waist line, known as an android body type, is found to be associated with postural instability in women aged 50-65 years of age (Hita-Contreras et al., 2013). Body fat accumulation in the abdominal region is related to more instability (Cieślińska-Świder et al., 2017; Ochi et al., 2010). Price et al. (2006) found 17.7% of individuals with a waist-to-hip ratio of >0.99 have suffered a fall in the past 6 months compared to 13.7% of those with a ratio of 0.89-0.92. Further, WC, an anthropometric measure that reflects abdominal fat mass, has been found a predictor for fall risk (Silvia Gonçalves Ricci Neri et al., 2019). Specifically, Neri et al. (2019), compared obese to nonobese individuals and determined individuals with a mean WC of 98.7 cm exhibit a greater center of pressure displacement on a force platform and an increased fear of falling, and a higher proportion have increased fall risk compared to those with a mean WC of 81.7 cm. While we know body fat accumulation and distribution is directly associated with fall risk, and body fat measured below the waistline is a better predictor of incidence of falls, a gap remains as to what specific body fat distribution below the waistline to be most predictive of balance and fall risk.

Lower extremity body anthropometric measures, such as CC, are a risk factor for lower extremity frailty in the elderly population (Landi et al., 2014; Sun et al., 2017). This is thought to be explained through its “less biased” association with muscle mass than other body sites. For example, the calf is generally less affected by body fat deposits as compared to the waist or thigh circumference and thus is a purer surrogate marker of skeletal muscle mass, which is linked to balance (Santos et al., 2019; Szulc, Beck, Marchand, & Delmas, 2005). Similar to CC, TC is highly correlated to appendicular skeletal muscle mass, not only in older adults but also young-to-middle-aged adults (Santos et al., 2019). TC may be a better indicator of leg-muscle mass compared to hip circumference measures as TC is less influenced by bone and gluteal fat (Snijder et al., 2003). Thigh lean mass has been found associated with dynamic balance after adjusting for BMI and muscle strength (Bani Hassan, Phu, Vogrin, & Duque, 2022). Site-specific fat and muscle mass is associated with functional impairment (Ochi et al., 2010), which may be the link to increased fall risk.

Age related loss of muscle mass, a condition known as sarcopenia, leads to decreased muscle strength and performance resulting in poor lower extremity function (Larsson et al., 2018). Sarcopenia is known as a major risk factor for falls in older adults (Yeung et al., 2019). Body anthropometric measures are reliable markers for frailty and indicators of sarcopenia in older adults (Tosato et al., 2017). Landi et al. (2014) and Stewart et al. (2002) determined a larger CC is positively related to lower frailty and protective against falling. In fact, CC is a surrogate marker for diagnosing sarcopenia in adults 40-89 years of age (Kawakami et al., 2015). Calf circumference measures of <36 cm for males and <34 cm for females are associated with low muscle mass (Kawakami et al., 2020) and a CC of <31 cm is associated with high risk of disability (Rolland et al., 2003). TC is also a strong predictor of muscle mass (Mienche et al., 2019). Mienche et al.(2019) found TC measures <49 cm in men and <44 cm in women are associated with low muscle mass. Lower TC is also linked to decreased walking speed and a slower chair sit to stand test in older adults (Visser et al., 2002). In addition to CC, TC is also a known marker to diagnose sarcopenia (Mienche et al., 2019).

Combining anthropometric measures that generally reflect different body tissues (fat and muscle) into a single variable may, in some instances, result in improved health outcome prediction. Given that WC tends to reflect central adiposity, CC tends to reflect appendicular muscle mass, and TC reflects skeletal muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003), the ratios of WC to CC (WC/CC) and WC to TC (WC/TC) are potentially worth exploring as predictors of health outcomes. Indeed, studies demonstrate that WC/CC, compared to each single measure on its own, is a better index for assessing the disproportionality between abdominal fat and leg muscle mass, risk of cardiovascular disease (Kim et al., 2011), and health-related quality of life in the elderly (Yang et al., 2020). Though, research on the relationships between WC/CC and aspects of balance is much more limited, they were recently examined by Wu et al. (2019). Wu et al. (2019) demonstrated this in a nationally representative sample ≥40 years of age, finding that individuals with lower CC and TC or higher waist-to-calf ratio (WCR) and waist-to-thigh ratio (WTR) have a greater odds of having vestibular dysfunction, a significant factor in static balance control. However, this study performed only a cursory comparison of the predictive ability of WC/CC and WC/TC on vestibular balance versus more standard anthropometric variables. Moreover, while gender was included as a covariate, the analyses were conducted with men and women combined, which is questionable given the known gender-specific differences in anthropometric variables (Perissinotto, Pisent, Sergi, Grigoletto, & Enzi, 2002). Thus, while we know that traditional body anthropometry variables (BMI, WC, etc.) are linked to balance, little research has analyzed this relative predictive power of more novel anthropometric variables

(WC/CC and WC/TC) on balance status in nationally representative samples. Further, the role of sex in the relative predictiveness of these measures remains understudied.

Although using ratios like WC/CC and WC/TC sometimes results in improved predictive power as compared to their component circumference values alone, changing the scaling of one or more variables in a ratio could theoretically offer even better predictions. For example, BMI is a measure of weight by squared height, which is preferred to weight by height, or weight by the cube of height, due to its close association with body fat (Keys, Fidanza, Karvonen, Kimura, & Taylor, 2014). Likewise, WC by squared or cubed height, places a greater emphasis on central adiposity and increases the incidence of developing hypertension in young adults (Fuchs et al., 2005). In children, Almeida et al. (2016) determined squared WC to height ratio and squared CC or squared hip circumference contributed to the prediction of percent body fat. Thus, it is possible that the associations with balance measures could be strengthened by changing the scaling of WC/CC or WC/TC through squaring one of the lower extremity circumference values.

Overall Summary of the Literature Review

In sum, present research identifies the relationship between PA and balance, body anthropometrics and balance, and CVD risk and balance. However, this research has largely been conducted in older adults or with small intervention-based studies. A limitation within PA research is the lack in examining how PA intensities (LPA and MVPA) are associated to static balance in a middle-aged adult population. Additionally, the utilization of a nationally representative population to compare multiple measures of body anthropometrics will allow for better generalizability on the relationship with static balance. Further a gap remains as to what specific body fat distribution below the waistline to be most predicative of balance and fall risk. CVD presence is knowingly linked to fall risk; however, the relationship between presence of vascular disease and balance has not been determined in a middle-aged adult aged population via ABPI score. Thus, the present dissertation proposes to explore the relationship between cardiovascular disease, PA, and obesity on balance in a nationally representative population of middle-aged adults.

CHAPTER III METHODS

Study design

This study included secondary data taken from the 1999-2000, 2001-2002, and 2003-2004 National Health and Examination Survey (NHANES). NHANES is a nationally representative sample of non-institutionalized Americans, which is accomplished by a complex, multistage probability sampling design. The NHANES population excludes all in supervised care or custody in institutional settings, all active-duty military personnel, active-duty family members living overseas, and any other U.S. citizens residing outside the 50 states and the District of Columbia. Included in the population are those in non-institutional group quarters (such as college or university residence halls). Oversampling of certain population subgroups allows for an increase in the reliability and precision of health status indicator estimates.

NHANES protocols are approved by the National Center for Health Statistics Ethics Review Board. Informed consent was obtained from all participants and the research adhered to the Declaration of Helsinki. The Darden College of Education and Professional Studies Human Subjects Research Committee at Old Dominion University determined this study was exempt from full review by the Institutional Review Board.

STUDY 1 OF DISSERTATION

Study Population

Data were obtained from the 1999-2000 and 2001-2002 years of NHANES. Demographic information was collected as home interviews of survey participants via computer-assisted personal interviewing methodology. Participation in muscle strengthening activities was assessed at the mobile examination center interview. Self-reported interview records were reviewed by the

NHANES field office staff for accuracy and completeness. Basic demographic data to be used in this analysis were age, gender, race/ethnicity, and education level. Body mass index (BMI) was calculated from height and weight measured at mobile examination centers. A questionnaire on muscular strengthening activity was included as a covariate that asked the participants to answer yes or no to the following: "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscle such as lifting weights, push-ups, or sit ups?" Participants underwent a comprehensive health examination in a mobile examination center. This included objective balance testing, as assessed through the 4-condition Romberg Test of Standing Balance and an assessment of peripheral arterial disease via ABPI score.

Balance Testing

This analysis included data on 2,146 adults who had complete data for study variables. Adults included in the analysis were between 40-64 years of age. Individuals were excluded from examination if they met any of the following criteria: dizziness or unsteadiness while standing, weighing over 275 lbs., waist circumference that does not fit a standard-sized safety belt, use of a leg brace to stand, or amputations of the lower limbs (*Centers for Disease Control and Prevention (CDC)*, 1999-2000).

Static balance was assessed utilizing the Romberg Test of Standing Balance on Firm and Compliant Surfaces (Romberg Balance Test) (Khasnis & Gokula, 2003; Shu, Chen, & He, 2020), which evaluates the ability to balance unassisted under four conditions, with each condition increasing in difficulty. Prior to testing, each participant completed a pre-examination questionnaire to determine his or her ability to participate in the test. If participants were eligible to participate, they began with condition 1; this makes use of all the sensory inputs (central vestibular system, vision, and proprioception) by having participants stand with their eyes open, feet together, and arms folded across the waist, holding the elbows with the hands. Condition 2 tested balance with only vestibular and proprioceptive inputs available by having participants stand in the same position as test condition 1 but with their eyes closed. In test condition 3, participants stood on a foam-padded surface with their eyes open, which reduced proprioceptive input but left visual and vestibular cues available. Finally, in condition 4, participants stood on the foam-padded surface with their eyes closed to use solely the vestibular system. Test conditions 1 and 2 were conducted for 15 seconds each while conditions 3 and 4 were conducted for 30 seconds each. Balance was scored on a pass/fail basis in all conditions (Agrawal et al., 2011; Bermúdez-Rey et al., 2017; Loprinzi & Brosky, 2014). Test failure was defined as the participant: 1) using arms or feet to maintain balance, 2) beginning to fall or requiring that a technician intervene to maintain balance, or 3) needing to open their eyes (conditions 2 and 4 only). Participants were allowed one re-test for each condition. Individuals who failed any of the four conditions were placed into a poor static balance category. Individuals who passed all four conditions were placed into a good static balance category. There were 2,146 adults eligible to be analyzed. This dataset included those who completed condition 4 (Pass) (n=1,574) compared to those who failed any condition (Fail) (n=5,72). Further details of balance testing procedures are available at https://wwwn.cdc.gov/nchs/data/nhanes/1999-2000/manuals/ba.pdf.

Ankle-Brachial Pressure Index

ABPI, which was used as the ratio of tibial to brachial systolic blood pressure, was assessed on participants 40 years of age or older. Included in this analysis were those 40-64 years of age (n=2,146). Exclusion criteria includes bilateral amputations, weight over 400 lb, and conditions such as: casts, ulcers, dressings, illness, or equipment failure. Following a brief rest period, systolic pressure of the brachial artery was measured on the right arm and posterior tibial artery of both ankles. For participants aged 40-59 years, systolic pressure was measured twice; however, it was measured only once in participants over the age of 60 years. Appropriate cuff size was determined prior to the cuff being placed on the participant's arm. Since ABPI scores were recorded as whole numbers, these scores were categorized to indicate participants with an at-risk ABPI score of ≤0.9 or not-at-risk ABPI of >0.9. These cutoff points were chosen because individuals with a ABPI of ≤0.9 are at a greater risk of all-cause mortality compared to individuals with a ABPI of >0.9 (Mlacak et al., 2006).

Statistical analysis

Data were downloaded from the NHANES website and merged using Statistical Analysis System (SAS) software (SAS Institute Inc., Cary, North Carolina). Data analysis was conducted using SPSS Complex Samples (Version 22, IBM Corp, Armond, NY, USA). Mobile Examination Center (MEC) and 4-year sample population weights were utilized in the analysis to account for over-sampling and nonresponse using the WEIGHT statement in SAS PROC FREQ in the National Center for Health Statistics instructions. Differences between continuous variables (age, BMI) were found using the complex samples, general linear model. Differences between categorical variables (race/ethnicity, education, gender, and answering yes or no to participating in muscle strengthening activities within the past 30 days) were found using a complex sample, Rao-Scott Adjusted Chi-Square statistic. Logistic regression of complex samples was used to estimate the odds ratio and 95% confidence intervals of ABPI score associated with balance status (pass or fail). A $p \leq 0.05$ is considered statistically significant.

STUDY 2 OF DISSERTATION

Study Population

The 2003-2004 survey years of the NHANES served as the source of data for this observational, cross-sectional secondary data analysis. The main measurements included minutes of light and moderate-vigorous physical activity and pass/fail Romberg Balance Test, which occurred in the mobile examination center during the examination component. Middle-aged adults were included in the analysis who were 40-64 years of age. In a sub-analysis, we also included older adults age ≥65 years of age to compare to the middle-aged adults. Adults were included if they had complete data for physical activity and balance testing, as well as complete data for other relevant variables (gender, ethnicity, education, history of falling, and BMI). Individuals were excluded from balance testing if they met any of the following criteria: dizziness or unsteadiness while standing, weighing over 275 lbs., waist circumference that does not fit a standard-sized safety belt, use of a leg brace to stand, or amputations of the lower limbs (Centers for Disease Control and Prevention (CDC), 1999-2000). For the physical activity monitor component, individuals were also excluded if they used a wheelchair or had other impairments that prevented them from walking or wearing a physical activity monitor.

Balance Testing

Balance was assessed utilized the Romberg Test of Standing Balance on adults >40 years of age, as previously described in *study 1*. Balance was categorized into poor/good balance as previously described in *study 1.*

Accelerometer Data and Analysis

The accelerometer used to track PA was an ActiGraph AM-7164 (ActiGraph, Ft. Walton Beach, FL) (Crouter, DellaValle, Haas, Frongillo, & Bassett, 2013). Accelerometers were not worn during activities such as swimming or water aerobics, due to the device not being waterproof, and participants were instructed to remove the device at bedtime. Accelerometers were worn around the participants' waist near the iliac crest on the right side for 7 consecutive days. Non-wear was defined by a minimum period of 60 consecutive minutes of no activity counts, with an allowance of 2 minutes or less of activity counts between 0 and 100 ("Examination Data Overview: National Health and Nutrition Examination Survey," 2003-2004). Participants with at least 4 days of 10 or more hours per day of valid wear time were included in the analysis to adequately capture habitual PA patterns. Accelerometers detect and record the intensity of movement, frequency, and duration of PA through generating an activity count. One-minute time intervals were used in NHANES, and intensity was summed over each 1-minute period.

First, MVPA was classified as activity counts of ≥2,020 per minute and LPA was classified as activity counts between 100-2,019 per minute (Boyer, Wolff-Hughes, Bassett, Churilla, & Fitzhugh, 2016; Loprinzi & Brosky, 2014; Wolff-Hughes et al., 2015). The physical activity monitor considers LPA as activity counts of 100-760 range, and leisure time physical activity as 760-2019; thus, we combined these categories into one light activity count measure for analysis. Minutes per day of MVPA and LPA were averaged across all valid worn days to determine average daily MVPA and LPA.

Additional Variables

Demographic information was collected at home interviews of survey participants via computer-assisted personal interviewing methodology. Self-reported interview records were reviewed by the NHANES field office staff for accuracy and completeness. Basic demographic data used in this analysis were age, gender, race/ethnicity, and education level. Body mass index (BMI) was calculated from height and weight measured at mobile examination centers. A questionnaire on balance was included as a covariate that asked participants to answer yes or no to the following: "During the past 12 months, have you had dizziness, difficulty with balance or difficulty with falling?"

Statistical Analysis

Data were downloaded from the NHANES website (except for the accelerometer data) and merged using Statistical Analysis System (SAS) software (Version 9.4 SAS Institute Inc., Cary, North Carolina). To account for over-sampling, complex design features of NHANES, and nonresponse of individuals during data collection, adjusted 2-year population mobile examination center weights derived from web-application accelerometer files (Van Domelen, n.d.) were used to generate estimates according to the National Center for Health Statistics analytical guidelines (Johnson et al., 2013). Differences between categorical demographic variables (race/ethnicity, education, gender, falling/balance questionnaire) by static balance were evaluated using a complex sample, Rao-Scott Adjusted Chi-Square statistic. Differences between continuous variables (BMI, age, MVPA, and LPA) by static balance were evaluated using a complex sample, general linear model procedure that is equivalent to a t-test (IBM, 2020). Further pairwise comparison was examined for differences between measures whose 95%CI did not cross 1.0.

The accelerometer data were processed and downloaded using a web application (Van Domelen, n.d.). The algorithm used to extract and analyze the accelerometer data was selected as "simple," which takes a conservative approach for defining non-wear time. The associations between participation in MVPA and LPA and static balance were computed via multivariate logistic regression. We determined the odds of having good static balance in association with increased participation in MVPA and LPA, with poor static balance as the reference category. The continuous variable of MVPA was split into 10-minute increments, because MVPA accumulated in short bouts of 10-min increments has been found to have protective health benefits (White, Gabriel, Kim, Lewis, & Sternfeld, 2015). LPA, in contrast, was split into 60-minute increments, similar to Loprinzi and Bronsky (2014) who found an increase of LPA by 60 minutes was associated with improved balance. Collectively, the variables in the multivariate analysis included LPA (60-min increments), MVPA (10-minute increments), age, BMI, gender, ethnicity, education, and dizziness/impaired balance/previous falls as the independent and control variables, and static balance as the dependent variable. Statistical significance was set at $p \leq 0.05$ for all tests.

STUDY 3 OF DISSERTATION

Study Population

Data for this observational, cross-sectional secondary data analysis were collected from the 2003-2004 survey years of NHANES. This analysis included adults 40-64 years of age, but a sub-analysis included older adults age ≥65 years of age for comparison. The main measurements included pass/fail on the Romberg Test of Standing Balance and body anthropometric data from the mobile examination centers examination component. Adults were included in the analysis if they had complete data for physical activity, balance testing, and relevant anthropometric data. Individuals were excluded from balance testing if they met any of the following criteria: dizziness or unsteadiness while standing, weighing over 275 lbs., WC that does not fit a standard-sized safety belt, use of a leg brace to stand, or amputations of the lower limbs (*Centers* *for Disease Control and Prevention (CDC)*, 1999-2000). For the physical activity monitor component, individuals were excluded if they used a wheelchair or had other impairments that prevented them from walking or wearing a physical activity monitor. There were no medical, safety, or other exclusions for the body measures protocol.

Anthropometric and Body Composition Measures

Body measurements used in this analysis were WC, TC, CC, and BMI. BMI is a ratio measure of mass to height squared of an individual and correlates relatively strongly with body fat (Nuttall, 2015). Body weight was measured during the mobile examination center component to the nearest 0.1 kg using a Toledo digital scale (Mettler-Toledo LLC, Columbus, OH). Standing height was measured with a fixed Seca electronic stadiometer (SECA, Hamburg, Germany). BMI (in kg/m^2) is calculated from these data. Circumference measurements were taken on all survey participants. Measurements were taken with a tape measure while participants were standing or sitting for the calf measurement. WC was taken at the level of the uppermost lateral border of the ilium in the midaxillary line. TC was taken at a midpoint, found as the middle point between the inguinal crease and proximal border of the patella. The CC on the right calf was taken at the greatest circumference in a plane perpendicular to the long axis of the calf. All measurements were taken to the nearest 0.1 cm. In addition, ratio measurements were calculated in the analysis to determine the best association with balance. They are as follows: waist to thigh circumference (WC/TC), waist to thigh circumference squared (WC/TC^2), waist to calf circumference (WC/CC), and waist to calf circumference squared (WC/CC^2). All body anthropometric measures were separated into quartiles for interpretability.

Balance Testing

Balance was assessed utilized the Romberg Test of Standing Balance on adults >40 years of age, as previously described in *study 1*. Balance was categorized into poor/good balance as previously described in *study 1*.

Accelerometer Data and Analysis

An ActiGraph AM-7164 (ActiGraph, Ft. Walton Beach, FL) (Crouter et al., 2013) was used to measure physical activity data as previously described in *study 2*.

Additional Variables

Demographic information was collected at home interviews of survey participants via computer-assisted personal interviewing methodology. Self-reported interview records were reviewed by the NHANES field office staff for accuracy and completeness. Basic demographic data used in this analysis was age, gender, race/ethnicity, and education level. A questionnaire on balance was included as a covariate that asked participants to answer yes or no to the following: "During the past 12 months, have you had dizziness, difficulty with balance or difficulty with falling?"

Statistical Analysis

Data were downloaded from the NHANES website (except for the accelerometer data) and merged using Statistical Analysis System (SAS) software (Version 9.4 SAS Institute Inc., Cary, North Carolina). To account for over-sampling, complex design features of NHANES, and nonresponse of individuals during data collection adjusted 2-year population mobile examination center weights derived from web-application accelerometer files (Van Domelen, n.d.) were used to generate estimates according to the National Center for Health Statistics analytical guidelines (Johnson et al., 2013). Differences between categorical demographic variables (race/ethnicity, education, gender, falling/balance questionnaire) by static balance were evaluated using a complex sample, Rao-Scott Adjusted Chi-Square statistic. Differences between continuous variables (age, MVPA, and LPA) by static balance were evaluated using a complex sample, general linear model procedure that is equivalent to an independent t-test (IBM, 2020).

The associations between body anthropometric measures (BMI, WC, TC, CC, WC/TC, WC/CC, WC/TC^2, WC/CC^2) and static balance were computed via univariate and multivariate logistic regression. We determined the odds of having good static balance in association with higher BMI, WC, TC, CC, WC/TC, WC/CC, WC/TC^2, WC/CC^2, with poor static balance as the reference category. Univariate logistic regression determined the individual relationship each body anthropometric measure had on having good static balance. Multivariate logistic regression computed each body anthropometric measure individually adjusted for covariates of age, ethnicity, education, LPA and MVPA in Model 1; and age, ethnicity, education, LPA and MVPA, and dizziness/impaired balance/falling within the past 12 months in Model 2. Further pairwise comparison was examined for differences between measures whose 95%CI did not cross 1.0. The threshold for statistical significance was set at a $p \leq 0.05$.

Receiver Operating Characteristic (ROC) analysis, using adjusted 2-year population mobile examination center weights and various R functions from the package "rnhanesdata" by Leroux, Crainiceanu, Smirnova, and Caeo (2018) and Leroux et al. (2019) were then used to calculate area under ROC curves (AUC) between each body anthropometric variable (BMI, WC, TC, CC, WC/TC^2, WC/CC^2) and good static balance. The AUC analysis was adjusted for age, ethnicity, education, LPA, MVPA, and dizziness/impaired balance/falling. Anthropometric variables are ranked in decreasing order of their predictive performance as measured by the AUC in separate predictor logistic regression with good static balance as outcome. The AUC value is a measure used for classification performance for binary classifiers (Flach, Hernández-Orallo, & Ramirez, 2011). Higher AUC values indicate a better classifier. The AUC data can be interpreted according to these guidelines (Laurson, Eisenmann, & Welk, 2011; Swets, 1988): non-informational/equal to change (AUC=0.5), less accurate (0.5<AUC≥0.7), moderately accurate (0.7<AUC≥0.9), highly accurate (0.9<AUC≥1.0), and a discriminatory test (AUC=1.0).

CHAPTER IV STUDY 1

FUNCTIONAL BALANCE AMONG MIDDLE-AGED ADULTS IS A RISK FACTOR FOR CARDIOVASCULAR DISEASE

Introduction

Cardiovascular disease (CVD) is the leading cause of death in both men and women in the United States (Heron, 2019). The prevalence of coronary heart disease (CHD) is estimated to increase by 26% from 2010-2040 (Odden et al., 2011). The risk of developing CHD by age 40 years is one in two for men and one in three for women (Lloyd-Jones et al., 1999). Annual CVD costs (both direct and indirect) for U.S. adults are estimated to exceed $1.1 trillion by 2035, leading to significant economic strain (RTI International, 2017).

Given the individual and societal burdens of CVD, early detection of individuals who are at a greater likelihood of developing these disorders is of critical importance. Ankle-brachial pressure index (ABPI) is a non-invasive reliable predictor for identifying CVD (Ono et al., 2003). In particular, it is a valuable tool to detect early peripheral arterial disease (PAD), and is an independent marker for cardiovascular risk (Thurston & Dawson, 2019). ABPI is calculated by dividing the systolic blood pressure measured at the ankle by the systolic blood pressure measured in the brachial artery (Al-Qaisi et al., 2009). A fall in blood pressure in the artery at the ankle compared to the brachial artery would suggest stenosis between the aorta and the ankle, particularly in the arteries of the leg. A normal ABPI ratio is at least 1.0, whereas an ABPI of <0.9 is considered diagnostic for PAD (Al-Qaisi et al., 2009), which doubles the risk of cardiovascular mortality (McKenna et al., 1991). In a 15-year longitudinal study, each decrement of ABPI by 0.10 significantly increased cardiovascular mortality by 30% (Mlacak et al., 2006). Even middle-aged individuals with a poor ABPI score are at an increased risk of CVD mortality (Chang et al., 2009), demonstrating that this measure has a high clinical value.

Interestingly, it appears that CVD in older individuals (>65 years) is related to not just an increased risk of mortality but also to falling (Juraschek et al., 2019). Falls are the leading cause of unintentional injury among adults (Verma et al., 2016), and >50% of those who suffer a fall require hospitalization (Park, 2018). While the burden of falls is widely known in the elderly, less population-based research has targeted adults <65 years of age. Verma et al. (2016) estimated that 11.4% of community-dwelling adults aged 45-64 years suffered a fall over the previous year (Verma et al., 2016), and this resulted in an estimated 3.5 million fall-related injuries among this group. Consequently, identifying practical and widely available methods to assess fall risk in middle-aged adults is a priority. Agrawal et al.(2011) found that the modified Romberg balance test is a reliable predictor of balance and fall risk in adults.

There is growing interest in the links between CVD and falling since these conditions often coincide with one another (Juraschek et al., 2019). In theory, individuals with CVD may be at greater risk of falling because balance is partly dependent on a well-functioning cardiovascular system. The cardiovascular system, for example, supplies blood, oxygen, and nutrients to various organs (brain, skeletal muscle, etc.) involved in balance and is also involved in regulating blood pressure with changes in posture (Serrador, Schlegel, Black, & Wood, 2009). Further, individuals with CVD are more likely to be treated with medications, such as antihypertensives, that may modestly increase the risk of falls when they are initially administered or when dosages are changed (Kahlaee, Latta, & Schneider, 2018). However, whether CVD risk factors, including ABPI, are associated with balance in middle-aged adults is not well understood, particularly at the population level.

Thus, the purpose of this study was to assess standing balance among middle-aged adults with or without PAD as defined by an ABPI <0.9. The population-representative National Health and Nutrition Examination Survey (NHANES) was used given the availability of balance and ABPI data in middle-aged adults.

Methods

Study Population

Data were obtained from the 1999-2000 and 2001-2002 years of NHANES. Demographic information was collected as home interviews of survey participants via computer-assisted personal interviewing methodology. Participation in muscle strengthening activities was assessed at the mobile examination center interview. Self-reported interview records were reviewed by the NHANES field office staff for accuracy and completeness. Basic demographic data to be used in this analysis were age, gender, race/ethnicity, and education level. Body mass index (BMI) was calculated from height and weight measured at mobile examination centers. A questionnaire on muscular strengthening activity was included as a covariate that asked the participants to answer yes or no to the following: "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscle such as lifting weights, push-ups, or sit ups?" Participants underwent a comprehensive health examination in a mobile examination center. This included objective balance testing, as assessed through the 4 condition Romberg Test of Standing Balance and an assessment of peripheral arterial disease via ABPI score.

Balance Testing

This analysis included data on 2,146 adults who had complete data for study variables. Adults included in the analysis were between 40-64 years of age. Individuals were excluded from examination if they met any of the following criteria: dizziness or unsteadiness while standing, weighing over 275 lbs., waist circumference that does not fit a standard-sized safety belt, use of a leg brace to stand, or amputations of the lower limbs (*Centers for Disease Control and Prevention (CDC)*, 1999-2000).

Static balance was assessed utilizing the Romberg Test of Standing Balance on Firm and Compliant Surfaces (Romberg Balance Test) (Khasnis & Gokula, 2003; Shu et al., 2020), which evaluates the ability to balance unassisted under four conditions, with each condition increasing in difficulty. Prior to testing, each participant completed a pre-examination questionnaire to determine his or her ability to participate in the test. If participants were eligible to participate, they began with condition 1; this makes use of all the sensory inputs (central vestibular system, vision, and proprioception) by having participants stand with their eyes open, feet together, and arms folded across the waist, holding the elbows with the hands. Condition 2 tested balance with only vestibular and proprioceptive inputs available by having participants stand in the same position as test condition 1 but with their eyes closed. In test condition 3, participants stood on a foam-padded surface with their eyes open, which reduced proprioceptive input but left visual and vestibular cues available. Finally, in condition 4, participants stood on the foam-padded surface with their eyes closed to use solely the vestibular system. Test conditions 1 and 2 were conducted for 15 seconds each while conditions 3 and 4 were conducted for 30 seconds each. Balance was scored on a pass/fail basis in all conditions (Agrawal et al., 2011; Bermúdez-Rey et al., 2017; Loprinzi & Brosky, 2014). Test failure was defined as the participant: 1) using arms or feet to maintain balance, 2) beginning to fall or requiring that a technician intervene to maintain balance, or 3) needing to open their eyes (conditions 2 and 4 only). Participants were allowed one re-test for each condition. Individuals who failed any of the four conditions were placed into a poor static balance category. Individuals who passed all four conditions were placed into a good static balance category. There were 2,146 adults eligible to be analyzed. This dataset included those who completed condition 4 (Pass) (n=1,574) compared to those who failed any condition (Fail) (n=572). Further details of balance testing procedures are available at https://wwwn.cdc.gov/nchs/data/nhanes/1999-2000/manuals/ba.pdf.

Ankle-brachial Pressure Index

ABPI, which was used as the ration of tibial to brachial systolic blood pressure, was assessed on participants 40 years of age or older. Included in this analysis were those 40-64 years of age (n=2,146). Exclusion criteria includes bilateral amputations, weight over 400 lbs., and conditions such as: casts, ulcers, dressings, illness, or equipment failure. Following a brief rest period, systolic pressure of the brachial artery was measured on the right arm and posterior tibial artery of both ankles. For participants aged 40-59 years, systolic pressure was measured twice; however, it was measured only once in participants over the age of 60 years. Appropriate cuff size was determined prior to the cuff being placed on the participant's arm based off midpoint circumference of the participant's upper arm and then referred to a table adapted from the Human Blood Pressure Determination by Sphygmomanometry by the American Heart Association. Since ABPI scores were recorded as whole numbers, these scores were categorized to indicate participants with an at-risk ABPI score of ≤0.9 or not-at-risk category ABPI of >0.9. These cutoff points were chosen because individuals with a ABPI of <0.9 are at a greater risk of all-cause mortality compared to individuals with an ABPI of >0.9 (Mlacak et al., 2006).

Statistical analysis

Data were downloaded from the NHANES website and merged using Statistical Analysis System (SAS) software (SAS Institute Inc., Cary, North Carolina). Data analysis was conducted using SPSS Complex Samples (Version 22, IBM Corp, Armond, NY, USA). Mobile Examination Center (MEC) and 4-year sample population weights were utilized in the analysis to account for over-sampling and nonresponse using the WEIGHT statement SAS PROC FREQ in the National Center for Health Statistics instructions. Differences between continuous variables (age, BMI) were found using the complex samples, general linear model. Differences between categorical variables (race/ethnicity, education, gender, and physical activity questionnaire) were found using a complex sample, Rao-Scott Adjusted Chi-Square statistic. Logistic regression of complex samples was used to estimate the odds ratio and 95% confidence intervals of ABPI score associated with balance status (pass or fail). A $p \leq 0.05$ is considered statistically significant.

Results

Of the individuals who completed the Romberg Balance protocol, 2,146 met our inclusion criteria, were aged 40-64 years, completed RABPI measurements, and responded to basic demographic information. **Table 1** presents demographic characteristics by good (n=1,574) and poor (n=572) balance. Age ($p<0.001$), education level ($p<0.001$), race/ethnicity ($p=0.003$), and participation in muscle strengthening activities ($p=0.002$) differed significantly by balance status while gender and BMI did not. Participants in the poor balance group were 3.4 years older compared to those with good balance. The prevalence of non-Hispanic whites was higher in the good balance group than the poor balance group (77.5% vs. 69.7%). In addition, the prevalence of having more than a high school diploma was higher in the good balance group than the poor balance group (62.4% vs. 49.6%).

The prevalence of at-risk vs. not-at-risk RABPI by balance status is shown in **Table 2.** Among the group with good balance, the prevalence of at-risk RABPI was 1.3%, while it was 4.2% among those with poor balance (p=0.001). Using logistic regression, individuals with at-risk RABPI had 3.38 (95% CI: 1.66-6.87; p=0.001) times the odds of poor balance compared to individuals with not-at-risk RABPI. The odds ratio of 3.38 is of a moderate association between variables (Chen, Cohen, & Chen, 2010). The odds ratio was attenuated when age and BMI were entered into the model as covariates, but the association between RABPI status and balance was still significant (odds ratio: 2.39, 95% CI: 1.09-5.26; p=0.031).

Table 1. Characteristics of the Participants by Balance Status

Characteristics	Good balance (n = 1,574)	Poor balance (n= 572)	p-value
Age (years)	49.5± 0.2	52.9± 0.4	<0.001*
BMI (kg•m^{-2})	28.0 ± 0.2	27.6 ± 0.3	0.124
Gender (n, %)			0.385
Male	821 (50.3)	281 (47.7)	
Female	753 (49.7)	291 (52.3)	
Race/Ethnicity (n, %)			0.003*
Mexican American	359 (5.2)	138 (5.7)	
Other Hispanic	56 (4.2)	39 (8.2)	
Non-Hispanic white	813 (77.5)	250 (69.7)	
Non-Hispanic black	297 (9.2)	128 (12.0)	
Other	49 (4.0)	17 (4.3)	
Education Level (n, %)			<0.001*
< High School Diploma	399 (14.1)	212 (24.9)	
High School Diploma,GED	353 (23.5)	136 (25.5)	
> High School Diploma	822 (62.4)	224 (49.6)	
Muscle strengthening activities (n,%)			
Yes	393 (27.0)	86 (17.3)	0.002*
No	1162 (72.0)	474 (80.6)	
Unable to do	19 (0.9)	12 (2.1)	

Continuous data are mean ± SE. For categorical data, the numbers inside parentheses are percentages weighted to U.S. population while the numbers outside parentheses are unweighted counts. *p≤0.05

Table 2. Prevalence of at-risk RABPI among participants with good and poor balance in the National Health and Nutrition Examination Survey (NHANES), 1999-2002

RABPI Score	**Good Balance (n=1,574)**	**Poor Balance (n=572)**	**p-value**
Not-at-risk RABPI (>0.90)	98.7%	95.9%	0.001
At-risk RABPI (≤0.90)	1.3%	4.2%	

Right Ankle-Brachial Pressure Index (RABPI), *p≤0.05

Discussion

The novelty of the present study is the positive association between poor RABPI and poor balance in a middle-aged population. Specifically, this study provides evidence that middle-aged adults (40-64 years) with poor cardiovascular health, as measured by RABPI, are at higher odds of having poor functional static balance, measured through the Romberg Balance Test. Multiple previous studies confirm that PAD in older adults is associated with poor balance and/or fall risk (Gardner & Montgomery, 2001; Matsushita et al., 2017). Gardner and Montgomery (2001) found that the prevalence of stumbling and unsteadiness was 1.86 times higher in older individuals with physician-diagnosed PAD than in controls, and the prevalence of falling was 1.73 times higher. Additionally, Matsushita et al. (2017) determined poor ABPI of ≤0.90 and borderline poor ABPI of 0.91-1.00 suggestive of PAD were independently associated with poor Short Physical Performance Battery (SPPB) score compared to a normal ABPI of 1.11-1.20 in adults aged 71-90 years. The SPPB consisted of three components of physical function (chair stand, standing balance, and gait speed) and one component of upper body strength (grip strength) (Guralnik et al., 1994). The results from these studies coincide with the findings of the present study in which individuals with poor RAPBI have higher odds of having poor static balance. Further, we extend the findings by Gardner and Montgomery and Matsushita (2001) by demonstrating that this occurs in middle-aged individuals using a nationally representative population. Thus, it appears that middle-aged adults with poor RAPBI are also susceptible to having poor functional static balance.

McDermott et al. (2004) determined participants with ABPI levels of 0.9-1.1 to have consistently lower leg strength than ABPI of 1.10-1.50 (defined as the absence of PAD

(McDermott et al., 2004). Individuals with PAD are found to have impaired endothelial function (Yataco, Corretti, Gardner, Womack, & Katzel, 1999) in the lower extremities, which is linked to increased inflammation (Gregorio Brevetti et al., 2003), and oxidative stress (G. Brevetti et al., 2001). Systemic vascular function has been found to be associated with lower-limb muscular power (Heffernan et al., 2012). In the present study, individuals with good balance participated in greater muscle strengthening activities compared to those with poor balance (see **Table 1**). Given the important role of skeletal muscle strength on standing balance (Szulc et al., 2005), these results point to a potential relationship for individuals with good balance and muscle strengthening activities.

Further, Tanaka et al.(2016) identified those with poor ABI (≤0.9) (and diagnosed heart failure) as having poorer standing balance based off a single-balance test measurement; this was supported by the present study which found poor RABPI (≤0.9) to be associated with higher odds of having poor static balance, based off a 4 condition-standing balance examination. Although older adults are the most studied in terms of fall risk and poor balance, middle-aged adults also tend to have a high frequency of falls leading to significant health risk (Talbot et al., 2005). One in four middle-aged adults report a fall at least once in a 2-year period (Talbot et al., 2005). Thus, the importance of this present study is to confirm the higher presence of poor static balance in a middle-aged population with poor ABI scores. Middle-aged adults demonstrate an increasing incidence of disease, lower levels of physical activity, and physiological changes in postural sway and balance (Talbot et al., 2005).

There are some notable strengths and limitations to this analysis. The NHANES uses a cross-sectional design and cannot support causal or temporal inferences despite the notable statistical power associated with the data sets. Nonetheless, this dataset is nationally representative of middle-aged and older adults in the United States and thus is largely generalizable. The Romberg Test of Standing Balance was utilized to determine poor or good balance; although this does not assess both static and dynamic balance, this test is a common standard assessment in clinical and research settings (Lin et al., 2020). Confounding variables have been attempted to be minimized through the inclusion of a model adjusting for potential predictors of age and BMI.

Conclusion

In conclusion, this study aimed to determine the relationship between ABPI and static balance in middle-aged adults using a nationally representative sample. Middle-aged adults with a poor RABPI score are at higher odds of poor balance, assessed through the Romberg Test of Standing Balance. In addition, those who have good balance report to participate in muscle strengthening activities, which are known to have likely protective effects against development of PAD and falls. Future research is warranted to evaluate whether improving ABPI through lifestyle and pharmacological interventions is associated with improvements in balance.

CHAPTER IV STUDY 2

THE ASSOCIATION OF MODERATE-TO-VIGOROUS AND LIGHT INTENSITY PHYSICAL ACTIVITY ON STATIC BALANCE IN MIDDLE-AGED ADULTS

Introduction

Falls are the leading cause of fatal and nonfatal injury among adults ≥65 years of age (Bergen et al., 2016; Verma et al., 2016). While the burden of falls in the elderly is widely known, less population-based research has targeted adults <65 years of age (Talbot et al., 2005). Verma et al. (2016) estimated that 11.4% of community-dwelling adults aged 45-65 suffered a fall over the previous year, which was linked to approximately 3.5 million fall-related injuries in this population. Other studies demonstrate that balance failure rates increase markedly after age 40 (Agrawal et al., 2009; Agrawal et al., 2011; Koo et al., 2015). These studies exemplify the importance of balance not just in the elderly but even in middle-aged populations (40-65 years of age). Balance largely predicts falls, in that those with poor balance have a greater risk of falls and poorer quality of life (Moncada & Mire, 2017; Perera et al., 2018).

Balance is related to functional postural control, which is the ability to maintain a posture (sitting or standing), move between postures, and not fall when reacting to an external stimulus (Pollock et al., 2000). Postural control includes both static and dynamic balance (Harrison et al., 2021; Pollock et al., 2000). According to Rogers et al. (2013), dynamic balance is the ability to maintain postural stability while performing specific movements. Static balance is defined as maintaining an upright position (sitting/standing) against gravitational forces (Dunleavy et al., 2019). Static balance is often measured while standing on different surfaces with eyes open or closed, such as during the Romberg Test of Standing Balance (Melo et al., 2017; Rogers et al., 2013). As individuals age, static balance (as measured by the Clinical Test of Sensory Interaction for Balance, a test of postural sway velocity) declines at a rate of approximately 1% each year (Takeshima et al., 2014). Loss of static balance within the middle-to-older adult years is linked to a higher risk of falling, increased dependency, illness, and in some cases mortality (Fujita et al., 2015; Monteiro, Forte, Carvalho, Barbosa, & Morais, 2021). Balance and postural training are beneficial in fall reduction in the elderly (Kuptniratsaikul et al., 2011) and also recommended for younger, healthy populations (Lesinski, Hortobágyi, Muehlbauer, Gollhofer, & Granacher, 2015). Physical activity (PA) and exercise play a major role in the prevention of falls through improved balance, gait function, and muscular strength (Perera et al., 2018). Thus, understanding how PA impacts balance may aid in reducing the risk of falls and potentially lead to greater quality of life.

Participation in PA is associated with improved balance. Bulbulian and Hargan (2000) found that older adults (69.1±4.4 years) who were physically active were able to balance almost 20 seconds longer during the Romberg Test of Standing Balance than those who were inactive. While much research has examined the impact of PA on balance in older adults, less is known about the effects of PA on balance in middle-aged populations. Indeed, many of the studies that examine PA in individuals >45 years also include older adults (>65 years) in the analysis (Bermúdez-Rey et al., 2017; Blodgett et al., 2015; Dogra & Stathokostas, 2012; Loprinzi & Brosky, 2014), and therefore the impact of PA on static balance in only a middle-aged population is not as well understood.

The role of PA intensity on balance is not fully clear. Loprinzi and Brosky (2014) found that for every 1-unit increase in log-transformed minutes of MVPA, odds of having good balance were 24% higher in adults aged >40 years (Loprinzi & Brosky, 2014). This same study found that every 60-min increase in light-intensity PA (LPA) demonstrated a 10% higher odds of having good balance (Loprinzi & Brosky, 2014). However, given that MVPA and LPA were represented on different scales, it is difficult to fully distinguish the role of PA intensity on balance in this study. Further, Pau et al. (2014) demonstrated that vigorous physical activity (VPA) was superior to improving parameters of gait and sit-to-stand time compared to LPA in individual's greater than 65 years. However, no difference was found in the improvement in postural sway following LPA and VPA training. Collectively, these results suggest the role of exercise intensity on balance may not be fully understood. Additionally, the role of PA intensity in middle-aged populations is less well known.

Given the limited research examining the effects of PA intensity on balance in middle-aged adults, the purpose of this study was to examine the influence of PA intensity on static balance in middle-aged individuals. We hypothesized that MVPA would result in higher odds of having good static balance compared to LPA in middle-aged adults.

Methods

Study Population

The 2003-2004 survey years of the NHANES served as the source of data for this observational, cross-sectional secondary data analysis. The main measurements included minutes of light and moderate-vigorous physical activity and pass/fail Romberg Balance Test, which occurred in the mobile examination centers during the examination component. Middle aged adults were included in the analysis who were 40-64 years of age. In a sub-analysis, we also included older adults age ≥65 years of age to compare to the middle-aged adults. Adults were included if they had complete data for physical activity and balance testing, as well as complete data for other relevant variables (gender, ethnicity, education, history of falling, height, weight, and BMI). Individuals were excluded from balance testing if they met any of the following criteria: dizziness or unsteadiness while standing, weighing over 275 lbs., waist circumference that does not fit a standard-sized safety belt, use of a leg brace to stand, or amputations of the lower limbs (Centers for Disease Control and Prevention (CDC), 1999-2000). For the physical activity monitor component, individuals were also excluded if they used a wheelchair or had other impairments that prevented them from walking or wearing a physical activity monitor.

Balance testing

Static balance was assessed utilizing the Romberg Test of Standing Balance on Firm and Compliant Surfaces (Romberg Balance Test) (Khasnis & Gokula, 2003; Shu et al., 2020), which evaluates the ability to balance unassisted under four conditions, with each condition increasing in difficulty. Prior to testing, each participant completed a pre-examination questionnaire to determine their ability to participate in the test. If participants were eligible to participate, they began with condition 1; this makes use of all the sensory inputs (central vestibular system, vision, and proprioception) by having participants stand with their eyes open, feet together, and arms folded across the waist, holding the elbows with the hands. Condition 2 tested balance with only vestibular and proprioceptive inputs available by having participants stand in the same position as test condition 1 but with their eyes closed. In test condition 3, participants stood on a foam-padded surface with their eyes open, which reduced proprioceptive input but left visual and vestibular cues available. Finally, in condition 4, participants stood on the foam-padded surface with their eyes closed to use solely the vestibular system. Test conditions 1 and 2 were conducted for 15 seconds each while conditions 3 and 4 were conducted for 30 seconds each. Balance was scored on a pass/fail basis in all conditions (Agrawal et al., 2011; Bermúdez-Rey et al., 2017; Loprinzi & Brosky, 2014). Test failure was defined as the participant: 1) using arms or feet to maintain balance, 2) beginning to fall or requiring that a technician intervene to maintain balance, or 3) needing to open their eyes (conditions 2 and 4 only). Participants were allowed one re-test for each condition. Individuals who failed any of the four conditions were placed into a poor static balance category. Individuals who passed all four conditions were placed into a good static balance category. Further details of balance testing procedures are available at https://wwwn.cdc.gov/nchs/data/nhanes/1999-2000/manuals/ba.pdf.

Accelerometer Data and Analysis

The accelerometer used to track PA was an ActiGraph AM-7164 (ActiGraph, Ft. Walton Beach, FL) (Crouter et al., 2013). Accelerometers were not worn during activities such as swimming or water aerobics, due to the device not being waterproof, and participants were instructed to remove the device at bedtime. Accelerometers were worn around the participants' waist near the iliac crest on the right side for 7 consecutive days. Non-wear was defined by a minimum period of 60 consecutive minutes of no activity counts, with an allowance of 2 minutes or less of activity counts between 0 and 100 ("Examination Data Overview: National Health and Nutrition Examination Survey," 2003-2004). Participants with at least 4 days of 10 or more hours per day of valid wear time were included in the analysis to adequately capture habitual PA patterns. Accelerometers detect and record the intensity of movement, frequency, and duration of PA through generating an activity count. One-minute time intervals were used in NHANES, and intensity was summed over each 1-minute period.

First, MVPA was classified as activity counts of ≥2,020 per minute and LPA was classified as activity counts between 100-2,019 per minute (Boyer et al., 2016; Loprinzi & Brosky, 2014; Wolff-Hughes et al., 2015). The physical activity monitor considers LPA as activity counts of 100-760 range, and leisure time physical activity as 760-2019; thus, we combined these categories into 1 light activity count measure for analysis. Minutes per day of MVPA and LPA were averaged across all valid worn days to determine average daily MVPA and LPA.

Additional variables

Demographic information was collected at home interviews of survey participants via computer-assisted personal interviewing methodology. Self-reported interview records were reviewed by the NHANES field office staff for accuracy and completeness. Basic demographic data used in this analysis were age, gender, race/ethnicity, and education level. Body mass index (BMI) was calculated from height and weight measured at mobile examination centers. A questionnaire on balance was included as a covariate that asked participants to answer yes or no to the following: "During the past 12 months, have you had dizziness, difficulty with balance or difficulty with falling?"

Statistical Analysis

Data were downloaded from the NHANES website (except for the accelerometer data) and merged using Statistical Analysis System (SAS) software (Version 9.4 SAS Institute Inc, Cary, North Carolina). To account for over-sampling, complex design features of NHANES, and nonresponse of individuals during data collection, adjusted 2-year population mobile examination center weights derived from web-application accelerometer files (Van Domelen, n.d.) were used to generate estimates according to the National Center for Health Statistics analytical guidelines (Johnson et al., 2013). Differences between categorical demographic variables (race/ethnicity, education, gender, falling/balance questionnaire) by static balance were evaluated using a complex sample, Rao-Scott Adjusted Chi-Square statistic. Differences between continuous variables (BMI, age, MVPA, and LPA) by static balance were evaluated using a complex sample, general linear model procedure that is equivalent to an independent t-test (IBM, 2020).

The accelerometer data were processed and downloaded using a web application (Van Domelen, n.d.). The algorithm used to extract and analyze the accelerometer data was selected as "simple," which takes a conservative approach for defining non-wear time. The associations between participation in MVPA and LPA and static balance were computed via multivariable logistic regression. We determined the odds of having good static balance in association with increased participation in MVPA and LPA, with poor static balance as the reference category. The continuous variable of MVPA was split into 10-minute increments, because MVPA accumulated in short bouts of 10-min increments has been found to have protective health benefits (White et al., 2015). LPA, in contrast, was split into 60-minute increments, similar to Loprinzi and Bronsky (2014) who found an increase of LPA by 60-min was associated with improved balance. Collectively, the variables in the multivariate analysis included LPA (60-min increments), MVPA (10-minute increments), age, BMI, gender, ethnicity, education, and dizziness/impaired balance/previous fall question as the independent and control variables, and static balance as the dependent variable. Further pairwise comparison was examined for differences between measures whose 95%CI did not cross one. Statistical significance was set at $p \leq 0.05$ for all tests.

Results

Middle-aged adults

The main analysis that focused on middle-aged adults included 1,068 participants (**Table 3**). Of the middle-aged adults, 700 participants had good static balance and 368 had poor static balance. Further, mean age was lower in participants with good balance than those with poor balance ($p < 0.001$), and BMI was significantly lower in the poor balance group compared to the good balance group (p=0.028). While gender and race/ethnicity did not vary between the balance groups, participants who had good balance were more educated (p<0.001) and less likely to self-report having problems with dizziness, balance, and falling in the past year than participants with poor balance (p<0.001). Participants with good static balance participated in a mean ± standard error (SE) of 24.4 ± 1.2 minutes per day of MVPA while for LPA it was 355.4 ± 3.3 minutes per day. In the poor static balance group, the mean ± SE minutes per day of MVPA was 23.0 ± 1.7 and for LPA it was 349.8 ± 4.7. No statistically significant differences were detected when comparing minutes of MVPA or LPA by balance group.

In separate unadjusted logistic regression analyses, no significant relationship was found between 10-minute increments of MVPA (odds ratio (OR): 1.04 95%CI: 0.95, 1.13, p=0.427) and having good static balance, or 60-minute increments of LPA (OR:1.05 95%CI: 0.97, 1.14, p=0.182) and having good static balance. Furthermore, after adjusting for covariates and simultaneously including both LPA and MVPA, both PA variables had nonsignificant odds (p=0.375, p=0.937) (LPA OR: 1.09, 95%CI: 0.94, 1.27 and MVPA OR: 1.01, 95% CI: 0.91, 1.12) of good static balance, as shown in *Table 4*. In contrast, age (p<0.001), BMI (p=0.036), education level (p<0.001), and having self-reported problems with dizziness, balance, and falling in the past year (p=0.007) were significantly associated with balance status in middle-aged adults (**Table 4**).

Table 3. Characteristics of the Participants, middle age (40-64 years).

Characteristics	**Good Static Balance (n= 700)**	**Poor Static Balance (n= 368)**	**P-value**
Age (years)	49.5 ± 0.34	52.2 ± 0.43	<0.001*
BMI (kg·m^{-2})	28.5 ± 0.24	27.5 ± 0.36	0.028*
Gender (n, %)			0.905
Male	348 (48.7)	177 (48.3)	
Female	352 (51.3)	191 (51.7)	
Race/Ethnicity (n, %)			0.325
Mexican Hispanic	133 (5.2)	79 (5.8)	
Other Hispanic	15 (2.7)	11 (3.9)	
Non-Hispanic white	375 (76.9)	192 (73.8)	
Non-Hispanic black	148 (10.9)	68 (9.8)	
Other	29 (4.3)	18 (6.6)	
Education Level (n, %)			<0.001*
< High School Diploma	118 (8.7)	112 (18.3)	
High School Diploma, GED	158 (22.7)	104 (30.7)	
> High School Diploma	424 (68.6)	152 (51.0)	
Dizziness/Balance/Falling problems in the past year			<0.001*
Yes	122 (17.4)	108 (29.2)	
No	578 (82.6)	260 (70.8)	
MVPA (min/day)	24.4 ± 1.2	23.0 ± 1.7	0.481
LPA (min/day)	355.4 ± 3.3	349.8 ± 4.7	0.265

Continuous data are mean ± SE. For categorical data, the numbers inside parentheses are percentages weighted to U.S. population while the numbers outside parentheses are unweighted counts. *p≤0.05

Table 4. Odds ratio (95% CI) from multivariate logistic regression on the association between physical activity and odds of having good static balance in the middle age group (40-64 years of age).

Middle Age (40-64 years) (n=1068)		
Characteristics	**Odds Ratio (95% CI)**	**P-value**
60-min LPA	1.09 (0.94, 1.27)	0.375
10-min MVPA	1.01 (0.91, 1.12)	0.937
Age (years)	0.94 (0.92, 0.96)	<0.001*
BMI (kg•m^2)	1.04 (1.00, 1.08)	0.036*
Female (vs male)	1.14 (0.84, 1.56)	0.372
Race/Ethnicity		0.752
Mexican American vs Non-Hispanic White	1.03 (0.55, 1.91)	
Other Hispanic vs Non-Hispanic White	0.64 (0.33, 1.24)	
Non-Hispanic Black vs Non-Hispanic White	1.09 (0.73, 1.62)	
Other/Multi Racial vs Non-Hispanic White	0.75 (0.36, 1.56)	
Education Level		<0.001*
Some high school vs some college	0.36 (0.23, 0.58)	
High school diploma/GED vs some college	0.51 (0.35, 0.74)	
No dizziness/Balance/Falling problems in the past year (vs yes)	1.74 (1.20, 2.55)	0.007*

CI= Confidence Interval; LPA=light physical activity; MVPA= moderate to vigorous physical activity; BMI= body mass index
Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test). A single multivariate logistic regression model was computed including both MVPA and LPA. Male is the reference group for gender.
LPA is expressed as a 60-minute interval change; MVPA is expressed as a 10-minute interval change *$p \leq 0.05$

Older adults

Table 5 depicts characteristics of the older adult population. Within older adults, 236 participants had good static balance and 588 had poor static balance. Older adults with good static balance had a mean ± SE of 10.1 ± 0.94 min/day of MVPA while for LPA it was 302.2 ± 4.9 min/day. For the poor static balance group, MVPA was 7.9 ± 0.61 min/day and for LPA it was 274.9 ± 4.4 min/day. The differences in MVPA and LPA between balance groups were statistically significant ($p=0.044$, $p<0.001$, respectively). As shown in **Table 5**, older adults with good balance were significantly younger ($p<0.001$), had higher BMI ($p=0.001$), and were less likely to have problems with dizziness, balance, and falling in the past year ($p=0.038$) than participants with poor balance.

In separate unadjusted logistic regression analyses, LPA and MVPA were significantly associated with having higher odds of good balance (LPA OR: 1.28, 95%CI:1.15, 1.41, $p<0.001$ and MVPA OR: 1.25, 95%CI: 1.08, 1.45, $p=0.006$). **Table 6** depicts odds ratios from an adjusted multivariate logistic regression examining the association between PA and the odds of having good balance in older adults. In this analysis, every 60-min increase in LPA was associated with high odds of good static balance (OR: 1.19, 95% CI: 1.09 1.31, $p=0.001$), while no significant difference between every 10-min increases in MVPA and odds of good static balance was found (OR:1.11, 95% CI: 0.95, 1.31, $p=0.182$). In addition to age ($p<0.001$) a pairwise comparison found being Mexican American ($p=0.007$) or Other/Multi Racial ($p=0.028$) compared to non-Hispanic white was associated with having decreased odds of good static balance.

Table 5. Characteristics of the Participants, older population (≥ 65 years).

Characteristics	**Good Balance (n= 236)**	**Poor Balance (n= 588)**	**P-value**
Age (years)	71.7 ± 0.48	74.5 ± 0.35	<0.001*
BMI (kg•m^{-2})	29.0 ± 0.33	27.4 ± 0.24	0.001*
Gender (n, %)			0.363
Male	129 (48.4)	307 (44.8)	
Female	107 (51.6)	281 (55.2)	
Race/Ethnicity (n, %)			0.252
Mexican American	38 (2.4)	121 (3.3)	
Other Hispanic	4 (1.6)	11 (2.0)	
Non-Hispanic white	157 (85.7)	379 (83.8)	
Non-Hispanic black	33 (8.7)	57 (6.6)	
Other	4 (1.6)	20 (4.3)	
Education Level (n, %)			0.376
< High School Diploma	88 (25.7)	227 (28.0)	
High School Diploma, GED	60 (29.1)	154 (31.4)	
> High School Diploma	88 (45.2)	207 (40.7)	
Dizziness/Balance/Falling problems in the past year			0.038*
Yes	46 (21.2)	169 (29.6)	
No	190 (78.8)	419 (70.4)	
MVPA (min/day)	10.1 ± 0.94	7.9 ± 0.61	0.044*
LPA (min/day)	302.2 ± 4.9	274.9 ± 4.38	<0.001*

Continuous data are mean ± SE. For categorical data, the numbers inside parentheses are percentages weighted to U.S. population while the numbers outside parentheses are unweighted counts. *p≤0.05

Table 6. Odds ratio (95% CI) from multivariate logistic regression on the association between physical activity and odds of having good static balance in an older adult population (≥65 years of age).

Older Age (≥ 65 years) (n=824)		
Characteristics	**Odds Ratio (95% CI)**	**P-value**
60-min LPA	1.19 (1.09, 1.31)	0.001*
10-min MVPA	1.11 (0.95, 1.31)	0.182
Age (years)	0.92 (0.89, 0.96)	<0.001*
BMI (kg•m^{-2})	1.04 (0.99, 1.09)	0.085
Female (vs male)	0.96 (0.71, 1.29)	0.761
Race/Ethnicity		0.067
Mexican American vs Non-Hispanic White	0.52 (0.33, 0.81)*	
Other Hispanic vs Non-Hispanic White	0.61 (0.12, 3.15)	
Non-Hispanic Black vs Non-Hispanic White	1.12 (0.52, 2.39)	
Other/Multi Racial vs Non-Hispanic White	0.38 (0.16, 0.89)*	
Education Level		0.486
Some high school vs some college	1.00 (0.65, 1.56)	
High school diploma/GED vs some college	0.83 (0.52, 1.34)	
No dizziness/Balance/Falling problems in the past year (vs yes)	1.33 (0.82, 2.20)	0.218

CI= Confidence Interval; LPA=light physical activity; MVPA= moderate to vigorous physical activity; BMI= body mass index
Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test). A single multivariate logistic regression model was computed including both MVPA and LPA.
LPA is expressed as a 60-minute interval change; MVPA is expressed as a 10-minute interval change *p≤0.05 and significant pairwise comparison

Discussion

The purpose of this study was to examine whether having good static balance in middle-age is associated with MVPA and LPA. Interestingly, MVPA and LPA were not associated with static balance in this sample of middle-aged American adults, but LPA was significantly associated with balance in older adults. Specifically, in older adults, when adjusting for potentially confounding variables and MVPA, every 60-min increase in LPA was associated with 19% higher odds of good static balance. These results suggest the important contribution of LPA on static balance in older-aged adults, whereas it appears neither MVPA nor LPA is associated with good static balance in middle-aged adults.

The study that is most directly comparable to the current investigation is that of Loprinzi and Brosky (2014). They concluded that middle-aged and older adults (>40 years of age) have 10% higher odds of good balance with every 60-minute increase in LPA and 24% higher odds of having good balance with every 1-unit increase in log-transformed MVPA. While their analysis did control for age (binned by decade), the lack of PA effects in middle-age within the present study suggests separate analyses by age category may be warranted. In addition, their study did not account for the combined effects of PA intensity on balance. It is likely that individuals have a wide range of combined LPA and MVPA levels, which should be controlled for when examining the relationships between PA and balance. In the present study, we found that when including both types of PA in our multivariate logistic regression, LPA and MVPA were not associated with good balance in the middle-aged population, but LPA was associated with good balance in the older population.

One rationale as to why LPA was significantly associated with good static balance in older adults, while MVPA was not, is the fact that mean MVPA in that age group was well below the 150 min/week (or 21.4 min/day) recommended by the Physical Activity Guidelines for Americans ((2018). Population-reference data for U.S. adults by Wolff-Hughes et al. (2015) shows that although both LPA and MVPA decline after age 40, the relative drop in MVPA is more precipitous. Further, as confirmed by Evenson et al. (2012), choice of cut point for determining MVPA in the elderly remains a point of debate, and the threshold that was used in this study (2,020 counts/min) gives the impression that the elderly perform little-to-no MVPA. Had we used a lower threshold for MVPA, it is possible that our models would have shown MVPA to be associated with balance. Overall, these results extend the literature regarding the contribution of PA intensity to balance in middle-aged and older adults but also suggest that future studies examine how using different cut points for LPA and MVPA in these age groups impacts the associations.

In line with other research, age was an important predictor of balance in this study. While the burden of falls in the elderly is widely known, less population-based research has targeted adults <65 years of age (Talbot et al., 2005). When examining the impact of age on balance, the prevalence of failure in the condition 4 Romberg Balance Test progresses with age such that a failure of 9.7% is reported in adults 40-49 years, increasing to 15.5% in adults 50-59, 34.7% in adults 60-69, and 60% in adults ≥70 years of age (Bermúdez-Rey et al., 2017). Further, Liaw et al. (2009) determined elderly individuals (60-80 years) have a higher degree of postural imbalance compared to middle-age (40-59 years) and young (19-35 years) adults. Specifically, their study utilized a Sensory Organization Test (SOT) that included a balance condition 5, in which subjects close their eyes and a platform is swayed; this alters visual and somatosensory input, similar to that of the condition 4 of the Romberg Balance Test (Hong, Park, Kwon, Kim, & Koo, 2015). The SOT provides a score of 100% for the highest stability and 0 for the least stability (Liaw et al., 2009). The older-adult average stability score (67.6 ± 6.5) was significantly lower than the middle-age (69.9 ± 5.8) and young-age (76.3 ± 5.7) groups. As one ages, stability and postural control is altered, which could impact one's ability to maintain balance. Collectively, the results from these studies corroborate the findings in the present study in that increased age (in both middle-aged and older adults) was significantly associated with a reduced odds of good balance on the Romberg Balance Test. Increased loss of muscular strength, endurance, joint flexibility, and balance inhibit PA and performance of basic functional tasks (Lohne-Seiler, Kolle, Anderssen, & Hansen, 2016). However, it also seems that reduced PA negatively impacts, or is at least correlated with, static balance after the age of 60 years.

Other predictors of balance in this analysis included BMI and a self-reported history of dizziness, difficulty with balance, or falling problems in the past year. Interestingly, increased BMI was associated with a trend toward good static balance (p=0.036, OR=1.04, (%CI: 1.00,1.08) in the middle-aged population; the OR was the same size in older adults but not significant, likely due to a slightly smaller sample size. The present study does align with Loprinzi and Brosky (2014), who also found adults ≥40 years with increased BMI from NHANES to have higher odds of increased functional balance on the Romberg Test of Standing Balance. Other research has found positive, negative, or null associations between BMI and balance or fall risk in older adults (Cho, Seo, Lin, Lohrmann, & Chomistek, 2018; Dutil et al., 2013; Mitchell et al., 2014). A potential rationale behind the observed association in the present study is that BMI may be representing other health and physiological characteristics in middle-aged and older adults, like general health status or skeletal muscle mass, which is closely linked to balance and fall risk (Gouveia et al., 2020). The loss of substantial amounts of weight, particularly in middle and older age, may be indicative of underlying disease and/or an accelerated muscle loss with aging (Miller & Wolfe, 2008).

The strengths of this study are the use of a nationally representative dataset of middle-aged and older adults in the United States, and thus the results are largely generalizable. This study also contributes knowledge into the association of exercise intensity on balance in the middle-aged adult population, given that much of these data focuses on older adults. Confounding variables were attempted to be minimized through the inclusion of models adjusting for potential balance predictors, such as age, BMI, ethnicity, education, and dizziness/impaired balance/falling problems within the previous year. While there are numerous strengths, this study is not without limitations. The NHANES uses a cross-sectional design and cannot support strong causal or temporal inferences despite the notable statistical power associated with the data sets. The Romberg Test of Standing Balance was utilized to determine poor or good balance; although this does not assess both static and dynamic balance, this test is a common standard assessment in clinical and research settings (Lin et al., 2020). While we included LPA and MVPA as continuous variables in our analysis, we did not directly examine the interaction between high/low MVPA/LPA on balance. Further, although our MVPA analysis in older adults was based on a set count-per-minute threshold that is common across PA research, future studies may consider using relative-intensity cut-points based on age.

Conclusion

LPA and MVPA were not associated with good static balance in middle-aged adults; however, we did find that LPA was significantly associated with good static balance in older adults. Poor balance is directly associated with fall risk and is a major health concern in the aging population (Papalia et al., 2020). With the significant relationship between age and fall risk, identifying risk profiles, screening tools, and relationships that could aid in prevention strategies throughout the middle-to-older-adult years is vital. Future studies should be aimed at examining other risk factors for falls in the middle adult population, which is lacking in research. This may aid in identifying those individuals who are at a greater likelihood for falls and, thus, provide a means for early intervention in preventing falls before they occur.

CHAPTER IV STUDY 3

THE ASSOCATIONS BETWEEN ANTHROPOMETRY AND STATIC BALANCE IN A MIDDLE-AGED POPULATION

Introduction

Obesity is linked to decreased lower extremity function and fall risk in older adults (Mitchell et al., 2014). One study of older adults who were obese (Body Mass Index (BMI) ≥30 kg/m^2), for example, showed they had a 31% higher risk of falls compared to healthy-weight individuals (Mitchell et al., 2014). This increased risk of falls in obese individuals remains even after adjusting for confounders such as diabetes, hypertension history, smoking, age, race/ethnicity, and gender (Bermúdez-Rey et al., 2017). Specifically, in regard to the impact of obesity on static balance, obese individuals have a 18.75% failure rate on the Romberg Test of Standing Balance compared to a 9.45% failure rate in individuals with a normal BMI (Bermúdez-Rey et al., 2017).

BMI is closely linked to body fat percentage in the general population (Romero-Corral et al., 2008). Studies not only identify significant associations between high BMI with poor balance and fall risk but also between body fat distribution (Bermúdez-Rey et al., 2017; Mitchell et al., 2014; Silvia G R Neri et al., 2020). Body fat accumulation in the abdominal region is related to instability in middle-aged women (Cieślińska-Świder et al., 2017; Hita-Contreras et al., 2013; Ochi et al., 2010). Further, in a study of adults older than 75 years, 17.7% of men with a waist-to-hip ratio (WHR) of >0.99 suffered a fall in the past 6 months compared to 13.7% of those with a ratio of 0.891-0.920; and in women 25.8% with a WHR >0.90 compared to 17.7% with a WHR ≤0.79

(Price et al., 2006). Body fat distribution in the middle and lower regions of the body may help identify greater fall risk.

Calf circumference (CC) reflects appendicular skeletal muscle mass and thigh circumference (TC) reflects whole body skeletal muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003). In the elderly, CC is a tool to identify risk of lower extremity frailty (Landi et al., 2014; Sun et al., 2017). This is thought to be explained by the fact that CC has a “less biased” association with muscle mass than other body sites. The calf is generally less affected by body fat deposits as compared to the waist or thigh and thus is a better surrogate marker of skeletal muscle mass, which is linked to balance (Santos et al., 2019; Szulc et al., 2005). Similar to CC, TC is highly correlated to appendicular skeletal muscle mass, not only in older adults but also young-to-middle-aged adults (Santos et al., 2019). TC may be a better indicator of leg-muscle mass compared to hip circumference measures, as TC is less influenced by bone and gluteal fat (Snijder et al., 2003). Specific anthropometric measures represent a greater association with skeletal muscle mass and thus could be more closely associated with balance (Wu et al., 2019; Zagyapan et al., 2012).

Age-related loss of muscle mass, a condition known as sarcopenia, leads to decreased muscle strength, resulting in poor lower extremity function (Larsson et al., 2018) and falls in older adults (Yeung et al., 2019). Stewart et al. (2002) and Landi et al. (2014) established that a larger CC is related to a lower frailty score and protective against falling. In fact, CC is a surrogate marker for diagnosing sarcopenia in adults 40-89 years of age (Kawakami et al., 2015). Reductions in CC and TC are reflective of decreased muscle mass and may be indicative of poor balance. Wu et al. (2019) demonstrated in a nationally representative sample of adults ≥40 years of age that having lower CC and TC was associated with having vestibular dysfunction, a significant factor in static balance control. Notably, greater muscle mass is associated with better balance in the elderly (Castillo-Rodríguez et al., 2020).

Combining anthropometric measures that generally reflect different body tissues (fat and muscle) into a single variable may, in some instances, result in improved health outcome predictions. Given that waist circumference (WC) tends to reflect central adiposity and that CC and TC tend to reflect appendicular muscle mass, the ratios of WC to CC (WC/CC) and WC to TC (WC/TC) are potentially worth exploring as predictors of health outcomes. Indeed, studies demonstrate that WC/CC, compared to each single measure on its own, is a better index for assessing the disproportionality between abdominal fat and leg muscle mass, risk of cardiovascular disease (Kim et al., 2011), and health-related quality of life in the elderly (Yang et al., 2020). Though, research on the relationships between WC/CC and aspects of balance is much more limited. Wu et al. (2019) demonstrated that individuals ≥40 years of age with lower CC and TC or higher WC/CC and WC/TC have a greater odds of having vestibular dysfunction. While this study included gender as a control variable in the modeling, men and women were still analyzed together, which may not be ideal given known sex differences in body size, composition, and shape.

Although using ratios such as WC/CC and WC/TC sometimes results in improved predictive power compared to their component circumference values alone, changing the scaling of one or more variables in a ratio may potentially be more closely associated with health outcomes. For example, BMI is a measure of weight by squared height, which is preferred to weight by height or weight by the cube of height, due to its close association with body fat (Keys et al., 2014). Likewise, WC by squared or cubed height, places a greater emphasis on central adiposity and increases the incidence of developing hypertension in young adults (Fuchs et al., 2005). In children, Almeida et al. (2016) determined squared WC-to-height ratio and squared CC or squared hip circumferences contributed to the prediction of percent body fat. Thus, it is possible that the associations with balance measures could be strengthened by changing the scaling of WC/CC or WC/TC through squaring one of the circumference values.

We aimed to determine which body anthropometric measures were most closely associated with good static balance in a nationally representative sample of middle-aged adults (40-64 years of age). Secondary analyses included adults ≥ 65 years of age for comparison. Participants were separated into gender, middle- and older-age groups, and the body anthropometric measures of: BMI, WC, CC, TC, WC/CC, WC/CC^2, WC/TC, and WC/TC^2 were included in the analysis to determine the odds of having good static balance. We explored which body anthropometric measures are more closely associated with static balance. We hypothesized WC/CC^2 and WC/TC^2 would have a stronger association with static balance than all other variables. Further, we examined how age group (middle age vs. older age) and gender impacted these associations.

Methods

Study Population

Data for this observational, cross-sectional secondary data analysis were collected from the 2003-2004 survey years of NHANES. This analysis included adults 40-64 years of age and a sub-analysis included older adults age ≥65 years of age for comparison. The main measurements included pass/fail on the Romberg Test of Standing Balance, and body anthropometric data from the mobile examination centers examination component. Adults were included in the analysis if they had complete data for PA, balance testing, and relevant anthropometric data. Individuals were excluded from balance testing if they met any of the following criteria: dizziness or unsteadiness while standing, weighing over 275 lbs, WC that does not fit a standard-sized safety belt, use of a leg brace to stand, or amputations of the lower limbs (*Centers for Disease Control and Prevention (CDC)*, 1999-2000). For the PA monitor component, individuals were excluded if they used a wheelchair or had other impairments that prevented them from walking or wearing a PA monitor. There were no medical, safety, or other exclusions for the body measures protocol.

Anthropometric and Body Composition Measures

Body measurements used in this analysis were BMI, WC, CC, and TC. BMI is a ratio measure of mass to height squared of an individual and correlates relatively strongly with body fat (Nuttall, 2015). Body weight was measured during the mobile examination center component to the nearest 0.1 kg using a Toledo digital scale (Mettler-Toledo LLC., Columbus, OH). Standing height was measured with a fixed stadiometer (SECA, Hamburg, Germany). BMI (in kg/m^2) is calculated from these data. Circumference measurements were taken with a tape measure while participants were standing or sitting for the calf measurement. WC was taken at the level of the uppermost lateral border of the ilium in the midaxillary line. The CC on the right calf was taken at the greatest circumference in a plane perpendicular to the long axis of the calf. TC was taken at a midpoint, found as the middle point between the inguinal crease and proximal border of the patella. All measurements were taken to the nearest 0.1 cm. In addition, ratio measurements were calculated as follows: waist-to-calf circumference (WC/CC), and waist-to calf-circumference squared (WC/CC^2), waist-to-thigh circumference (WC/TC), and waist-to-thigh circumference squared (WC/TC^2). All body anthropometric measures were separated into quartiles for interpretability purposes.

Balance Testing

Static balance was assessed utilizing the Romberg Test of Standing Balance on Firm and Compliant Surfaces (Romberg Balance Test) (Khasnis & Gokula, 2003; Shu et al., 2020), which evaluates the ability to balance unassisted under four conditions, with each condition increasing in difficulty. Prior to testing, each participant completed a pre-examination questionnaire to determine their ability to participate in the test. If participants were eligible to participate, they began with condition 1; this makes use of all the sensory inputs (central vestibular system, vision, and proprioception) by having participants stand with their eyes open, feet together, and arms folded across the waist, holding the elbows with the hands. Condition 2 tested balance with only vestibular and proprioceptive inputs available by having participants stand in the same position as test condition 1 but with their eyes closed. In test condition 3, participants stood on a foam-padded surface with their eyes open, which reduced proprioceptive input but left visual and vestibular cues available. Finally, in condition 4, participants stood on the foam-padded surface with their eyes closed to use solely the vestibular system. Test conditions 1 and 2 were conducted for 15 seconds each while conditions 3 and 4 were conducted for 30 seconds each. Balance was scored on a pass/fail basis in all conditions (Agrawal et al., 2011; Bermúdez-Rey et al., 2017; Loprinzi & Brosky, 2014). Test failure was defined as the participant: 1) using arms or feet to maintain balance, 2) beginning to fall or requiring that a technician intervene to maintain balance, or 3) needing to open their eyes (conditions 2 and 4 only). Participants were allowed one re-test for each condition. Individuals who failed any of the four conditions were placed into a poor static balance category. Individuals who passed all four conditions were placed into a good static balance category. Further details of balance testing procedures are available at https://wwwn.cdc.gov/nchs/data/nhanes/1999-2000/manuals/ba.pdf.

Accelerometer Data and Analysis

The accelerometer used to track PA was an ActiGraph AM-7164 (ActiGraph, Ft. Walton Beach, FL) (Crouter et al., 2013). Accelerometers were not worn during activities such as swimming or water aerobics, due to the device not being waterproof, and participants were instructed to remove the device at bedtime. Accelerometers were worn around the participants' waist near the iliac crest on the right side for 7 consecutive days. Non-wear was defined by a minimum period of 60 consecutive minutes of no activity counts, with an allowance of 2 minutes or less of activity counts between 0 and 100 ("Examination Data Overview: National Health and Nutrition Examination Survey," 2003-2004). Participants with at least 4 days of 10 or more hours per day of valid wear time were included in the analysis to adequately capture habitual PA patterns. Accelerometers detect and record the intensity of movement, frequency, and duration of PA through generating an activity count. One-minute time intervals were used in NHANES, and intensity was summed over each 1-minute period.

First, MVPA was classified as activity counts of ≥2,020 per minute and LPA was classified as activity counts between 100-2,019 per minute (Boyer et al., 2016; Loprinzi & Brosky, 2014; Wolff-Hughes et al., 2015). The physical activity monitor considers LPA as activity counts of 100-760 range, and leisure time physical activity as 760-2019; thus, we combined these categories into 1 light activity count measure for analysis. Minutes per day of MVPA and LPA were averaged across all valid worn days to determine average daily MVPA and LPA.

Additional Variables

Demographic information was collected at home interviews of participants via computer-assisted personal interviewing methodology. Basic demographic data used in this analysis were age, gender, race/ethnicity, and education level. A questionnaire on balance was included that asked participants to answer yes or no to the following: "During the past 12 months, have you had dizziness, difficulty with balance or difficulty with falling?"

Statistical Analysis

Data were downloaded from the NHANES website (except for the accelerometer data) and merged using Statistical Analysis System (SAS) software (Version 9.4 SAS Institute Inc., Cary, North Carolina). To account for over-sampling, complex design features of NHANES, and nonresponse of individuals during data collection, adjusted 2-year population mobile examination center weights derived from web-application accelerometer files (Van Domelen, n.d.) were used to generate estimates according to the National Center for Health Statistics analytical guidelines (Johnson et al., 2013). Differences between categorical demographic variables (race/ethnicity, education, gender, falling/balance questionnaire) by static balance were evaluated using a complex sample, Rao-Scott Adjusted Chi-Square statistic. Differences between continuous variables (age, MVPA, and LPA) by static balance were evaluated using a complex sample, general linear model procedure that is equivalent to an independent t-test (IBM, 2020).

The associations between body anthropometric measures (BMI, WC, CC, TC, WC/CC, WC/CC^2, WC/TC, and WC/TC^2) and static balance were computed via univariate and multivariable logistic regression. We determined the odds of having good static balance (versus poor static balance) in association with quartiles of BMI, WC, CC, TC, WC/CC, WC/CC^2,WC/TC, and WC/TC^2; quartile one served as the reference group. Univariate logistic regression determined the individual relationship of each body anthropometric measure with good static balance. In addition to reporting the significance of the test of main effects from the SPSS output, pairwise comparisons, with quartile 1 as the reference group, were examined for quartiles 2, 3, and 4 (a 95%CI not crossing 1.0 indicated statistical significance). Multivariate logistic regression computed each body anthropometric measure individually adjusted for covariates of age, ethnicity, education, LPA and MVPA in Model 1; and age, ethnicity, education, LPA and MVPA, and dizziness/impaired balance/falling within the past 12 months in Model 2. The threshold for statistical significance was set at a $p \leq 0.05$.

Receiver Operating Characteristic (ROC) analysis, using adjusted 2-year population mobile examination center weights and various R functions from the package "rnhanesdata" by (Leroux et al., 2018) and (Leroux et al., 2019), was then used to calculate area under ROC curves (AUC) between each body anthropometric variable (BMI, WC, CC, TC, WC/CC, WC/CC^2,WC/TC, and WC/TC^2) and good static balance. The AUC analysis was adjusted for age, ethnicity, education, LPA, MVPA, and dizziness/impaired balance/falling. Anthropometric variables are ranked in decreasing order of their predictive performance as measured by the AUC in separate predictor logistic regression with good static balance as the outcome. The AUC value is a measure used for classification performance for binary classifiers (Flach, Hernández-Orallo, & Ramirez, 2011). Higher AUC values indicate a better classifier. The AUC data can be interpreted according to these guidelines (Laurson, Eisenmann, & Welk, 2011; Swets, 1988): non-informational/equal to change (AUC=0.5), less accurate ($0.5<AUC\geq0.7$), moderately accurate ($0.7<AUC\geq0.9$), highly accurate ($0.9<AUC\geq1.0$), and a discriminatory test (AUC=1.0).

Results

Middle-Aged Adults

Descriptive statistics for the participants are shown in **Table 7**. Of middle-aged adults included in the analysis, 1,050 met our inclusion criteria, 687 had good static balance, and 363 had poor static balance. In those with good static balance, mean age was lower ($p<0.001$), they were more educated ($p<0.001$), and a higher percentage reported not having dizziness/balance/falling problems within the previous 12 months ($p<0.001$) compared to those with poor balance. As shown in **Table 7**, significant differences ($p\leq0.05$) in body anthropometric variables were present between those with good and poor balance, with the exceptions of BMI and WC in women and WC in men.

Table 7. Demographic and Body Anthropometrics of the middle-aged adults.

Characteristics	Good Balance (n= 687)	Poor Balance (n= 363)	P-value
Age (years)	49.4 ± 0.4	52.3 ± 0.5	<0.001*
Female			
BMI(kg•m^{-2})	28.3 ± 0.4	27.5 ± 0.4	0.217
WC(cm)	93.6 ± 0.7	94.2 ± 0.8	0.583
CC(cm)	38.7 ± 0.3	37.5 ± 0.4	0.021*
TC(cm)	54.0 ± 0.4	51.9 ± 0.6	0.019*
WC/CC(cm)	2.42 ± 0.01	2.52 ± 0.01	<0.001*
WC/CC^2(cm)	0.063 ± 0.001	0.068 ± 0.001	<0.001*
WC/TC(cm)	1.74 ± 0.01	1.83 ± 0.01	<0.001*
WC/TC^2(cm)	0.033 ± 0.000	0.036 ± 0.001	<0.001*
Male			
BMI(kg•m^{-2})	28.7 ± 0.4	27.4 ± 0.4	0.028*
WC(cm)	102.4 ± 0.9	101.8 ± 1.2	0.663
CC(cm)	40.1 ± 0.3	38.6 ± 0.4	0.006*
TC(cm)	54.5 ± 0.5	52.0 ± 0.6	0.003*
WC/CC(cm)	2.55 ± 0.01	2.64 ± 0.02	0.003*
WC/CC^2(cm)	0.064 ± 0.001	0.069 ± 0.001	0.002*
WC/TC(cm)	1.89 ± 0.01	1.96 ± 0.02	<0.001*
WC/TC^2(cm)	0.035 ± 0.000	0.038 ± 0.001	<0.001*
LPA (min/week)	356.0 ± 3.4	348.6 ± 4.5	0.157
MVPA (min/week)	24.5 ± 1.3	22.6 ± 1.7	0.375
Gender (n, %)			0.978
Male	341 (48.7)	176 (48.6)	
Female	346 (51.3)	187 (51.4)	
Race/Ethnicity (n, %)			0.364
Mexican American	128 (5.1)	78 (5.8)	
Other Hispanic	15 (2.7)	10 (3.6)	
Non-Hispanic white	372 (77.2)	190 (74.0)	
Non-Hispanic black	143 (10.6)	67 (9.8)	
Other	29 (4.4)	18 (6.7)	
Education Level (n, %)			<0.001*
< High school diploma	116 (8.7)	111 (18.4)	
High school diploma or GED	157 (22.9)	102 (30.5)	
Some college or more	416 (68.4)	150 (51.0)	
Dizziness/Balance/Falling problems in the past year			<0.001*
Yes	121 (17.6)	106 (28.9)	
No	566 (82.4)	257 (71.1)	

Continuous data are mean ± SE. For categorical data, the numbers inside parentheses are percentages weighted to U.S. population while the numbers outside parentheses are unweighted counts

BMI: body mass index, CC: calf circumference, LPA: light physical activity; MVPA: moderate-vigorous physical activity, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared; . *p≤0.05

Table 8 demonstrates univariate logistic regression analysis in female middle-aged populations. Higher CC and TC had a significantly ($p \leq 0.05$) greater odd of having good static balance in middle aged females. Further, middle-aged females in the highest quartile of WC/CC, WC/CC^2, WC/TC, and WC/TC^2 compared to the lowest quartile had a significantly ($p \leq 0.05$) decreased odds of having good static balance. For clarity, a larger WC measure and smaller CC or TC will result in a larger ratio; thus, those with a small ratio indicates a larger CC or TC compared to the WC measures. Similarly, separate univariate logistic regression within the middle-aged male population (**Table 9**) found significant ($p \leq 0.05$) negative relationships between having high WC/CC, WC/CC^2, WC/TC, WC/TC^2 and good static balance. Although the overall test of model effects was not statistically significant for BMI, CC, or TC, pairwise analysis determined significant differences in relation to good static balance between the 4^{th} quartile and the 1^{st} quartile of BMI ($p=0.026$), CC ($p=0.035$), and TC (0.017). Within both females and males, univariate analysis found older age, less education, and having dizziness/balance/falling problems within the previous 12 months to be significantly associated with having decreased good static balance.

Table 8. Univariate associations between good balance and anthropometric parameters and selected control variables in middle-aged females (n=533).

Body Measures	Odds Ratio (CI:95%)	p-value
BMI(kg•m^{-2})		0.239
< 24.3	1.00	
24.3-28.0	0.88 (0.42, 1.85)	
28.1-32.8	0.98 (0.55, 1.23)	
> 32.8	1.48 (0.82, 2.68)	
WC(cm)		0.254
< 86.1	1.00	
86.1-94.6	0.70 (0.37, 1.36)	
94.7-104.9	0.58 (0.32, 1.05)	
>104.9	0.97 (0.58, 1.61)	
CC(cm)		0.047*
≤ 35.2	1.00	
35.3-37.6	1.59 (0.98, 2.59)	
37.7-40.7	1.35 (0.75, 2.41)	
> 40.7	2.22 (1.15, 4.30)*	
TC(cm)		0.032*
< 48.3	1.00	
48.3-52.7	1.71 (1.04, 2.81)*	
52.8-57.6	1.52 (0.90, 2.56)	
> 57.6	2.38 (1.31, 4.33)*	
WC/TC(cm)		0.042*
< 1.7	1.00	
1.7-1.77	0.56 (0.26, 1.18)	
1.78-1.90	0.53 (0.24, 1.21)	
> 1.90	0.37 (0.20, 0.69)*	
WC/TC^2(cm)		0.021*
< 0.02967	1.00	
0.02968-<0.03329	0.83 (0.37, 1.85)	
0.03329-0.03808	0.50 (0.21, 1.20)	
> 0.03808	0.31 (0.15, 0.65)*	
WC/CC(cm)		0.005*
< 2.301	1.00	
2.302-2.481	0.76 (0.41, 1.41)	
2.482-2.694	0.42 (0.34, 0.75)*	
> 2.694	0.37 (0.22, 0.64)*	
WC/CC^2(cm)		0.004*
< 0.0590	1.00	
0.0590- <0.0652	0.60 (0.27, 1.33)	
0.0652-0.0726	0.46 (0.21, 1.01)	
> 0.0726	0.22 (0.11, 0.43)*	
Age (years)	0.94 (0.91, 0.97)	0.001*
MVPA (min/day)	1.08 (0.88, 1.32)	0.447
LPA (min/day)	1.04 (0.88, 1.24)	0.593
Education		0.011*
Some high school vs some college or more	0.42 (0.22, 0.80)	
High school diploma/GED vs some college or more	0.47 (0.26, 0.85)	
Ethnicity		0.781
Mexican American vs non-Hispanic white	0.80 (0.43, 1.48)	
Other Hispanic vs non-Hispanic white	0.99 (0.47, 2.09)	
Non-Hispanic black vs non-Hispanic white	0.88 (0.58, 1.36)	
Other/multi-racial vs non-Hispanic white	0.73 (0.35, 1.51)	
Dizzy/balance/falling problems the past year (yes vs no)	0.47 (0.30, 0.75)	0.004*

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, $WC/CC^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared
Odds ratio is expressed with the 95% confidence interval, *$p \leq 0.05$

Table 9. Univariate associations between good balance and anthropometric parameters and selected control variables in middle-aged males (n=517).

Body Measures	Odds Ratio (CI:95%)	p-value
BMI(kg•m^{-2})		0.133
< 25.2	1.00	
25.2- 27.9	1.38 (0.83, 2.32)	
28.0 – 31.0	1.25 (0.68, 2.30)	
> 31.0	2.64 (1.14, 6.09)*	
WC(cm)		0.110
< 93.4	1.00	
93.4-100.7	0.67 (0.44, 1.01)	
100.8-109.2	0.81 (0.36, 1.84)	
> 109.2	1.11 (0.51, 2.41)	
CC(cm)		0.177
< 36.7	1.00	
36.7-38.9	1.51 (0.61, 3.78)	
39.0-41.2	1.83 (0.72, 4.66)	
> 41.2	2.80 (1.09, 7.21)*	
TC(cm)		0.088
< 49.8	1.00	
49.8-52.8	1.28 (0.64, 2.53)	
52.9-56.3	2.11 (0.89, 5.02)	
> 56.3	3.58 (1.30, 9.88)*	
WC/TC(cm)		0.001*
< 1.800	1.00	
1.800-<1.903	1.13 (0.63, 2.00)	
1.903-2.017	0.56 (0.29, 1.08)	
> 2.017	0.27 (0.13, 0.56)*	
WC/TC^2(cm)		<0.001*
<0.0327	1.00	
0.0327-<0.0362	1.06 (0.59, 1.92)	
0.0362-0.0396	0.52 (0.20, 1.35)	
> 0.0396	0.19 (0.08, 0.47)*	
WC/CC(cm)		0.030*
< 2.450	1.00	
2.450-<2.596	0.80 (0.39, 1.63)	
2.596-2.735	0.56 (0.30, 1.04)	
> 2.735	0.33 (0.17, 0.62)*	
WC/CC^2(cm)		0.016*
< 0.0609	1.00	
0.0609-<0.0666	0.59 (0.34, 1.03)	
0.0666-0.0729	0.36 (0.19, 0.67)*	
> 0.0729	0.24 (0.09, 0.63)*	
Age (years)	0.93 (0.90, 0.97)	0.003*
MVPA (min/day)	1.02 (0.94, 1.11)	0.572
LPA (min/day)	1.07 (0.96, 1.20)	0.195
Education		0.002*
Some high school vs some college or more	0.28 (0.15, 0.51)	
High school diploma/GED vs some college or more	0.67 (0.44, 1.02)	
Ethnicity		0.353
Mexican American vs non-Hispanic white	0.91 (0.44, 1.90)	
Other Hispanic vs non-Hispanic white	0.48 (0.18, 1.27)	
Non-Hispanic black vs non-Hispanic white	1.24 (0.73, 2.10)	
Other/multi-racial vs non-Hispanic white	0.48 (0.16, 1.43)	
Dizzy/balance/falling problems the past year (yes vs no)	0.60 (0.40, 0.89)	0.014*

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC^{2}: waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^{2} waist circumference to thigh circumference ratio squared; Odds ratio is expressed with the 95% confidence interval, *$p \leq 0.05$ and significant pairwise comparison

Multivariate logistic regression in middle-aged females (**Table 10**) found when dizziness/balance/falling question is not included in the model (*Odds Ratio Model 1*), larger CC and TC indicated a significantly ($p \leq 0.05$) higher odds to have good static balance. Furthermore, females with larger WC/CC^{2} and WC/TC^{2} and have a significantly decreased odds to have good static balance compared to the reference group. When the dizziness/balance/falling question was included as a covariate in the model (Model 2) similar results were produced, except that increased CC no longer remained significant. . Multivariate logistic regression in middle-aged males (**Table 11**) (Model 1 and 2) found higher WC/CC, WC/CC^{2}, WC/TC, and WC/TC^{2}, have a significantly ($p \leq 0.05$) decreased odd of having good static balance.

Table 10. Multivariate association between good balance and anthropometric parameters, controlling for covariates in middle-aged females (n=533).

Body Measure	Odds Ratio M1 (CI:95%)	Odds Ratio M2 (CI:95%)
BMI(kg•m^{-2})		
< 24.3	1.00	1.00
24.3-28.0	0.95 (0.41, 2.20)	0.94 (0.40, 2.19)
28.1-32.8	1.03 (0.55, 1.92)	1.02 (0.55, 1.87)
> 32.8	1.71 (0.94, 3.17)	1.62 (0.92, 2.85)
WC(cm)		
< 86.1	1.00	1.00
86.1-94.6	0.73 (0.36, 1.51)	0.75 (0.35, 1.59)
94.7-104.9	0.66 (0.35, 1.23)	0.64 (0.35, 1.15)
>104.9	1.20 (0.76, 1.90)	1.18 (0.75, 1.86)
CC(cm)		
≤ 35.2	1.00	1.00
35.3-37.6	1.43 (0.78, 2.60)	1.42 (0.77, 2.61)
37.7-40.7	1.20 (0.64, 2.25)	1.18 (0.63, 2.22)
> 40.7	1.88 (1.04, 3.41)†	1.80 (0.98, 3.31)
TC(cm)		
< 48.3	1.00	1.00
48.3-52.7	1.85 (1.02, 3.37)†	1.85 (1.04, 3.28)†
52.8-57.6	1.46 (0.77, 2.77)	1.37 (0.72, 2.60)
> 57.6	2.34 (1.36, 4.01)†	2.54 (1.36, 3.73)†
WC/TC(cm)		
< 1.7	1.00	1.00
1.7-1.77	0.68 (0.33, 1.41)	0.64 (0.30, 1.35)
1.78-1.90	0.63 (0.27 1.47)	0.64 (0.28, 1.46)
> 1.90	0.57 (0.26, 1.23)	0.57 (0.25, 1.31)
WC/TC^2(cm)		
< 0.02967	1.00	1.00
0.02968-<0.03329	0.92 (0.39, 2.16)	0.94 (0.40, 2.22)
0.03329-0.03808	0.56 (0.22, 1.42)	0.57 (0.21, 1.51)
> 0.03808	0.41 (0.20, 0.83)†	0.43 (0.22, 0.85)†
WC/CC(cm)		
< 2.301	1.00	1.00
2.302-2.481	0.88 (0.43, 1.82)	0.88 (0.42, 1.84)
2.482-2.694	0.52 (0.26, 1.03)	0.52 (0.26, 1.0)
> 2.694	0.55 (0.27, 1.11)	0.56 (0.27, 1.17)
WC/CC^2(cm)		
< 0.0590	1.00	1.00
0.0590- <0.0652	0.69 (0.34, 1.43)	0.69 (0.34, 1.41)
0.0652-0.0726	0.51 (0.24, 1.11)	0.51 (0.23, 1.12)
> 0.0726	0.31 (0.14, 0.67)†	0.33 (0.14, 0.74)†

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared
Odds ratio is expressed with the 95% confidence interval †p≤0.05

Table 11. Multivariate association between good balance and anthropometric parameters, controlling for covariates in middle-aged males (n=517)

Body Measure	Odds Ratio M1 (CI:95%)	Odds Ratio M2 (CI:95%)
BMI(kg•m^{-2})		
< 25.2	1.00	1.00
25.2- 27.9	1.29 (0.72, 2.30)	1.35 (0.76, 2.41)
28.0 – 31.0	1.30 (0.66, 2.55)	1.25 (0.62, 2.54)
> 31.0	2.37 (0.94, 5.97)	2.35 (0.92, 5.96)
WC(cm)		
< 93.4	1.00	1.00
93.4-100.7	0.64 (0.35, 1.16)	0.62 (0.34, 1.14)
100.8-109.2	0.84 (0.32, 2.17)	0.84 (0.31, 2.28)
> 109.2	1.14 (0.43, 3.02)	1.13 (0.42, 3.00)
CC(cm)		
< 36.7	1.00	1.00
36.7-38.9	1.35 (0.48, 3.84)	1.34 (0.49, 3.70)
39.0-41.2	1.48 (0.51, 4.31)	1.48 (0.49, 4.41)
> 41.2	2.20 (0.76, 6.35)	2.11 (0.73, 6.06)
TC(cm)		
< 49.8	1.00	1.00
49.8-52.8	1.15 (0.54, 2.41)	1.17 (0.56, 2.57)
52.9-56.3	1.62 (0.70, 3.75)	1.58 (0.68, 3.67)
> 56.3	2.56 (0.94, 6.96)	2.53 (0.92, 6.93)
WC/TC(cm)		
< 1.800	1.00	1.00
1.800-<1.903	1.22 (0.65, 2.31)	1.22 (0.66, 2.23)
1.903-2.017	0.65 (0.33, 1.31)	0.69 (0.34, 1.39)
> 2.017	0.39 (0.17, 0.90)†	0.39 (0.17, 0.91)†
WC/TC^2(cm)		
<0.0327	1.00	1.00
0.0327-<0.0362	1.35 (0.73, 2.52)	1.37 (0.73, 2.56)
0.0362-0.0396	0.77 (0.27, 2.20)	0.83 (0.29, 2.44)
> 0.0396	0.31 (0.13, 0.75)†	0.31 (0.12, 0.78)†
WC/CC(cm)		
< 2.450	1.00	1.00
2.450-<2.596	0.82 (0.39, 1.75)	0.83 (0.39, 1.75)
2.596-2.735	0.63 (0.31, 1.29)	0.66 (0.33, 1.33)
> 2.735	0.48 (0.24, 0.93)†	0.50 (0.25, 0.98)†
WC/CC^2(cm)		
< 0.0609	1.00	1.00
0.0609-<0.0666	0.65 (0.35, 1.19)	0.70 (0.39, 1.25)
0.0666-0.0729	0.40 (0.21, 0.76)†	0.43 (0.22, 0.84)†
> 0.0729	0.35 (0.12, 1.05)	0.37 (0.13, 1.07)

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared
Odds ratio is expressed with the 95% confidence interval †p≤0.05

The AUC analyses included covariates of age, ethnicity, education, LPA, MVPA, and dizziness/balance/falling questionnaire (**Table 12**). This analysis determined that, in both females and males, the strongest anthropometric predictor of good static balance was WC/TC^2; 0.7006 and 0.7295, respectively. The second strongest predictor of good static balance was WC/CC^2 in both females and males; 0.6971 and 0.7183, respectively. The third strongest predictor of good static balance in females was WC/TC (0.6995) and in males was TC (0.7172).

Table 12. Adjusted area under the curve values for anthropometric parameters and good balance in middle-aged adults (40-64 years).

Female AUC		**Male AUC**	
Rank	**AUC Value**	**Rank**	**AUC Value**
WC/TC^2	0.7006	WC/TC^2	0.7295
WC/CC^2	0.6971	WC/CC^2	0.7183
WC/TC	0.6955	TC	0.7172
TC	0.6901	WC/TC	0.7120
WC/CC	0.6888	CC	0.7105
CC	0.6874	BMI	0.7035
BMI	0.6825	WC/CC	0.7032
WC	0.6772	WC	0.6891

Rank order is based of AUC value from highest predictor to lowest predictor
AUC Rank: non-informational/equal to change (AUC=0.5), less accurate (0.5<AUC≥0.7), moderately accurate (0.7<AUC≥0.9), highly accurate (0.9<AUC≥1.0), and a discriminatory test (AUC=1.0).
Covariates included: Age, ethnicity, education, LPA, MVPA, and dizziness/balance/falling question
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, $WC/CC^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared

Older-Aged Adults

Within older adults (≥65 years of age), 230 had good static balance and 575 had poor static balance (**Table 13**). Those with good static balance had a significantly lower age ($p<0.001$) and participated in more LPA ($p=0.001$) and MVPA ($p=0.005$). Within females, body anthropometric variables of BMI, CC, TC, WC/TC, WC/TC^2, WC/CC, and WC/CC^2 were significantly ($p \leq 0.05$) different between those with good and poor static balance. Within men, CC, WC/TC, WC/TC^2, and WC/CC^2 were significantly different between those with good and poor static balance.

Table 13. Demographic and body anthropometrics of the older-aged adults (≥65 years).

Characteristics	Good Balance (n= 230)	Poor Balance (n= 575)	P-value
Age (years)	71.1 ± 0.5	74.7 ± 0.3	<0.001*
Female			
BMI(kg•m^{-2})	29.0 ± 0.4	27.4 ± 0.4	0.016*
WC(cm)	97.7 ± 1.0	96.1 ± 0.9	0.316
CC(cm)	38.8 ± 0.2	36.6 ± 0.3	<0.001*
TC(cm)	53.2 ± 0.6	49.6 ± 0.4	<0.001*
WC/TC(cm)	1.85 ± 0.02	1.95 ± 0.01	0.001*
WC/TC^2(cm)	0.036 ± 0.001	0.040 ± 0.000	<0.001*
WC/CC(cm)	2.52 ± 0.03	2.64 ± 0.02	0.009*
WC/CC^2(cm)	0.066 ± 0.001	0.073 ± 0.001	<0.001*
Male			
BMI(kg•m^{-2})	28.0 ± 0.4	27.9 ± 0.3	0.878
WC(cm)	104.3 ± 1.0	104.3 ± 0.9	0.976
CC(cm)	38.4 ± 0.3	37.7 ± 0.3	0.037*
TC(cm)	50.9 ± 0.4	49.8 ± 0.4	0.138
WC/TC(cm)	2.05 ± 0.01	2.10 ± 0.01	<0.001*
WC/TC^2(cm)	0.041 ± 0.000	0.043 ± 0.000	0.006*
WC/CC(cm)	2.72 ± 0.02	2.77 ± 0.02	0.074
WC/CC^2(cm)	0.071 ± 0.001	0.074 ± 0.001	<0.001*
LPA (min/week)	309.0 ± 5.5	274.4 ± 5.2	<0.001*
MVPA (min/week)	11.2 ± 1.1	7.7 ± 0.7	0.005*
Gender (n, %)			0.468
Male	126 (48.2)	299 (44.9)	
Female	104 (51.8)	276 (55.1)	
Race/Ethnicity (n, %)			0.259
Mexican American	38 (2.5)	120 (3.4)	
Other Hispanic	4 (1.6)	11 (2.0)	
Non-Hispanic white	153 (85.9)	369 (83.7)	
Non-Hispanic black	31 (8.3)	55 (6.5)	
Other	4 (1.7)	20 (4.4)	
Education Level (n, %)			0.311
< High school diploma	85 (24.8)	233 (28.0)	
High school diploma or GED	59 (29.2)	149 (30.9)	
Some college or more	86 (46.0)	203 (41.1)	
Dizziness/Balance/Falling problems in the past year			0.057
Yes	45 (21.0)	167 (29.8)	
No	185 (79.0)	408 (70.2)	

Continuous data are mean ± SE. For categorical data, the numbers inside parentheses are percentages weighted to U.S. population while the numbers outside parentheses are unweighted counts.

BMI: body mass index, CC: calf circumference, LPA: light physical activity; MVPA: moderate-vigorous physical activity, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared, *p≤0.05

Separate univariate logistic regression analysis (**Table 14**) within the female population found all body anthropometric measures to be significant ($p \leq 0.05$) with balance other than WC. Higher BMI, CC, and TC were found to significantly ($p \leq 0.05$) associate with higher odds of good static balance in females. Further, higher WC/TC, WC/TC^2, WC/CC, and WC/CC^2 were significantly associated ($p \leq 0.05$) with lower odds of good static balance in females. In males *(***Table 15***)*, a higher BMI significantly associated ($p \leq 0.05$) with higher odds of good balance. Higher WC/TC, WC/TC^2, and WC/CC^2 were significantly associated with lower odds of having good static balance. There was a trend toward higher TC to significantly associate with higher odds of good static balance ($p=0.059$), specifically between the 3rd and 4th quartile compared to the 1st quartile. Based on pairwise quartile comparisons in males, significant differences between the 4th quartile of CC compared to 1st ($p=0.037$) were found. Also, significance was found between the 3rd quartile of WC compared to 1st ($p=0.013$). For TC, pairwise comparisons for the 3rd quartile ($p=0.005$) and the 4th quartile (0.017) vs. the 1st quartile were significant. In both males and females, those with a lower age ($p<0.001$) and participation in more LPA ($p<0.001$) have higher odds of good static balance.

Table 14. Univariate associations between good balance and anthropometric parameters and selected control variables in older-age females (n=380).

Body Measure	**Odds Ratio (CI:95%)**	**p-value**
BMI(kg•m^{-2})		0.041*
<24.06	1.00	
24.06-27.26	1.80 (1.01, 3.19)*	
27.27- 30.76	2.02 (0.93, 4.36)	
> 30.76	3.19 (1.55, 6.54)*	
WC(cm)		0.355
< 88.2	1.00	
88.3- 95.3	1.24 (0.78, 1.96)	
95.4-103.8	0.87 (0.36, 2.09)	
>103.8	1.43 (0.76, 2.70)	
CC(cm)		0.003*
< 34.0	1.00	
34.0 -36.2	1.72 (0.61, 4.84)	
36.3-39.3	2.71 (1.03, 7.13)*	
>39.3	5.61 (2.41, 13.07)*	
TC(cm)		0.001*
< 45.6	1.00	
45.6-49.3	2.88 (1.17, 7.08)*	
49.4-54.2	3.17 (1.13, 8.89)*	
>54.2	6.74 (2.95, 15.39)*	
WC/TC(cm)		0.005*
>1.79	1.00	
1.79-1.94	0.53 (0.28, 0.99)*	
1.95-2.09	0.44 (0.22, 0.86)*	
> 2.09	0.23 (0.11, 0.51)*	
WC/TC^2(cm)		0.001*
<0.03365	1.00	
0.03356-<0.03914	0.51 (0.26, 0.98)*	
0.03914-0.04471	0.31 (0.15, 0.66)*	
> 0.04471	0.21 (0.10, 0.47)*	
WC/CC(cm)		0.022*
< 2.44	1.00	
2.44-2.62	0.68 (0.32, 1.45)	
2.63-2.82	0.70 (0.26, 1.84)	
>2.82	0.18 (0.07, 0.46)*	
WC/CC^2(cm)		0.002*
<0.06399	1.00	
0.06399-<0.07234	0.44 (0.24, 0.82)*	
0.07234-0.08055	0.27 (0.11, 0.62)*	
> 0.08055	0.13 (0.05, 0.37)*	
Age (years)	0.90 (0.85, 0.94)	<0.001*
MVPA (min/day)	1.40 (1.04, 1.89)	0.031*
LPA (min/day)	1.18 (1.02, 1.37)	0.031*
Education		0.569
Some high school vs some college or more	0.87 (0.43, 1.73)	
High school diploma/GED vs some college or more	1.16 (0.53, 2.55)	
Ethnicity		0.415
Mexican American vs non-Hispanic white	0.69 (0.34, 1.41)	
Other Hispanic vs non-Hispanic white	0.75 (0.14, 4.08)	
Non-Hispanic black vs non-Hispanic white	1.84 (0.96, 3.53)	
Other/multi-racial vs non-Hispanic white	0.64 (0.25, 1.65)	
Dizzy/balance/falling problems the past year (yes vs no)	1.12 (0.64, 1.94)	0.677

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, $WC/CC^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared; Odds ratio is expressed with the 95% confidence interval, *$p \leq 0.05$

Table 15. Univariate associations between good balance and anthropometric parameters and selected control variables in older-age males (n=425).

Body Measure	**Odds Ratio (CI:95%)**	**p-value**
BMI(kg•m^{-2})		0.039*
<24.77	1.00	
24.77-26.85	2.46 (1.19, 5.09)*	
26.89-29.80	2.17 (1.08, 4.38)*	
>29.80	1.48 (0.59, 3.71)	
WC(cm)		0.076
<95.6	1.00	
95.6-102.6	1.76 (0.78, 3.95)	
102.7-110.7	2.82 (1.29, 6.17)*	
>110.7	1.18 (0.42, 3.34)	
CC(cm)		0.232
<35.2	1.00	
35.2-37.2	2.27 (0.66, 7.80)	
37.3-39.5	2.27 (0.86, 5.98)	
>39.5	2.53 (1.07, 5.99)*	
TC(cm)		0.059
< 46.1	1.00	
46.1-49.3	1.31 (0.75, 2.28)	
40.4-52.4	2.36 (1.34, 4.13)*	
> 52.4	2.72 (1.23, 6.03)*	
WC/TC(cm)		0.003*
< 1.981	1.00	
1.981-2.082	1.28 (0.76, 2.16)	
2.083-2.192	1.04 (0.52, 2.07)	
> 2.192	0.39 (0.22, 0.70)*	
WC/TC^2(cm)		0.004*
< 0.039	1.00	
0.029-0.041	0.86 (0.38, 1.96)	
0.042-0.047	0.52 (0.25, 1.07)	
> 0.047	0.27 (0.15, 0.48)*	
WC/CC(cm)		0.418
< 2.62		
2.62-2.75	1.17 (0.46, 3.01)	
2.76-2.91	1.02 (0.45, 2.28)	
> 2.91	0.49 (0.19, 1.30)	
WC/CC^2(cm)		0.003*
< 0.0674		
0.0674-<0.0741	0.59 (0.33, 1.06)	
0.0741-0.0805	0.79 (0.42, 1.50)	
> 0.0805	0.34 (0.19, 0.60)*	
Age, 1 year or higher	0.91 (0.88, 0.95)	<0.001*
MVPA (min/day)	1.15 (0.95, 1.40)	0.145
LPA (min/day)	1.44 (1.25, 1.66)	<0.001*
Education		0.353
Some high school vs some college or more	0.76 (0.43, 1.33)	
High school diploma/GED vs some college or more	0.56 (0.26, 1.24)	
Ethnicity		0.150
Mexican American vs non-Hispanic white	0.74 (0.45, 1.24)	
Other Hispanic vs non-Hispanic white	0.79 (0.09, 7.02)	
Non-Hispanic black vs non-Hispanic white	0.73 (0.32, 1.96)	
Other/multi-racial vs non-Hispanic white	0.09 (0.10, 0.73)	
Dizzy/balance/falling problems the past year (yes vs no)	2.92 (1.73, 4.91)	<0.001*

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, $WC/CC^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared
Odds ratio is expressed with the 95% confidence interval, *p≤0.05 and significant pairwise comparison

Gender-specific multivariate logistic regression models that examine the odds of good balance in older adults found little-to-no impact with the inclusion or exclusion of the dizziness/balance/falling question. For older-age females (**Table 16**), being in higher quartiles of BMI, CC, and TC (particularly quartile 4) increased the odds of good static balance. For WC/TC, WC/TC^2, WC/CC, and WC/CC^2, those in quartile 4 had lower odds of good balance than those in quartile 1. In males (**Table 17**), the third quartile of WC compared to lowest was associated with higher odds of good static balance, whereas the highest quartiles of WC/TC^2 and WC/CC^2 were associated with lower odds of good static balance.

Table 16. Multivariate associations between good balance and anthropometric parameters, controlling for covariates in older-age females (n=380).

Body Measure	Odds Ratio M1 (CI:95%)	Odds Ratio M2 (CI:95%)
BMI(kg•m^{-2})		
<24.06	1.00	1.00
24.06-27.26	1.56 (0.82, 2.97)	1.56 (0.83, 2.95)
27.27- 30.76	2.01 (1.03 3.94)†	2.01 (1.02, 4.00)†
> 30.76	3.08 (1.58, 5.98)†	3.08 (1.58, 6.01)†
WC(cm)		
< 88.2	1.00	1.00
88.3- 95.3	1.22 (0.70, 2.11)	1.22 (0.72, 2.08)
95.4-103.8	1.01 (0.35, 2.87)	1.01 (0.36, 2.87)
>103.8	1.51 (0.68, 3.33)	1.51 (0.70, 3.27)
CC(cm)		
< 34.0	1.00	1.00
34.0 -36.2	1.46 (0.47, 4.51)	1.45 (0.45, 4.68)
36.3-39.3	2.13 (0.76, 5.99)	2.13 (0.76, 5.96)
>39.3	3.78 (1.62, 8.81)†	3.78 (1.63, 8.79)†
TC(cm)		
< 45.6	1.00	1.00
45.6-49.3	2.06 (0.80, 5.33)	2.07 (0.79, 5.38)
49.4-54.2	2.16 (0.69, 6.73)	2.17 (0.70, 6.66)
>54.2	4.50 (2.00, 10.15)†	4.52 (1.98, 10.29)†
WC/TC(cm)		
>1.79	1.00	1.00
1.79-1.94	0.68 (0.36, 1.31)	0.68 (0.36, 1.31)
1.95-2.09	0.57 (0.26, 1.25)	0.57 (0.27, 1.23)
> 2.09	0.34 (0.14, 0.83)†	0.34 (0.14, 0.81)†
WC/TC^2(cm)		
<0.03365	1.00	1.00
0.03356-<0.03914	0.60 (0.28, 1.27)	0.60 (0.28, 1.27)
0.03914-0.04471	0.38 (0.16, 0.89)†	0.38 (0.16, 0.89)†
> 0.04471	0.36 (0.17, 0.75)†	0.36 (0.17, 0.73)†
WC/CC(cm)		
< 2.44	1.00	1.00
2.44-2.62	0.89 (0.39, 2.02)	0.89 (0.39, 2.02)
2.63-2.82	0.90 (0.29, 2.84)	0.90 (0.30, 2.74)
>2.82	0.25 (0.08, 0.73)†	0.25 (0.08, 0.72)†
WC/CC^2(cm)		
<0.06399	1.00	1.00
0.06399-<0.07234	0.58 (0.29, 1.13)	0.58 (0.29, 1.14)
0.07234-0.08055	0.35 (0.14, 0.88)†	0.34 (0.14, 0.88)†
> 0.08055	0.19 (0.06, 0.59)†	0.19 (0.06, 0.59)†

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared
Odds ratio is expressed with the 95% confidence interval †p≤0.05

Table 17. Multivariate association between good balance and anthropometric parameters, controlling for covariates in older-age males (n=425).

Body Measure	**Odds Ratio M1 (CI:95%)**	**Odds Ratio M2 (CI:95%)**
BMI(kg•m^{-2})		
<24.77	1.00	1.00
24.77-26.85	2.12 (0.94, 4.81)	2.07 (0.89, 4.85)
26.89-29.80	1.85 (0.87, 3.96)	2.02 (0.98, 4.15)
>29.80	1.34 (0.53, 3.43)	1.36 (0.53, 3.50)
WC(cm)		
<95.6	1.00	1.00
95.6-102.6	1.55 (0.61, 3.93)	1.64 (0.59, 4.56)
102.7-110.7	2.50 (1.01, 6.19)†	2.68 (1.10, 6.50)†
>110.7	1.04 (0.35, 3.08)	1.12 (0.36, 3.50)
CC(cm)		
<35.2	1.00	1.00
35.2-37.2	2.00 (0.62, 6.45)	2.23 (0.63, 7.96)
37.3-39.5	1.74 (0.61, 5.00)	1.95 (0.68, 5.59)
>39.5	1.71 (0.71, 4.12)	1.84 (0.76, 4.49)
TC(cm)		
< 46.1	1.00	1.00
46.1-49.3	0.99 (0.53, 1.87)	0.94 (0.48, 1.85)
40.4-52.4	1.88 (0.83, 4.26)	2.03 (0.89, 4.65)
> 52.4	2.17 (0.77, 6.11)	2.32 (0.81, 6.63)
WC/TC(cm)		
< 1.981	1.00	1.00
1.981-2.082	1.25 (0.62, 2.53)	1.22 (0.61, 2.43)
2.083-2.192	1.11 (0.50, 2.49)	1.11 (0.51, 2.41)
> 2.192	0.51 (0.23, 1.16)	0.52 (0.24, 1.15)
WC/TC^2(cm)		
< 0.039	1.00	1.00
0.029-0.041	0.91 (0.34, 2.48)	0.95 (0.39, 2.32)
0.042-0.047	0.60 (0.25, 1.44)	0.56 (0.22, 1.42)
> 0.047	0.42 (0.19, 0.93)†	0.43 (0.20, 0.92)†
WC/CC(cm)		
< 2.62	1.00	1.00
2.62-2.75	1.45 (0.50, 4.25)	1.46 (0.50, 4.26)
2.76-2.91	1.23 (0.45, 3.38)	1.31 (0.50, 3.45)
> 2.91	0.63 (0.20, 1.98)	0.62 (0.22, 1.79)
WC/CC^2(cm)		
< 0.0674	1.00	1.00
0.0674-<0.0741	0.67 (0.35, 1.27)	0.68 (0.36, 1.26)
0.0741-0.0805	1.17 (0.49, 2.82)	1.16 (0.45, 2.95)
> 0.0805	0.51 (0.25, 1.02)†	0.50 (0.25, 1.01)†

Reference group was poor balance (i.e., failed condition 4 of the Romberg Balance Test).
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared
Odds ratio is expressed with the 95% confidence interval †$p \leq 0.05$

AUC analysis (**Table 18**) in older-age females determined the following as the top three predictors of good static balance: WC/CC^2 (0.7430), CC (0.7392), and TC (0.7371). In older-age males, the strongest three predictors of good static balance were WC/TC (0.7382), and WC/TC^2 (0.7377), and BMI (0.7337).

Table 18. Adjusted area under the curve values for anthropometric parameters and good balance in older-aged adults (≥65 years).

Female AUC		Male AUC	
Rank	**AUC Value**	**Rank**	**AUC Value**
WC/CC^2	0.7430	WC/TC	0.7382
CC	0.7392	WC/TC^2	0.7377
TC	0.7371	BMI	0.7337
WC/TC^2	0.7354	WC	0.7322
BMI	0.7294	TC	0.7300
WC/CC	0.7251	WC/CC	0.7298
WC/TC	0.7239	CC	0.7256
WC	0.7216	WC/CC^2	0.7247

Rank order is based of AUC value from highest predictor to lowest predictor
AUC Rank: non-informational/equal to change (AUC=0.5), less accurate (0.5<AUC≥0.7), moderately accurate (0.7<AUC≥0.9), highly accurate (0.9<AUC≥1.0), and a discriminatory test (AUC=1.0).
Covariates included: Age, ethnicity, education, LPA, MVPA, and dizziness/balance/falling question
BMI: body mass index, CC: calf circumference, LPA: light physical activity expressed as a 60-minute interval change; MVPA: moderate-vigorous physical activity expressed as a 10-minute interval change, TC: thigh circumference, WC: waist circumference, WC/CC: waist circumference to calf circumference ratio, WC/CC$^{2:}$ waist circumference to calf circumference ratio squared, WC/TC: waist circumference to thigh circumference ratio, , WC/TC^2 waist circumference to thigh circumference ratio squared

Discussion

The purpose of this study was to examine how various anthropometric measures were associated with having good static balance, particularly in middle-aged adults, a group that is less well-studied than the elderly. A number of anthropometric variables were associated with balance in middle-aged. Specifically, both univariate and multivariate analyses determined a higher ratio of WC/TC^2 and WC/CC^2 to be significantly associated with decreased odds of good static balance in both females and males. AUC results confirm these findings in middle-aged females and males in that WC/TC^2 and WC/CC^2 had the highest AUC values, suggesting that these squared variables are more associated with having good balance than non-squared ratios.

Similar, albeit slightly different, findings were demonstrated in the older population, in that both univariate and multivariate analyses indicated WC/TC^2 and WC/CC^2 in females and males were associated with balance. Interestingly, when examining which variables had the highest AUC for older adults, WC/CC^2 and CC had the two highest values for females and WC/TC and WC/TC^2 had the two highest values for males. Univariate and multivariate analyses also demonstrated a significant association with balance when examining WC/TC for older males and CC for older females.

Collectively, these data in middle-aged and older-aged adults suggest that a WC/CC^2 and WC/TC^2 are closely associated with static balance. This may be from the emphasis placed on CC and TC and thus the importance of skeletal muscle mass in these measures, though this is speculative. Future studies may consider examining how WC/TC^2 and WC/CC^2 relate to dynamic balance measures as well as the incidence of falls. If they turn out to predict falls significantly better than other anthropometric variables, these variables could potentially be measured along with other established markers of fall risk in clinical settings.

There do appear to be some gender differences in our results. Confirmed from previous studies (Stewart et al., 2002; Wu et al., 2019), the present study identified higher CC and TC to be significantly associated with having good static balance in females, regardless of age. Middle-aged females with a CC >40.7 cm and older-age females with a CC >39.3 cm were significantly associated with having good static balance. This change in CC exemplifies the important shift in skeletal muscle mass as one ages. Kawakami et al. (2015) positively correlated CC to skeletal muscle mass through a cut-off value of <33 cm in females to predict low muscle mass. Apart from middle-age, Stewart et al. (2002) measured a corrected CC in females ≥70 years of age and suggested larger calf muscles to be protective against falling. The calf measure was corrected by subtracting calf skinfold measurement multiplied by pi from calf girth, which adjusted for subcutaneous adipose tissue and fluid accumulation to provide a more valid measure of lean muscle tissue (Stewart et al., 2002). While Stewart et al. (2002) did not link CC directly to balance, it provided an example of the importance of lean muscle tissue related to fall risk, which may offer a link between skeletal muscle mass and static balance as found in the present study. Further, the present study identified TC >57.6 cm for middle-aged females and >45.6 cm for older-age females to be significantly related to good static balance. While not specific to females, Wu et al. (2019) determined older adults ≥65 years with lower TC to have higher odds of having vestibular dysfunction. TC is highly correlated to appendicular skeletal muscle mass, though CC is known to be a better marker and predictor of appendicular skeletal muscle mass (Santos et al., 2019). CC and TC were the strongest AUC predictors of good static balance in older-age females following WC/CC^2.

In the univariate or multivariate analyses, no significant relationships between CC or TC and good static balance were found in males. This may be due to the males in the present study having a relatively large amount of appendicular skeletal muscle mass to begin with. Cut-offs for low-muscle mass in adult males age 40-89 years are <34 cm for CC (Kawakami et al., 2015) and <49 cm for TC (Mienche et al., 2019). In the present study, both middle- and older-age males in the poor balance group had mean CC and TC measures that were above these cut-off values (see **Table 7** and **Table 13**), meaning that the prevalence of low muscle mass was not high. Whether a significant relationship between CC and TC would exist in a population with a higher prevalence of suboptimal muscle mass cannot be determined from the present study.

High WC/CC and WC/TC in middle-aged adults were significantly associated with decreased odds of good static balance in the present study. Similar findings from Wu et al. (2019) determined individuals ≥ 40 years with higher values of these measures had elevated odds of vestibular dysfunction. Waist circumference is tightly associated with visceral or central fat distribution (Daniels, Khoury, & Morrison, 2000), which is linked to poor balance (Ochi et al., 2010). As previously established, TC and CC are closely linked to skeletal muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003). Thus, a higher WC/CC would indicate a greater amount of centrally mediated adipose tissue compared to skeletal muscle mass. It is well established that individuals with less muscle mass also have worse balance (Szulc et al., 2005). The present study bolstered this information by examining this relationship separated by age and gender. Further, we examined the relationship of other more novel measures of anthropometrics on balance such as WC/CC^2 and WC/TC^2. Given the important link between TC and CC on skeletal muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003) and balance (Kawakami et al., 2015; Mienche et al., 2019) and the relationship between WC/CC and WC/TC on vestibular dysfunction (Wu et al., 2019), squaring these variables may place a greater emphasis on skeletal muscle mass and provide a greater association with static balance status. Both univariate and multivariate analyses in the present study found that higher WC/CC^2 and WC/TC^2 were significantly associated with decreased odds of having good static balance, regardless of age or gender. Further, the AUC analyses in middle-aged adults also indicated that these were stronger predictors of balance in both males and males, compared to other anthropometric measures assessed.

The strengths of this study are the use of a nationally representative dataset of middle-aged and older-aged adults in the United States which allows this study to be highly generalizable. While this study contributes to the general knowledge into the association between anthropometry and static balance, its primary focus in the middle-aged population bolsters past and current research. Confounding variables were attempted to be minimized through the inclusion of models adjusting for potential balance predictors such as age, ethnicity, education, LPA, MVPA, and dizziness/balance/falling problems within the previous year. This study is not without limitations. NHANES uses a cross-sectional design and thus results cannot support strong causal or temporal inferences despite the notable statistical power associated with these data sets. The Romberg Test of Standing Balance was utilized to determine poor or good static balance, and although it does not assess dynamic balance, it is a common standard assessment in clinical and research settings (Lin et al., 2020).

Conclusion

While a number of anthropometric measures were significantly associated with balance, in both middle-aged males and females, univariate and multivariate analyses found that higher WC/CC^2 and WC/TC^2 values to significantly associate with lower odds of good static balance. In both genders, AUC predicative ability resulted in WC/TC^2 followed by WC/CC^2 to be the highest predictors of good static balance in middle-aged adults. Similar to middle-aged adults, older-age males and females with higher WC/CC^2 and WC/TC^2 have significantly decreased odds of having good static balance, though AUC did not find these the highest predictors of good static balance. Falls are a leading concern in the aging population; however, middle-aged adult research on balance is lacking. Collectively, these findings demonstrate that WC/TC^2 and WC/CC^2 are associated with balance in middle-aged and older adults.

CHAPTER VI SUMMARY AND CONCLUSIONS

Falls are a leading concern in the aging population (Bergen et al., 2016; Verma et al., 2016). Although less population-based research has targeted adults < 65 years of age, Koo et al. (2015) determined vestibular contributions to balance increase above age 40. Further, in a middle-age population, one in four adults report falling at least once in a two-year period (Talbot et al., 2005). Loss of balance within the middle-to-older-adult years is linked to a higher risk of falling, increased dependency, illness, and in some cases mortality (Howe et al., 2011). In the middle-age years, adults begin decreasing PA levels and physiological changes alter postural stability leading to decreased balance (Ito et al., 2018). The specific role these variables have on balance in middle-age remains underexplored, despite considerable evidence in older adult populations.

In older adults, peripheral arterial disease (PAD), an independent marker of cardiovascular risk (Thurston & Dawson, 2019), and ankle-brachial pressure index (ABPI), a non-invasive predictor for identifying cardiovascular disease (CVD), (Ono et al., 2003), are related to falling (Juraschek et al., 2019). Multiple studies confirm that PAD in older adults is associated with poor balance and/or fall risk (Gardner & Montgomery, 2001; Matsushita et al., 2017). However, whether poor balance is associated with increased CVD risk as assessed by ABPI in middle-aged adults is not well understood. Total PA is known to play a major role in the prevention of falls through balance, gait function, and muscular strength in older adults (Sherrington et al., 2019). Yet one remaining question that persists is the extent to which PA intensity affects balance, especially in middle-aged populations. Loprinzi and Brosky (2014) determined that, in American adults ≥40 years, every 60-min increase in LPA is associated with

10% higher odds of functional balance, and every 1-unit increase in daily log-transformed MVPA is associated with 23% higher odds of good balance. However, this study did not include LPA as a covariate when examining MVPA and vice versa. Thus, the isolated effects of LPA or MVPA on balance are not fully accounted for. Further, most research analyzes PA-balance across broad age ranges, and when these populations are combined it is impossible to say whether PA is related to balance similarly in middle-aged and older adults. Obesity is also linked to decreased lower extremity function and fall risk in older adults (Mitchell et al., 2014). Studies not only identify significant associations between obesity and poor balance, but also body fat distribution (Bermúdez-Rey et al., 2017; Mitchell et al., 2014; Silvia G R Neri et al., 2020). In comparison to traditional measures like BMI and WC, novel measures of anthropometry may offer better a representation of fat distribution, skeletal muscle mass, and be more predictive of balance. For example, studies demonstrate a WC-to-CC ratio, compared to each single measure of WC or CC, is a better index for assessing the disproportionality between abdominal fat and leg muscle mass (Kim et al., 2011). A mechanism for this finding is that these measures simultaneously incorporate information about body composition, body fat distribution, and muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003), which we know to be associated with balance (Castillo-Rodríguez et al., 2020). While those with higher lower extremity circumferences have higher amounts of skeletal muscle mass (Wu et al., 2019), squaring these variables of the lower extremity in ratio measures may place a higher emphasis on lean muscle mass, which is the main focus of the relationship between body anthropometric measures and balance.

To our knowledge, nationally representative population-based studies in middle-aged adults were incomplete regarding the associations between 1) ABPI and balance, 2) the independent associations of MVPA and LPA on balance, and 3) the body anthropometric measures most closely associated with balance. Dysfunction in static balance begins to decline as early as age 40 years. However, little population-based research has examined the predictors of such decline in middle-aged populations. The overall purpose of this dissertation was to explore the role of CVD, PA intensity, and body anthropometrics on balance in a nationally representative middle-age population (40-64 years) from the National Health and Nutrition Examination Survey (NHANES).

Study 1 was a comprehensive data analysis to determine if balance was impaired in U.S. middle-aged adults with poor RABPI, a marker of CVD. It was hypothesized that middle-aged individuals with poor RABPI would be at greater risk for poor static balance on the Romberg Test of Standing Balance. For study 1, 1,046 middle-aged adults from 1999-2000 NHANES were included in logistic regression modeling of functional assessments of vestibular balance, through the Romberg Test of Standing Balance, and CVD, assessed through RABPI. The hypothesis was confirmed that individuals with at-risk RABPI have 3.38 (95%CI 1.66, 6.87; p=0.001) odds of poor balance as compared to those with normal RABPI. The novelty of study 1 was the positive association found between poor RABPI and poor balance in a middle-aged population. Tanaka et al. (2016) identified older adults with poor ABI (≤0.9) (and diagnosed heart failure) as having poorer standing balance based off a single-balance test measurement, while Gardner and Montgomery (2001) found older adults with physician-diagnosed PAD have a 1.73 higher prevalence rate of falling. Further, we extend these findings by demonstrating that middle-aged adults with poor RAPBI are also susceptible to having poor static balance. Further, in this study middle-aged adults who have good balance report more frequently participating in muscle-strengthening activities, which may be linked to higher skeletal muscle mass and may likely have protective effects against development of PAD and falls (Castillo-Rodríguez et al., 2020; Pizzimenti et al., 2020). Future mechanistic-based studies should evaluate whether impaired vascular function directly associated with CVD influences balance and fall risk in middle-aged adults. Additional research is warranted into whether impaired balance in those with reduce ABPI can be improved through lifestyle interventions such as PA, resistance training, and nutrition. Overall, study 1 determined balance is an important independent functional assessment in conjunction with ABPI score to detect middle-aged adults at a higher risk of CVD and falls.

Study 2 assessed the association of LPA and MVPA with odds of having good static balance in middle-aged adults. It was hypothesized that middle-aged adults who participate in high levels of LPA and MVPA will have better static balance, and that MVPA would have a stronger relationship compared to LPA. For study 2, 1,068 middle-aged adults (40-64 years) from 2003-2004 NHANES were included in the main measurements of LPA and MVPA and static balance via Romberg Test of Standing Balance. Physical activity was collected via accelerometer worn for 7 consecutive days. Our hypothesis was not confirmed, as no significant relationships between higher amounts of MVPA or LPA and having good static balance in the middle-aged population were observed. Loprinzi and Bronsky (2014) determined adults ≥40 years of age have a 10% higher odds of good balance with every 60-minute increase in LPA and 24% higher odds with every 1-unit increase in log-transformed MVPA. However, they did not include LPA as a covariate when examining the role of MVPA on static balance, nor did they separate the analyses by middle and older age. Thus, the independent role of MVPA or LPA was not fully elucidated in middle-aged adults.

Study 2 of the present dissertation extended these findings by examining the independent roles of MVPA and LPA on balance, as well as specific age effects on the PA intensity-balance relationship. When both intensities of PA are included in multivariate logistic regression, LPA and MVPA were not associated with good balance in middle age (40-64 years). Although a sub-analysis in adults ≥65 years old partially confirmed Loprinzi and Bronsky (2014) findings, that every 60-minute increase in LPA was significantly associated with 19% higher odds of good balance, no relationship was found with MVPA. A rationale as to why MVPA was found not to be significant in the older age group may be due to the mean MVPA in that group being well below the 21.4 min/day recommendation by the Physical Activity Guidelines for Americans (2018). Population-reference data for U.S. adults by Wolff-Hughes et al. (2015) show that although both LPA and MVPA decline after age 40, the relative drop in MVPA is more precipitous. Thus, a future direction should be aimed at examining how using different cut-points for LPA and MVPA in these age groups impacts this association with balance. Further, age was an important predictor of balance, which is confirmed by Bermúdez Ray et al. (2017) who determined failure of the Romberg Balance Test condition 4 to increase with age. Collectively, the results in the present study confirm that increased age (in both middle-aged and older adults) was significantly associated with a reduced odds of having good balance on the Romberg Balance Test.

Interestingly, study 2 also found that every 1-unit increase in BMI was associated with 1.04 (95%CI: 1.00, 1.08, p=0.038) odds of having good static balance in the middle-adult population. Although speculative, BMI within middle-age may be more representative of skeletal muscle mass, which is linked to better balance and decreased fall risk (Gouveia et al., 2020). Bradbury et al. (2017) reported adults 40-69 years of age who participate in more PA had lower body fat percentage, regardless of BMI level. In older adults, Concela Carral et al. (2019) found both static and dynamic balance become poorer as BMI increases, potentially due to an increased amount of abdominal fat (Hughes et al., 2004) and diminished postural control (Teasdale et al., 2007). Conversely, in the present study a higher BMI was associated with good static balance in middle age. A potential rationale behind this observed association may be that BMI is representing other health and physiological characteristics in middle-aged and older adults, like general health status or skeletal muscle mass, which is closely linked to balance and fall risk (Gouveia et al., 2020). The loss of substantial amounts of weight, particularly in middle and older age, may be indicative of underlying disease and/or an accelerated muscle loss with aging (Miller & Wolfe, 2008). Future direction could aim to extend the relationship between skeletal muscle mass, abdominal fat, and balance in the middle-aged population.

Study 3 explored the strength of associations between various anthropometric measures and good static balance in middle-aged adults. It was hypothesized that novel measures of WC/CC^2 and WC/TC^2 would have stronger associations with static balance than measures of BMI, WC, CC, TC, WC/CC, and WC/TC. For study 3, 1,050 middle-aged adults were included from the 2003-2004 NHANES data analysis. Subjects were separated by gender and a sub-analysis included older adults ≥65 years. Univariate logistic regression determined the individual relationship of each anthropometric measure with good static balance, while multivariate logistic regression adjusted for covariates of age, ethnicity, education, LPA, MVPA and dizziness/impaired balance/falling within the previous 12 months. An area under the ROC curve (AUC) was then used to rank anthropometric variables in decreasing order of their predictive performance in separate logistic regressions with good static balance as the outcome. In both the univariate and multivariate analyses, higher WC/CC^2 and WC/TC^2 (amongst other anthropometric measures) were significantly associated with decreased odds of good static balance in middle-aged males and females. AUC results confirmed our hypothesis that WC/TC^2

followed by WC/CC^2 to be better predictors of good static balance (albeit modestly) compared to non-squared values in middle-aged males and females. Though speculative, this may be from the emphasis placed on CC and TC and thus the importance of skeletal muscle mass in these measures (Hodgkiss & McCarthy, 2017; Santos et al., 2019).

There were gender differences present in the results, particularly in the older aged population. Confirmed from previous studies (Stewart et al., 2002; Wu et al., 2019), the present study identified higher CC and TC as being significantly associated with having good static balance in females, regardless of age. TC is highly correlated to appendicular skeletal muscle mass (Hodgkiss & McCarthy, 2017), though CC is known to be a better marker of appendicular skeletal muscle mass (Santos et al., 2019). In older females, CC and TC were the strongest AUC predictors of good static balance following WC/CC^2. Although in males, no significant relationships between CC or TC and good static balance were found. However, WC/TC, WC/TC^2 and BMI had the highest AUC and thus were the strongest predictors. Compared to low skeletal muscle cut-off values from Mienche et al. (2019), both middle- and older-aged males in the present study had a higher mean CC and TC, indicating the prevalence of low muscle mass was not high. A significant relationship between CC and TC and balance may exist in a population with higher prevalence of suboptimal muscle mass, although this could not be determined from this study and may be a direction of future studies.

Given the important link between TC and CC on skeletal muscle mass (Hodgkiss & McCarthy, 2017; Rolland et al., 2003) and balance (Kawakami et al., 2015; Mienche et al., 2019), and the relationship between WC/CC and WC/TC on vestibular dysfunction (Wu et al., 2019), squaring these variables may place a greater emphasis on skeletal muscle mass and provide a greater association of static balance status. The present study bolstered this information by examining this relationship separated by age and gender and by examining more novel measures of anthropometrics (WC/TC^2 and WC/CC^2). Collectively, these data demonstrate higher WC/TC^2 and WC/CC^2 were significantly associated with decreased odds of good static balance, regardless of age or gender. Further, the AUC analyses in middle-aged adults also indicated that these were stronger predictors of balance in both females and males compared to other anthropometrics. Future studies may consider examining the relationship between WC/TC^2 and WC/CC^2 and dynamic balance measures, as well as incidence of falls. If these measures turn out to predict falls significantly better than other anthropometric variables, these novel measures could potentially be included with other established markers of fall risk in clinical settings.

Falls are a leading concern in the aging population, though middle-aged-adult research on balance is lacking. Overall, findings from the three studies comprised within this dissertation find middle-aged adults do differ from older adults in how factors of cardiovascular health, PA, and body anthropometrics impact balance. Balance studies within the middle-aged population are lacking, and a strength of this study was utilizing NHANES data, which makes these studies high generalizable. Future research may aim to evaluate common ailments impacting older adult health, such as fall risk, in the middle-age population, whose daily lifestyle choices affect the aging process and could potentially lessen the burden of illness, disability, and decreased quality of life and independence associated with aging.

REFERENCES

2018 Physical Activity Guideliens Advisory Commitee. (2018). 2018 Physical activity guidelines advisory committee scientific report. In. Washington, DC: US Department of Health and Human Services.

Agrawal, Y., Carey, J. P., Della Santina, C. C., Schubert, M. C., & Minor, L. B. (2009). Disorders of Balance and Vestibular Function in US Adults: Data From the National Health and Nutrition Examination Survey, 2001-2004. *Archives of Internal Medicine, 169*(10), 938-944. doi:10.1001/archinternmed.2009.66

Agrawal, Y., Carey, J. P., Hoffman, H. J., Sklare, D. A., & Schubert, M. C. (2011). The modified Romberg Balance Test: Normative data in U.S. adults. *Otology & Neurotology 32*(8), 1309-1311. doi:10.1097/MAO.0b013e31822e5bee

Al-Qaisi, M., Nott, D. M., King, D. H., & Kaddoura, S. (2009). Ankle brachial pressure index (ABPI): An update for practitioners. *Vascular health and risk management, 5*, 833-841. doi:10.2147/vhrm.s6759

Almeida, S. M., Furtado, J. M., Mascarenhas, P., Ferraz, M. E., Silva, L. R., Ferreira, J. C., . . . Ferraz, F. P. (2016). Anthropometric predictors of body fat in a large population of 9-year-old school-aged children. *Obesity Science & Practice, 2*(3), 272-281. doi:10.1002/osp4.51

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: A review of the literature. *Maturitas, 75*(1), 51-61. doi:10.1016/j.maturitas.2013.02.009

Aoyagi, Y., & Katsuta, S. (1990). Relationship between the starting age of training and physical fitness in old age. *Can J Sport Sci, 15*(1), 65-71.

Bani Hassan, E., Phu, S., Vogrin, S., & Duque, G. (2022). Appendicular and mid-thigh lean mass are associated with muscle strength, physical performance, and dynamic balance in older persons at high risk of falls. *Gait & Posture, 93*, 90-95. doi:10.1016/j.gaitpost.2022.01.022

Battaglia, G., Giustino, V., Messina, G., Faraone, M., Brusa, J., Bordonali, A., . . . Dominguez, L.-J. (2020). Walking in Natural Environments as Geriatrician’s Recommendation for

Fall Prevention: Preliminary Outcomes from the "Passiata Day" Model. *Sustainability, 12*(7). doi:10.3390/su12072684

Bergen, G., Stevens, M. R., & Burns, E. R. (2016). Falls and fall injuries among adults aged ≥65 years - United States, 2014. *Morbidity and Mortality Weekly Report (MMWR), 65*(37), 993-998. doi:10.15585/mmwr.mm6537a2

Bermúdez-Rey, M. C., Clark, T. K., & Merfeld, D. M. (2017). Balance screening of vestibular function in subjects aged 4 years and older: A living laboratory experience. *Frontiers in Neurology 8*, 631. doi:10.3389/fneur.2017.00631

Blodgett, J., Theou, O., Kirkland, S., Andreou, P., & Rockwood, K. (2015). The association between sedentary behaviour, moderate-vigorous physical activity and frailty in NHANES cohorts. *Maturitas, 80*(2), 187-191. doi:10.1016/j.maturitas.2014.11.010

Boyer, W. R., Wolff-Hughes, D. L., Bassett, D. R., Churilla, J. R., & Fitzhugh, E. C. (2016). Accelerometer-derived total activity counts, bouted minutes of moderate to vigorous activity, and insulin resistance: NHANES 2003–2006. *Preventing Chronic Disease, 13*, E146. doi:10.5888/pcd13.160159

Bradbury, K. E., Guo, W., Cairns, B. J., Armstrong, M. E. G., & Key, T. J. (2017). Association between physical activity and body fat percentage, with adjustment for BMI: A large cross-sectional analysis of UK Biobank. *BMJ Open, 7*, e011843. doi:10.1136/bmjopen-2016-011843

Brevetti, G., Martone, V. D., de Cristofaro, T., Corrado, S., Silvestro, A., Di Donato, A. M., . . . Scopacasa, F. (2001). High levels of adhesion molecules are associated with impaired endothelium-dependent vasodilation in patients with peripheral arterial disease. *Journal of Thrombosis and Haemostasis, 85*(1), 63-66.

Brevetti, G., Silvestro, A., Di Giacomo, S., Bucur, R., Di Donato, A., Schiano, V., & Scopacasa, F. (2003). Endothelial dysfunction in peripheral arterial disease is related to increase in plasma markers of inflammation and severity of peripheral circulatory impairment but not to classic risk factors and atherosclerotic burden. *Journal of Vascular Surgery, 38*(2), 374-379. doi:10.1016/s0741-5214(03)00124-1

Bulbulian, R., & Hargan, M. L. (2000). The effect of activity history and current activity on static and dynamic postural balance in older adults. *Physiology & Behavior, 70*(3-4), 319-325. doi:10.1016/s0031-9384(00)00272-9

Castillo-Rodríguez, A., Onetti-Onetti, W., Sousa Mendes, R., & Luis Chinchilla-Minguet, J. (2020). Relationship between leg btrength and balance and lean body mass. Benefits for active aging. *Sustainability, 12*(6), 2380. doi:10.3390/su12062380

CDC. (2018). Heart disease and stroke deaths hitting middle age adults in large numbers [Press release]. Retrieved from https://www.cdc.gov/media/releases/2018/p0906-Heart-disease-stroke-deaths.html

Centers for Disease Control and Prevention (CDC). (1999-2000). Hayattsville, MD; U.S.: Department of Health and Human Services, Centers for Disease Control and Prevetion Retrieved from https://wwwn.cdc.gov/nchs/data/nhanes/1999-2000/manuals/ba.pdf.

Chang, S.-T., Chu, C.-M., Hsu, J.-T., Pan, K.-L., Lin, P.-G., & Chung, C.-M. (2009). Role of ankle-brachial pressure index as a predictor of coronary artery disease severity in patients with diabetes mellitus. *The Canadian Journal of Cardiology, 25*(9), e301-e305. doi:10.1016/s0828-282x(09)70140-0

Chen, H., Cohen, P., & Chen, S. (2010). How big is a big odds ratio? Interpreting the magnitudes of odds ratios in epidemiological studies. *Communications in Statistics - Simulation and Computation, 39*(4), 860-864. doi:10.1080/03610911003650383

Cho, B.-Y., Seo, D.-C., Lin, H.-C., Lohrmann, D. K., & Chomistek, A. K. (2018). BMI and central obesity with falls among community-dwelling older adults. *American Journal of Preventive Medicine, 54*(4), e59-e66. doi:10.1016/j.amepre.2017.12.020

Cieślińska-Świder, J., Furmanek, M. P., & Błaszczyk, J. W. (2017). The influence of adipose tissue location on postural control. *Journal of Biomechanics, 60*, 162-169. doi:10.1016/j.jbiomech.2017.06.027

Concela Carral, J. M., Ayán, C., Sturzinger, L., & Gonzalez, G. (2019). Relationships between body mass index and static and dynamic balance in active and inactive older adults. *Journal of Geriatric Physical Therapy, 42*(4). doi:10.1519/JPT.0000000000000195

Cooper, R., Mishra, G. D., & Kuh, D. (2011). Physical activity across adulthood and physical performance in midlife: Findings from a british birth cohort. *American Journal of Preventive Medicine, 41*(4), 376-384. doi:10.1016/j.amepre.2011.06.035

Crouter, S. E., DellaValle, D. M., Haas, J. D., Frongillo, E. A., & Bassett, D. R. (2013). Validity of ActiGraph 2-regression model, Matthews cut-points, and NHANES cut-points for assessing free-living physical activity. *Journal of Physical Activity & Health, 10*(4), 504-514. doi:10.1123/jpah.10.4.504

Daniels, S. R., Khoury, P. R., & Morrison, J. A. (2000). Utility of different measures of body fat distribution in children and adolescents. *American Journal of Epidemiology, 152*(12), 1179-1184. doi:10.1093/aje/152.12.1179

Dogra, S., & Stathokostas, L. (2012). Sedentary behavior and physical activity are independent predictors of successful aging in middle-aged and older adults. *Journal of Aging Research 2012*, 190654. doi:10.1155/2012/190654

Dunleavy, K., Lulofs-MacPherson, K., & Slowik, A. K. (2019). 3 - Relationship Between Impairments and Function. In K. Dunleavy & A. K. Slowik (Eds.), *Therapeutic Exercise Prescription* (pp. 60-81). St. Louis: Elsevier.

Dunsky, A. (2019). The effect of balance and boordination exercises on quality of life in older adults: A mini-review. *Frontiers in Aging Neuroscience, 11*, 318. doi:10.3389/fnagi.2019.00318

Dutil, M., Handrigan, G. A., Corbeil, P., Cantin, V., Simoneau, M., Teasdale, N., & Hue, O. (2013). The impact of obesity on balance control in community-dwelling older women. *Age 35*(3), 883-890. doi:10.1007/s11357-012-9386-x

Era, P., Sainio, P., Koskinen, S., Haavisto, P., Vaara, M., & Aromaa, A. (2006). Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology*, *52*(4), 204-213. doi:10.1159/000093652

Evenson, K. R., Buchner, D. M., & Morland, K. B. (2012). Objective measurement of physical activity and sedentary behavior among US adults aged 60 years or older. *Preventing Chronic Disease, 9*, E26.

Examination Data Overview: National Health and Nutrition Examination Survey. (2003-2004). Retrieved from https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/overviewexam.aspx?BeginYear=2003

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical Costs of Fatal and Nonfatal Falls in Older Adults. *Journal of the American Geriatrics Society, 66*(4), 693-698. doi:10.1111/jgs.15304

Fowkes, F. G., Murray, G. D., Butcher, I., Heald, C. L., Lee, R. J., Chambless, L. E., . . . McDermott, M. M. (2008). Ankle brachial index combined with Framingham Risk Score to predict cardiovascular events and mortality: A meta-analysis. *Journal of American Medical Association 300*(2), 197-208. doi:10.1001/jama.300.2.197

Fuchs, F. D., Gus, M., Moreira, L. B., Moraes, R. S., Wiehe, M., Pereira, G. M., & Fuchs, S. C. (2005). Anthropometric indices and the incidence of hypertension: A comparative analysis. *Obesity Research, 13*(9), 1515-1517. doi:10.1038/oby.2005.184

Fujita, E., Takeshima, N., Hasegawa, T., Narita, M., Kato, Y., Koizumi, D., & Rogers, M. (2015). Comparison of static and dynamic balance in healthy but untrained versus frail community-dwelling older adults. *Physical Medicine and Rehabilitation-International, 2*(5), 1046.

Gardner, A. W., & Montgomery, P. S. (2001). Impaired balance and higher prevalence of falls in subjects with intermittent claudication. *The Journals of Gerontology: Series A, 56*(7), M454-M458. doi:10.1093/gerona/56.7.M454

Gouveia, É. R., Ihle, A., Gouveia, B. R., Kliegel, M., Marques, A., & Freitas, D. L. (2020). Muscle mass and muscle strength relationships to balance: The role of age and physical activity. *Journal of Aging and Physical Activity 28*(2), 262-268. doi:10.1123/japa.2018-0113

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., . . . Wallace, R. B. (1994). A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of gerontology, 49*(2), M85-M94. doi:10.1093/geronj/49.2.M85

Harrison, L. J., Lepley, L. K., Stevens, S. L., Coons, J. M., Fuller, D. K., & Caputo, J. L. (2021). The relationship between functional movement and static and dynamic balance ability. *Athletic Training & Sports Health Care, 13*(6), e375-e382. doi:10.3928/19425864-20210401-04

Hassinen, M., Komulainen, P., Lakka, T. A., Väisänen, S., & Rauramaa, R. (2005). Associations of body composition and physical activity with balance and walking ability in the elderly. *Journal of Physical Activity and Health, 3*, 298-306. doi:10.1123/jpah.2.3.298

He, X. Z., & Baker, D. W. (2004). Body mass index, physical activity, and the risk of decline in overall health and physical functioning in late middle age. *American Journal of Public Health, 94*(9), 1567-1573. doi:10.2105/ajph.94.9.1567

Heffernan, K. S., Chalé, A., Hau, C., Cloutier, G. J., Phillips, E. M., Warner, P., . . . Fielding, R. A. (2012). Systemic vascular function is associated with muscular power in older adults. *Journal of Aging Research, 2012*, 386387. doi:10.1155/2012/386387

Herdman, S. J., Blatt, P., Schubert, M. C., & Tusa, R. J. (2000). Falls in patients with vestibular deficits. *American Journal of Otolaryngology, 21*(6), 847-851.

Heron, M. (2019). Deaths: Leading causes for 2017. *National Vital Statistics Reports, 68*(8).

Hita-Contreras, F., Martínez-Amat, A., Lomas-Vega, R., Álvarez, P., Mendoza, N., Romero-Franco, N., & Aránega, A. (2013). Relationship of body mass index and body fat distribution with postural balance and risk of falls in Spanish postmenopausal women. *Menopause, 20*(2). doi:10.1097/gme.0b013e318261f242.

Hodgkiss, A. M., & McCarthy, H. D. (2017). Thigh circumference measurement as a potential marker of leg skeletal muscle mass – cross sectional study in a U.S. population age 39–69 years. *Proceedings of the Nutrition Society, 76*(OCE1), E14. doi:10.1017/S0029665117000143

Hong, S. K., Park, J. H., Kwon, S. Y., Kim, J.-S., & Koo, J.-W. (2015). Clinical efficacy of the Romberg test using a foam pad to identify balance problems: a comparative study with the sensory organization test. *European Archives of Otorhinolaryngology, 272*(10), 2741-2747. doi:10.1007/s00405-014-3273-2

Howe, T. E., Rochester, L., Neil, F., Skelton, D. A., & Ballinger, C. (2011). Exercise for improving balance in older people. *Cochrane Database of Systematic Reviews*(11), CD004963. doi:10.1002/14651858.CD004963.pub3

Hughes, V. A., Roubenoff, R., Wood, M., Frontera, W. R., Evans, W. J., & Fiatarone Singh, M. A. (2004). Anthropometric assessment of 10-y changes in body composition in the elderly. *The American Journal of Clinical Nutrition 80*(2), 475-482. doi:10.1093/ajcn/80.2.475

IBM. (2020). How do I do an independent-samples t test or an ANOVA model in SPSS Statistics Complex Samples? 419089. Retrieved from https://www.ibm.com/support/pages/how-do-i-do-independent-samples-t-test-or-anova-model-spss-statistics-complex-samples

Ito, T., Sakai, Y., Yamazaki, K., Nishio, R., Ito, Y., & Morita, Y. (2018). Postural strategy in elderly, middle-aged, and young people during local vibratory stimulation for proprioceptive inputs. *Geriatrics (Basel, Switzerland), 3*(4), 93. doi:10.3390/geriatrics3040093

Jansen, Bhangu, J., de Rooij, S., Daams, J., Kenny, R. A., & van der Velde, N. (2016). The association of cardiovascular disorders and falls: A systematic review. *Journal of the American Medical Directors Association 17*(3), 193-199. doi:10.1016/j.jamda.2015.08.022

Jefferis, B. J., Iliffe, S., Kendrick, D., Kerse, N., Trost, S., Lennon, L. T., . . . Whincup, P. H. (2014). How are falls and fear of falling associated with objectively measured physical activity in a cohort of community-dwelling older men? *BMC Geriatrics, 14*(1), 114. doi:10.1186/1471-2318-14-114

Jivraj, S., Goodman, A., Pongiglione, B., & Ploubidis, G. B. (2020). Living longer but not necessarily healthier: The joint progress of health and mortality in the working-age population of England. *Popul Stud (Camb), 74*(3), 399-414. doi:10.1080/00324728.2020.1767297

Johnson, C. L., Paulose-Ram, R., Ogden, C. L., Carroll, M. D., Kruszon-Moran, D., Dohrmann, S. M., & Curtin, L. R. (2013). National health and nutrition examination survey: analytic guidelines, 1999-2010. *Vital Health Stat 2*(161), 1-24.

Juraschek, S. P., Daya, N., Appel, L., Miller III, E., McEvoy, J., Matsushita, K., . . . Selvin, E. (2018). Orthostatic hypotension and risk of clinical and subclinical cardiovascular disease in middle-aged adults. *Journal of the American Heart Association 7*(10). doi:10.1161/jaha.118.008884

Juraschek, S. P., Daya, N., Appel, L. J., Miller Iii, E. R., Matsushita, K., Michos, E. D., . . . Selvin, E. (2019). Subclinical cardiovascular disease and fall risk in older adults: Results from the Atherosclerosis Risk in Communities Study. *Journal of the American Geriatrics Society, 67*(9), 1795-1802. doi:10.1111/jgs.16041

Juraschek, S. P., Daya, N., Appel, L. J., Miller Iii, E. R., Windham, B. G., Pompeii, L., . . . Selvin, E. (2016). Orthostatic hypotension in middle-age and risk of falls. *American Journal of Hypertension, 30*(2), 188-195. doi:10.1093/ajh/hpw108

Kahlaee, H., Latta, M., & Schneider, C. (2018). Association between chronic or acute use of antihypertensice class of medications and falls in older adults. A systematic reivew and meta-analysis. *American Journal of Hypertension 31*(4), 467-479.

Kawakami, R., Miyachi, M., Sawada, S. S., Torii, S., Midorikawa, T., Tanisawa, K., . . . Oka, K. (2020). Cut-offs for calf circumference as a screening tool for low muscle mass: WASEDA'S Health Study. *Geriatrics & Gerontology International, 20*(10), 943-950. doi:10.1111/ggi.14025

Kawakami, R., Murakami, H., Sanada, K., Tanaka, N., Sawada, S. S., Tabata, I., . . . Miyachi, M. (2015). Calf circumference as a surrogate marker of muscle mass for diagnosing sarcopenia in Japanese men and women. *Geriatrics & Gerontology International, 15*(8), 969-976. doi:10.1111/ggi.12377

Keys, A., Fidanza, F., Karvonen, M. J., Kimura, N., & Taylor, H. L. (2014). Indices of relative weight and obesity. *International Journal of Epidemiology, 43*(3), 655-665. doi:10.1093/ije/dyu058

Khabazkhoob, M., Emamian, M. H., Hashemi, H., Shariati, M., & Fotouhi, A. (2017). Prevalence of Overweight and Obesity in the Middle-age Population: A Priority for the Health System. *Iranian Journal of Public Health, 46*(6), 827-834.

Khasnis, A., & Gokula, R. M. (2003). Romberg's test. *Journal of Postgraduate Medicine, 49*(2), 169-172.

Kim, S.-K., Choi, Y. J., Huh, B. W., Kim, C.-S., Park, S. W., Lee, E. J., . . . Huh, K. B. (2011). Ratio of waist-to-calf circumference and carotid atherosclerosis in Korean patients with type 2 diabetes. *Diabetes Care, 34*(9), 2067-2071. doi:10.2337/dc11-0743

Koo, J.-W., Chang, M. Y., Woo, S.-y., Kim, S., & Cho, Y.-S. (2015). Prevalence of vestibular dysfunction and associated factors in South Korea. *BMJ Open, 5*(10), e008224. doi:10.1136/bmjopen-2015-008224

Kuptniratsaikul, V., Praditsuwan, R., Assantachai, P., Ploypetch, T., Udompunturak, S., & Pooliam, J. (2011). Effectiveness of simple balancing training program in elderly patients with history of frequent falls. *Clinical interventions in aging, 6*, 111-117. doi:10.2147/CIA.S17851

Landi, F., Onder, G., Russo, A., Liperoti, R., Tosato, M., Martone, A. M., . . . Bernabei, R. (2014). Calf circumference, frailty and physical performance among older adults living in the community. *Clinical Nutrition, 33*(3), 539-544. doi:10.1016/j.clnu.2013.07.013

Larsson, L., Degens, H., Li, M., Salviati, L., Lee, Y. i., Thompson, W., . . . Sandri, M. (2018). Sarcopenia: Aging-Related Loss of Muscle Mass and Function. *Physiological Reviews, 99*(1), 427-511. doi:10.1152/physrev.00061.2017

Leroux, A., Crainiceanu, C., Smirnova, E., & Cao, Q. (2018). rnhanes: NHANES Accelerometry Data Pipeline (Version R Package Version 1.0). Retrieved from https://github.com/andrew-leroux/rnhanesdata

Leroux, A., Di, J., Smirnova, E., McGuffey, E. J., Cao, Q., Bayatmokhtari, E., . . . Crainiceanu, C. (2019). Organizing and analyzing the activity data in NHANES. *Statistics in Biosciences, 11*, 262-287. doi:10.1007/s12561-018-09229-9

Lesinski, M., Hortobágyi, T., Muehlbauer, T., Gollhofer, A., & Granacher, U. (2015). Dose-Response Relationships of Balance Training in Healthy Young Adults: A Systematic Review and Meta-Analysis. *Sports Medicine, 45*(4), 557-576. doi:10.1007/s40279-014-0284-5

Liaw, M.-Y., Chen, C.-L., Pei, Y.-C., Leong, C.-P., & Lau, Y.-C. (2009). Comparison of the static and dynamic balance performance in young, middle-aged, and elderly healthy people. *Chang Gung medical journal, 32*(3), 297-304.

Lin, Q., Zheng, Y., Lian, P., Guo, Y., Huang, H., Luo, Z., . . . Liang, J. (2020). Quantitative static and dynamic assessment of balance control in stroke patients. *Journal of Visualized Experiments* (159), e60884. doi:10.3791/60884

Lloyd-Jones, D. M., Larson, M. G., Beiser, A., & Levy, D. (1999). Lifetime risk of developing coronary heart disease. *The Lancet, 353*(9147), 89-92. doi:10.1016/S0140-6736(98)10279-9

Lohne-Seiler, H., Kolle, E., Anderssen, S. A., & Hansen, B. H. (2016). Musculoskeletal fitness and balance in older individuals (65–85 years) and its association with steps per day: a cross sectional study. *BMC Geriatrics, 16*, 6. doi:10.1186/s12877-016-0188-3

Loprinzi, P. D., & Brosky, J. A., Jr. (2014). Objectively measured physical activity and balance among U.S. adults. *The Journal of Strength & Conditioning Research, 28*(8), 2290-2296. doi:10.1519/JSC.0000000000000402

Manemann, S. M., Chamberlain, A. M., Boyd, C. M., Miller, D. M., Poe, K. L., Cheville, A., . . . Roger, V. L. (2018). Fall Risk and Outcomes Among Patients Hospitalized With

Cardiovascular Disease in the Community. *Circulation: Cardiovascular Quality and Outcomes, 11*(8), e004199. doi:10.1161/CIRCOUTCOMES.117.004199

Marques, E. A., Figueiredo, P., Harris, T. B., Wanderley, F. A., & Carvalho, J. (2017). Are resistance and aerobic exercise training equally effective at improving knee muscle strength and balance in older women? *Archives of gerontology and geriatrics, 68*, 106-112.

Matsushita, K., Ballew, S. H., Sang, Y., Kalbaugh, C., Loehr, L. R., Hirsch, A. T., . . . Coresh, J. (2017). Ankle-brachial index and physical function in older individuals: The Atherosclerosis Risk in Communities (ARIC) study. *Atherosclerosis, 257*, 208-215. doi:10.1016/j.atherosclerosis.2016.11.023

McDermott, M. M., Criqui, M. H., Greenland, P., Guralnik, J. M., Liu, K., Pearce, W. H., . . . Schneider, J. R. (2004). Leg strength in peripheral arterial disease: associations with disease severity and lower-extremity performance. *Journal of Vascular Surgery, 39*(3), 523-530. doi:10.1016/j.jvs.2003.08.038

McKenna, M., Wolfson, S., & Kuller, L. (1991). The ratio of ankle and arm arterial pressure as an independent predictor of mortality. *Atherosclerosis, 87*(2-3), 119-128. doi:10.1016/0021-9150(91)90014-t

Melo, R. d. S., Marinho, S. E. d. S., Freire, M. E. A., Souza, R. A., Damasceno, H. A. M., & Raposo, M. C. F. (2017). Static and dynamic balance of children and adolescents with sensorineural hearing loss. *Einstein (São Paulo), 15*(3), 262-268. doi:10.1590/S1679-45082017AO3976

Mienche, M., Setiati, S., Setyohadi, B., Kurniawan, J., Laksmi, P. W., Ariane, A., & Tirtarahardja, G. (2019). Diagnostic performance of calf circumference, thigh circumference, and SARC-F questionnaire to identify sarcopenia in elderly compared to Asian working group for sarcopenia's diagnostic standard. *Acta Medica Indonesiana 51*(2), 117-127.

Miller, S. L., & Wolfe, R. R. (2008). The danger of weight loss in the elderly. *Journal of Nutrition, Health, and Aging 12*(7), 487-491. doi:10.1007/bf02982710

Mitchell, R. J., Lord, S. R., Harvey, L. A., & Close, J. C. T. (2014). Associations between obesity and overweight and fall risk, health status and quality of life in older people. *Australian and New Zealand Journal of Public Health, 38*(1), 13-18. doi:10.1111/1753-6405.12152

Mlacak, B., Blinc, A., Pohar, M., & Stare, J. (2006). Peripheral arterial disease and ankle-brachial pressure index as predictors of mortality in residents of Metlika County, Slovenia. *Croat Med J, 47*(2), 327-334.

Moncada, L. V. V., & Mire, L. G. (2017). Preventing Falls in Older Persons. *American Family Physician 96*(4), 240-247.

Monteiro, A. M., Forte, P., Carvalho, J., Barbosa, T. M., & Morais, J. E. (2021). Relationship between fear of falling and balance factors in healthy elderly women: A confirmatory analysis. *Journal of Women & Aging, 33*(1), 57-69. doi:10.1080/08952841.2019.1681244

Nelson-Wong, E., Appell, R., McKay, M., Nawaz, H., Roth, J., Sigler, R., . . . Walker, M. (2012). Increased fall risk is associated with elevated co-contraction about the ankle during static balance challenges in older adults. *European Journal of Applied Physiology, 112*(4), 1379-1389. doi:10.1007/s00421-011-2094-x

Neri, S. G. R., Gadelha, A. B., de David, A. C., Ferreira, A. P., Safons, M. P., Tiedemann, A., & Lima, R. M. (2019). The Association Between Body Adiposity Measures, Postural Balance, Fear of Falling, and Fall Risk in Older Community-Dwelling Women. *Journal of Geriatric Physical Therapy, 42*(3), E94-E100. doi:10.1519/jpt.0000000000000165

Neri, S. G. R., Tiedemann, A., Gadelha, A. B., & Lima, R. M. (2020). Body fat distribution in obesity and the association with falls: A cohort study of Brazilian women aged 60 years and over. *Maturitas, 139*, 64-68. doi:10.1016/j.maturitas.2020.06.009

Nuttall, F. Q. (2015). Body mass index: Obesity, BMI, and health: A critical review. *Nutrition Today, 50*(3), 117-128. doi:10.1097/NT.0000000000000092

Ochi, M., Tabara, Y., Kido, T., Uetani, E., Ochi, N., Igase, M., . . . Kohara, K. (2010). Quadriceps sarcopenia and visceral obesity are risk factors for postural instability in the middle-aged to elderly population. *Geriatrics & Gerontology International, 10*(3), 233-243. doi:10.1111/j.1447-0594.2010.00610.x

Odden, M. C., Coxson, P. G., Moran, A., Lightwood, J. M., Goldman, L., & Bibbins-Domingo, K. (2011). The impact of the aging population on coronary heart disease in the United States. *The American Journal of Medicine*(124), 827-833. doi:doi:10.1016/j.amjmed.2011.04.010

Ono, K., Tsuchida, A., Kawai, H., Matsuo, H., Wakamatsu, R., Maezawa, A., . . . Nojima, Y. (2003). Ankle-Brachial Blood Pressure Index Predicts All-Cause and Cardiovascular

Mortality in Hemodialysis Patients. *Journal of the American Society of Nephrology, 14*(6), 1591. doi:10.1097/01.ASN.0000065547.98258.3D

Osuka, Y., Yabushita, N., Kim, M., Seino, S., Nemoto, M., Jung, S., . . . Tanaka, K. (2015). Association between habitual light-intensity physical activity and lower-extremity performance: a cross-sectional study of community-dwelling older Japanese adults. *Geriatr Gerontol Int, 15*(3), 268-275. doi:10.1111/ggi.12268

Papalia, G. F., Papalia, R., Diaz Balzani, L. A., Torre, G., Zampogna, B., Vasta, S., . . . Denaro, V. (2020). The Effects of Physical Exercise on Balance and Prevention of Falls in Older People: A Systematic Review and Meta-Analysis. *Journal of Clinical Medicine, 9*(8), 2595. doi:10.3390/jcm9082595

Park, S.-H. (2018). Tools for assessing fall risk in the elderly: a systematic review and meta-analysis. *Aging Clinical and Experimental Research, 30*(1), 1-16. doi:10.1007/s40520-017-0749-0

Pau, M., Leban, B., Collu, G., & Migliaccio, G. M. (2014). Effect of light and vigorous physical activity on balance and gait of older adults. *Archives of gerontology and geriatrics, 59*(3), 568-573. doi:10.1016/j.archger.2014.07.008

Perera, T., Tan, J. L., Cole, M. H., Yohanandan, S. A. C., Silberstein, P., Cook, R., . . . Thevathasan, W. (2018). Balance control systems in Parkinson's disease and the impact of pedunculopontine area stimulation. *Brain, 141*(10), 3009-3022. doi:10.1093/brain/awy216

Perissinotto, E., Pisent, C., Sergi, G., Grigoletto, F., & Enzi, G. (2002). Anthropometric measurements in the elderly: age and gender differences. *British Journal of Nutrition, 87*(2), 177-186. doi:10.1079/BJN2001487

Pietiläinen, K. H., Kaprio, J., Borg, P., Plasqui, G., Yki-Järvinen, H., Kujala, U. M., . . . Rissanen, A. (2008). Physical inactivity and obesity: a vicious circle. *Obesity (Silver Spring, Md.), 16*(2), 409-414. doi:10.1038/oby.2007.72

Pizzimenti, M., Meyer, A., Charles, A.-L., Giannini, M., Chakfé, N., Lejay, A., & Geny, B. (2020). Sarcopenia and peripheral arterial disease: A systematic review. *Journal of Cachexia, Sarcopenia and Muscle, 11*(4), 866-886. doi:10.1002/jcsm.12587

Pollock, A. S., Durward, B. R., Rowe, P. J., & Paul, J. P. (2000). What is balance? *Clinical rehabilitation, 14*(4), 402-406. doi:10.1191/0269215500cr342oa

Price, G. M., Uauy, R., Breeze, E., Bulpitt, C. J., & Fletcher, A. E. (2006). Weight, shape, and mortality risk in older persons: Elevated waist-hip ratio, not high body mass index, is associated with a greater risk of death. *The American Journal of Clinical Nutrition, 84*(2), 449-460. doi:10.1093/ajcn/84.2.449

Riebe, D., Franklin, B. A., Thompson, P. D., Garber, C. E., Whitfield, G. P., Magal, M., & Pescatello, L. S. (2015). Updating ACSM's Recommendations for Exercise Preparticipation Health Screening. *Med Sci Sports Exerc, 47*(11), 2473-2479. doi:10.1249/mss.0000000000000664

Rodgers, J. L., Jones, J., Bolleddu, S. I., Vanthenapalli, S., Rodgers, L. E., Shah, K., . . . Panguluri, S. K. (2019). Cardiovascular Risks Associated with Gender and Aging. *Journal of cardiovascular development and disease, 6*(2), 19. doi:10.3390/jcdd6020019

Rogers, M. E., Page, P., & Takeshima, N. (2013). Balance training for the older athlete. *International Journal of Sports Physical Therapy, 8*(4), 517-530.

Rolland, Y., Lauwers-Cances, V., Cournot, M., Nourhashémi, F., Reynish, W., Rivière, D., . . . Grandjean, H. (2003). Sarcopenia, calf circumference, and physical function of elderly women: A cross-sectional study. *Journal of the American Geriatrics Society 51*(8), 1120-1124. doi:10.1046/j.1532-5415.2003.51362.x

Romero-Corral, A., Somers, V. K., Sierra-Johnson, J., Thomas, R. J., Bailey, K. R., Collazo-Clavell, M. L., . . . Lopez-Jimenez, F. (2008). Accuracy of body mass index to diagnose obesity in the US adult population *International Journal of Obesity (London), 32*(6), 959-966. doi:10.1038/ijo.2008.11

RTI International. (2017). *Cardiovascular disease cost will exceed $1 trillion by 2035: Nearly half of Americans will develop pre-existing cardiovascular disease conditions, analysis shows.* Retrieved from www.sciencedaily.com/releases/2017/02/170214162750.htm

Santos, L. P., Gonzalez, M. C., Orlandi, S. P., Bielemann, R. M., Barbosa-Silva, T. G., Heymsfield, S. B., & Group, C. S. (2019). New Prediction Equations to Estimate Appendicular Skeletal Muscle Mass Using Calf Circumference: Results From NHANES 1999–2006. *Journal of Parenteral and Enteral Nutrition, 43*(8), 998-1007. doi:10.1002/jpen.1605

Serrador, J., Schlegel, T., Black, F., & Wood, S. (2009). Vestibular effects on cerebral blood flow. *BMC neuroscience, 10*(1), 1-9.

Sherrington, C., Fairhall, N. J., Wallbank, G. K., Tiedemann, A., Michaleff, Z. A., Howard, K., . . . Lamb, S. E. (2019). Exercise for preventing falls in older people living in the community. *The Cochrane database of systematic reviews, 1*(1), CD012424-CD012424. doi:10.1002/14651858.CD012424.pub2

Shu, Y., Chen, X., & He, W. (2020). Biomechanical Analysis of Dynamic and Static Balance with Different Arm Postition. *38th International Society of Biomechanics in Sport Conference 38*(1), 676.

Simonsick, E. M., Lafferty, M. E., Phillips, C. L., Leon, C. F. M. d., Kasl, S. V., Seeman, T. E., . . . Lemke, J. H. (1993). Risk due to inactivity in physically capable older adults. *American Journal of Public Health, 83*(10), 1443-1450. doi:10.2105/ajph.83.10.1443

Snijder, M. B., Dekker, J. M., Visser, M., Yudkin, J. S., Stehouwer, C. D. A., Bouter, L. M., . . . Seidell, J. C. (2003). Larger thigh and hip circumferences are associated with better glucose tolerance: The hoorn study. *Obesity Research, 11*(1), 104-111. doi:10.1038/oby.2003.18

Stewart, A. D., Stewart, A., & Reid, D. M. (2002). Correcting calf girth discriminates the incidence of falling but not bone mass by broadband ultrasound attenuation in elderly female subjects. *Bone, 31*(1), 195-198. doi:10.1016/s8756-3282(02)00811-6

Sun, Y.-S., Kao, T.-W., Chang, Y.-W., Fang, W.-H., Wang, C.-C., Wu, L.-W., . . . Chen, W.-L. (2017). Calf Circumference as a Novel Tool for Risk of Disability of the Elderly Population. *Scientific Reports, 7*(1), 16359. doi:10.1038/s41598-017-16347-9

Szulc, P., Beck, T. J., Marchand, F., & Delmas, P. D. (2005). Low skeletal muscle mass is associated with poor structural parameters of bone and impaired balance in elderly men—The MINOS Study. *Journal of Bone and Mineral Research, 20*(5), 721-729. doi:10.1359/JBMR.041230

Takeshima, N., Islam, M. M., Rogers, M. E., Koizumi, D., Tomiyama, N., Narita, M., & Rogers, N. L. (2014). Pattern of age-associated decline of static and dynamic balance in community-dwelling older women. *Geriatrics & Gerontology International, 14*(3), 556-560. doi:10.1111/ggi.12132

Talbot, L. A., Musiol, R. J., Witham, E. K., & Metter, E. J. (2005). Falls in young, middle-aged and older community dwelling adults: perceived cause, environmental factors and injury. *BMC public health, 5*, 86-86. doi:10.1186/1471-2458-5-86

Tanaka, S., Kamiya, K., Masuda, T., Hamazaki, N., Matsuzawa, R., Nozaki, K., . . . Ako, J. (2016). Low ankle brachial index is associated with the magnitude of impaired walking endurance in patients with heart failure. *International Journal of Cardiology, 224*, 400-405. doi:10.1016/j.ijcard.2016.09.060

Teasdale, N., Hue, O., Marcotte, J., Berrigan, F., Simoneau, M., Doré, J., . . . Tremblay, A. (2007). Reducing weight increases postural stability in obese and morbid obese men. *International Journal of Obesity (London), 31*(1), 153-160. doi:10.1038/sj.ijo.0803360

Thurston, B., & Dawson, J. (2019). Ankle Brachial Pressure Index: An update for the vascular specialist and general practitioner. *Vascular, 27*(5), 560-570. doi:10.1177/1708538119842395

Tosato, M., Marzetti, E., Cesari, M., Savera, G., Miller, R. R., Bernabei, R., . . . Calvani, R. (2017). Measurement of muscle mass in sarcopenia: from imaging to biochemical markers. *Aging Clin Exp Res, 29*(1), 19-27. doi:10.1007/s40520-016-0717-0

Van Domelen, D. R. (n.d.). Web App for Processing NHANES Accelerometer DATA. Retrieved from https://jhubiostatistics.shinyapps.io/process_nhanes_app/

Verma, S. K., Willetts, J. L., Corns, H. L., Marucci-Wellman, H. R., Lombardi, D. A., & Courtney, T. K. (2016). Falls and fall-related injuries among community-dwelling adults in the United States. *PLoS one, 11*(3), e0150939. doi:10.1371/journal.pone.0150939

Visser, M., Kritchevsky, S. B., Goodpaster, B. H., Newman, A. B., Nevitt, M., Stamm, E., & Harris, T. B. (2002). Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70 to 79: the health, aging and body composition study. *J Am Geriatr Soc, 50*(5), 897-904. doi:10.1046/j.1532-5415.2002.50217.x

White, D. K., Gabriel, K. P., Kim, Y., Lewis, C. E., & Sternfeld, B. (2015). Do Short Spurts of Physical Activity Benefit Cardiovascular Health? The CARDIA Study. *Medicine and Science in Sports and Exercise, 47*(11), 2353-2358. doi:10.1249/MSS.0000000000000662

Wolff-Hughes, D. L., Fitzhugh, E. C., Bassett, D. R., & Churilla, J. R. (2015). Waist-Worn Actigraphy: Population-Referenced Percentiles for Total Activity Counts in U.S. Adults. *Journal of Physical Activity and Health 12*(4), 447-453. doi:10.1123/jpah.2013-0464

Wu, C.-J., Kao, T.-W., Chen, Y.-Y., Peng, T.-C., Wang, C.-C., Zhou, Y.-C., . . . Chen, W.-L. (2019). Examining the association between vestibular function and lower extremity circumference in an aged population. *Geriatrics & Gerontology International, 19*(7), 622-627. doi:10.1111/ggi.13679

Yang, S., Liu, M., Wang, S., Jia, W., Han, K., & He, Y. (2020). Waist–Calf Circumference Ratio Is an Independent Risk Factor of HRQoL in Centenarians. *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy, Volume 13*, 277-287. doi:10.2147/DMSO.S231435

Yataco, A. R., Corretti, M. C., Gardner, A. W., Womack, C. J., & Katzel, L. I. (1999). Endothelial reactivity and cardiac risk factors in older patients with peripheral arterial disease. *The American Journal of Cardiology, 83*(5), 754-758. doi:10.1016/S0002-9149(98)00984-9

Yazdanyar, A., & Newman, A. B. (2009). The burden of cardiovascular disease in the elderly: morbidity, mortality, and costs. *Clinics in geriatric medicine, 25*(4), 563-vii. doi:10.1016/j.cger.2009.07.007

Yeung, S. S. Y., Reijnierse, E. M., Pham, V. K., Trappenburg, M. C., Lim, W. K., Meskers, C. G. M., & Maier, A. B. (2019). Sarcopenia and its association with falls and fractures in older adults: A systematic review and meta-analysis. *Journal of Cachexia, Sarcopenia and Muscle, 10*(3), 485-500. doi:10.1002/jcsm.12411

Zagyapan, R., Iyem, C., Kurkcuoglu, A., Pelin, C., & Tekindal, M. A. (2012). The Relationship between Balance, Muscles, and Anthropomorphic Features in Young Adults. *Anatomy Research International, 2012*.

Zecevic, A. A., Salmoni, A. W., Speechley, M., & Vandervoort, A. A. (2006). Defining a fall and reasons for falling: comparisons among the views of seniors, health care providers, and the research literature. *The Gerontologist, 46*(3), 367-376.

VITA

HANNAH MARTHA TWIDDY

Department of Human Movement Science

2016 Student Recreation Center, Norfolk VA 23517

Education

Postdoctoral — Fulbright Postdoctoral Fellowship, 2022-2023
Research Center for Generational Health and Aging
University of Newcastle, Australia

Ph.D. — Human Movement Science: Applied Kinesiology, 2018-present
Certificate: Global Health
Old Dominion University, Norfolk VA

M.S. — Human Movement Science: Exercise Physiology, 2016
Thesis: The Relationship Between Landing Error Scoring System-Real Time and Dorsiflexion Range of Motion in Recreational Athletes
Old Dominion University, Norfolk VA

B.S. — Exercise Science, 2014
Minor: Psychology
University of North Carolina Wilmington, Wilmington NC

Professional Experience

2020-2021 — Doctoral Fellowship: Darden College of Education and Professional Studies: Old Dominion University

2018-2020 — Graduate Research Assistant: Human Movement Science Department Cardiometabolic Lab: Old Dominion University

2014-2016 — Graduate Program Assistant of Fitness and Wellness: Recreation and Wellness Fitness and Wellness: Old Dominion University

Publications

Reynolds LJ, **Twiddy HM**, Mlynarczyk M, Wilson PB. (2021). Homocysteine is not associated with physical activity levels in pregnant women. *Journal of Maternal Fetal and Neonatal Medicine.* 1-8 Advanced online publication. doi:10.1080/14767058.2021.1941855

Reynolds LJ, **Twiddy HM.** (2021). Chapter 19, Populations Across the Lifespan. In T.A.Hardens & L. Edwards (Eds). ACSM's Resources for the Personal Trainer, 10th edition. Philadelphia: Lippincott Williams & Wilkins.

Ehlert, A. M., **Twiddy, H. M.,** & Wilson, P. B. (2020). The Effects of Caffeine Mouth Rinsing on Exercise Performance: A Systematic Review, *International Journal of Sport Nutrition and Exercise Metabolism*, *30*(5), 362-373. doi:10.1123/ijsnem.2020-0083