NEUROMUSCULAR ACTIVATION DURING BALANCE TESTING IN YOUNG, MIDDLE-AGED, AND OLDER ADULTS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Health, Nutrition, and Exercise Sciences
Option: Exercise and Nutrition Science

March 2021

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Aging results in structural changes that inhibit functional balance with daily activities. The purpose of this research was to investigate the relationship of neuromuscular activation of the upper leg to balance and fall risk in the adult population. Eighteen males (32.44yrs ± 14.06) and 32 females (41.88yrs ± 18.07) completed strength and balance assessments with surface electromyography. Results indicated a significant age effect on the Clinical Test of Sensory Integration and Balance score ($p = 0.019$), and a significant gender effect on knee flexion torque ($p < 0.001$) and knee extension torque ($p < 0.001$). Linear regression determined a significant association between reduced muscle coactivation, gender, and age to predict Fall Risk Sway Velocity Index scores ($p = 0.010$, $R^2 = .218$). Middle-aged adults had worse balance scores, and females demonstrated weaker muscular strength; reduced neuromuscular coactivation, age, and gender predicted 21.8% of the variability in Fall Risk scores.

ACKNOWLEDGEMENTS

First, I would like to thank the College of Human Sciences and Education and the Department of Health, Nutrition, and Exercise Sciences at North Dakota State University for the opportunity to succeed. Second, I would like to thank my committee, fellow graduate students, and family and friends for all the love, support, and encouragement I have received over the years.

DEDICATION

I dedicate this Thesis to my parents, Paul and Cindy, my brother, Dylan, and my guardian angels, Gabriel and Justin.

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CHAPTER I. INTRODUCTION

Age-related weakness and functional decline are among the most important factors associated with falls among older adults (Crozara et al., 2016; Morcelli et al., 2014). Previous research has suggested older adult falls are associated with deficits in muscle weakness, strength, power, and balance (Crozara et al., 2016; Morcelli et al., 2014). The natural progression of aging results in structural changes that inhibit functional balance with daily activities (Martínez-López Emilio, Hita-Contreras, Jiménez-Lara, Latorre-Román, & Martínez-Amat, 2014). Understanding the causes of functional imbalance is pertinent given approximately 30% of falls result in injury that requires some level of medical attention (Martínez-López Emilio et al., 2014).

Thibaud et al. (2012) defined a fall as an event in which the participant unintentionally comes to rest on the ground or at a lower level. It is estimated that one third of the population over 65 years experiences one or more falls per year (approximately 12 million individuals). Increasingly, one half of the population over 85 experiences one or more falls per year (Thibaud et al., 2012). Healthcare treatment costs for fall-related injuries were 1.85 times higher than the cost of implementing a fall-prevention program in 2014 (Martínez-López Emilio et al., 2014). Furthermore, in 2017, the geriatric population contributed 6.0% of Medicare spending, 8.0% of Medicaid spending, and 5.0% out of pocket spending for fall related injuries alone (Haddad, Bergen, & Florence, 2019). By 2060, the predicted population of 65+ years is approximately 94.7 million; thus, it is critical to understand the etiology of falls and develop the best prevention strategy.

Sarcopenia is defined as the age-related loss of skeletal muscle mass (B. C. Clark & Manini, 2008). The natural progression of sarcopenia aids in the decrease of muscle force output because of the reduction in the number and size of muscle fibers (Crozara et al., 2016). Healthy aging is dependent on a multitude of factors, but muscle composition and function are among the most important. Lean muscle mass provides approximately 50% of total bodyweight in young adults but ultimately declines to 25% by the time adults reach the age of 75-80 years with muscle mass most prevalent in the lower limbs, more specifically, the vastus lateralis (Springer Dordrecht Heidelberg, 2011). The cross-sectional area of the VL is diminished as much as 40% between the ages of 20 and 80 years (Springer Dordrecht Heidelberg, 2011). Therefore, assessing muscle activation during isometric and isokinetic maximal contractions as well as during a balance assessment will assist in determining the differences in muscle activation among ages and genders and its' relation to falls.

Purpose of the Study

The purpose of this research was to investigate the relationship of neuromuscular activation of the quadriceps and hamstring muscles to balance and fall risk in the adult population.

Research Questions

The goal of this study was to answer the following research questions:

1. What is the relationship among neuromuscular activation, balance, and fall risk in young, middle-aged, and older adults?
2. What are the differences in strength, neuromuscular activation, and balance scores between younger and middle-aged men and women?

Significance of the Study

Determining the gender differences among men and women as well as the age differences across the adult human lifespan can aid in providing the best prevention strategy for falls, thus, lowering healthcare costs, increasing quality of life, and increasing life longevity.

Delimitations of the Study

1. The research population widely encompassed university students and faculty; therefore, it cannot be generalizable to the entirety of the public population.
2. Participants were recruited for a Strength-Vision-Balance Study with this present study as a subdivision of research conducted.

Limitations of the Study

1. Participants completed strength and balance assessments to the best of their abilities.
2. Larger participant pool in the younger age group.
3. Data collection interruption due to COVID-19 virus.

Definition of Terms

- Fall - an event in which the participant unintentionally comes to rest on the ground or at a lower level (Thibaud et al., 2012).
- Sarcopenia - the age-related loss of skeletal muscle mass (B. C. Clark & Manini, 2008).
- Neuromuscular activation – excitation of motor neurons leads to force production in a population of muscle fibers (D. J. Clark et al., 2010).
- Electromyography – tool used to monitor muscular activity and evaluate muscle quality (Hun Jang et al., 2018).
- Dynamometer – device used for measuring force, torque, and power.
- Dynamic – characterized by constant change, movement, or activity.
- Static – lack of change, movement, or activity.
- Balance – an individual's ability to perform a task while maintaining a stable position (Miller, Heath, Dickinson, & Bressel, 2015).

- Central nervous system – complex of nerve tissues that controls the activity of the body – includes brain and spinal cord.
- Muscle fiber – a muscle cell inside skeletal muscle composed of myofibrils that contract when stimulated.

CHAPTER II. LITERATURE REVIEW

Falls

Balance is defined as an individual's ability to execute a task while sustaining a stable position (Miller et al., 2015). Balance requires a compilation of several biological systems such as nerve conduction, joint health, muscle strength, and muscle power. However, disease or dysfunction in any of these biological systems can result in impaired functional movement. These impairments in functional movement can lead to mobility limitations, frailty, falls, and decreased quality of life (Miller et al., 2015).

Home hazards and personal risk factors are the most common determinants of indoor related falls among frail adults (Li et al., 2006). According to Masud & Morris (2001), in a one-year period, the amount of individuals >65 years that fall at least once per year range from 28-35% whereas, individuals >75 years range from 32-42%. Approximately 65% of women and 44% of men fall indoors while individuals <75 years of age are more likely to fall outdoors. Ultimately, there are potentially over 400 extrinsic and intrinsic risk factors for falls with an impact of morbidity, mortality, hospitalization, and physiological atrophy (Masud & Morris, 2001).

A vast majority of literature focuses on falls in the geriatric population with scarce amounts studying the younger or middle-aged populations. This gap in the literature needs to be filled to best determine fall risk across an entire adult lifespan. Using maximal strength, balance, and muscle activation assessments, researchers may determine which specific populations suffer from falls and fall related injuries more frequently. Ultimately, the human lifespan is growing longer, and it is crucial research continues to grow with it.

Changes in Muscle Mass with Aging

Skeletal muscle mass and force deterioration has a significant impact on the quality of life in the aging population. Furthermore, the declination of bodily functions and mobility is common among individual's in their ninth decade of life (Naro et al., 2019). With advancing age, the structure of skeletal muscle is transformed due to an increase in intramuscular adipose tissue, alteration of the angle of pennation, and a reduction in muscle fiber cross-sectional area (Naro et al., 2019).

Studies have shown regular exercise and physical activity lowers the severity of myonuclear apoptosis, which is believed to cause the loss of muscle later in life (Fiatarone et al., 1994; Kalapotharakos et al., 2004; Leeuwenburgh, Gurley, Strotman, & Dupont-Versteegden, 2005; Viña, Rodriguez-Mañas, Salvador-Pascual, Tarazona-Santabalbina, & Gomez-Cabrera, 2016). Endurance and strength training elicit muscular damage, releasing inflammatory cytokines and growth factors such as: insulin like growth factor-1 (IGF-1), fibroblast growth factor (FGF), and mechano growth factor (MGF). These growth factors stimulate the escalation of satellite cell release into the muscle fibers, ultimately increasing the fiber cross-sectional area. In addition, endurance exercise promotes innervation and metabolic disruption that alerts various signaling pathways to promote mitochondrial biogenesis and metabolism (Marzetti et al., 2017).

However, due to sarcopenia (the age-related loss of muscle mass), muscle fiber size decreases over time. The annual decline percentage of skeletal muscle mass in the older population from previous studies ranged from -0.53 to -1.29% per year (Cruz-Jentoft & Morley, 2012). In addition, according to a specific Health, Aging, and Body Composition Study, data showed an increase in intramuscular adipose tissue in the mid-thigh during a 5-year follow-up, suggesting an annual increase of intramuscular adipose tissue of 9.7% in men and 5.8% in women (Cruz-Jentoft & Morley, 2012). From the research, it can be concluded that the skeletal muscle mass declines as individuals grow older; furthermore, the composition of the muscle itself changes resulting with a greater infiltration of adipose tissue into the muscle (Cruz-Jentoft & Morley, 2012).

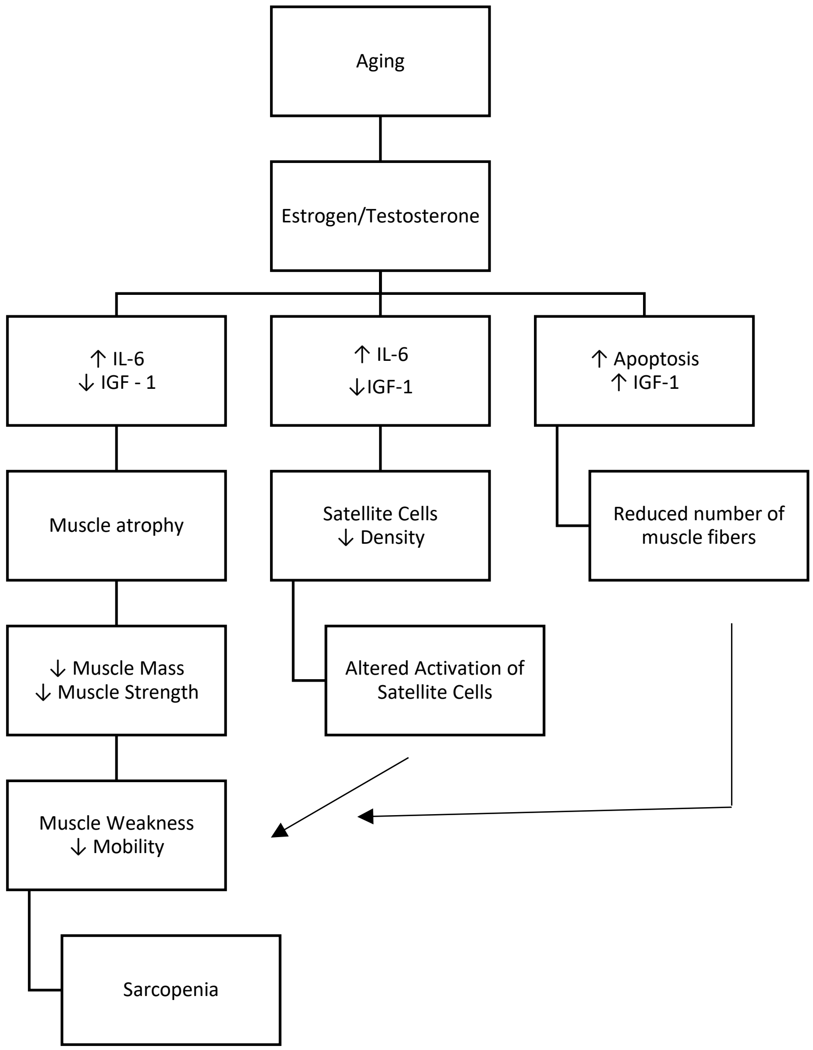

Figure 1. Cytokines associated with Sarcopenia.
Adapted from Springer Dordrecht Heidelberg (2011).

Changes in Muscle Strength with Aging

Valid and reliable assessments of muscular strength are necessary in the geriatric population due to sarcopenia. A variety of assessments most commonly used to measure muscular strength include a cable tensiometer, non-motorized dynamometer (hand-grip dynamometer), motorized dynamometer (Biodex dynamometer), or by using a one- or three-repetition maximum tests using exercise machines or free weights (Hurley, 1995). Of these, the motorized dynamometer is the most widely used and accepted because of the ability to measure isometric, isokinetic, and eccentric muscle strength in various locations of the body. Isokinetic strength is assessed by accelerating and contracting again a resistance moving at a constant velocity, whereas isometric strength is assessed by contracting against a resistance that has zero velocity. Joint angle changes and muscle length does not occur during isometric contractions. Lastly, eccentric strength is the tension being applied to a muscle as it lengthens (*SYSTEM 4 (Advantage BX Software 5.2X) INSTRUCTIONS FOR USE 850-000 840-000 852-000,* n.d.). Sedentary individuals have reductions in maximal isometric and isokinetic force-generating capacity which have been linked to sarcopenia, thus eliciting further examination to locate the root cause (Symons, Vandervoort, Rice, Overend, & Marsh, 2005).

One of the main risk factors of falls in the geriatric population is lower extremity weakness (Cattagni et al., 2018). To combat this weakness, resistance training (RT) is commonly used because of the muscle fiber type shifts and changes within the trained muscles (Miller et al., 2015). Different changes in fiber type may play a key role in reactive balance to aid in unexpected balance challenges (Miller et al., 2015).

Muscle fiber shifts result in an increase in myosin heavy chain II in the aging population. RT also impacts muscle mass and strength due to an increase in the number of myofibrils –

typically the Type II fibers – which warrant the greatest increase in muscle size (Marzetti et al., 2017). In addition, the recruitment of muscle satellite cells is induced due to physical activity and exercise (Marzetti et al., 2017).

In a 2015 study conducted by Miller et al. (2015), young adults (M = 24 ± 4 years) had their muscular strength and balance tested using the Thorstensson test and a force platform to determine the muscle fiber types and their correlation to balance. A partial correlation analysis exhibited a significant negative correlation between percentage of knee extensor Type II muscle fiber and large backwards perturbations ($r = -.62$, $p = .001$); thus, resulting in a faster recovery of balance following a backward disruption. These results theorize that muscle fiber type and strength is associated with reactive balance and movements alike (Miller et al., 2015). Because the aforementioned research was only conducted on the younger population, further research is needed to be made generalizable to older adults.

Although older adults are presumably at the greatest risk for muscle loss and strength, middle-aged adults may present physiologic changes that exhibit the early onset of sarcopenia (English et al., 2016). Research conducted by English et al. (2016) examined the effect of leucine supplementation on muscle anabolism and skeletal muscle health during 14 days of bedrest in middle-aged adults (45-60 years). Pre-bedrest consisted of 3 days of in-patient ambulatory stay while bedrest was achieved during days 4-18 with day 18 denoted as post-bedrest. Lean body mass, fat mass, lean leg mass, and body fat percentage were calculated by dual-energy X-ray absorptiometry (DEXA) on days 3, 10, and 17. Additionally, unilateral knee and ankle extensor strength was measured using the Biodex System 4 dynamometer. Overall, bedrest had a negative impact on lean tissue mass with the control group experiencing 2.9% ± 0.5% in lean body mass and 5.1% ± 0.9% in leg lean mass. Knee extensor peak torque at both 60°/s (-15% ± 2%) and

180°/s (-19% ± 3%) decreased significantly ($p < 0.05$) as well as muscle quality (-9% ± 2%, $p < 0.05$) due to the 14 day bedrest (English et al., 2016). The results from this study provide insight that bedrest significantly impacts lean skeletal muscle mass and function in healthy middle-aged adults with the loss much greater than previously researcher younger adult cohorts. Additionally, this study illustrates evidence that middle-aged adults undergo physiologic changes which exhibit the early onset of sarcopenia suggesting muscle mass and strength decrease much sooner than the latter stages of life.

Similarly, Sowers et al. (2005) researched 3-year lean and fat mass changes in 712 middle-aged (34-58 years) African American and Caucasian women. Bioelectrical impedance was used to determine lean and fat mass, and lower leg strength was measured using a portable isometric chair. Over the 3-year observation period, approximately 9% of women lost more than 2.5kg of lean mass (>6% decrease); moreover, 30% of women gained more than 2.5kg of fat mass (>7.5%). Additionally, lean mass was positively correlated with leg strength (partial $r = 0.33$, 95% CI: 0.27, 0.42); however, the women that lost 2.5kg of lean mass and gained 2.5kg of fat mass did not present lower leg strength after the 3-year period (Sowers et al., 2005). These results coincide with the previously mentioned study in which sarcopenia is prevalent earlier in life in addition to later.

Gender Differences

The epidemiology and risk factors for falls among the geriatric population have been largely researched and identified in the previous decades (Chang & Do, 2015). Moreover, gender differences have been noted across many populations with elderly women having higher fall rates than elderly men (63.6% vs 54.3%) (Public Health Agenct of Canada, 2014). However, gender-specific research in terms of generalizability and potential risk factors is few and far between. Because of the limited research, Chang & Do (2015) conducted research to estimate the prevalence of falls by gender, sociodemographic, lifestyle/behavioral, and medical factors. The study included data on individuals 65 years and older (N = 14,887) via the Canadian Community Health Survey-Healthy Aging (CCHS-HA). Of the individuals who completed the fall-related questions on the CCHS-HA, fall prevalence was significantly higher in women (22.4%) than in men (17.4%) from 2008-2009. More importantly, fall related fractures were approximately 2.6 times greater in women (2.4%) than in men (0.9%). Furthermore, the odds of falls increased as the number of comorbid conditions increased in both genders, and fall prevalence increased with age in both genders as a result of age-related deficits in physical, sensory, and cognitive function (Chang & Do, 2015).

Overall, the results confirm that older women are more likely to fall or suffer from fall-related injuries than older men. However, despite women having a greater risk of falling, men have higher mortality rates associated with falling. In addition, the large difference in falls between genders highlights the associations between falls and different sociodemographic, lifestyle/behavioral, and medical factors (Chang & Do, 2015). Despite the high incidence of falls recorded in women mentioned, the probability of an injury due to a fall is 18% in women and 24% in men according to Błaszczyszyn, Konieczny, & Pakosz (2019).

Previous research on the differences in cross-sectional area and lean mass using different body composition analyses between men and women of different age groups showed decreases in whole lean body mass, calf muscle, arm muscle, and leg mass across their lifespan. However, a greater decrease in muscle cross-sectional area is seen in men rather than women. In addition, higher age was associated with larger amounts of low density lean tissue (ICC = .52) suggesting greater adipose tissue infiltration (Cruz-Jentoft & Morley, 2012).

The aforementioned research suggests men have lower cross-sectional area as they grow older, but contradictory research suggests women have higher prevalence of falls. These contradictory statistics and conclusions elicit further examination and analysis.

Balance

Balance system assessments are commonly used to determine fall risk and balance impairments in the aging population. Utilizing these assessments may provide earlier indications of fall risk and/or balance deterioration which can be used to combat these progressions later in life. Ultimately, these assessments can protect future fallers and older adults with a greater risk of injury. Understanding the determinants of falls can aid in the prevention of future life-threatening occurrences. The Berg Balance test, four-square step test (FSST), one-legged stance, Biodex Balance System SD and more have been adopted to assess balance.

Dynamic Balance Tests

The four-square step test, five-step test, and the Berg Balance test are all examples of dynamic balance tests, meaning they are motion assessments. According to Nelson-Wong et al. (2012), the four-square step test (FSST) consists of stepping over four single-point walking canes lying on the ground at 90° angles of each other. Participants step over the canes in a clockwise then counterclockwise rotation as quickly as possible, without touching the canes. The researchers concluded groups classified as fallers had much slower times (M = 14.22 ± 1.86 s) than groups classified as non-fallers (M = 8.87 ± 1.62 s) (Nelson-Wong et al., 2012). Dawson, Dzurino, Karleskint, & Tucker (2018) also used the FSST to assess dynamic balance. They found an excellent test-retest reliability (ICC [3, 1] = .92) of the FSST as a balance assessment as well as a tool to explore the coordination, directional change, and cognitive components of balance (Dawson et al., 2018).

The five-step test is used to measure the functional, dynamic balance during the action of stepping onto and back off a 10-cm step, five times in a row, as fast as possible (Moreira, Bilton, Dias, Ferriolli, & Perracini, 2016). Similar to Nelson-Wong et al. (2012), the researchers in Moreira et al. (2016) discovered high-risk fallers had significantly higher five-step time ($p = .03$; $M = 18.5$ s) than low-risk fallers ($M = 16.9$ s) suggesting worse balance.

Lastly, the Berg Balance test consists of 14 subtests performed in a specific order (Bogle Thorbahn, Newton, & Chandler, 1996):

1. Sitting to standing
2. Standing unsupported
3. Sitting unsupported
4. Standing to sitting
5. Transfers
6. Standing with eyes closed
7. Standing with feet together
8. Reaching forward with an outstretched arm
9. Retrieving object from floor
10. Turning to look behind
11. Turning 360°
12. Placing alternate foot on stool
13. Standing with one foot in front of the other foot
14. Standing on one foot

Each subtest is scored on a five-point scale dependent on time and quality of performance with the highest possible score being 56. The researchers discovered 85.2% (n =46) of non-fallers scored higher than 45 points on the Berg Balance test, whereas, 81.8% (n = 8) of fallers scored less than 45 points (Bogle Thorbahn et al., 1996). These results suggest non-fallers score higher on the balance test than fallers, thus, providing a validated assessment of balance.

The Berg Balance test utilizes both static and dynamic assessments to determine fall-risk and balance. Other types of static balance assessments include one-legged stance, quiet stance, Romberg, and the Biodex Balance System SD.

Static Balance Tests

Static balance challenges are common in assessing fall risk and balance in all ages and genders. In addition to examining dynamic balance with the FSST, Nelson-Wong et al. (2012) also used a series of static balance challenges in progressing difficulty: Romberg with eyes open/closed, Sharpened Romberg with eyes open/closed, and Single Leg Standing with eyes open. Participants stood in these positions until a time limit was reached (60s for the Romberg and Sharpened Romberg, and 30s for the Single Leg Standing) or they failed to maintain their balance. All balance challenges, excluding Romberg eyes closed, had high predictive utility of falls (Sensitivity = .88, specificity = .73, odd ratios = 19.3) suggesting accurate representations of fall risk.

Likewise, Moreira et al. (2016) also used the one-legged stance in addition to the five-step test to determine balance and fall risk. The researchers observed that fallers with high fall risk had significantly lower right leg (M = 8.0 vs 10.6 s, p = .032) and left leg stance time (M = 7.8 vs 10.1 s, p = .039) than non-fallers suggesting higher fall risk individuals present physical functioning limitations (Moreira et al., 2016).

The Biodex Balance System SD has become a common technique in determining fall risk in individuals. It provides a fall risk screening test protocol that compares balance test results to age-dependent normative data. The fall risk test measures an individual's postural sway velocity to predict risk (*BALANCE SYSTEM^{TM} SD (version 4.x) Instructions for use for the following products*, 2018). In addition, the Modified Clinical Test of Sensory Integration and Balance (m-CTSIB) is used to provide a generalized assessment of an individual's ability to balance and explore deficits in certain areas (Dawson et al., 2018). The CTSIB is a standard test for balance assessment on a static surface (*BALANCE SYSTEM^{TM} SD (version 4.x) Instructions for use for the following products*, 2018).

Dawson et al. (2018) examined the reliability, correlation, and validity of commonly used assessment tools to measure balance. These assessment tools included the four-square step test (FSST) and the Biodex Balance System SD. They discovered FSST showed strong to excellent test-retest reliability (ICC [3, 1] = .88, .92) while the Biodex m-CTSIB demonstrated strong test-retest reliability (ICC [3, 1] = .75). These results showed strong reliability among balance assessments and demonstrate adequate fall risk assessments.

Neuromuscular Activation

Musculature

Lower extremity muscle weakness is a dominant risk factor for falls in older adults (Crozara et al., 2016). It remains unclear whether lower-extremity muscle groups are inadequate in physically active older adult fallers. Varying researchers have discovered older adult fallers have lower knee and ankle extension/flexion torque and power than older adult non-fallers. However, other researchers have concluded no differences between these groups (Crozara et al., 2016). Because the research in the literature correlates fallers with lower knee extension and flexion torque and power, it is necessary to investigate these parameters further to confirm or deny these claims.

Vastus Lateralis

The vastus lateralis (VL) is a unipennate muscle located on the anterior subdivision of the thigh (Biondi & Varacallo, 2019). Of the four quadriceps muscles, the vastus lateralis is the largest, strongest, and most powerful and is located laterally adjacent to the femur (Biondi & Varacallo, 2019). It contributes approximately 40% of overall quadricep strength to the quadriceps muscle group (Biondi & Varacallo, 2019). Its primary function is as an extensor of the knee, but in cohesion with the vastus medialis, it is also a stabilizer of the knee joint (Biondi & Varacallo, 2019). During normal gait patterns, the VL contracts to protect and prepare the knee for the heel strike with the ground. The entire quadriceps muscle group is responsible for absorbing the force produced by this heel strike (Biondi & Varacallo, 2019).

The VL is utilized in various research applications as a reference of muscle activity during isometric and isokinetic knee extension/flexion exercises. Because it is among the largest and strongest of the quadriceps muscles, its measurements can provide vital information to balance and falls. Therefore, assessing muscle activity of this muscle should provide the most accurate depiction of muscular strength, balance impairment, and falls.

Examining the physiologic changes associated with balance impairment, Crozara et al. (2016) and Laughton et al. (2003) conducted research using surface electromyography placed on knee and ankle extensors/flexors during isometric and isokinetic maximal voluntary contraction dynamometry. Both researchers placed electrodes on the VL, biceps femoris, and tibialis anterior. In addition, Laughton et al. (2003) measured muscle activity in the soleus whereas Crozara et al. (2016) measured muscle activity in the rectus femoris and lateral gastrocnemius. Both researchers discovered lower muscle activity of the VL and subsequent muscles correlated with greater balance impairment and falls (Crozara et al., 2016; Laughton et al., 2003).

Therefore, it can be concluded the VL muscle is an acceptable muscle to measure muscle activity and its correlation to balance and falls.

Biceps Femoris

The biceps femoris muscle is comprised of two individual muscles: biceps femoris long head and biceps femoris short head (Rodgers & Raja, 2019). It is located on the posterior subdivision of the thigh and is a prime mover for knee flexion. During a normal gait pattern, the hamstring muscles begin to activate and develop extension force at the hip and resist knee extension at about 75% of the swing phase of the leg (Rodgers & Raja, 2019). In addition, these muscles also act as a knee stabilizer (Rodgers & Raja, 2019).

Comparatively to the VL muscle, the biceps femoris is widely used to measure muscle activity and its correlation to balance impairment and falls as an antagonist to the VL. As previously mentioned, Crozara et al. (2016) and Laughton et al. (2003) conducted research on various knee and ankle extensors/flexors. Of those flexors, the biceps femoris was used. Again, as mentioned, the researchers found a relationship between the muscle activity of the agonist and antagonist muscle groups and balance impairment and falls (Crozara et al., 2016; Laughton et al., 2003). Thus, utilizing the biceps femoris for measurement of muscle activity of knee flexors is acceptable in relating the results to balance and falls.

Surface Electromyography

Surface electromyography (sEMG) is a method used to analyze various muscular conditions during functional activities. It records and analyzes the changes of electrical activity of muscle during specific movement patterns (Yukio Fukuda et al., 2010). The electrical signal received is the action potential of all the muscle fibers within a motor unit that a single motor neuron innervates (Yukio Fukuda et al., 2010).

Using self-adhesive electrodes, data acquisition and analysis hardware and software, and trained, reliable professionals, sEMG can be used to determine neuromuscular deficits in diverse regions of the body. Understanding the differences in data signal strength, pattern, and amplitude is necessary to develop conclusions based on muscular use in different test batteries and assessments. Developing these conclusions can lead to greater knowledge of the human body in different age groups and populations.

Because motor unit activation and coordination decrease with age, it is necessary to assess neuromuscular changes and how they affect joint torque and power output in addition to how they are related to fall risk (Crozara et al., 2016). Understanding fall risk manifestation aids in the prevention and disruption of future falls, injuries, and even fatalities. Surface electromyography is a tool used to prevent and interrupt aging progressions related to sarcopenia and the effects it incurs on the human musculature.

Validity of Surface Electromyography

Validation of sEMG techniques is necessary to ensure that all measurements are recorded and analyzed accurately among researchers (Rainoldi, Bullock-Saxton, Cavarretta, & Hogan, 2001). However, standardization within sEMG techniques may provide some limitation to research. Rainoldi et al. (2001) conducted a study with an aim to outline the aspects of electrode positioning and statistical tools. In addition, they wished to provide knowledge on the repeatability of spectral and amplitude variables estimates, muscle fiber conduction velocity, rate of change of specific variables, and lastly, the repeatability of maximal voluntary contractions (MVC) measurements of the vastus medialis obliquus and vastus lateralis muscles. Three subsequent sessions were investigated per subject (N = 9, ranged 18-38 years). Before EMG data were recorded, subjects were instructed to perform three MVC isometric contractions, each less than five seconds. These contractions were used as reference points for the subsequent contractions. Next, 50-second MVC isometric contractions were performed twice at 50% MVC value of the initial reference points. Muscle activation of the VL and vastus medialis obliquus were acquired using sEMG. Using the Fisher test, Standard Error of the Mean (SEM), Intraclass Correlation Coefficient (ICC), and the degree of repeatability were assessed. The repeatability of the maximal voluntary contractions in terms of SEM results were normalized to the mean of each individual subject. The error range of 1.1-6.4% elicits a high level of accuracy and repeatability. In relation to the sEMG variables, the mean spectral frequency ($F = 4.1\text{-}15$, $p < .05$) and average rectified value ($F = 7.6\text{-}23.5$, $p <.05$) intercept were the most repeatable for both the vastus lateralis and vastus medialis obliquus muscles. Another repeatable variable for the vastus lateralis muscle was the muscle fiber conduction velocity ($F = 2.6\text{-}12.4$, $p < .05$). Therefore, it is concluded there is a high level of repeatability of quadriceps (vastus medialis obliquus and vastus lateralis muscles) maximal voluntary contraction measurements of the surface electromyography.

Routinely, surface electrodes are used for superficial muscles due to the ease of use and non-invasive nature; furthermore, they are able to gain a sample from a larger cross-sectional area of a muscle than intramuscular electrodes (Hackett, Reed, Halaki, & Ginn, 2014). Despite this advantage, surface electrode use has a drawback because of the ability to receive signals from underlying or adjacent muscles, leading to the corruption of these signals (Hackett et al., 2014). To determine the validity of surface electrodes, Hackett et al. (2014) performed an experiment assessing the use of surface and intramuscular electrodes to record muscle activity of the lower fibers of the serratus anterior during isometric and dynamic contractions.

The researchers recruited seven participants between the ages of 19 and 23 years to perform MVCs in five different normalization tests with both surface and intramuscular electrodes attached. Ramped maximum isometric load for shoulder abduction, flexion, adduction, and extension were measured prior to testing and electrode placement. Flexion, extension, abduction, adduction, and dynamic bench press isometric and dynamic exercises were then performed to elicit high serratus anterior muscle activity. Researchers found a significant difference between muscle activity recorded from the different ramped isometric tests ($F_{3,18} = 31.01$, $p < .05$) and between the correspondence between test and electrode type ($F_{3,18} = 5.70$, $p < .05$). A Tukey post hoc analysis revealed higher muscle activity recordings from the intramuscular electrodes ($p < .05$) than the surface electrodes in the ramped isometric abduction and flexion tests but showed no difference ($p > .05$) between the differing electrode types during adduction and extension tests. Overall, the researchers concluded both intramuscular and surface electrodes recorded low serratus anterior activity during all adduction and extension tests. Thus, these results indicate the surface electrodes did not pick up any signals from underling or adjacent muscles. Despite this similarity, intramuscular electrodes recorded higher levels of muscle activity in the lower fibers of the serratus anterior during the dynamic and isometric tests than the surface electrodes. Therefore, from these findings, it can be concluded that surface electromyography is not valid to use on the lower fibers of the serratus anterior. However, further research should be completed to determine whether the intramuscular and surface electrodes recorded activity from the entire muscle itself.

The previous two studies mentioned added contradicting results to the literature about the use of surface electromyography. The latter stated the common use of surface electromyography because of the non-invasive nature, ease of use, and gaining a sample of a larger cross-sectional area of muscle. Because the latter study could not be certain the intramuscular electrodes were gathering signals from the muscle in its entirety, surface electromyography may be the more accurate option.

Reliability of Surface Electromyography

Consistency among sEMG variables and researchers is vital for short- and long-term reliability to ensure measurements resemble the level of muscle electrical activity to generate force, day to day, subject to subject, and trial to trial (Kollmitzer, Ebenbichler, & Kopf, 1999). To determine the short- and long-term reliability of frequency and time of the sEMG measurements, Kollmitzer et al. (1999) conducted research using maximum and sub maximum isometric knee extension. Highly physically active adults (N = 18) voluntarily performed maximum and sub maximum isometric knee extension tests with surface electromyographic electrodes on the vastus lateralis, rectus femoris, and vastus medialis oblique muscles. Three-repetitions with intervals of 90 minutes were conducted to assess within-day measurements. Furthermore, day assessments were conducted on three different days, six-weeks a part. Bland-Altman plots, Pearson's coefficient of correlation, and intraclass correlation coefficient were used for intra-subject differences, comparison between measurements, and measures of repeatability among the results. All assessments resulted in high accuracy for the sub maximum (50% MVC) target force torque measurements (M = 49.73 ± .72 %MVC). Overall reliability of the MVC torque assessments were described as excellent (ICC = 97%) with a high between-subject-factor ($var_{subject}$ = 87.4%) and average random effects variance (var_{error} = 10.2%). Additionally, median frequency reliability was excellent (ICC = 88.7%) with a high between-subject-factor ($var_{subject}$ = 85.6%) and low random effects variance (var_{error} = 3.5%). Table 5 further illustrates the variability factors of torque and sEMG parameters. Overall, the data results concluded high reliable short-term and acceptably reliable long-term sEMG measurements in the amplitude (RMS: root mean square) and frequency (median fatigue) parameters. Moreover, reliability of the sEMG measurements were higher during 50% MVC knee extension than 100% MVC. The results of this research suggest the reliability of the quadriceps muscle sEMG measurements with the following considerations: sub maximum, isometric contractions, stable positioning of the leg, and reliable positioning of the sEMG electrodes.

Table 1.

Variability factors of torque and sEMG parameters.

Variability Factors	Toque MVC (%)	MF 50% MVC (%)	MF Fatigue (%)	RMS 50% MVC (%)	RMS Fatigue (%)
Between subjects	87.4	85.6	83.5	61.4	35.2
Within subjects:					
Between 3 min	0.0	0.4	-	1.9	-
Between 90 min	0.1	1.6	4.5	6.8	18.3
Between 6 weeks	2.3	8.9	7.7	15.2	24.8
Error factor	10.2	3.5	4.3	16.7	21.7
Intra class corr.	97.3	88.7	87.3	73.7	45.0

Placement

The SENIAM (Surface Electromyography of the Non-Invasive Assessment of Muscles) project developed recommendations for sEMG sensors and sensor placement procedures and signal processing methods. The research was conducted by the Biomedical Health and Research Program (BIOMED II) of the European Union (Hermes, H.J., Freriks, 2010). Recommendations for thirty individual muscles has been developed in the following regions of the human body: shoulder or neck, trunk or lower back, arm or hand, hip and upper leg, and lower leg and foot.

SENIAM's recommendations have been used worldwide for decades. Table 1 outlines sEMG electrode placement on both the vastus lateralis and biceps femoris in various research. Despite the description's differences, the locations on the muscle are relatively similar providing congruent electrode locations.

Table 2.

Electrode placement comparisons.

Authors	Vastus Lateralis Placement	Biceps Femoris Placement
SENIAM	2/3 on the line from anterior iliaca superior to the lateral patella (20 mm distance between electrodes)	½ on the line between the ischial tuberosity and lateral epicondyle of tibia (20 mm distance between electrodes)
Kollmitzer et al. (1999)	Superficial to the belly, 10 cm above the superior border of the patella	N/A
Laughton et al. (2003)	Superficial to the belly	Superficial to the belly
Rainoldi, Bullock-Saxton, Cavarretta, and Hogan (2001)	2/3 on the line from anterior iliaca superior to the lateral patella (20 mm distance between electrodes)	N/A
Fauth et al. (2010)	¼ the distance from the lateral knee joint to the anterior superior iliac spine	½ between the ischial tuberosity and insertion point on the fibular head

Additionally, figures 3 and 4 show SENIAM's sensor location recommendations for both the VL and biceps femoris. These diagrams correspond with the sensor location superficial to the belly of both muscles from Kollmitzer et al. (1999) and Laughton et al. (2003) as well as the placements from Fauth et al. (2010).

Preparation

Skin preparation is necessary for adequate signal conduction during sEMG use. Inherent noise and movement artifact can result in a disruption of the signal and skew the EMG recordings (Chowdhury et al., 2013). Therefore, the literature has centralized a simplified procedure for sEMG preparation (Fauth et al., 2010; Kollmitzer et al., 1999; Rainoldi et al., 2001; Ruiz-Muñoz & Cuesta-Vargas, 2014):

1. Shave (if necessary) any excess hair.
2. Gentle abrasion of the skin.
3. Cleanse with alcohol pads.
4. Allow the area to air dry prior to electrode placement.
5. Using the literature guidelines, place the electrodes on the skin.
6. Secure the electrodes with tape to limit electrode/skin detachment.

Analyzation

Various sEMG data acquisition, analysis hardware, and software have been used to analyze neuromuscular activation signals from varying muscles. However, the most widely used and researched system is the sEMG MP150 (recently upgraded to MP160) machine (Biopac Systems Inc., Goleta, CA) (Biopac Systems Inc., 2019). The MP150 is a 16-channel system with differing signal rates with speeds up to 400KHz. Used in unison with Acq*Knowledge* software, the MP150 hardware provides a complete data acquisition and analysis system that is approved for human research (Biopac Systems Inc., 2019).

After competition of data collection, the sEMG signals must be manipulated and processed. Root-mean square (RMS) rectifying and band-pass filtering are required to minimize unwanted signal inherent noise and movement artifact. The RMS value is used to normalize values in relation to maximum force and torque output (Yukio Fukuda et al., 2010). Table 2 displays differing research band-pass filtering methods.

Table 3.

Band-pass filtration methods.

Authors	Low band-pass	High band-pass
(Yukio Fukuda et al., 2010)	500 Hz	20 Hz
(Ekstrom, Osborn, & Hauer, 2008)	500 Hz	10 Hz
(Kollmitzer et al., 1999)	300 Hz	15 Hz
(Rainoldi et al., 2001)	450 Hz	10 Hz

In the aforementioned research articles, RMS was used to normalize and quantify values from maximal strength assessments. These normalized values are displayed as percentages of a maximal voluntary isometric contraction and compared across movements and tests to determine neuromuscular activation deficits and strengths.

Summary

Balance requires a compilation of several biological systems such as nerve conduction, joint health, muscle strength, and muscle power. However, disease or dysfunction in any of these biological systems can result in impaired functional movement. These impairments in functional movement may lead to mobility limitations, frailty, falls, and decreased quality of life (Miller et al., 2015).

One of the main risk factors of falls in the geriatric population is lower extremity weakness (Cattagni et al., 2018). To combat this weakness, resistance training is commonly used because of the muscle fiber type shifts and changes within the trained muscles (Miller et al., 2015). Due to sarcopenia, muscle fiber size decreases over time resulting in overall weakness and greater fall risk. Lower extremity muscle weakness is a dominant risk factor for falls in older adults (Crozara et al., 2016). Because the research in the literature correlates fallers with lower knee extension and flexion torque and power, it is necessary to investigate these parameters further to confirm or deny these claims.

Moreover, gender differences have been noted across many populations with elderly women having higher fall rates than elderly men. Furthermore, the odds of falls increases as the number of comorbid conditions increases in both genders, and fall prevalence increases with age in both genders as a result of age-related deficits in physical, sensory, and cognitive function (Chang & Do, 2015).

Balance system assessments are commonly used to determine fall risk and balance impairments in the aging population. Utilizing these assessments may provide earlier indications of fall risk and/or balance deterioration which can be used to combat these progressions later in life. The Berg Balance test, four-square step test (FSST), one-legged stance, Biodex Balance System SD and more have been adopted to assess balance. Both dynamic and static balance assessments are useful in predicting fall risk and muscular weakness; furthermore, among those mentioned in this literature review, all have been proven to be safe, reliable, and valid.

The VL is utilized in various research applications as a reference of muscle activity during isometric and isokinetic knee extension/flexion exercises. Because it is among the largest and strongest of the quadriceps muscles, its measurements can provide vital information to balance and falls. Comparatively to the vastus lateralis muscle, the biceps femoris is widely used to measure muscle activity and its correlation to balance impairment and falls as an antagonist to the vastus lateralis.

sEMG is a method used to analyze various muscular conditions during functional activities. It records and analyzes the changes of electrical activity of muscle during specific movement patterns (Yukio Fukuda et al., 2010). Because motor unit activation and coordination decrease with age, it is necessary to assess neuromuscular changes and how they affect joint torque and power output in addition to how they are related to fall risk (Crozara et al., 2016). Consistency among sEMG variables and researchers is vital for short- and long-term reliability to ensure measurements resemble the level of muscle electrical activity to generate force, day to day, subject to subject, and trial to trial (Kollmitzer et al., 1999)

SENIAM's recommendations for sEMG electrode placement have been used worldwide for decades. Fauth et al. (2010), Kollmitzer et al. (1999), Laughton et al. (2003), and Rainoldi et al. (2001) outline sEMG electrode placement on both the vastus lateralis and biceps femoris in their various research. Despite the description's differences, the locations on the muscle are relatively similar providing congruent electrode locations.

Skin preparation is necessary for adequate signal conduction during surface electromyography use. Inherent noise and movement artifact can result in a disruption of the signal and skew the EMG recordings (Chowdhury et al., 2013) After competition of data collection, the sEMG signals must be manipulated and processed. RMS rectifying and band-pass filtering are required to minimize unwanted signal inherent noise and movement artifact. The RMS value is used to normalize values in relation to maximum force and torque output (Yukio Fukuda et al., 2010).

It is estimated that one third of the population over 65 years experiences one or more falls per year (approximately 12 million individuals). Increasingly, one half of the population over 85 experiences one or more falls per year (Thibaud et al., 2012). Healthcare treatment costs for fall-related injuries were 1.85 times higher than the cost of implementing a fall-prevention program in 2014 (Martínez-López Emilio et al., 2014). Furthermore, in 2017, the geriatric population contributed 6.0% of Medicare spending, 8.0% of Medicaid spending, and 5.0% out of pocket spending for fall related injuries alone (Haddad et al., 2019). By 2060, the predicted population of 65+ years is approximately 94.7 million; thus, it is critical to understand the etiology of falls and develop the best prevention strategy.

Furthermore, though the older adult population is most at risk for falls related to sarcopenia, early research has suggested the onset of sarcopenia occurs much earlier and begins closer to middle-aged years. However, strategies such as resistance training have been utilized to delay the onset or progression of sarcopenia. Using maximal strength, balance, and muscle activation assessments, researchers can determine which specific populations suffer from falls and fall related injuries more frequently. Ultimately, the human lifespan is growing longer, and it is crucial research continues to grow with it.

Table 4.

Summary of surface electromyography and balance studies.

Publication	N (Age and Gender)	Muscles used	Methods	Highlighted Conclusion
Laughton et al. (2002)	85 (70 older [>65 years; 21M, 49F], 15 younger [22-32 years; 7M, 8F])	Tibialis anterior, soleus, vastus lateralis, biceps femoris	MVIC, 10 force plate quiet standing trials	Significant increases in muscle activation and coactivation of antagonistic muscle groups in older adults vs younger during quiet standing.
Nelson-Wong et al. (2011)	23 (66-80 years; 8M, 15F)	Bilateral tibialis anterior and gastrocnemius muscles	Performed 5 static balance challenges	Co-contraction about the ankle can be predictive of performance
Morcelli et al. (2014)	44 (60-85 years; F)	Internal oblique, rectus femoris, multifidus, gluteus maximus, biceps femoris	Isokinetic strength during hip flexion, extension, abduction, and adduction	Fallers had significantly lower hip extension, abduction, adduction strength and flexion, extension and abduction power compared to non-fallers. Non-fallers had 27.4% greater activation of rectus femoris during hip flexion
Cattagni et al. (2018)	48 (75-80 years; 14M, 35F)	Soleus, gastrocnemius medialis and lateralis, and tibialis anterior	MVC used to assess neural and muscular factors in fallers vs non-fallers	Lower plantar-flexor activation and twitch torque in fallers than non-fallers

N number, *M* male, *F* female, *MVIC* maximal voluntary isometric contraction, *MVC* maximal voluntary contraction

CHAPTER III. METHODOLOGY

Purpose

The purpose of this research was to investigate the relationship between neuromuscular activation of the quadriceps and hamstring muscles, balance, and fall risk in the adult population. Neuromuscular activation was determined through sEMG during a maximal strength and balance assessment. The goal of this study was to answer the following research questions:

1. What is the relationship among neuromuscular activation, balance, and fall risk among young, middle-aged, and older adults?
2. What are the differences in strength, neuromuscular activation, and balance scores between younger and middle-aged men and women?

Recruitment

Males and females between the ages of 18-80, stratified as younger (18-40) and middle-aged (41-64) and older (65-80), were recruited. Approximately half of the 50 total population were aimed for each group. Flyers, word of mouth, NDSU listserves, electronic advertisements, and social media were used to recruit participants. They were included upon completion of the 2019 Physical Activity Readiness Questionnaire (PAR-Q)+ and Health History Survey. Participants were included if they were deemed generally healthy adults by the PAR-Q+ and between the ages of 18-80 years. Exclusion criteria included previous or current injuries in their neck, back, legs, or hands that prevents strength and balance testing, cannot provide informed consent, have a leg or arm amputation that would limit bilateral testing, blindness or previous eye injury or have lost an eye, are pregnant or perceive they may be pregnant, previous diagnosis of a spinal cord injury, stroke, respiratory diseases, or other neuromuscular disease or other disease that may impair motor function such as, but not limited to, multiple sclerosis, Parkinson's, or Alzheimer's, known eye disease such as age-related macular degeneration and glaucoma, or have below 20-40 acuity and impaired contrast sensitivity. Written informed consents were obtained prior to testing. This research was approved by the NDSU IRB #HE19261.

Anthropometric Measures

Upon arrival at the laboratory, participants' height and body mass were measured with a Stadiometer (Seca 213, Chino, CA, USA) and an Industrial Wash-Down Scale (DA-Series, Denver Instrument, Arvada, CO, USA). Prior to testing, participants were instructed to complete a five-minute self-paced warm-up on a stationary bike (Monark 818E Ergomedic, Vansbro, Sweden).

Neuromuscular Function

Participants completed a test battery examining lower body muscle strength using the Biodex Pro4 system dynamometer. Isometric strength was assessed at 75° extension of the knee with two warm-up and familiarization attempts followed by three maximal attempts of knee extension and flexion. Each extension and flexion attempt were three seconds in length with three seconds between direction of force production. Isokinetic maximal torque was assessed at various velocities from 0-300 degrees per second for knee extension-flexion. Three maximal attempts at the various velocities were collected in order to examine strength/power velocity curves, the rate of torque development, and eccentric muscle torque. Lastly, passive/eccentric muscle torque was evaluated for the knee extensor muscles using three maximal attempts with two subsequent warm-up attempts prior.

In addition, sEMG data was collected during maximal strength and balance assessments using muscle sensor sEMG electrodes (Red Dot 2560 monitoring electrodes, 3M Healthcare, London, Ontario, Canada) placed on the VL and lateral biceps femoris. The areas of placement were shaved with a standard hand razor and cleaned with alcohol prior to electrode placement. Data from the electrodes was collected and stored using the sEMG MP150 machine (Biopac Systems Inc., Goleta, CA) and saved under the participant's given number before being transferred onto an encrypted hard drive.

Data from each participant was band-pass filtered with a high band-pass of 10 Hz and a low band-pass of 450 Hz to minimize unwanted signal inherent noise and movement artifact. Subsequently, the root-mean-square (RMS) rectifying method was used to normalize values in relation to maximum force and torque output. Following filtration, coactivation of the VL and BF during balance testing was established by calculating the absolute value of the ratio of activation between the muscles.

Balance and Fall Risk Assessment

The Biodex Balance System SD (Biodex Medical Systems, Inc, Shirley New York, USA) was used to evaluate the dependent variables: balance and fall risk. For balance testing, the Clinical Test of Sensory Interaction and Balance (CTSIB) assessment was utilized. The CTSIB is a standardized test for identifying individuals with mild-to-severe balance problems and consists of six conditions: (1) eyes open/firm surface, (2) eyes closed/firm surface, (3) visual conflict/firm surface, (4) eyes open/dynamic surface, (5) eyes closed/dynamic surface, (6) visual conflict/dynamic surface. Visual impairment 3D glasses were used for visual conflict conditions. The CTSIB also identifies a person's Sway Index, which is calculated by the mean absolute deviation of an individual's average position during a test. A higher Sway Index indicates a greater unsteadiness during the test, suggesting worse balance.

Each participant stood on the force platform in their socks facing the display monitor screen. Each condition was performed for 30 seconds with a 10 second rest between each trial. The first trial was practice followed by a second trial used for data analysis. Each participant was instructed to keep their center of balance in the middle of the platform and stay as still as possible. Visual feedback on the monitor was given for the eyes open and visual conflict trials.

The standard Fall Risk protocol was used to allow identification of potential fall candidates. The test results are quantified and compared to age dependent normative. The protocol consists of four conditions: eyes open/comfortable stance, eyes closed/comfortable stance, eyes open/narrow stance, eyes closed/narrow stance. Each condition was performed for 45 seconds with a 30 second rest between conditions. Again, the first trial was practice followed by a second trial used for data analysis. Similar to the CTSIB, participants were instructed to keep their center of balance in the middle of the platform and stay as still as possible.

Statistical Analysis

This study was a cross-sectional design. A linear regression model was used to interpret the differences in neuromuscular function, balance, and muscle activation to predict fall risk for the different age groups. An Analysis of Variance Analysis (ANOVA) with Bonferroni post hoc analysis was used to analyze the differences among the different age groups, genders, neuromuscular function, balance, fall risk, and muscle activation. All statistical analysis was performed using IBM SPSS Statistics Premium 26.0 (International Business Machines Corporation, Armonk, NY) with a statistical significance set at an alpha-level of 0.05.

CHAPTER IV. RESEARCH ARTICLE

Abstract

The natural progression of aging results in structural changes that inhibit functional balance with daily activities. The purpose of this research was to investigate the relationship of neuromuscular activation of the upper leg to balance and fall risk in the adult population. Eighteen males (32.44yrs ± 14.06) and 32 females (41.88yrs ± 18.07) completed strength and balance assessments with surface electromyography (sEMG). Results indicated a significant age effect on the Clinical Test of Sensory Integration and Balance (CTSIB) composite score ($p = 0.019$), and a significant gender effect on knee flexion torque ($p < 0.001$) and knee extension torque ($p < 0.001$). Linear regression determined a significant association between reduced upper leg muscle coactivation, gender, and age to predict Fall Risk Sway Velocity Index (SVI) scores ($p = 0.010$, $R^2 = .218$). In conclusion, middle-aged adults had worse balance scores, females demonstrated weaker muscular strength than males, and reduced neuromuscular coactivation, age, and gender predicted 21.8% of the variability in Fall Risk SVI scores.

Introduction

Balance requires a compilation of several biological systems such as nerve conduction, joint health, muscle strength, and muscle power. However, disease or dysfunction in any of these biological systems can result in impaired functional movement. These impairments in functional movement may lead to mobility limitations, frailty, falls, and decreased quality of life (Miller et al., 2015).

One of the main risk factors of falls in the geriatric population is lower extremity weakness (Cattagni et al., 2018). To combat this weakness, resistance training is commonly used because of the muscle fiber type shifts and changes within the trained muscles (Miller et al., 2015). Due to sarcopenia, muscle fiber size decreases over time resulting in overall weakness and greater fall risk. Lower extremity muscle weakness is a dominant risk factor for falls in older adults (Crozara et al., 2016). Because the research in the literature correlates fallers with lower knee extension and flexion torque and power, it is necessary to investigate these parameters further to confirm or deny these claims.

Moreover, gender differences have been noted across many populations with elderly women having higher fall rates than elderly men. Furthermore, the odds of falls increases as the number of comorbid conditions increases in both genders, and fall prevalence increases with age in both genders as a result of age-related deficits in physical, sensory, and cognitive function (Chang & Do, 2015).

Balance system assessments are commonly used to determine fall risk and balance impairments in the aging population. Utilizing these assessments may provide earlier indications of fall risk and/or balance deterioration which can be used to combat these progressions later in life.

Surface electromyography (sEMG) is a method used to analyze various muscular conditions during functional activities. It records and analyzes the changes of electrical activity of muscle during specific movement patterns (Yukio Fukuda et al., 2010). Because motor unit activation and coordination decrease with age, it is necessary to assess neuromuscular changes and how they affect joint torque and power output in addition to how they are related to fall risk (Crozara et al., 2016).

It is estimated that one third of the population over 65 years experiences one or more falls per year (approximately 12 million individuals). Increasingly, one half of the population over 85 experiences one or more falls per year (Thibaud et al., 2012). Healthcare treatment costs for fall-related injuries were 1.85 times higher than the cost of implementing a fall-prevention program in 2014 (Martínez-López Emilio et al., 2014). Furthermore, in 2017, the geriatric population contributed 6.0% of Medicare spending, 8.0% of Medicaid spending, and 5.0% out of pocket spending for fall related injuries alone (Haddad et al., 2019). By 2060, the predicted population of 65+ years is approximately 94.7 million; thus, it is critical to understand the etiology of falls and develop the best prevention strategy.

The purpose of this research was to investigate the relationship between neuromuscular activation of the quadriceps and hamstring muscles, balance, and fall risk in young, middle-aged, and older adults. Given low sample size in older adults, a secondary question was to quantify how gender influences the difference in strength, activation, and balance in younger and middle-aged adults.

Methods

Recruitment

Males and females between the ages of 18-80, stratified as younger (18-40) and middle-aged (41-64) and older (65-80), were recruited. Approximately half of the 50 total population were aimed for each group. Flyers, word of mouth, NDSU listserves, electronic advertisements, and social media were used to recruit participants. They were included upon completion of the 2019 Physical Activity Readiness Questionnaire (PAR-Q)+ and Health History Survey. Participants were included if they were deemed generally healthy adults by the PAR-Q+ and between the ages of 18-80 years. Exclusion criteria included previous or current injuries in their neck, back, legs, or hands that prevents strength and balance testing, cannot provide informed consent, have a leg or arm amputation that would limit bilateral testing, blindness or previous eye injury or have lost an eye, are pregnant or perceive they may be pregnant, previous diagnosis of a spinal cord injury, stroke, respiratory diseases, or other neuromuscular disease or other disease that may impair motor function such as, but not limited to, multiple sclerosis, Parkinson's, or Alzheimer's, known eye disease such as age-related macular degeneration and glaucoma, or have below 20-40 acuity and impaired contrast sensitivity. Written informed consents were obtained prior to testing. This research was approved by the North Dakota State University Institutional Review Board #HE19261.

Anthropometric Measures

Upon arrival at the laboratory, participants' height and body mass were measured with a Stadiometer (Seca 213, Chino, CA, USA) and an Industrial Wash-Down Scale (DA-Series, Denver Instrument, Arvada, CO, USA). Prior to testing, participants were instructed to complete a five-minute self-paced warm-up on a stationary bike (Monark 818E Ergomedic, Vansbro, Sweden).

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Participants completed a test battery examining lower body muscle strength using the Biodex Pro4 system dynamometer. Isometric strength was assessed at 75° extension of the knee with two warm-up and familiarization attempts followed by three maximal attempts of knee extension and flexion. Each extension and flexion attempt were three seconds in length with three seconds between direction of force production. Isokinetic maximal torque was assessed at various velocities from 0-300 degrees per second for knee extension-flexion. Three maximal attempts at the various velocities were collected in order to examine strength/power velocity curves, the rate of torque development, and eccentric muscle torque. Lastly, passive/eccentric muscle torque was evaluated for the knee extensor muscles using three maximal attempts with two subsequent warm-up attempts prior.

In addition, surface electromyography (sEMG) data was collected during maximal strength and balance assessments using muscle sensor sEMG electrodes (Red Dot 2560 monitoring electrodes, 3M Healthcare, London, Ontario, Canada) placed on the vastus lateralis and lateral biceps femoris (Hermes, H.J., Freriks, 2010). The areas of placement were shaved with a standard hand razor and cleaned with alcohol prior to electrode placement (Fauth et al., 2010; Kollmitzer et al., 1999; Rainoldi et al., 2001; Ruiz-Muñoz & Cuesta-Vargas, 2014). Data from the electrodes was collected and stored using the sEMG MP150 machine (Biopac Systems Inc., Goleta, CA) and saved under the participant's given number before being transferred onto an encrypted hard drive.

Data from each participant was band-pass filtered with a high band-pass of 10 Hz and a low band-pass of 450 Hz to minimize unwanted signal inherent noise and movement artifact. Subsequently, the root-mean-square (RMS) rectifying method was used to normalize values in relation to maximum force and torque output. Following filtration, coactivation of the VL and BF during balance testing was determined by calculating the absolute value of the ratio of activation between the muscles.

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The Biodex Balance System SD (Biodex Medical Systems, Inc, Shirley New York, USA) was used to evaluate the dependent variables: balance and fall risk. For balance testing, the Clinical Test of Sensory Interaction and Balance (CTSIB) assessment was utilized. The CTSIB is a standardized test for identifying individuals with mild-to-severe balance problems and consists of six conditions: (1) eyes open/firm surface, (2) eyes closed/firm surface, (3) visual conflict/firm surface, (4) eyes open/dynamic surface, (5) eyes closed/dynamic surface, (6) visual conflict/dynamic surface. Visual impairment 3D glasses were used for visual conflict conditions.

The CTSIB also identifies a person's Sway Index, which is calculated by the mean absolute deviation of an individual's average position during a test. A higher Sway Index indicates a greater unsteadiness during the test, suggesting worse balance (*BALANCE SYSTEM^{TM} SD (version 4.x) Instructions for use for the following products*, 2018).

Each participant stood on the force platform in their socks facing the display monitor screen. Each condition was performed for 30 seconds with a 10 second rest between each trial. The first trial was practice followed by a second trial used for data analysis. Each participant was instructed to keep their center of balance in the middle of the platform and stay as still as possible. Visual feedback on the monitor was given for the eyes open and visual conflict trials.

The standard Fall Risk protocol was used to allow identification of potential fall candidates. The test results are quantified and compared to age dependent normative. The protocol consists of four conditions: eyes open/comfortable stance, eyes closed/comfortable stance, eyes open/narrow stance, eyes closed/narrow stance. Each condition was performed for 45 seconds with a 30 second rest between conditions. Again, the first trial was practice followed by a second trial used for data analysis. Similar to the CTSIB, participants were instructed to keep their center of balance in the middle of the platform and stay as still as possible.

Statistical Analysis

This study was a cross-sectional design. For the primary aim, a linear regression model was used to interpret the differences in neuromuscular function, balance, and muscle activation to predict fall risk for the different age groups (young, middle-aged, and older adults). For the secondary aim, an Analysis of Variance (ANOVA) with Bonferroni post hoc analysis was used to analyze the gender differences in neuromuscular function, balance, fall risk, and muscle activation in young and middle-aged adults. All statistical analysis was performed using IBM

SPSS Statistics Premium 26.0 (International Business Machines Corporation, Armonk, NY) with a statistical significance set at an alpha-level of 0.05.

Results

A total of 50 participants including 18 males (32.44yrs ± 14.06) and 32 females (41.88yrs ± 18.07) completed the study (Table 5). There was a significant age effect on the CTSIB composite score ($F_{1,42} = 5.983$, $p = 0.019$, partial $\eta^2 = 0.125$) (Figure 2); however, there was no significant age or gender effect in the fall risk composite scores. Gender had a significant impact on knee flexion torque ($F_{1,42} = 47.732$, $p < 0.001$, partial $\eta^2 = 0.532$) (Figure 3) and knee extension torque ($F_{1,42} = 28.045$, $p < 0.001$, partial $\eta^2 = 0.400$) (Figure 4) but no age effect was observed.

Results of the multiple linear regression indicated there was a significant effect between Fall Risk SVI composite scores and coactivation (Beta = -.099), gender (Beta = -2.39), and age (Beta = .310) ($F_{3,46} = 4.277$, $p = 0.010$, $R^2 = .218$) (Table 13).

Table 5.

Participant total population with age means and standard deviations.

		N	Mean	SD
Young (18-40yrs)	Male	14	25.86	5.74
	Female	15	24.20	4.60
Middle-aged (41-64yrs)	Male	4	55.50	8.19
	Female	13	54.46	6.45
Older (65-80yrs)	Male	0	-	-
	Female	4	67.25	1.26
Total	Male	18	32.44	14.06
	Female	32	41.88	18.07

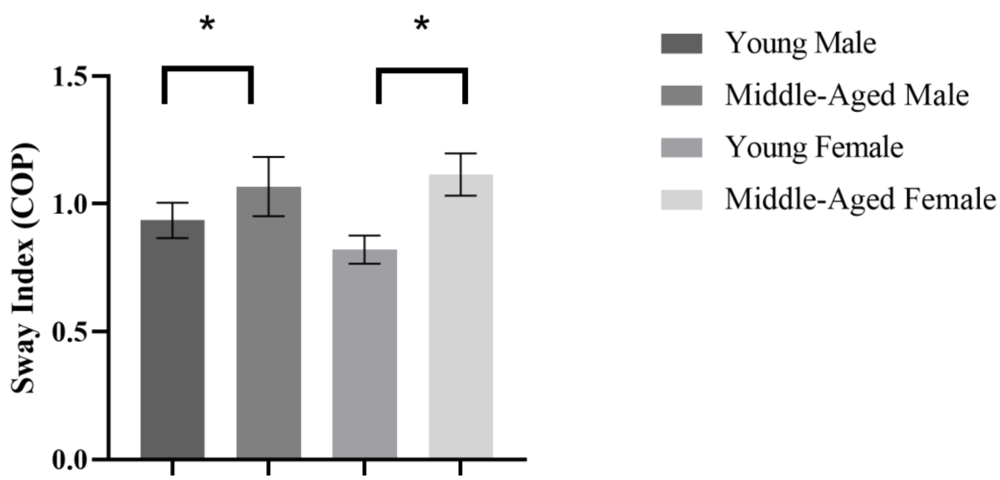

Figure 2. A comparison of CTSIB sway index composite scores between genders and age groups (mean ± SE). * denotes significant age effect between male and female.

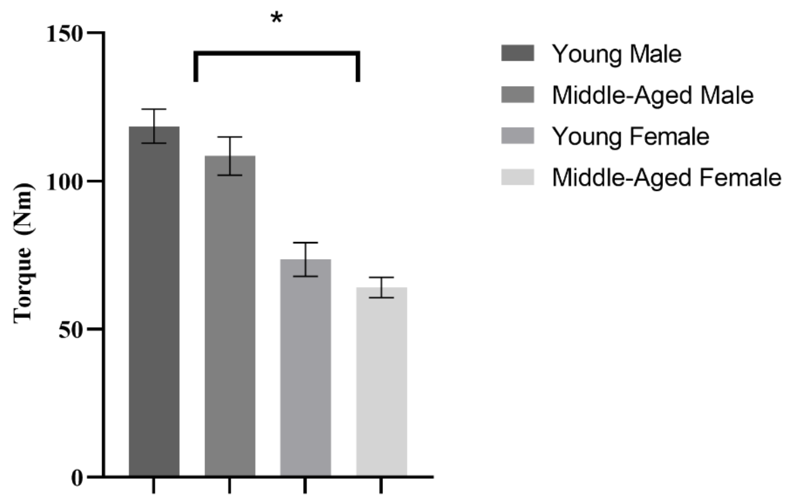

Figure 3. A comparison of isometric knee flexion torque outputs between genders and age groups (mean ± SE). * denotes significant gender effect between males and females.

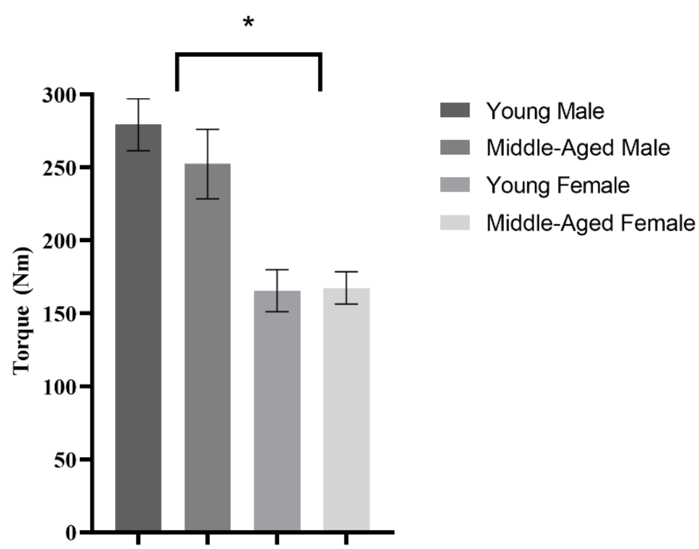

Figure 4. A comparison of isometric knee extension torque output between genders and age groups (mean ± SE). * denotes significant gender effect between males and females.

Table 6.

Means, standard deviations, and p-values of torques, Fall Risk protocol composite scores, and CTSIB protocol composite score.

	Young Adults		Middle Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
Knee Extension Torque (Nm)	279 ± 66.7	166 ± 55.8	252 ± 47.6	167 ± 39.7	P < .001 (.400)*	P = .508 (.011)	P = .447 (.014)
Knee Flexion Torque (Nm)	118 ± 21.7	73.5 ± 21.9	108 ± 12.9	64.0 ± 12.3	P < .001 (.532)*	P = .139 (.051)	P = .963 (.000)
Fall Risk Velocity Composite	7.05 ± 2.27	7.37 ± 2.39	8.91 ± 3.78	18.14 ± 25.81	P = .322 (.023)	P = .192 (.040)	P = .354 (.020)
Fall Risk SVI Composite	10.7 ± 1.84	11.78 ± 1.88	11.88 ± 1.74	14.52 ± 4.96	P = .082 (.070)	P = .069 (.077)	P = .463 (.013)
Fall Risk Z-score Composite	1.12 ± 0.829	1.61 ± 0.843	1.27 ± 0.832	2.65 ± 2.29	P = .059 (.082)	P = .222 (.035)	P = .362 (.020)
CTSIB Composite	0.935 ± 0.260	0.821 ± 0.213	1.07 ± 0.232	1.11 ± 0.297	P = .698 (.004)	P = .019 (.125)*	P = .361 (.020)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, SVI = sway velocity index, CTSIB = clinical test of sensory integration and balance.

Table 7.

Means, standard deviations, and p-values of sEMG normalized coactivation of the VL and BF during the Fall Risk comfortable stance trials.

	Young Adults		Middle-Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
sEMG Fall Risk Comfy EO VL	0.178 ± 0.300	0.028 ± .033	0.126 ± 0.110	0.615 ± 1.65	P = .584 (.007)	P = .388 (.018)	P = .303 (.025)
sEMG Fall Risk Comfy EC VL	0.140 ± 0.206	0.034 ± 0.041	0.137 ± 0.146	1.02 ± 2.83	P = .066 (.078)	P = .349 (.021)	P =.678 (.004)
sEMG Fall Risk Comfy EO BF	0.124 ± 0.217	0.027 ± 0.032	0.072 ± 0.053	0.184 ± 0.272	P = .854 (.001)	P = .143 (.050)	P = .574 (.008)
sEMG Fall Risk Comfy EC BF	0.130 ± 0.193	0.042 ± 0.047	0.102 ± 0.084	0.083 ± 0.089	P = .810 (.001)	P = .328 (.023)	P = .298 (.026)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, EO = eyes open, EC = eyes closed, VL = vastus lateralis, BF = biceps femoris.

Table 8.

Means, standard deviations, and p-values of sEMG normalized coactivation of the VL and BF during the Fall Risk narrow stance trials.

	Young Adults		Middle-Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
sEMG Fall Risk Narrow EO VL	0.091 ± 0.102	0.030 ± 0.032	0.161 ± 0.169	0.674 ± 1.41	P = .558 (.008)	P = .289 (.027)	P = .338 (.022)
sEMG Fall Risk Narrow EC VL	0.454 ± 1.29	0.032 ± 0.030	0.151 ± 0.148	0.554 ± 1.07	P = .733 (.003)	P = .426 (.015)	P = .155 (.048)
sEMG Fall Risk Narrow EO BF	0.091 ± 0.108	0.061 ± 0.052	0.141 ± 0.082	0.200 ± 0.271	P =.092 (.066)	P = .735 (.003)	P = .659 (.005)
sEMG Fall Risk Narrow EC BF	0.110 ± 0.117	0.073 ± 0.065	0.186 ± 0.141	0.203 ± 0.228	P = .651 (.005)	P = .160 (.047)	P = .302 (.025)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, EO = eyes open, EC = eyes closed, VL = vastus lateralis, BF = biceps femoris.

Table 9.

Means, standard deviations, and p-values of sEMG normalized coactivation of the VL during the CTSIB firm surface trials.

	Young Adults		Middle-Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
sEMG CTSIB Firm EO VL	0.373 ± 1.06	0.038 ± 0.048	0.123 ± 0.186	0.206 ± 0.252	P = .547 (.009)	P = .843 (.001)	P = .318 (.024)
sEMG CTSIB Firm EC VL	0.385 ± 1.04	0.043 ± 0.083	0.118 ± 0.106	0.197 ± 0.213	P = .990 (.000)	P = .174 (.044)	P = .535 (.009)
sEMG CTSIB Firm Conflict VL	0.340 ± 0.936	0.033 ± 0.042	0.152 ± 0.170	0.166 ± 0.178	P = .658 (.005)	P = .085 (.069)	P = .786 (.002)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, EO = eyes open, EC = eyes closed, VL = vastus lateralis, CTSIB = clinical test of sensory integration and balance.

Table 10.

Means, standard deviations, and p-values of sEMG normalized coactivation of the VL during CTSIB foam surface trials.

	Young Adults		Middle-Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
sEMG CTISB Foam EO VL	0.482 ± 1.137	0.042 ± 0.041	0.127 ± 0.086	0.322 ± 0.508	P = .686 (.004)	P = .518 (.010)	P = .150 (.049)
sEMG CTSIB Foam EC VL	0.542 ± 0.973	0.111 ± 0.068	0.282 ± 0.201	0.416 ± 0.307	P = .549 (.009)	P = .646 (.005)	P = .324 (.023)
sEMG CTSIB Foam Conflict VL	0.400 ± 0.790	0.060 ± 0.049	0.135 ± 0.146	0.275 ± 0.298	P = .478 (.012)	P = .892 (.000)	P = .199 (.039)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, EO = eyes open, EC = eyes closed, VL = vastus lateralis, CTSIB = clinical test of sensory integration and balance.

Table 11.

Means, standard deviations, and p-values of sEMG normalized coactivation of the BF during CTSIB firm surface trials.

	Young Adults		Middle-Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
sEMG CTSIB Firm EO BF	0.079 ± 0.101	0.043 ± 0.045	0.052 ± 0.052	0.140 ± 0.158	P = .470 (.013)	P = .339 (.022)	P = .096 (.065)
sEMG CTSIB Firm EC BF	0.082 ± 0.104	0.060 ± 0.064	0.068 ± 0.052	0.139 ± 0.144	P = .175 (.043)	P = .984 (.000)	P = .180 (.042)
sEMG CTSIB Firm Conflict BF	0.088 ± 0.102	0.055 ± 0.073	0.036 ± 0.021	0.133 ± 0.186	P = .084 (.069)	P = .736 (.003)	P = .380 (.018)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, EO = eyes open, EC = eyes closed, BF = biceps femoris, CTSIB = clinical test of sensory integration and balance.

Table 12.

Means, standard deviations, and p-values of the sEMG normalized coactivation of the BF during CTSIB foam surface trials.

	Young Adults		Middle-Aged Adults				
	Males	Females	Males	Females	Gender Effect	Age Effect	Gender x Age
sEMG CTSIB Foam EO BF	0.105 ± 0.109	0.041 ± 0.035	0.125 ± 0.096	0.136 ± 0.186	P = .261 (.030)	P = .967 (.000)	P = .060 (.082)
sEMG CTSIB Foam EC BF	0.134 ± 0.126	0.054 ± 0.049	0.195 ± 0.071	0.192 ± 0.214	P = .133 (.053)	P = .580 (.007)	P = .061 (.081)
sEMG CTSIB Foam Conflict BF	0.086 ± 0.088	0.049 ± 0.051	0.102 ± 0.110	0.117 ± 0.162	P = .273 (.029)	P = .786 (.002)	P= .095 (.065)

Young = 18-40 years, Middle-aged = 41-64, Mean ± Standard Deviation, * denotes significance, (#) denotes partial η^2, EO = eyes open, EC = eyes closed, BF = biceps femoris, CTSIB = clinical test of sensory integration and balance.

Table 13.

Linear regression model for SVI Fall Risk protocol composite scores.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F change	df1	df2	Sig. F Change
1	0.467[a]	0.218	0.167	3.02335	0.218	4.277	3	46	0.01

a = predictors: coactivation (Beta = -.099), gender (Beta = -2.39), age (Beta = .310).

Discussion

The purpose of this research was to investigate the relationship between neuromuscular activation of the quadriceps and hamstring muscles, balance, and fall risk in young, middle-aged, and older adults. Results of the multiple linear regression with younger, middle-aged, and older adults indicated reduced coactivation, gender, and age can significantly predict Fall Risk SVI composite scores. Given a low sample size in older adults, a secondary aim was to quantify how gender influences the difference in strength, activation, and balance in younger and middle-aged adults. There was a significant age effect on the CTSIB composite score suggesting even middle-aged adults (regardless of gender) demonstrate worse balance compared to younger adults. However, there was no significant age or gender interaction effect in the fall risk composite scores indicating middle-aged males and females were negatively influenced to a similar degree. Gender did have a significant impact on knee flexion torque and knee extension torque but no age effect was observed. These data indicated middle-aged females expressed a reduction in strength parameters regardless of whether they were classified as younger or middle-aged. This research is the first to assess muscle activation and balance in individuals across multiple age groups rather than specific aged populations, and the use of the Biodex Balance System SD expands current literature by providing different modes of use when coupled with sEMG of the upper leg.

The results of the regression model with younger, middle-aged, and older adults indicated that 21.8% of the variance in SVI Fall Risk composite scores can be predicted from reduced coactivation, gender, and different age groups. Reduced coactivation represents the ability of the agonist muscle to contract with less inhibition from the antagonist muscle (Monica E. Busse, Wiles, & Van Deursen, 2006) and was determined by calculating the absolute value of the ratio of activation between the muscles from the fifth condition (eyes closed/foam surface) in the CTSIB balance protocol. This condition of the balance protocol was selected due to the difficulty of the task (high variability in scores) which likely presented a more accurate representation of sway index and overall balance. Although a degree of coactivation in healthy adults is considered normal for movement capability and gait patterns, impaired or excessive coactivation can lead to abnormal movement patterns or the inability to stabilize center of gravity in a short period of time (M. E. Busse, Wiles, & van Deursen, 2005).

Many studies reported previously have not incorporated an all-inclusive age population (Cattagni et al., 2018; Laughton et al., 2003; Morcelli et al., 2014; Nelson-Wong et al., 2012). For example, Cattagni et al. (2018) included a population size of 48 with 14 males and 35 females between the ages of 75-80 years. Morcelli et al. (2014) included an all-female participant group of 44 between the ages of 60-85 years. Lastly, Nelson-Wong et al. (2011) had 23 participants with 8 males and 15 females between 66-80 years. In contrast, Laughton et al. (2002) researched a more inclusive population with 85 total participants, 70 older, ages 65+ (21 males, 49 females) and 15 younger, ages 22-32 years (21 males, 49 females). Despite including a younger population, Laughton et al. (2002) did not include a middle-aged population group to fill the gap between 32 – 65 years. These studies focused more on the older group groups rather than an all-inclusive age range resulting in specified research findings. Consequently, due to the COVID-19 virus, our older adult population recruitment was greatly diminished, ultimately resulting in a limited and small older adult sample size. Regardless, the varying age population of our study contributes to current literature by adding cross-sectional research findings across an adult lifespan.

The gender and age interaction effects of knee extension and flexion were not statistically significant but young females recorded the lowest knee extension torque and middle-aged/older females recorded the lowest knee flexion torque. Fall risk SVI composite scores were lowest in the young male group, and highest in the middle-aged/older female suggesting young males have better balance and lower sway velocity than young females, middle-aged males, and middle-aged females. Although our study was not designed to evaluate all the specific mechanisms, we speculate the findings could be due to a greater muscular cross-sectional area and differences in muscle fiber types expression. Type I, IIA, and IIB muscle fiber types are larger for young men than young women with type II fibers tending to be larger than type I in men and with the opposite being true in women (Staron et al., 2000). Vision acuity and contrast differences in the lower versus upper visual field also represent potential areas to strengthen the model of significant factors that predict fall risk with aging (McCourt, Leone, & Blakeslee, 2015).

This is the first known study to utilize both the CTSIB and Fall Risk protocol on the Biodex Balance System SD coupled with sEMG of the upper leg to investigate the relationship between neuromuscular activation of the quadriceps and hamstring muscles, strength, and fall risk in the adult population. This study was successful in demonstrating age and gender main effects of knee flexion and extension torque in various adult age groups and exhibiting a predictive relationship that included neuromuscular coactivation and fall risk. Data from this research was mostly obtained from a majority of white/Caucasian participants with various physical activity regimes; it may not be transferable to other ethnic populations.

Conclusion

Gender plays a role in knee extension and flexion torque output, but not in CTSIB or fall risk balance composite scores. Moreover, CTSIB composite scores increase even in middle-aged individuals indicating worse balance. Coactivation in healthy adults is considered normal for movement capability and gait patterns, impaired or excessive coactivation can lead to abnormal movement patterns or the inability to stabilize center of gravity in a short period of time (M. E. Busse et al., 2005). Researchers may use the information from this research study to further understand how gender and age play a role in balance and fall risk in the adult population. In addition, occupational therapists, physical therapists, and trainers may use this information to provide more gender and age-specific training exercises to better suit their clientele.

Results of the multiple linear regression indicated significant variability in Fall Risk SVI composite scores which can be predicted by reduced upper leg sEMG coactivation, gender, and age. Further research is needed to elicit these findings in other populations. Furthermore, there is opportunity to assess sEMG characteristics of the lower leg and findings among age groups, genders, and physical activity levels as well as muscle fiber type percentage contributions to balance.

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APPENDIX A. IRB APPROVAL LETTER

NDSU NORTH DAKOTA STATE UNIVERSITY

August 6, 2019

Dr. Kyle Hackney
Health, Nutrition & Exercise Sciences

IRB Approval of Protocol #HE19261, "Aging and Balance: Interactions between neuromuscular function and the lower visual field"
Co-investigator(s) and research team: Ryan McGrath, Mark McCourt

Protocol Reviewed: 7/5/2019
Protocol Status Update Due prior to: 7/4/2022

Research site(s): NDSU Funding Agency: NIH
Review Type: Expedited category # 4
IRB approval is based on the revised protocol submission (received 8/6/2019). Please use the approved consent form (version received 8/6/2019).

Additional approval from the IRB is required:
o Prior to implementation of any changes to the protocol (Protocol Amendment Request Form).
o For continuation of the project beyond the approval period (Continuing Review Report Form). A reminder is typically sent approximately 4 weeks prior to the expiration date; timely submission of the report the responsibility of the PI. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved prior to the expiration date.

Other institutional approvals:
• Research projects may be subject to further review and approval processes.

A report is required for:
o Any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence (Report of Unanticipated Problem or Serious Adverse Event Form).
o Any significant new findings that may affect risks to participants.
o Closure of the project (Protocol Termination Report).

Research records are subject to random or directed audits at any time to verify compliance with human subjects protection regulations and NDSU policies.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

Sincerely,

Kristy Shirley

Kristy Shirley, CIP, Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult www.ndsu.edu/irb. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

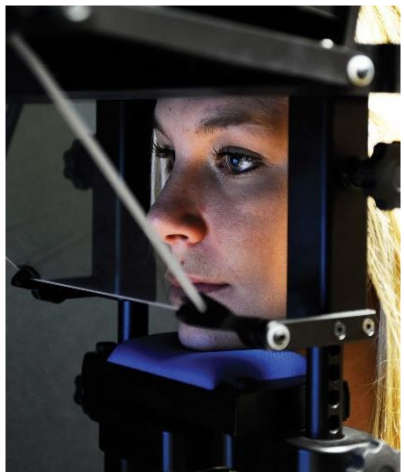
INSTITUTIONAL REVIEW BOARD
NDSU Dept 4000 | PO Box 6050 | Fargo ND 58108-6050 | 701.231.8995 | Fax 701.231.8098 | ndsu.edu/irb

Shipping address: Research 1, 1735 NDSU Research Park Drive, Fargo ND 58102

APPENDIX B. RECRUITMENT FLYER

Research Study Recruitment - Aging and Balance:
Interactions between neuromuscular function and the lower visual field

You are being invited to participate in a collaborative research study between the Department of Health, Nutrition, and Exercise Sciences and the Department of Psychology. This research study will be looking at the interaction between changes in neuromuscular function and vision and how these effect balance and fall risk.



- We are recruiting males and females between 18-80 years of age that are generally healthy. .
- Participants will be excluded from the study if they:
  - Have had any previous or current injuries in their neck, back, legs or hands that prevents strength and balance testing.
  - Are not fluent in English and able to provide informed consent.
  - Have a leg or arm amputation that would limit testing.
  - Are blind or have a previous eye injury or have lost an eye.
  - Diagnosed glaucoma or age-related macular degeneration.
  - Other minor exclusions apply.
- The time commitment for this study is approximately 2 hours.
- Payment/compensation- You will be provided $50 dollars for completing the entire study.

This research is conducted under the direction of Dr. Kyle Hackney, Associate Professor, Department of Health, Nutrition and Exercise Sciences, in collaboration with Ryan McGrath, PhD; Sherri Stastny, PhD, and Mark McCourt, PhD. Support for this project was provided by NDSU Center for Visual and Cognitive Neuroscience, Pilot Project Program proposal and has been approved by the NDSU Institutional Review Board (#HE19261).

If interested, please contact Kyle J. Hackney, PhD. Kyle.hackney@ndsu.edu

APPENDIX C. INFORMED CONSENT

NDSU NORTH DAKOTA STATE UNIVERSITY

Health, Nutrition, and Exercise
Sciences 1301 Centennial Blvd
Fargo, ND 58108-6050
(701)231-8011

Aging and Balance:
Interactions between neuromuscular function and the lower visual field

This study is being conducted by: Kyle Hackney, PhD, Associate Professor; Ryan McGrath, PhD, Assistant Professor; Sherri Stastny, PhD, Professor; Mark McCourt, PhD, Professor at North Dakota State University.

Key Information about this study:

This consent form is designed to inform you about the study you are being asked to participate in. Here you will find a brief summary about the study; however you can find more detailed information later on in the form.

We are looking for participants for a study exploring balance and fall risk with aging. We are interested in learning more about how vision and neuromuscular changes occurring with aging may influence balance and fall risk.

- We are recruiting males and females between 18-80 years of age.
- Participants will be included if they complete they are generally healthy based on completed health questionnaires.
- Participants will be excluded from the study if they:
    - Have had any previous or current injuries in their neck, back, legs or hands that prevents strength and balance testing.
    - Are not able to provide informed consent.
    - Have a leg or arm amputation that would limit testing.
    - Are blind or have a previous eye injury or have lost an eye.
    - previous or current injuries in their neck, back, legs or hands that prevents
    - Are pregnant or perceive you may be pregnant.
    - Previous diagnosis of a spinal cord injury, stroke, respiratory diseases, or other neuromuscular disease or other disease that may impair motor function such as, but not limited to, multiple sclerosis, Parkinson's, or Alzheimer's.
    - Known eye disease such as age-related macular degeneration, glaucoma, etc.
    - Have greater than 20/40 acuity or impaired contrast sensitivity.
- Risks/Benefits- There is minimal risk for participating in this study. You may have some low to mild soreness after strength and balance testing, but this should go away after 24-72 hours. You could fall during balance testing an injure muscles, tendons, and bones but this would be very rare. You may be able to help others in the future to reduce

falls.

- The time commitment for this study is approximately 2 hours.
- Payment/compensation- You will be provided $50 dollars for completing the entire study. $25 will provided after the vision testing and $25 will be provided after the neuromuscular testing.
- For this study you will complete some vision testing, neuromuscular strength testing, vision testing, and balance/fall risk testing.

Why am I being asked to take part in this study?

You are generally healthy between the ages of 18-80 years.

What will I be asked to do?

You will be asked to complete vision, strength, and balance testing in order to characterize differences in younger, middle age, and older/elderly individuals. Next, we will try to understand how these variables interact with one another. For the vision testing you will be asked to view various content on a computer screen and provide feedback on your perception of the images to the researchers. For the strength testing you will sit in a chair and kick your leg out at maximal force for several repetitions at different speeds. Several electrodes will also be attached to various muscle groups while you performed strength and balance testing. For the balance testing, you will stand on the platform and attempt to keep yourself in the center of the platform under various conditions. For this we will ask you to perform on one leg, with your eyes closed, and with 3D glasses on to make the test more challenging.

Where is the study going to take place, and how long will it take?

This study will take place in Bentson-Bunker Fieldhouse (room 14, 15, 16) at North Dakota State University. The testing session will take approximately 2 hours total time.

What are the risks and discomforts?

It is not possible to identify all potential risks in research; however, reasonable safeguards have been taken to minimize known risks. If new findings develop during the course of the research, which may change your willingness to participate, we will tell you about these findings.

There is minimal risk for participating in this study. You may have some low to mild soreness after strength and balance testing but this should go away after 24-72 hours. Also, the balance testing could result in a fall but members of the research team will be there to spot you during the assessment to prevent any issues. There is also a small risk of mild skin irritation from the surface electrodes on your muscles.

What are the expected benefits of this research?

- **Individual Benefits:** There few benefits for participating, such as, you can request access to your strength, vision, and balance data and see how you compare to others based on age and gender.

Societal Benefits: You may be able to help others in the future. If we understand more about how neuromuscular function interacts with vision impairment and falls, we can better customize exercise programming for fall prevention, while simultaneously working to prevent/correct visual changes through exercise, nutrition, and dietary supplementation.

Do I have to take part in this study?

Your participation in this research is your choice. If you decide to participate in the study, you may change your mind and stop participating at any time without penalty or loss of benefits to which you are already entitled. Your decision will not affect your relationship with NDSU

Will it cost me anything to participate? There is no cost for participating in this study. **What are the alternatives to being in this study?**

Instead of being in this research, you may choose not to participate.

Can my participation in the study end early?

If you fail to show up for a scheduled session or choose not to continue in the study after completing some of the testing, you will be removed from the study. You will be compensated for what you did complete.

Will I receive any compensation for participating in the study?

You will not be compensated for this study. Your participation is voluntary. $50 total will be provided for participation. $25 will be earned after the neuromuscular/balance session, $25 earned after the vision testing. Partial compensation will be allowed.

What happens if I am injured because of the study?

If you are injured during the course of this study, you should contact Kyle J. Hackney, PhD at 701.231.6706. Treatment for mild discomfort will be available including general first aid. However, more serious emergency treatment will need to be provided by a licensed medical professional.

Payment for this treatment must be provided by you and your third party payer (such as health insurance, Medicare, etc). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of you participation in this research.

What if I have questions?

Before you decide whether you'd like to participate in this study, please ask any questions that come to mind now. Later, if you have questions about the study, you can contact Kyle J. Hackney at 701.231.6706 or at kyle.hackney@ndsu.edu.

What are my rights as a research participant?

You have rights as a research participant. All research with human participants is reviewed by a committee called the *Institutional Review Board (IRB)* which works to protect your rights and welfare. If you have questions about your rights, an unresolved question, a concern or complaint about this research you may contact the IRB office at 701.231.8995, toll-free at 855-800-6717 or via email (ndsu.irb@ndsu.edu).

Documentation of Informed Consent:
You are freely making a decision whether to be in this research study. Signing this form means that

1. you have read and understood this consent form
2. you have had your questions answered, and
3. you have decided to be in the study.

Image/photo release:
If you agree to consent, can we use photos of you performing the tests in research posters, publications, or on websites to help us explain our study results and recruit other students to NDSU?

Yes________ No ___

You will be given a copy of this consent form to keep.

______________________________________ ________________
Your signature Date

______________________________________ ________________
Your printed name Date

______________________________________ ________________
Signature of researcher explaining study Date

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Printed name of researcher explaining study