Balance, Dual-Task Walking and Power in Traditional Taekwondo Athletes

by

Shelly Rader-Todd

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Exercise Science

Middle Tennessee State University
August 2023

Thesis Committee:

Dr. Jennifer Caputo, Chair

Dr. Samantha Johnson

Dr. Sandra Stevens

This research is dedicated to every adult attempting to improve their health and wellness.

ACKNOWLEDGEMENTS

My committee has been unyielding in support throughout this project. Dr. Stevens, I would not have been here without you. From the admissions process to the final steps of this journey, you have been a pillar in my success. You made the statistics easy to understand, and I am appreciative you have invested your talents in my success. To Dr. Johnson, your input with my thesis, including expertise in the balance protocol and the chart design, is second to none. You gave me great respect for the research process and pushed me to expand my comprehension. I owe you so much gratitude. My committee chair, Dr. Caputo, your oversight and forward thinking made this project successful. You are one of the best teachers I have had, and have instilled your passion for knowledge throughout the program. I extend my deepest gratitude for your oversight and positive encouragement.

In addition to my committee, many others have ensured my success throughout the process. To my spouse, Bryan, I would not have been able to achieve this level of education without you. You have been the glue to my achievement and helped me realize that nothing is impossible. My parents have instilled the importance of education and inspired my passion for learning. Without them, I would not have made it this far in life. My friends and family have been a wealth of support cheering me on when the skies were grey, and I am grateful to have them in my corner. Laura Wiser and Andy Hyde, thank you for providing unconditional friendship to me across the decades. Undoubtedly, you have played a key role in my success. Dr. Merredith Mooth, I appreciate you contacting me in class for comradery and peer review. Little did I know we would continue to work

together to the finish line. You have kept me sane throughout the program, and I am honored to have you as my friend.

Alexis Meyer, thank you for your support during the data collection process. Your grit and perseverance contributed to the success of this research, and I appreciate you more than you will know. My friend Tinna, thank you for standing by me when times were tough. I appreciate the gentle nudges to help me push to the finish line. Lastly, I would like to thank the Choong Sil Taekwondo Federation and its schools that have supported me during the project. My Taekwondo family has instilled the importance of courtesy, integrity, perseverance, self-control, and indomitable spirit into every aspect of my being. This group of individuals has taught me the meaning of loyalty and trust, for which I am forever grateful.

ABSTRACT

Improvements in worldwide life expectancy have created challenges for healthcare systems and families in navigating age-related declines in cognitive and physical function. These changes impact the ability to live independently as declines in lower body power, balance, and dual-tasking abilities increase injury risk. Taekwondo integrates functional movements that may slow age-related physical and cognitive declines. Data from 46 Taekwondo practitioners consisted of verticle jump height, dual-task walking, and balance. Participants were divided into young (18 – 34 years), middle-aged (35 – 54 years), and older groups (55 – 80 years). There was a statistically significant decrease in vertical jump height of 29.4% from the young to the middle-aged group ($F(2, 43) = 12.39$, $p = .00$). There were no significant relationships between age groups for dual-task walking. Balance scores with eyes closed on a firm surface for the middle-aged group fell below the 50th percentile on the BTrackS general population normative data. All other balance scores were at or above the 50th percentile. Evidence suggests Taekwondo may slow the decline of aging, potentially sustaining the ability to live independently.

TABLE OF CONTENTS

Page

Page

Page

LIST OF TABLES AND FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Age-related physical and cognitive declines can substantially influence an individual's quality of life and limit one's ability to live independently. Aging is associated with decreased body power, mental acuity, balance, and the ability to move about safely in physical environments leading to an increased risk of falling. Research indicates a 1.25% annual decline in muscle power after 30 years of age (Gava et al., 2014). One out of three adults 65 years and older experiences at least one fall yearly (Bergen et al., 2016; Stevens et al., 2012). Normative data indicates median gait speeds for older adults are approximately 1.3 meters per second (Kasovic et al., 2021). Furthermore, Yogev-Seligmann et al. (2010) found dual-task activities combining walking and talking, slow gait speeds in adults 65 years and older to 1.18 ± 0.23 meters per second. Modern advances in healthcare have lengthened life expectancy, increasing burdens on the healthcare system. In fact, by 2034, adults 65 years and over will outnumber children (*An Aging Nation: Projected Number of Children and Older Adults,* 2018).

The age-related declines in physical and mental capacity typically begin within the fifth decade of life, but the mechanisms are not entirely understood (Hall et al., 2017). Loss of power in the lower extremities results from muscle loss and can diminish an aging adult's ability to maneuver throughout the environment. A decrease in muscle power can impact one's ability to perform basic movements, including ambulating, stair climbing, and rising from a seated position (Hruda et al., 2003). In addition, studies indicate that declines in balance also contribute to mobility detriments. Postural instability has been associated with these declines (Horak, 2006) and promotes locomotor falls in aging adults (Holviala et al., 2012). Functional tasks, such as standing, can be impaired in older adults leading to additional risk for injuries (Aslan et al., 2007). Gait speed also slows due to changes in the neuromuscular system (Boyer et al., 2017; Uematsu et al., 2018) and can impact daily functional movements and loss of independence. Gait speed is considered a strong indicator of wellness (White et al., 2013). White et al. (2013) indicated that participants with a moderate to fast decline in gait speed over two years experienced a higher mortality rate.

Deterioration of cognitive abilities also increases the risk of falls and injuries in aging adults. According to van Schoor et al. (2002), uncertainty exists in the specific area of cognition responsible since most researchers have only measured general cognitive function. However, evidence supports a link between "immediate memory" and recurrent falls. Immediate memory is associated with an individual's active ability to focus and stay attentive to the environment (van Schoor et al., 2002). A specific impact of cognitive decline in aging is on dual-task ability. Dual-task ability is defined as producing a motor movement, for example, walking, with cognitive activities such as reading (Glenn et al., 2015). Implementing both activities requires an individual to divide attention across multiple tasks, progressively challenging as one ages, leading to alterations in functional movements and overall well-being (Glenn et al., 2014; Lindenberger et al., 2000).

Beauchet et al. (2008) indicated that dual-task walking increased the risk of recurrent falls by 19.1% in older adults.

Exercise has been identified as an intervention that can slow and improve age-related physical and cognitive function (Bherer et al., 2013). However, few studies combine the impact of multicomponent forms of exercise on the aging population's lower body power, balance, and dual-tasking abilities. There also is little knowledge about the effects of exercise on dual-tasking abilities. Henderson et al. (2017) noted that aerobic exercise improves gait speed and is linked with functional fitness. Research also indicates that one-hour resistance and aerobic training for one-hour sessions three times per week produced cognitive improvements after 52 hours of exercise for sedentary adults over 60 years (Gomes-Osman et al., 2018). Outcomes of a balance training program implementing strength and aerobic exercises in a community-based group of older adults indicated multiple component exercise programs could improve physical and cognitive function (Shubert et al., 2010). Incorporating components of aerobic, resistance, and balance exercises into a program could optimize physical and cognitive functioning in the aging adult.

Taekwondo, a Korean martial art style, is a form of exercise that combines cognitive, physical, and dual-task skills in training. Additionally, this practice integrates balance and dynamic movements that could be essential for independent function and mobility while preventing balance detriments in the aging adult (Cromwell et al., 2007). The movements of this practice are adaptable and can be utilized for various physical and cognitive challenges producing opportunities for participation for many.

Purpose of the Study

This thesis consists of one study of adults that train in Taekwondo. The proposed investigation aims to quantify lower body power, dual-task abilities, and balance in individuals who train in traditional Taekwondo and compare balance scores to existing data in the adult population. It was hypothesized that taekwondo training helps preserve these properties throughout adulthood, indicated by a less than 25% change among age groups in lower body muscle power and dual-task walking as age increases and scoring at or above the 50% normative data scale for age using the BTrackS Modified Clinical Test of Sensory Integration and Balance (mCTSIB) scale. Each of the four balance assessments will be measured separately.

Significance of the Study

Modern advances in healthcare enable adults to live longer; however, this outcome increases demands on the healthcare system and families. Maintaining independence in the older adult population is related to retaining physical and cognitive abilities. It is known that physical and cognitive functional detriments can strip away one's ability to live independently and hamper life quality. While research is lacking on participation in Taekwondo with older adults, which can be easily accessed within the community, it is arguable this form of exercise can temper the physical and cognitive decline of the aging process. If evidence indicates Taekwondo can slow the loss of lower body power, dual-task ability, and balance, recommendations for engaging in practice could reduce reliance on the health care system and families for the older adult.

.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The literature review begins with an overview of the prevalence of aging and its impact on society. The physiological and cognitive changes of the aging process and its relationship to the increased risk of falling are then presented. The following section examines an exercise intervention to reverse physical and cognitive decline and enhance functional performance. The final section addresses the martial art, Taekwondo, as a potential modality to address age-related physical and cognitive changes.

Aging Demographics and Impact on Society

As the demographic structure of society changes, modern research is shifting towards a focus on aging and its impact on physical and cognitive well-being. Pressures of an increased median shift in the aging population are anticipated to strain the healthcare systems, supply chains, the economy, and society (Howdon & Rice, 2017; Olshansky et al., 2009). The changes in the demographic structure are noted worldwide and are believed to be attributed to declines related to fertility, reduced mortality rates, and increased longevity (Harper, 2014). Currently, 11% of the world's population is > 60 years, and this percentage will increase to 22% by the year 2050, encompassing approximately 9.4 billion individuals (Kanasi et al., 2016; Roberts et al., 2018). In the United States, the Social Security Administration (SSA) predicts from now until 2032, mortality will decrease in all areas of the population by 0.86 percent (Olshansky et al., 2009). Furthermore, according to the SSA, Olshansky et al. (2009) assessed that from 2032 to 2082, mortality would fall even further for those under 65 years by 0.73 percent each year. Recent data indicates a worldwide shift in life expectancy related to the COVID-19 pandemic in 2020, with >1 year of life lost in both males and females to life expectancy at birth (Aburto et al., 2021). According to Aburto et al. (2021), more significant losses were observed in males at 2.2 years in the United States and 1.7 years in Lithuania compared to other countries.

An increase in life span is creating economic challenges for world societies. The worldwide population of older adults is perceived as a threat to financial stability throughout the 21st century (Prince et al., 2015), placing elevated demands on healthcare spending that have resulted in higher ratios of elderly dependence and delayed retirement (Harper, 2010). The longevity trends have impacted governmental policy, political strategies, and individual financial behaviors (Harper, 2010; Harper, 2004). In growing economies, public health care spending has increased dramatically; between 1970 and 2007, it exceeded a four-fold increase (Jenkner & Leive, 2010). There is anticipated to be a decline in caregivers within the home within the next few decades, which will require a dramatic increase in institutionalization for this aging population, further elevating health care expenditures (Hajek et al., 2015). This decrease is also concerning as evidence suggests nursing home placement is strongly associated with physical and cognitive impairments (Luppa et al., 2009). Therefore, strategies to preserve or slow age-related changes to physical and cognitive function are crucial.

Physiological Changes in Aging

The biological processes of aging impact the nervous and muscular systems, ultimately impairing physical function. Such factors include a decrease in motor neurons, reduced signaling of insulin growth factor I, an increase in cytokines, and oxidative stress leading to impairment of skeletal muscle (Aagaard et al., 2010; Tieland et al., 2018). The interruptions result in the loss of type II muscle fibers responsible for power generation, leading to subsequent impairment of movement and loss of stability (Larsson, 2018). Movement impairment within an environment is associated with a disability because many daily activities require locomotion (Alcazar et al., 2021, Dodds et al., 2018). Furthermore, muscle power is responsible for gait adjustments during ambulation and the reactive ability to recover balance when falling (Caetano et al., 2019). A landmark study by Lexell et al. (1988) evaluated post-mortem (within three days) skeletal muscle fibers of 43 men aged 15 to 83 years considered previously in good health who experienced sudden, accidental death. Age-related atrophy of muscle started at the age of 25 years and increased exponentially afterward (Lexell et al., 1988). The authors did not reveal if any individuals in their sample had been regularly physically active preceding death. However, a longitudinal study in which healthy adults were compared to older adults with limited mobility concluded that a significant power decline in both groups was potentially related to loss of neuromuscular activation (Reid et al., 2013).

Changes in Muscle Structure

Movements, including walking and gripping, involve the coordination of numerous muscles to produce intentional actions by an optimal functioning nervous system. Neuromuscular changes are commonly believed to be the underlying cause of changes to skeletal muscle associated with aging. The neuromuscular system organizes intentional muscular movement initiated by as many as 10 billion neurons (Kandel et al., 2012). The aging process leads to a decreased neural interaction within the muscles, known as denervation, leading to muscular atrophy and inevitable neuron death, causing weakness and functional impairment (Bean et al., 2002; Carraro et al., 2017; Soendenbroe et al., 2021).

Muscle atrophy is associated with the slowing of and weakness in skeletal muscles and is the most common form of muscular decline related to aging (Larsson et al., 2019). Disruptions in the skeletal muscle sarcomeres, including fiber type transitions, atrophy of fibers, and diminished activation of the nervous system, may result in reduced velocity, force production, and strength, ultimately leading to impairment in physical function and disability (Reid & Fielding, 2012; Tieland et al., 2018). Additionally, non-age-related factors, including poor nutrition and lack of physical exercise, are thought to influence changes in skeletal muscle (Larsson et al., 2018). Prolonged physical activity disruptions can accelerate muscle mass loss by as much as one kilogram in 10 days (Kortebein et al., 2017). While multiple factors appear to have a role in muscle atrophy, research supports changes in the nervous system as a primary cause of muscular decline (Padilla et al., 2021; Soendenbroe et al., 2021; von Haehline et al., 2010).

The loss of muscle mass in older adults is related to diminishing muscle fibers and atrophy in conjunction with the infiltration of fat and collagen within the muscle (Aagaard et al., 2010). Sarcopenia, in its literal meaning, is the "poverty of the flesh" (von Haehling et al., 2010) or the age-related decline of muscle mass associated with advancing age, which is associated with a progressive deterioration of muscle and physical function (Baumgartner et al., 1998). Studenski et al. (2011) added sarcopenia occurs when muscle mass drops two standard deviations below the mean of controls and gait speed decreases to less than 0.8m/s. Annual leg muscle mass loss has been reported at a median decline of 0.47% in men and 0.37% in women over 45years, with the losses increasing to 0.80-0.98% for males and 0.64-0.70% in females after 75 years old (Mitchell et al., 2012). Moreover, Mitchell et al. (2012) reported that women and men lost between 3.7% and 4.7% of muscle mass every decade after 70 years. On a global scale, sarcopenia was estimated to have a 10% prevalence in adults ≥ 60 years (Shafiee et al. 2017). It was more likely in non-Asian individuals, which was hypothesized to be related to the lower baseline muscle mass in the Asian population (Shafiee et al., 2017). Previous investigations have also noted the change in prevalence based on age, with sarcopenia being present in 10 to 24% of adults under 70 years old and more than 50% of adults over 80 years old (Baumgartner et al., 1998). Sarcopenia might start in some muscles earlier than others and primarily affects the type II muscle fibers (Aagaard et al., 2009; Andersen, 2003; Kosek et al., 2006).

The decline in muscle from aging-induced sarcopenia has a multifaceted impact on muscle strength and power, leading to a high rate of detrimental outcomes in older adults (Shafiee et al., 2017). Of importance, a reduction in muscle strength increases the risk of falling in older adults (von Haehling et al., 2010). Therefore, maintaining skeletal muscle is essential for preserving independence and physical function while reducing fall risk (Lang et al., 2010). However, sarcopenia can be effectively managed and adverse effects mitigated (Shafiee et al., 2017). Knowing muscles exert mechanical stress on the skeletal system, retaining and improving bone density and reducing fracture probability

(Karlsson et al., 2020), interventions for addressing sarcopenia must encompass progressive resistance training and nutritional interventions (von Haehling et at., 2010).

Muscular Power

Muscular strength is the ability of a muscle or group of muscles to produce force upon an object (Bohannon, 1987) and has historically been a cornerstone for predicting physical function. Muscular power is similar to the outcome of muscle strength, with additional consideration given to contraction velocity, and is now thought to be more predictive of the ability to perform daily living activities for adults 65 years and older than muscular strength (Aagaard et al., 2010; Sherwood et al., 2019). Activities such as walking, standing from a seated position, and stair climbing require lower body power; the ability to perform these actions are predictors of an individual's functionality in their environment (Foldvari et al., 1999). The loss of muscular power, specifically in the lower body, has also been associated with an increased incidence of falling (Simpkins & Yang, 2022; Skeleton et al., 2002). Jia et al. (2019) found 23 % of adults 65 years and older reported falls, and 34% stated they had balance or walking difficulties within the previous year.

Physiological alterations associated with advancing age that lead to a loss of power include loss of muscle mass, loss of type II muscle fibers, denervation of the nervous system with loss of motor unit activation, and inflammatory factors (Sherwood et al., 2019). The degenerative loss of type II fibers that occur with muscular atrophy ultimately hastens the decline of muscular power (McKinnon et al., 2017) and causes a slowing of movement (Lang et al., 2010). Furthermore, over the age of 65 years, McKinnin et al. (2017) indicated a reduction of 43% of cortical neurons. Evidence exists that demyelination occurs in the peripheral nervous system leading to inadequate neuromuscular interactions (Hourigan et al., 2015; McKinnon et al., 2017).

Power is decreased at twice the pace of muscular strength with aging for adults 60 years and older (McNeil et al., 2007). Gava et al. (2015) suggested skeletal muscle changes, including atrophy, may occur earlier in adulthood than once thought, evidenced by a linear decline in muscle power after the third decade of life. Therefore, interventions to address the decline in lower body power are essential to minimize potential deficits. A longitudinal study where healthy older adults were compared to older adults with limited mobility showed a significant decline in power in both groups was potentially related to loss of neuromuscular activation, reductions in contraction velocity, and decreased mobility (Reid et al., 2013). Efforts to maintain mobility and preserve functional fitness in the aging population can aid in safeguarding daily activities and are associated with maintaining muscle power (Glen et al., 2015; Steffen et al., 2002).

Impairments in functional status and decreased muscular power can limit an aging person's ability to perform daily activities. The decrease in muscular power also negatively impacts balance and places individuals at elevated risk for injury (Muehlbauer et al., 2015). The physiological changes with aging that impact balance are highlighted in the following section.

Balance

Sustaining balance in the aging adult is imperative for living independently (Aslan et al., 2008). Ruwer et al. (2005) defined balance as the CNS's ability to manage vestibular, visual, and proprioceptive messaging. Balance is divided into two types: static and dynamic. Static balance is the ability to control one's posture while standing (Rubega et al., 2021). Posture requires a complex integration of the musculoskeletal system, which provides feedback to the CNS about body positioning within an external environment (Maurer et al., 2005; Rubega et al., 2021). Diminished posture control can impair daily function, increasing fall risk and negatively impacting quality of life (Aslan et al., 2008). Dynamic balance describes maintaining postural control with movement and activity, such as walking (Rubega et al., 2021). Impairment in dynamic balance can destabilize the center of mass, resulting in falls if realignment is not achieved (Nnodim, 2015a).

Balance deteriorates with age due to various sensorimotor processes impairing postural stability (Lee et al., 2015). Defined as the ability to retain balance while standing, postural stability is related to the body's center of mass (Mapelli et al., 2014; Richmond et al., 2018). Muscle atrophy alters postural stability and gait (Benichou & Lord, 2016; Muehlbauer et al., 2015). These properties are related to the loss of motor neurons and innervation of muscle fibers (McNeil et al., 2015), in addition to the reduced influence of cognitive processes on reflexive lower limb movement (Schubert et al., 2008). Implementing daily tasks, including walking, stepping, and moving within an environment, requires balance (Chen & Chou, 2013). Disturbances in stability lead to increased risk for injuries in the elderly, and 30% of the occurrences result in functional decline, institutionalization, and death (Koushyar et al., 2019; Leirós-Rodríguez et al., 2020; Sterling et al., 2001).

Proprioception, a significant component of the sensorimotor process utilizing specialized neurons known as mechanoreceptors, refers to the awareness of body position and movement (Ribeiro & Oliveira, 2007). These mechanoreceptors detect joint position and movement (Hiemstra et al., 2001). When standing, proprioception is considered the primary moderator for balance (Fitzpatrick & McCoskey, 1994), and during walking, it aids in the organization of stepping (Nnodim & Yung, 2015). Conditions including dizziness, hypotension, decreased reaction time, and postural dysfunction (Orr et al., 2008) may lead to the inability to maneuver throughout the environment at will and a heightened fear of falling (Boelens et al., 2013). These conditions commonly occur in older adults leading to an increased risk for injury. Additionally, falls are linked to social isolation, increased dependence, and nursing home admissions (Stanmore et al., 2019). However, evidence suggests that exercises focused on balance may contribute to a 35% reduction in fall risk (Robertson et al., 2002). Further, Charles et al. (2020) noted that balance improvements could reduce three-year mortality risk by 12%.

Mayson et al. (2008) evaluated leg power in older adults to determine if velocity or strength was more predictive of balance and mobility. Balance measures were more impacted by limb velocity and reflected overall leg power (Mayson et al., 2008). This research shows that preserving static and dynamic balance may influence an individual's overall mobility and independent function within the environment. Due to the complexity of conditions accompanied by aging, interventions to improve generalized physical performance, such as exercise, can also increase balance. Addressing static and dynamic balance impairments could improve functionality as one age. However, little research has been conducted on evaluating balance changes with power training (Chen et al., 2021).

A decrease in balance has also been associated with cognitive decline, and this interrelationship is believed to contribute to injury in older adults (Xiao et al., 2020). An explanation for the dependence of balance on cognition may be related to the use of higher cerebellar actions implemented with movements such as walking (Smith-Ray et al., 2015). Additionally, the impact of aging on physical movement and stability has been correlated with an individual's ability to avoid cognitive distractions (Laessoe et al., 2008; Xiao et al., 2020). Addressing balance alterations through cognitive training could also improve physical functioning and reduce injury risk in the aging adult (Smith-Ray et al., 2015).

In summary, the natural physiological changes that occur with aging can decrease one's ability to function independently. The changes thought to begin in early adulthood led to a progressive loss of physical mobility through a decline in muscle mass and CNS activation within the body (Larsson et al., 2018; Soendenbroe et al., 2021). Over time, the collaboration of changes significantly impacts the ability to perform daily activities, causing muscles to weaken, physical movement to slow, and overall diminished function (Larsson et al., 2018). Introducing interventions to preserve muscular power and balance in the aging adult can aid in maintaining optimal physical function.

Cognitive Changes in Aging

Memory begins to deteriorate in the early stages of adulthood, as soon as the 20s and 30s (Salthouse, 2009). After the second decade, grey matter within the frontal lobe of the brain begins to atrophy and is linked to physical disability (Favaretto et al., 2018; Harada et al., 2013; Terry & Katzman, 2001). The death of neurons results in memory decline and impacts an individual's ability to perform physical and cognitive tasks (Harada et al., 2013; Hausdorff et al., 2008). The structural and functional alterations in the brain also result in older adults' increased inability to disregard distractions and decipher relevant information (Statsenko et al., 2021). Executive functions, including alternating between thoughts, working memory, and general inhibitory responses, allow individuals to function independently in the community setting (Miyake et al., 2000). Aging can impact these executive functions, decreasing the ability to decipher relevant information and physically adjust to alterations in functional movements (Buerskens & Bock, 2013).

Furthermore, physical movement has been linked with sensory and motor abilities and is believed to be connected to cognitive function (Pichierri et al., 2011). Although it is unclear in the literature why there is a connection between the two, there is a common agreement that more research is needed in this area. Postural stability may also be influenced by alterations in cognition (Laessoe et al., 2008), increasing the risk of falling (Liu-Ambrose et al., 2008). Engaging in cognitive stimulation while performing physical activity throughout adulthood could minimize cognitive decline and injury risk in the older adult while preventing injury.

Dual-Task Ability

The term "dual-task" describes performing a physical and a cognitive task simultaneously (Anderson et al., 2011). Assessing dual-task ability is a practical tool for evaluating cognition, postural stability, and fall risk (Muir-Hunter & Wittwer, 2016). Declines in dual-task abilities are thought to be related to diminished cognitive function. Furthermore, Muir-Hunter and Witter (2016) revealed a connection between dual-task and gait performance, cognitive impairment, and fall risk in older adults. Gait disorders exist in approximately 35% of individuals older than 70 years (Verghese et al., 2006) and have been linked with physical dependence on others for care and even death (Bennett et al., 1996; Tinetti, 2003). Early recognition and intervention could preserve independent living and extend one's lifespan.

There is no clear understanding of the connection between cognitive decline and the ability to perform a dual-task (Siu et al., 2009). According to Siu et al. (2009), proposed reasons for the reduction in dual-task balance with aging include:

1.) Dual-task ability relies on an individual's ability to concentrate and is encumbered by balance alterations
2.) Deficits in attentional focus related to impaired executive control centers of older adults and difficulty dividing attention among the tasks

Attention is determined by sensory input and one's ability to focus on a specific action while disregarding extraneous information (Siu et al., 2009). Interventions aimed at attentional focus may improve gait balance in older adults. Furthermore, Hausdorff et al. (2008) and Montero-Odasso et al. (2014) suggested dual-task gait may provide information about an individual's cognitive status due to shared cognitive pathways. It is believed that during dual-tasking, an individual is required to divide attention between the activities creating interference with attentional focus that can increase the risk for injury (Beauchet et al., 2009, Montero-Odasso et al., 2012). Daily activities that include walking and talking could place the aging adult at risk for falls. Knowing there appears to be a shared connection between dual-task gait and cognitive status, it would stand to reason that dramatic declines in gait could indicate the need for medical intervention to assess CNS function. Additionally, strategies for improving dual-task gait should include physical and cognitive training that focuses on retaining the functional movements of aging adults (Eggenberger et al., 2015).

In conclusion, it is known that cognitive changes begin early in adulthood and can alter mobility as one ages. Structural changes in the brain lead to declining efficiency in processing and storing information. This decline in executive function is thought to change posture and negatively impact gait leading to an elevated risk for injury. Furthermore, participating in dual-task physical activities may provide insight into one's cognitive status and allow improving and preserving these abilities throughout aging.

Interventions for Physical and Cognitive Age-Related Declines

Limiting Cognitive Decline with Exercise

Addressing age-related physical and cognitive decline can be advantageous in improving independence and reducing fall risk for the aging adult. Fratiglioni et al. (2004) evaluated lifestyle, social networks, and leisure activity and proposed that these components benefit the preservation of cognition and protection against dementia. Moreover, a meta-analysis including 30,331 participants without dementia for up to 12 years indicated physically active individuals significantly reduced the development of cognitive decline during their follow-up period, hence, shielding from a reduction in cognitive function (Sofi et al., 2010). Maintaining physical activity throughout all stages of adulthood may provide additional protection against this deterioration.

Although cognitive decline is inadequately understood, aerobic exercise may provide an answer for preventing or slowing the deterioration while enhancing memory. Various studies have evaluated the benefits of exercise regarding memory with cognition and the malleability or plasticity of the brain. The term "plasticity" refers to the ability of the CNS to repair damaged areas or create new pathways (Fawcett, 2009). Vaynman et al. (2003) evaluated the connection between signaling with brain-derived neurotrophic factor (BDNF) and aerobic exercise on the effects of synaptic plasticity in animals. Brain-derived neurotropic factors are potentially promoted through aerobic exercise to improve learning and memory, offset age-related deficits in cognition, and accelerate recovery from traumatic brain injury and diseases (Vaynman et al., 2003). Vaynman et al. (2003) hypothesized BDNFs, associated with neuron function, repair, and synaptogenesis, have possible neuroprotective effects and impact human cognitive function. Although studies have evaluated blood and serum specimens of BDNF concerning acute exercise and cognition in humans, questions remain about the accuracy of the samples due to the ability of BDNF to cross the blood-brain barrier.

Furthermore, a review by Piepmeier and Etnier (2015) indicated knowledge remains limited about the benefits of BDNF with cognition in humans and that further research is needed to evaluate the signaling pathways of BDNF and its isoforms which may have a counterproductive impact on cognition. Although there is still a need for further research, BDNF may be key to promoting the rebuilding of the CNS in the aging adult. Additionally, aerobic exercise could enhance memory and sustain cognitive function while reducing the risk of injury.

Limiting Physical Decline with Exercise

Various exercise programs, including resistance, aerobic, balance, and flexibility training, have shown effectiveness in improving balance and decreasing fall risk for aging adults. DiBrezzo et al. (2005) evaluated 19 senior participants in a low-cost 10-week exercise program that consisted of stretching, strengthening, and balance training exercises. Participants significantly improved dynamic balance and agility, lower and upper body strength, and upper extremity flexibility, showing exercise programs improved health outcomes (DiBrezzo et al., 2005). Although fall risk was not explicitly assessed in the study, improvements were noted in the participants' functional abilities associated with fall risk.

Incorporating a variety of exercise modalities into a fitness program may also decrease the risk of falls. Injury prevention should be a primary focus with the aging population as it can allow an individual to maintain independence and reduce fears of injury, leading to increased activity. In a meta-analysis, Giné-Garriga et al. (2014) found most multicomponent exercise programs for functionally impaired older adults significantly improved average gait speed and reduced functional disability and injuries. Villareal et al. (2011) also presented evidence that multicomponent exercise programs promoted cardiorespiratory fitness, balance, and strength improvements. Knowing gait speed is a clinical predictor of longevity for the aging adult (Glenn et al., 2015), participation in a physical fitness program that encompasses functional movements may improve and restore mobility decline (Giné-Garriga et al., 2014).

Improving Cognitive and Physical Performance through Exercise

Multiple forms of exercise are proposed to counteract age-related declines within the CNS because of improved bioenergy systems and blood flow. The brain requires 20% of the body's oxygen intake and glucose to function (Anderson et al., 2010). Exercise is thought to mitigate the age-related decline in blood flow to the brain and improve cognition (Anderson et al., 2010). Additionally, exercise offers a neuroprotective effect correlated with the preservation of cognitive abilities and a reduction in dementia and Alzheimer's disease (Weinberg & Gould, 2014). Lastly, Eggenberger et al. (2015) noted long-term multicomponent exercise programs utilizing cognitive-physical training have an advantage in preserving the physical functioning of the older adult.

Multicomponent exercise programs consisting of aerobic and memory training may provide the optimal advantage for cognitive preservation with aging. Eggenberger et al. (2015) evaluated participants in 3 groups, comparing a virtual reality dancing game, treadmill walking with verbal memory coaching, and treadmill walking alone. Additionally, all groups participated in balance and strength exercises. Simultaneous cognitive-physical training and dance significantly improved dual-task walking compared to physical activity alone (Eggenberger et al., 2015). Adding an exercise program that encompasses activities that require the simultaneous use of cognitive and physical abilities in the aging population may prolong one's ability to function independently.

Participation in a multicomponent exercise program that includes balance and dual-task training to address cognitive and physical declines can preserve functional abilities with aging. Martial arts, an ancient form of self-defense, is a physical and mental exercise that combines balance, dual-task movements, and power development. This ageless exercise was practiced originally for self-protection, meditation, and spirituality and is thought to have originated in India (Gulia & Dhauta, 2019). Since then, it has spread worldwide and taken on various styles influenced by a country's culture and environment. The variety of exercises produced with martial arts training may benefit the preservation of physical and cognitive function in the older adult and extend one's independence. There remains a continued need for extensive research on aging and exercise regarding the long-term benefits of physical mobility and cognitive performance.

Taekwondo

One martial art form, Taekwondo, incorporates dynamic balance, power, mental focus, cognition, and dual-tasking. Taekwondo originated in Korea in 1955 and developed to be a crude form of military training for self-defense, employing the hands and feet (Hong Hi, 1999). Today, Taekwondo incorporates both hands and feet for self-defense, exercise, and sport.

The physical demands of Taekwondo training include kicking, striking, and blocking, in addition to transferring body weight through stepping while moving the upper extremities (Cromwell et al., 2007). As such, some of the movements are performed on one leg. Striking with a kick necessitates extending one or both legs outward towards a target with high velocity, resulting in a powerful kick to attack or defend oneself. Producing the kicking movements requires lower body power from standing, moving, or jumping positions for offensive or defensive purposes. The starting position for a kick, known as stancing, can also influence the strike's power and the foot position. Jandačka et al. (2013) noted that during the execution of a proper stance, the velocity of the foot could result in maximum striking power. Kicking also incorporates balance, cognitive abilities, and dual-tasking skills in Taekwondo training.

Producing movements in Taekwondo requires balance to create stepping and kicking movements while maintaining postural stability. Participation in sports that require speed and precision of movements is known to improve posture control. Adults 19 to 22 years who trained in Taekwondo for a minimum of 12 months had improved balance over untrained individuals (Leong et al., 2011). Leong et al. (2011) recognized that practitioners of Taekwondo relied on other responses, such as somatosensory or vestibular feedback, without using vision to preserve balance (Leong et al., 2011). Pons van Dijk et al. (2013a) evaluated adults 40 to 71 years who participated in Taekwondo training and noted several aspects of balance improved while potentially reducing injuries.

Additionally, improving balance in forward movement can be advantageous in decreasing fall risk because walking and gait stability are associated with balance in older adults. In a recent study, Cromwell et al. (2022) evaluated the effectiveness of Taekwondo training in improving balance among adults aged 60-83 years. Their findings indicated participants significantly improved walking velocity and cadence, attributed to the various stances, kicks, blocks, and stepping required in Taekwondo training (Cromwell et al., 2007).

Taekwondo training has also been associated with improvements in cognition. Cho and Roh (2019) found participants who consistently trained in Taekwondo significantly improved their ColorWord test — a test used to evaluate cognitive function. Furthermore, women 65 years and older were noted to have increased neurotrophic factors associated with optimal cognitive functioning (Cho & Roh, 2019). Sparring in Taekwondo can also enhance cognitive abilities because it requires the utilization of various strikes and blocking skills while maneuvering against an opponent. A recent study evaluated the cognitive effects of one year of Taekwondo-based training on an adult population. In this research, Pons Van Dijk et al. (2013) assessed Digit Symbol Coding (Welchsler Adult Intelligence Scale Fourth Edition [WAIS-IV)]), Digit Span (WAIS-IV), Letter Fluency, Trial Making Tests A and B, and a subjective questionnaire administered pre and posttest related to aspects of balance. Participants over 40 years of age who trained in Taekwondo for 15 months improved cognition for information processing, speed, and inhibition (Pons van Dijk et al., 2013a).

Although exercise has been shown to improve dual-task abilities, there is no research on how Taekwondo training can affect dual-task abilities in aging adults. However, exercise and cognitive training can enhance an older adult's cognitive ability (Tait et al., 2017). Bherer et al. (2020) indicated synergistic cognitive outcomes from combining cognitive and exercise training, documenting a positive impact on dual-task abilities. Implementing mental and physical tasks is an integral part of training in Taekwondo. The coordination of hands and feet while performing sequences of movements and navigating the environment under verbal instructions is an essential part of the training. Another dual-task element in Taekwondo training is reaction time during sparring sessions. Reaction time refers to the time it takes to produce a physical response to a visual stimulus. In Taekwondo, sparring participants must use mental and cognitive assessments and respond with a physical action against an opponent. This response time is crucial for successful sports performance and implementing the art's self-defense attributes (Estevan & Falco, 2013).

Conclusion

Current research indicates aging results in physical function and cognition deficits. As a result, the risk of hospitalization or institutionalization is a concern, potentially impacting an individual's quality of life and independence. Although once thought to begin later in life, recent findings suggest physical and cognitive decline starts in early adulthood. Physical exercise and cognitive training are recommended as beneficial interventions for cerebral decline (Bherer et al., 2020). While multiple studies evaluate balance, cognitive function, lower body power, and dual-task abilities in the aging population, research is lacking in the martial art of Taekwondo.

Pons van Dijk et al. (2013) observed Taekwondo training improved cognitive function in multiple areas for adults over 40 years and may provide an affordable resource to slow age-related decline. Knowing that in adulthood, there are declines in lower body power, dual-task abilities, and balance, this study aims to evaluate those who train in Taekwondo throughout the adult age continuum and evaluate the changes observed with adults ages 18 - 34 years, 35 - 54 years, and 55 - 80 years. The purpose of the proposed investigation is to quantify balance, dual-task abilities, and lower body power in individuals who train in traditional Taekwondo. The balance test results will be compared to existing data on the adult population, while the dual-task ability and lower power scores will be compared between the groups.

CHAPTER III

METHODS

Participants

Adult males (*n* = 19) and females (*n* = 27) aged 18 to 80 years (*M* = *46* ± *14 years*) participated in the study. Participants had to be able to stand on both lower limbs evenly without pain, be in good health without uncontrolled symptoms or illness, able to continuously walk one mile without stopping, without active pregnancy, without a concussion in the past six months, and have no diagnosis of a cognitive disorder or uncontrolled vestibular conditions that could impede their ability to perform a cognitive task, standing, balancing, or walking. In addition, participants were required to have a minimum of six months of continuous Taekwondo training, at least one hour, one day per week, to qualify for the study. The study was approved by the University Institutional Review Board (see Appendix A), and participants provided written informed consent prior to participation.

Instrumentation

Assessment of Balance

The mCTSIB was used to assess static balance using BTrackS Balance Plate (Balance Tracking Systems inc., San Diago, CA, USA) attached to a laptop computer using BTrackS Assess Balance software (version 4). The testing protocol consists of four 20-second static balance trials, ultimately providing percentile ranking.

This test reliably measures control of postural sway and denotes volitional dynamic upper body movements without the support of assisted devices (Haworth et al., 2020). Goble et al. (2019) reported the test-retest reliability interclass correlation (ICC) of the BTrackS mCTSIB scored fair (0.47) to excellent (0.79) for day-to-day measurements, fair (0.46) to good (0.67) from week-to-week measurements, and fair (0.48) to good (0.68) for the month-to-month measurements.

Testing was administered in a quiet area with minimal distractions. The balance platform was placed on a solid and level floor, and the computer screen was placed outside the participant's sight. Before starting the testing procedures for the BTracks balance test, participants were asked to remove their shoes and read the on-screen instructions provided by the BTrackS software. Next, participants were asked to stand on the balance platform with feet parallel and approximately shoulder-width apart to ensure proper alignment and hands placed on their hips. When the participant notified the test administrator that they were ready, the mCTSIB was initiated. The readings were collected with eyes open (1st trial), eyes closed (2nd trial), and then with eyes open with a foam pad (3rd trial) and eyes closed with a foam pad (4th trial). There was a 10-second break between each of the balance trials. Participants remained standing on the balance platform during these small rest intervals.

Assessment of Dual-task Ability

Dual-task ability was examined using the methods of Yang et al. (2016), which were observed to have good to excellent reliability (ICC = 0.70 to 0.93). There were four 10m walking tasks: (1) walking forward without a mental tracking task; (2) walking forward with a mental tracking task; (3) walking backward without a mental tracking task; (4)

walking backward with a mental tracking task. All participants completed the walking task in this order. For the mental tracking test, participants were asked to count backward by 3's from the number 70 for forward walking and 110 for backward walking. Each correct and incorrect response was logged to calculate the percentage accuracy. Participants were informed that the test would begin with a "3-2-1 walk" countdown when conducting each walk assessment. For the mental tracking task, the randomly assigned number was given immediately before a "3-2-1 walk" countdown. Participants were given a one-minute standing break between each walking test.

Gait speed was measured during each walking task using a TCI Timing System (Brower Timing System LLC, USA). Two meters were added to the beginning and the end of the walking path to allow for acceleration and deceleration without affecting measurements Flansbier et al. (2005). A 14-meter walkway was marked to conduct these assessments, with markers at the beginning, 2-meter mark, 12-meter mark, and ending point.

Lower Body Power

A vertical jump test using Vertec (Jump USA, Sunnyvale, CA, USA) measured lower body power performance with a countermovement jump (CMJ). The CMJ has demonstrated good reliability in evaluating lower extremity power (Slinde et al., 2008). This test consisted of 3 trials of a countermovement jump with a 10 to 15-second rest period between each jump.

Participants were asked to stand with both feet flat on the floor, shoulder-width apart, standing adjacent to the Vertec with the dominant shoulder closest to the device. They were instructed to extend the dominant arm to the ceiling. The adjustable arm of the

Vertec was lowered to the height of the participant's middle fingertip touching the lowest flag. Next, the participant was instructed to bend their knees into a crouched position less than 90 degrees with arms positioned downward and behind them (Leard et al., 2007). During each jump, the participant's arms swung forward above their head, reaching maximal height while taping the flags. The flags altered from the initial position with the jump were moved away to prepare for the subsequent trial. Any additional flags tapped on the second and third attempts were shifted to the opposite side. The highest recorded jump height was recorded for each participant.

Procedures

Participants were recruited from multiple sites of the Choong-Sil Taekwondo organizations within the southeast region of the United States. The recruitment process resulted from posting flyers within the Taekwondo schools, social media posts, word of mouth, and weekly class and tournament announcements. Data collection occurred at Choong Sil Taekwondo schools and affiliate tournament sites in the southeastern United States. Participants were required to schedule an appointment time for participation and were tested one at a time. Upon arrival at the data collection site, verbal confirmation was obtained that participants met all inclusion criteria. Participants were also screened according to the American College of Sports Medicine Guidelines (ACSM's Guidelines for Exercise Testing and Prescription, 2021) to ensure they could participate without medical clearance. Once pre-participation forms were completed, participants were asked to complete a demographic questionnaire (See Appendix B). Height was measured using a stadiometer (SECA 222, Chino, CA, USA), and body mass was assessed using a digital scale (Tanita, Arlington Heights, IL, USA).

Assessments were completed in the following order for all participants: (1) balance; (2) dual-task walking (3) lower body power. The procedures were explained to the participants, and they were familiarized with each measurement with a 1-2 minute practice time before being assessed. A rest break of a minimum of one to two minutes occurred between each assessment to allow time for recovery.

Data Analysis

Means and standard deviations were calculated for all study-related variables. Data were separated and grouped by age to create three groups (young adults 18 - 34 years, middle-aged adults 35 - 54 years, and older adults 55 - 80 years). All participants were compared to normative data for determining the number of participants at or above the 50% ranking for age for the balance assessments. Three one-way analyses of variance (ANOVA) were run to determine differences among age groups for dual-task walking and lower body power test. Statistical significance was set to a $p < .05$. Results were compared to the usual decline reported in the literature to determine the differences among age groups for lower body power and dual-task walking and percentile ranking for age using the BTrackS mCTSIB scale for the balance test.

CHAPTER IV

RESULTS

Traditional taekwondo participants in this study included males (*n* =19) and females (*n* = 27) aged 43.5 years (± 13.6 years). Of the 48 participants who consented, two did not meet the participation criteria and were excluded, leaving a final sample of 46 participants. The mean height of the participants was 168.6 cm (± 9.4 cm), and mean body mass was 78.6 kgs (± 17.0 kgs).

Lower body muscle power means, and standard deviations are reported in figure 1. The data partially supported the hypothesis that there would be less than a 25% change in lower body power (vertical jump height) between age groups, respectively. The hypothesis was supported by a jump height decrease of 8.6% from the older to the middle age group. The decrease of 29.4% in lower body power from the middle age group to the youngest age group did not support the hypothesis.

There was a statistically significant difference in the jump height among groups (*F*(2, 43) = 12.39, *p* = .00). Post hoc comparisons using the Bonferroni correction test indicated the mean score for the 18 - 34 year age group was statistically higher than the jump height of the 35 - 54 year age group and the 55 - 80 year age group.

The second hypothesis was on dual-task walking among the groups. The means and standard deviations (in seconds) for each group are presented in figure 2. Forward

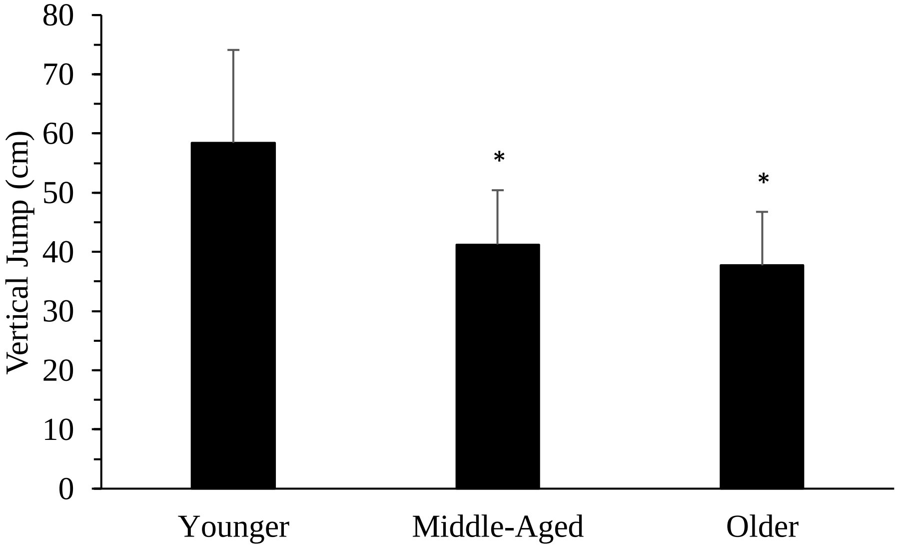


Figure 1

Comparison of Vertical Jump Performance between Young, Middle-Aged, and Older Participants, Respectively

Note. * Indicates a statistically significant difference from younger individuals.

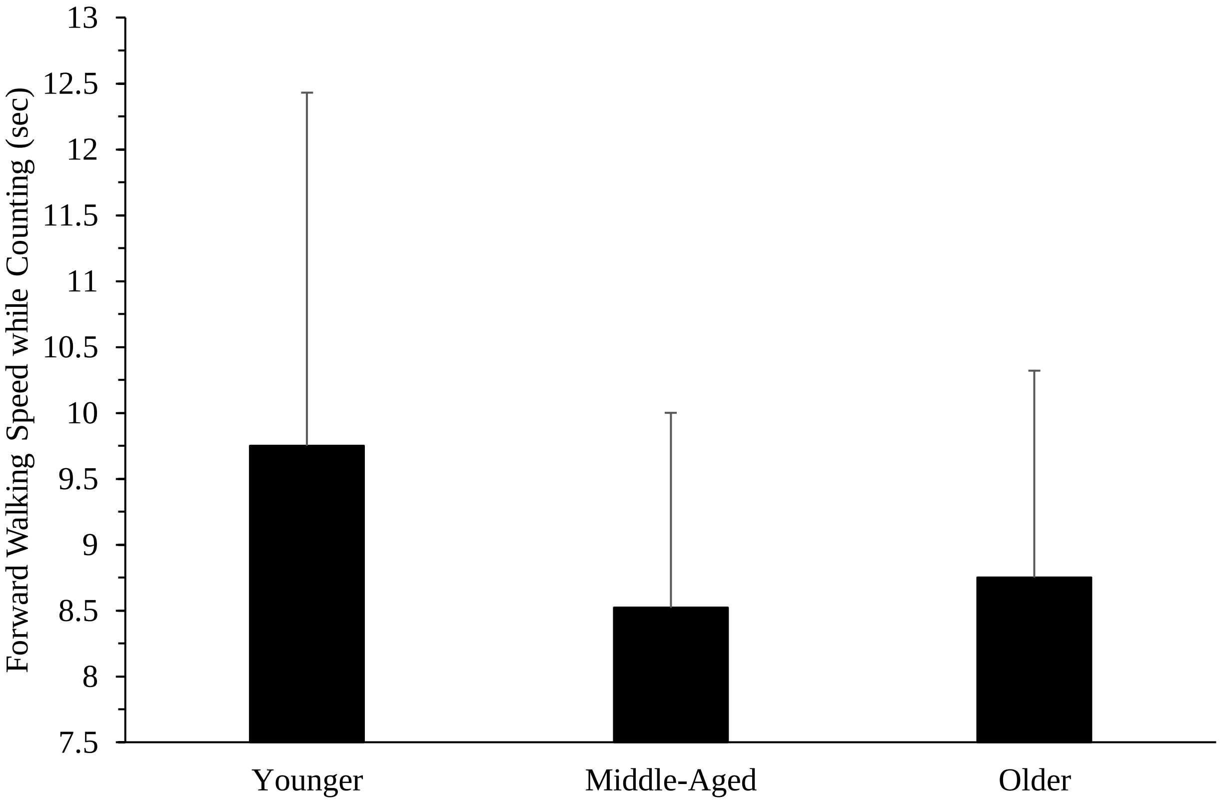


Figure 2

Comparison of Forward Walking Speed while Counting between Young, Middle-Aged, and Older Participants gait speed while counting was less than 25% different between the corresponding groups. Forward waking speed with counting increased by 12.7% from the younger to the middle-aged group and decreased by 2.7% from the middle-aged to the older group, supporting the hypothesis. Furthermore, there were no statistical differences in walking time between the groups with forward walking and counting ($F(2, 43) = 1.79$, $p = .18$).

The four balance scores of the younger, middle-aged, and older adult groups partially supported the third hypothesis. The 35 - 44 year age group fell below the 50th percentile score on the BTrackS normative data scale in the balance test with eyes closed on a firm surface and did not support the hypothesis. However, the balance tests in the 18 - 34 and 55 - 80 year age groups supported the hypothesis being at or above the 50th percentile on the BTrackS normative data scale. Refer to Table 1 and figure 3 for the descriptive statistics in each age group for the specific balance test scores.

Table 1

Balance Scores for Taekwondo Athletes

	Younger		Middle-Aged		Older	
Balance Scores (cm)	*M*	*SD*	*M*	*SD*	*M*	*SD*
Eyes open, firm surface	12.85	2.27	13.48	3.63	16.10	4.84
Eyes closed, firm surface	19.46	5.11	23.52*	4.68	27.90	12.88
Eyes open, foam pad	19.31	3.61	21.22	4.68	27.00	10.82
Eyes closed, foam pad	51.00	14.02	57.61	4.68	84.60	25.11

Note. * = below 50% of the BtrackS normative data scale

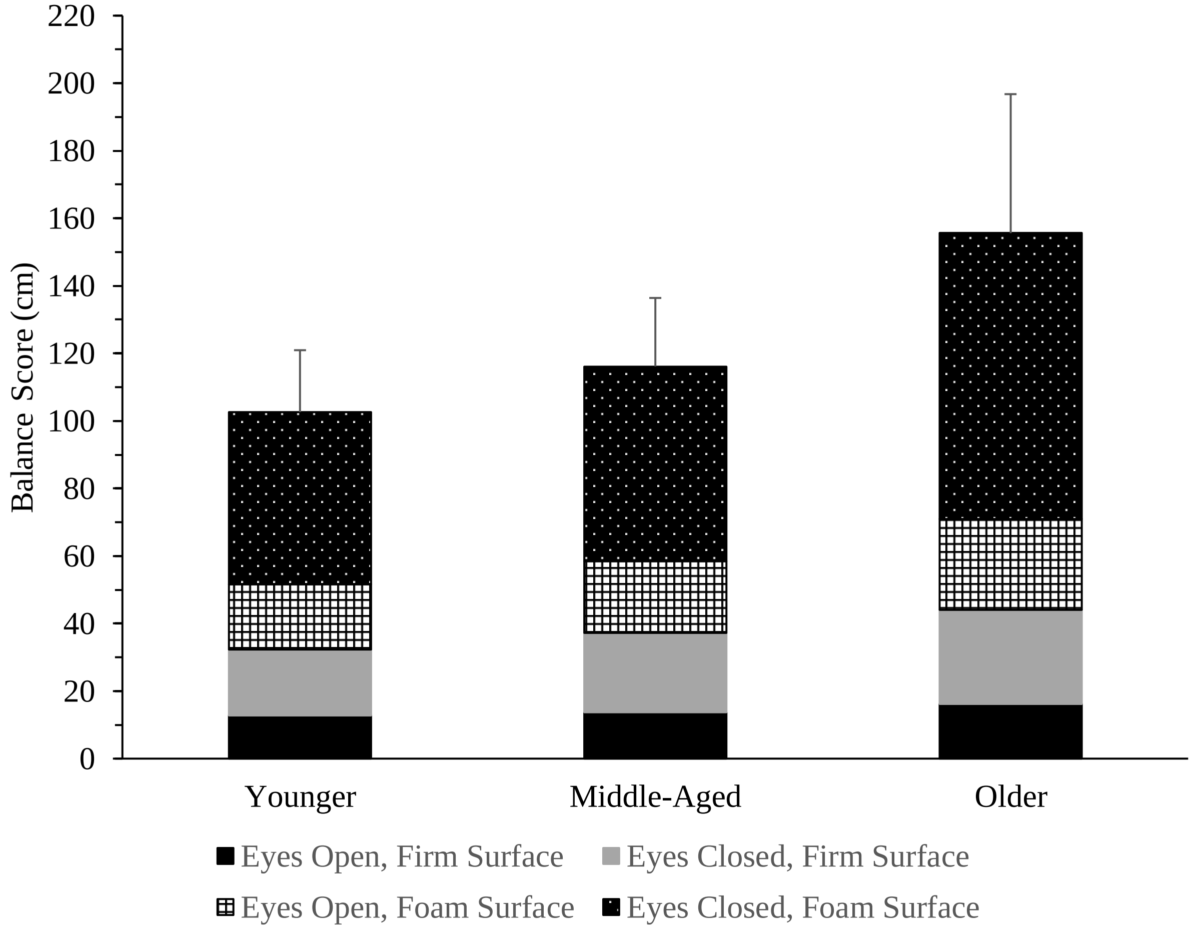


Figure 3

Descriptive Data for Performance on the Modified Clinical Test for Sensory Integration and Balance Among Young, Middle-Aged, and Older Adults

CHAPTER V

DISCUSSION

Traditional Taekwondo has been employed for decades as a method of self-defense using an intense style of physical training to sharpen physical and mental abilities. The movements used in this martial art support the physical and cognitive skills needed throughout adulthood. With life expectancy on the rise and limited resources for health care, preserving functional and cognitive abilities throughout the life span can facilitate prolonged independence, thus decreasing the financial burden on society. Traditional Taekwondo is an exercise form that supports lower body power, dual-task ability, and balance. This martial art can be adapted to various abilities and used throughout the lifespan, presenting a prospective option for maintaining functional ability as individuals age.

This investigation aimed to assess lower body power, dual-task ability, and balance in adult taekwondo athletes compared to expected changes with aging in the adult population. It was hypothesized that adult Taekwondo athletes would have less decline in lower body power and dual-task ability with aging, scoring less than a 25% change between age groups. Furthermore, it was also hypothesized the athletes would score at or above the 50th percentile of normative data for the balance tests.

Lower Body Power

Leg power decreases with aging and is needed to perform daily activities in supporting independent living (Alcazar et al., 2020; Campitelli et al., 2022). It was hypothesized in this study that lower body power would not decrease by more than 25% in moving from the youngest to the middle age to the oldest age group, respectively. Lower body power, measured by vertical jump height, was statistically different ($p = .00$) when evaluating the younger aged group ($M = 58.4$ cm ± 15.7 cm) compared to the middle-aged ($M = 41.3$ cm ± 9.2 cm) and older adults ($M = 37.7$ cm ± 9.0 cm). There was a decline of 29.4% between the 18 – 34 and 35 - 54-year age groups, which did not support the hypothesis. However, there was only an 8.6% decline between the middle-aged and the older adult groups, supporting the hypothesis.

Muscle power decreases by approximately 10% every decade after the third decade of life (Siparsky et al., 2013). This knowledge was used in selecting a 25% decline between the groups as the comparison standard. A possible explanation for the 29.4% decline from the younger to the middle-aged group could be related to a smaller sample of younger participants ($n = 13$) compared to the middle-aged group ($n = 23$). Increasing the sample size may provide a better understanding of the age group comparison for lower body power in future studies. Finally, evaluating the samples' history of lower extremity orthopedic injuries may also provide additional knowledge to explain the significant decline between the younger and middle-aged groups. In future investigations, evaluating the length of Taekwondo training between the groups would be interesting as it could resolve the potential for confounding variables related to jump height. Because fat accumulation and muscle mass loss impact jumping performance in adult athletes (Alvero-Cruz et al., 2021), evaluating the athletes' body composition may also help explain the differences between groups.

Dual-Task Walking

The second hypothesis evaluated dual-task ability in Taekwondo adult athletes. There was predicted to be less than a 25% decrease in dual-task walking from the younger to middle-aged and then from the middle-aged to the older group, respectively. Dual-task walking was assessed by a participant's time to walk forward for 10 meters while counting backward from 70 by 3s. Dual-task walking was not statistically different ($p = .18$) when comparing the younger ($M = 9.8$ seconds ± 2.7 seconds) to the middle-aged group ($M = 8.51$ seconds ± 1.5 seconds) and the middle-aged to the older group (M = 8.7 seconds ± 1.6 seconds) supporting the hypothesis of less than a 25% change between each group. Compared to the younger age group, the middle-aged and older adults produced faster dual-task forward walk times, which was an unexpected finding. The middle-aged group had a dual-task walk time that was 12.7% faster than the younger group. Additionally, dual-task walk times declined by 2.7% from the middle-aged to the older adults.

It was anticipated that middle-aged and older adults would decline in dual-task ability. A possible explanation could be the small sample size in the younger ($n = 13$) and the older groups ($n = 10$) compared to the middle-aged group ($n = 23$). The smaller population in the young and older groups could reflect extreme performance in the sample. Enrolling more participants in future studies may produce results more reflective of the population. Other considerations include the amount of training time in the sport. With the knowledge that dual-task ability can improve with practice (Ruffieux et al., 2015), individuals who start training as adults tend to continue training in Taekwondo throughout the adult continuum. Thus, they potentially have more training time than their younger counterparts.

Balance

Balance scores of the younger, middle-aged, and older adults partially supported the third hypothesis that participants would score at or above the 50th normative percentile for the BtrackS mCTSIB scale. The 35 - 54-year group fell under the 50th percentile for the eyes closed on a firm surface. The other balance test results for all groups supported the hypothesis. An explanation for the middle-aged group not meeting the median percentile could be that the participants had less training time than the other groups. Although the minimum training time for participation was six months, the various lengths of training time were not considered in this study. Additionally, the participants in the study traditionally train on foam mats in their Taekwondo schools. Training on an unstable surface could impact balance on solid surfaces, especially with less training experience.

The physiological decline associated with aging can impact daily functional movements necessary for independent living. Decreases in lower body power (Alcazar et al., 2021), dual-task walking (Beurskens & Bock, 2012), and balance (Marchesi et al., 2022) with aging are well documented in the literature and require both cognitive and physical elements (Foldvari et al., 2000). Taekwondo is a sport that combines these elements with lower body power, dual-task walking, and balance in training. Although two of the hypotheses were only partially supported, this investigation produced evidence that training in traditional Taekwondo can slow the progression of age-related physical and cognitive decline, making it a potential form of exercise for prolonging one's independence.

In conclusion, there is a gap in research on traditional Taekwondo training related to its benefit with aging. Future investigations should evaluate the optimal age and length of training needed to improve an adult's power, dual-task, and balance. Determining the optimal training frequency and intensity would provide additional knowledge to benefit future generations.

REFERENCES

Aagaard, P., Suetta, C., Caserotti, P., Magnusson, S. P., & Kjaer, M. (2010). Role of the nervous system in sarcopenia and muscle atrophy with aging: Strength training as a countermeasure. *Scandinavian Journal of Medicine & Science in Sports*, *20*(1), 49–64.

Aburto, J., Schöley, J., Kashnitsky, I., Zhang, L., Rahal, C., Missov, T. I., Mills, M. C., Dowd, J. B., & Kashyap, R. (2021). Quantifying impacts of the covid-19 pandemic through life-expectancy losses: A population-level study of 29 countries. *International Journal of Epidemiology*, *51*(1), 63–74.

ACSM's guidelines for exercise testing and prescription (11th ed.). (2021). Wolters Kluwer.

Alcazar, J., Aagaard, P., Haddock, B., Kamper, R. S., Hansen, S. K., Prescott, E., Alegre, L. M., Frandsen, U., & Suetta, C. (2020). Age- and sex-specific changes in lower-limb muscle power throughout the lifespan. *The Journals of Gerontology: Series A*, *75*(7), 1369–1378.

Alcazar, J., Aagaard, P., Haddock, B., Kamper, R. S., Hansen, S. K., Prescott, E., Ara, I., Alegre, L. M., Frandsen, U., & Suetta, C. (2021). Assessment of functional sit-to-stand muscle power: Cross-sectional trajectories across the lifespan. *Experimental Gerontology*, *152*, 111448.

Alvero-Cruz, J. R., Brikis, M., Chilibeck, P., Frings-Meuthen, P., Vico Guzmán, J. F., Mittag, U., Michely, S., Mulder, E., Tanaka, H., Tank, J., & Rittweger, J. (2021). Age-related decline in vertical jumping performance in masters track and field athletes: Concomitant influence of body composition. *Frontiers in Physiology, 12*, 643649.

An aging nation: Projected number of children and older adults. (2018, March 13). United States Census Bureau.

Andersen, J. L. (2003). Muscle fibre type adaptation in the elderly human muscle. *Scandinavian Journal of Medicine & Science in Sports*, *13*(1), 40–47.

Anderson, M., Bucks, R. S., & Bayliss, D. M. (2011). Effect of age on dual-task performance in children and adults. *Memory & Cognition*, *39,* 1241–1252.

Aslan, U., Cavlak, U., Yagci, N., & Akdag, B. (2008). Balance performance, aging and falling: A comparative study based on a Turkish sample. *Archives of Gerontology and Geriatrics*, *46*(3), 283–292.

Baumgartner, R. N., Koehler, K. M., Gallagher, D., Romero, L., Heymsfield, S. B., Ross, R. R., Garry, P. J., & Lindeman, R. D. (1998). Epidemiology of sarcopenia among the elderly in new mexico. *American Journal of Epidemiology, 147*(8), 755–763.

Bean, J. F., Kiely, D. K., Herman, S., Leveille, S. G., Mizer, K., Frontera, W. R., & Fielding, R. A. (2002). The relationship between leg power and physical performance in mobility-limited older people. *Journal of the American Geriatrics Society*, *50*(3), 461–467.

Beauchet, O., Annweiler, C., Dubost, V., Allali, G., Kressig, R., Bridenbaugh, S., Berrut, G., Assal, F., & Herrmann, F. (2009). Stops walking when talking: a predictor of falls in older adults? *European Journal of Neurology, 16*, 786–795.

Beauchet, O., Annweiler, C., Allali, G., Berrut, G., & Herrmann, F. R., Veronique Dubost. (2008). Recurrent falls and dual task-related decrease in walking speed: Is there a relationship? *American Geriatrics Society*, *56*(7), 1265–1269.

Benichou, O., & Lord, S. R. (2016). Rationale for strengthening muscle to prevent falls and fractures: A review of the evidence. *Calcified Tissue International*, *98*(6), 531–545.

Bennett, D. A., Beckett, L. A., Murray, A. M., Shannon, K. M., Goetz, C. G., Pilgrim, D. M., & Evans, D. A. (1996). Prevalence of parkinsonian signs and associated mortality in a community population of older people. *New England Journal of Medicine*, *334*(2), 71–76.

Bergen, G., Stevens, M., & Burns, E. (2016). *Falls and fall injuries among adults aged ≥ 65 years — United States, 2014* (65; 993-998). Morbidity and Mortality Weekly Report.

Beurskens, R., & Bock, O. (2012). Age-related deficits of dual-task walking: A review. *Neural Plasticity*, 1–9.

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *Journal of Aging Research*, *2013*, 1–8.

Bherer, L., Gagnon, C., Langeard, A., Lussier, M., Desjardins-Crépeau, L., Berryman, N., Bosquet, L., Vu, T., Fraser, S., Li, K. H., & Kramer, A. F. (2020). Synergistic effects of cognitive training and physical exercise on dual-task performance in older adults. *The Journals of Gerontology: Series B, 76*(8), 1533–1541.

Boelens, C., Hekman, E., & Verkerke, G. (2013). Risk factors for falls of older citizens. *Technology and Health Care, 21*(5), 521–533.

Bohannon, R. W. (1987). The clinical measurement of strength. *Clinical Rehabilitation, 1*(1), 5–16.

Boyer, K. A., Johnson, R. T., Banks, J. J., Jewell, C., & Hafer, J. F. (2017). Systematic review and meta-analysis of gait mechanics in young and older adults. *Experimental Gerontology, 95*, 63–70.

Beurskens, R., & Bock, O. (2013). Does the walking task matter? Influence of different walking conditions on dual-task performances in young and older persons. *Human Movement Science, 32*(6), 1456–1466.

Caetano, M. D., Lord, S. R., Allen, N. E., Song, J., Paul, S. S., Canning, C. G., & Menant, J. C. (2019). Executive functioning, muscle power and reactive balance are major contributors to gait adaptability in people with Parkinson's Disease. *Frontiers in Aging Neuroscience, 11*(154), 1–11.

Campitelli, A., Paulson, S., Vincenzo, J., Glenn, J. M., Gills, J. L., Jones, M. D., Powers, M., & Gray, M. (2021). Sit-to-stand power across the lifespan: A cross-sectional analysis. *Journal of Aging and Physical Activity*, 1–11.

Carraro, U., Kern, H., Gava, P., Hofer, C., Loefler, S., Gargiulo, P., Edmunds, K., Árnadóttir, Í., Zampieri, S., Ravara, B., Gava, F., Nori, A., Gobbo, V., Masiero, S., Marcante, A., Baba, A., Piccione, F., Schils, S., Pond, A., & Mosole, S. (2016). Recovery from muscle weakness by exercise and fes: Lessons from masters, active or sedentary seniors and sci patients. *Aging Clinical and Experimental Research*, *29*(4), 579–590.

Charles, A., Buckinx, F., Locquet, M., Reginster, J.-Y., Petermans, J., Gruslin, B., & Bruyère, O. (2019). Prediction of adverse outcomes in nursing home residents according to intrinsic capacity proposed by the world health organization. *The Journals of Gerontology: Series A*, *75*(8), 1594–1599.

Chen, T., & Chou, L.-S. (2013). Altered center of mass control during sit-to-walk in elderly adults with and without history of falling. *Gait & Posture*, *38*(4), 696–701.

Chen, T., & Yoshida, Y. (2021). Effects of power on balance and fall prevention in aging and older adults. *Topics in Geriatric Rehabilitation*, *37*(1), 7–11.

Cho, S.-Y., & Roh, H.-T. (2019). Taekwondo enhances cognitive function as a result of increased neurotrophic growth factors in elderly women. *International Journal of Environmental Research and Public Health*, *16*(6), 962.

Cromwell, R. L., Meyers, P. M., Meyers, P. E., & Newton, R. A. (2007). Tae kwon do: An effective exercise for improving balance and walking ability in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(6), 641–646.

DiBrezzo, R., Shadden, B. B., Raybon, B. H., & Powers, M. (2005). Exercise intervention designed to improve strength and dynamic balance among community-dwelling older adults. *Journal of Aging and Physical Activity*, *13*(2), 198–209.

Dodds, R., Kuh, D., Sayer, A., & Cooper, R. (2018). Can measures of physical performance in mid-life improve the clinical prediction of disability in early old age? Findings from a British birth cohort study. *Experimental Gerontology*, *110*, 118–124.

Eggenberger, P., Theill, N., Holenstein, S., Schumacher, V., & de Bruin, E. (2015). Multicomponent physical exercise with simultaneous cognitive training to enhance dual-task walking of older adults: A secondary analysis of a 6-month randomized controlled trial with 1-year follow-up. *Clinical Interventions in Aging*, 1711–1732.

Estevan, I., & Falco, C. (2013). Mechanical analysis of the roundhouse kick according to height and distance in Taekwondo. *Biology of Sport*, *30*(4), 275–279.

Favaretto, A., Lazzarotto, A., Margoni, M., Poggiali, D., & Gallo, P. (2018). Effects of disease modifying therapies on brain and grey matter atrophy in relapsing remitting multiple sclerosis. *Multiple Sclerosis and Demyelinating Disorders,* *3*(1), 1–10.

Fawcett, J. (2009). Molecular control of brain plasticity and repair. In *Progress in brain research* (pp. 501–509). Elsevier.

Fielding, R. A., LeBrasseur, N. K., Cuoco, A., Bean, J., Mizer, K., & Singh, M. (2002). High-velocity resistance training increases skeletal muscle peak power in older women. *Journal of the American Geriatrics Society*, *50*(4), 655–662.

Fitzpatrick, R., & McCloskey, D. I. (1994). Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. *The Journal of Physiology*, *478*(1), 173–186.

Foldvari, M., Clark, M., Laviolette, L., Bernstein, M. J., Castaneda, C., Pu, C. T., Hausdorff, J., Fielding, R. A., & Fiatarone Singh, M. A. (2000). Association of muscle power with functional status in community dwelling elderly women. *Medicine & Science in Sports & Exercise*, *31*(5), S378.

Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *The Lancet Neurology, 3*(6), 343–353.

Gava, P., Kern, H., & Carraro, U. (2015). Age-associated power decline from running, jumping, and throwing male masters world records. *Experimental Aging Research*, *41*(2), 115–135.

Giné-Garriga, M., Roqué-Fíguls, M., Coll-Planas, L., Sitjà-Rabert, M., & Salvà, A. (2014). Physical exercise interventions for improving performance-based measures of physical function in community-dwelling, frail older adults: A systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *95*(4), 753–769.

Glenn, J. M., Vincenzo, J., Canella, C. K., Binns, A., & Gray, M. (2015). Habitual and maximal dual-task gait speeds among sedentary, recreationally active, and masters athlete late middle-aged adults. *Journal of Aging and Physical Activity*, *23*(3), 433–437.

Goble, D. J., Brar, H., Brown, E. C., Marks, C., & Baweja, H. S. (2019). Normative data for the balance tracking system modified clinical test of sensory integration and balance protocol. *Medical Devices: Evidence and Research*, *Volume 12*, 183–191.

Gulia, S., & Dhauta, R., Dr. (2019). Traditional games in India: Their origin and status in progressive era. *International Journal of Physiology, Nutrition and Physical Education*, *4*(1), 1252–1254.

Hajek, A., Brettschneider, C., Lange, C., Posselt, T., Wiese, B., Steinmann, S., Weyerer, S., Werle, J., Pentzek, M., Fuchs, A., Stein, J., Luck, T., Bickel, H., Mösch, E., Wagner, M., Jessen, F., Maier, W., Scherer, M., Riedel-Heller, S. G., & König, H.-H. (2015). Longitudinal predictors of institutionalization in old age. *PLOS ONE*, *10*(12), e0144203.

Hall, K. S., Cohen, H. J., Pieper, C. F., Fillenbaum, G. G., Kraus, W. E., Huffman, K. M., Cornish, M. A., Shiloh, A., Flynn, C., Sloane, R., Newby, L., & Morey, M. C. (2016). Physical performance across the adult life span: Correlates with age and physical activity. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *72*(4), 572–578.

Harada, C. N., Natelson Love, M. C., & Triebel, K. (2013). Normal cognitive aging. *Clinics in Geriatric Medicine*, *29*(4), 737–752.

Harper, S. (2004). *Families in ageing societies* (1st ed.). Oxford University Press Academic UK.

Harper, S. (2010). The capacity of social security and health care institutions to adapt to an ageing world. *International Social Security Review, 63*(3-4), 177–196.

Harper, S. (2014). Economic and social implications of aging societies. *Science, 346*(6209), 587–591.

Hausdorff, J. M., Schweiger, A., Herman, T., Yogev-Seligmann, G., & Giladi, N. (2008). Dual-task decrements in gait: Contributing factors among healthy older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *63*(12), 1335–1343.

Haworth, J., Goble, D., Pile, M., & Kendall, B. (2020). Btracks limits of stability test is a reliable assessment of volitional dynamic postural control. *Gait & Posture*, *80,* 298–301.

Henderson, R. M., Leng, X., Chmelo, E. A., Brinkley, T. E., Lyles, M. F., Marsh, A. P., & Nicklas, B. J. (2016). Gait speed response to aerobic versus resistance exercise training in older adults. *Aging Clinical and Experimental Research, 29*(5), 969–976.

Hiemstra, L. A., Lo, I. K., & Fowler, P. J. (2001). Effect of fatigue on knee proprioception: Implications for dynamic stabilization. *Journal of Orthopaedic & Sports Physical Therapy, 31*(10), 598–605.

Holviala, J., Kraemer, W. J., Sillanpää, E., Karppinen, H., Avela, J., Kauhanen, A., Häkkinen, A., & Häkkinen, K. (2011). Effects of strength, endurance, and combined training on muscle strength, walking speed and dynamic balance in aging men. *European Journal of Applied Physiology*, *112*(4), 1335–1347.

Hong Hi, G. (1999). *Taekwon-do* (Fifth ed.). International Taekwon-do Federeation.

Horak, F. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, *35-S2*, ii7–ii11.

Hourigan, M. L., McKinnon, N. B., Johnson, M., Rice, C. L., Stashuk, D. W., & Doherty, T. J. (2015). Increased motor unit potential shape variability across consecutive motor unit discharges in the tibialis anterior and vastus medialis muscles of healthy older subjects. *Clinical Neurophysiology*, *126*(12), 2381–2389.

Howdon, D., & Rice, N. (2018). Health care expenditures, age, proximity to death and morbidity: Implications for an ageing population. *Journal of Health Economics*, *57*, 60–74.

Hruda, K. V., Hicks, A. L., & Mccartney, N. (2003). Training for muscle power in older adults: Effects on functional abilities. *Canadian Journal of Applied Physiology*, *28*(2), 178–189.

Jandačka, D., Estevan, I., Janura, M., & Falco, C. (2013). The impact of the initial stance position on lower limb joint kinetics in the taekwondo roundhouse kick. *Acta Gymnica*, *43*(2), 15–22.

Jenkner, E., & Leive, A. (2010). Health care spending issues in advanced economies. *Technical Notes and Manuals*, *2010*(16), 1–10.

Jia, H., Lubetkin, E. I., DeMichele, K., Stark, D. S., Zack, M. M., & Thompson, W. W. (2019). Prevalence, risk factors, and burden of disease for falls and balance or walking problems among older adults in the U.S. *Preventive Medicine*, *126*, 105737.

Kanasi, E., Ayilavarapu, S., & Jones, J. (2016). The aging population: Demographics and the biology of aging. *Periodontology 2000*, *72*(1), 13–18.

Kandel, E. R., Schwartz, J. H., Jassell, T. M., Siegelbaum, S. A., & Hudspeth, A. J. (2012). *Principles of neural science, fifth edition (principles of neural science (Kandel)* (5th ed.). McGraw-Hill Education / Medical.

Karlsson, M. K., & Rosengren, B. E. (2020). Exercise and peak bone mass. *Current Osteoporosis Reports*, *18*(3), 285–290.

Kasovic, M., Stefan, L., & Stefan, A. (2021). Normative data for gait speed and height norm speed in ≥ 60-year-old men and women. *Clinical Interventions in Aging*, *16*, 225–230.

Kosek, D. J., Kim, J., Petrella, J. K., Cross, J. M., & Bamman, M. M. (2006). Efficacy of 3 days/wk resistance training on myofiber hypertrophy and myogenic mechanisms in young vs. older adults. *Journal of Applied Physiology*, *101*(2), 531–544.

Koushyar, H., Bieryla, K. A., Nussbaum, M. A., & Madigan, M. L. (2019). Age-related strength loss affects non-stepping balance recovery. *PLOS ONE*, *14*(1), e0210049.

Laessoe, U., Hoeck, H. C., Simonsen, O., & Voigt, M. (2008). Residual attentional capacity amongst young and elderly during dual and triple task walking. *Human Movement Science*, *27*(3), 496–512.

Lang, T., Streeper, T., Cawthon, P., Baldwin, K., Taaffe, D. R., & Harris, T. B. (2009). Sarcopenia: Etiology, clinical consequences, intervention, and assessment. *Osteoporosis International*, *21*(4), 543–559.

Larsson, L., Degens, H., Li, M., Salviati, L., Lee, Y., Thompson, W., Kirkland, J. L., & Sandri, M. (2019). Sarcopenia: Aging-related loss of muscle mass and function. *Physiological Reviews*, *99*(1), 427–511.

Leard, J. S., Cirillo, M. A., Katsnelson, E., Kimiatek, D. A., Miller, T. W., Trebincevic, K., & Garbalosa, J. C. (2007). Validity of two alternative systems for measuring vertical jump height. *The Journal of Strength and Conditioning Research*, *21*(4), 1296–1299.

Lee, D.-K., Kang, M.-H., Lee, T.-S., & Oh, J.-S. (2015). Relationships among the y balance test, berg balance scale, and lower limb strength in middle-aged and older females. *Brazilian Journal of Physical Therapy*, *19*(3), 227–234.

Leirós-Rodríguez, R., Romo-Pérez, V., García-Soidán, J., & García-Liñeira, J. (2020). Percentiles and reference values for the accelerometric assessment of static balance in women aged 50–80 years. *Sensors*, *20*(3), 940.

Leong, H.-T., Fu, S. N., Ng, G. F., & Tsang, W. N. (2011). Low-level taekwondo practitioners have better somatosensory organisation in standing balance than sedentary people. *European Journal of Applied Physiology*, *111*(8), 1787–1793.

Lexell, J., Taylor, C. C., & Sjöström, M. (1988). What is the cause of the ageing atrophy? *Journal of the Neurological Sciences*, *84*(2-3), 275–294.

Lindenberger, U., Marsiske, M., & Baltes, P. B. (2000). Memorizing while walking: Increase in dual-task costs from young adulthood to old age. *Psychology and Aging*, *15*(3), 417–436.

Liu-Ambrose, T. Y., Ashe, M. C., Graf, P., Beattie, B., & Khan, K. M. (2008). Increased risk of falling in older community-dwelling women with mild cognitive impairment. *Physical Therapy, 88*(12), 1482–1491.

Luppa, M., Luck, T., Weyerer, S., Konig, H., Brahler, E., & Riedel-Heller, S. G. (2009). Prediction of institutionalization in the elderly. A systematic review. *Age and Ageing*, *39*(1), 31–38.

Marchesi, G., De Luca, A., Squeri, V., De Michieli, L., Vallone, F., Pilotto, A., Leo, A., Casadio, M., & Canessa, A. (2022). A lifespan approach to balance in static and dynamic conditions: The effect of age on balance abilities. *Frontiers in Neurology, 13*, 801142.

Mapelli, A., Zago, M., Fusini, L., Galante, D., Colombo, A., & Sforza, C. (2014). Validation of a protocol for the estimation of three-dimensional body center of mass kinematics in sport. *Gait & Posture*, *39*(1), 460–465.

Mayson, D. J., Kiely, D. K., LaRose, S. I., & Bean, J. F. (2008). Leg strength or velocity of movement. *American Journal of Physical Medicine & Rehabilitation*, *87*(12), 969–976.

McKinnon, N. B., Connelly, D. M., Rice, C. L., Hunter, S. W., & Doherty, T. J. (2017). Neuromuscular contributions to the age-related reduction in muscle power: Mechanisms and potential role of high velocity power training. *Ageing Research Reviews*, *35*, 147–154.

McNeil, C. J., Vandervoort, A. A., & Rice, C. L. (2007). Peripheral impairments cause a progressive age-related loss of strength and velocity-dependent power in the dorsiflexors. *Journal of Applied Physiology*, *102,* 1962–1968.

Mitchell, W., Williams, J., Atherton, P., Larvin, M., Lund, J., & Narici, M. (2012). Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Frontiers in Physiology*, *3*, 260.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.

Montero-Odasso, M., Oteng-Amoako, A., Speechley, M., Gopaul, K., Beauchet, O., Annweiler, C., & Muir-Hunter, S. W. (2014). The motor signature of mild cognitive impairment: Results from the gait and brain study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *69*(11), 1415–1421.

Muehlbauer, T., Gollhofer, A., & Granacher, U. (2015). Associations between measures of balance and lower-extremity muscle strength/power in healthy individuals across the lifespan: A systematic review and meta-analysis. *Sports Medicine*, *45*(12), 1671–1692.

Muir-Hunter, S., & Wittwer, J. (2016). Dual-task testing to predict falls in community-dwelling older adults: A systematic review. *Physiotherapy*, *102*(1), 29–40.

Nnodim, J. O. (2015). Balance and its clinical assessment in older adults - A review. *Journal of Geriatric Medicine and Gerontology*, *1*(1).

Olshansky, S., Goldman, D. P., Zheng, Y., & Rowe, J. W. (2009). Aging in America in the twenty-first century: Demographic forecasts from the MacArthur Foundation Research Network on an Aging Society. *Milbank Quarterly*, *87*(4), 842–862.

Orr, R., Raymond, J., & Fiatarone Singh, M. (2008). Efficacy of progressive resistance training on balance performance in older adults. *Sports Medicine*, *38*(4), 317–343.

Padilla, C. J., Harrigan, M. E., Harris, H., Schwab, J. M., Rutkove, S. B., Rich, M. M., Clark, B. C., & Arnold, W. (2021). Profiling age-related muscle weakness and wasting: Neuromuscular junction transmission as a driver of age-related physical decline. *GeroScience*, *43*(3), 1265–1281.

Pichierri, G., Wolf, P., Murer, K., & de Bruin, E. D. (2011). Cognitive and cognitive-motor interventions affecting physical functioning: A systematic review. *BMC Geriatrics*, *11*(1), 1–19.

Piepmeier, A. T., & Etnier, J. L. (2015). Brain-derived neurotrophic factor (bdnf) as a potential mechanism of the effects of acute exercise on cognitive performance. *Journal of Sport and Health Science*, *4*(1), 14–23.

Pons Van Dijk, G., Lenssen, A. F., Leffers, P., Kingma, H., & Lodder, J. (2013a). Taekwondo training improves balance in volunteers over 40. *Frontiers in Aging Neuroscience*, *5*, 1–10.

Prince, M. J., Wu, F., Guo, Y., Gutierrez Robledo, L. M., O'Donnell, M., Sullivan, R., & Yusuf, S. (2015). The burden of disease in older people and implications for health policy and practice. *The Lancet*, *385*(9967), 549–562.

Reid, K. F., & Fielding, R. A. (2012). Skeletal muscle power: A critical determinant of physical functioning in older adults. *Exercise Sport Science Review*, *40*(1), 4–12.

Reid, K. F., Pasha, E., Doros, G., Clark, D. J., Patten, C., Phillips, E. M., Frontera, W. R., & Fielding, R. A. (2013). Longitudinal decline of lower extremity muscle power in healthy and mobility-limited older adults: Influence of muscle mass, strength, composition, neuromuscular activation and single fiber contractile properties. *European Journal of Applied Physiology*, *114*(1), 29–39.

Ribeiro, F., & Oliveira, J. (2007). Aging effects on joint proprioception: The role of physical activity in proprioception preservation. *European Review of Aging and Physical Activity*, *4*(2), 71–76.

Richmond, S. B., Dames, K. D., Goble, D. J., & Fling, B. W. (2018). Leveling the playing field: Evaluation of a portable instrument for quantifying balance performance. *Journal of Biomechanics*, *75*, 102–107.

Roberts, A. W., Ogunwole, S. U., Blakeslee, L., & Rabe, M. A. (2018). *The population 65 years and older in the United States: 2016* (October 2018 ACS-38) [Report]. United States Census Bureau.

Robertson, M., Campbell, A., Gardner, M. M., & Devlin, N. (2002). Preventing injuries in older people by preventing falls: A meta-analysis of individual-level data. *Journal of the American Geriatrics Society*, *50*(5), 905–911.

Rubega, M., Di Marco, R., Zampini, M., Formaggio, E., Menegatti, E., Bonato, P., Masiero, S., & Del Felice, A. (2021). Muscular and cortical activation during dynamic and static balance in the elderly: A scoping review. *Aging Brain*, *1*, 100013.

Ruffieux, J., Keller, M., Lauber, B., & Taube, W. (2015). Changes in standing and walking performance under dual-task conditions across the lifespan. *Sports Medicine*, *45*(12), 1739–1758.

Ruwer, S., Rossi, A., & Simon, L. (2005). Balance in the elderly. *Brazilian Journal of Otorhinolaryngology*, *71*(3), 298–303.

Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging*, *30*(4), 507–514.

Schubert, M., Beck, S., Taube, W., Amtage, F., Faist, M., & Gruber, M. (2008). Balance training and ballistic strength training are associated with task-specific corticospinal adaptations. *European Journal of Neuroscience*, *27*(8), 2007–2018.

Shafiee, G., Keshtkar, A., Soltani, A., Ahadi, Z., Larijani, B., & Heshmat, R. (2017). Prevalence of sarcopenia in the world: A systematic review and meta-analysis of general population studies. *Journal of Diabetes & Metabolic Disorders*, *16*, 1–10.

Sherwood, J. J., Inouye, C., Webb, S. L., & O, J. (2020). Reliability and validity of the sit-to-stand as a muscular power measure in older adults. *Journal of Aging and Physical Activity*, *28*(3), 455–466.

Shubert, T. E., McCulloch, K., Hartman, M., & Giuliani, C. A. (2010). The effect of an exercise-based balance intervention on physical and cognitive performance for older adults. *Journal of Geriatric Physical Therapy*, *33*(4), 157–164.

Siparsky, P. N., Kirkendall, D. T., & Garrett, W. E. (2013). Muscle changes in aging. *Sports Health: A Multidisciplinary Approach*, *6*(1), 36–40.

Siu, K.-C., Chou, L.-S., Mayr, U., van Donkelaar, P., & Woollacott, M. H. (2009). Attentional mechanisms contributing to balance constraints during gait: The effects of balance impairments. *Brain Research*, *1248*, 59–67.

Slinde, F., Suber, C., Suber, L., Edwen, C., & Svantesson, U. (2008). Test-retest reliability of three different countermovement jumping test. *Journal of Strength and Conditioning Research*, *22*(2), 640–644.

Smith-Ray, R. L., Hughes, S. L., Prohaska, T. R., Little, D. M., Jurivich, D. A., & Hedeker, D. (2013). Impact of cognitive training on balance and gait in older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *70*(3), 357–366.

Soendenbroe, C., Andersen, J. L., & Mackey, A. L. (2021). Muscle-nerve communication and the molecular assessment of human skeletal muscle denervation with aging. *American Journal of Physiology-Cell Physiology*, *321*(2), C317–C329.

Sofi, F., Valecchi, D., Bacci, D., Abbate, R., Gensini, G. F., Casini, A., & Macchi, C. (2010). Physical activity and risk of cognitive decline: A meta-analysis of prospective studies. *Journal of Internal Medicine*, *269*(1), 107–117.

Stanmore, E. K., Mavroeidi, A., de Jong, L. D., Skelton, D. A., Sutton, C. J., Benedetto, V., Munford, L. A., Meekes, W., Bell, V., & Todd, C. (2019). The effectiveness and cost-effectiveness of strength and balance exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: A multi-centre, cluster randomised controlled trial. *BMC Medicine, 17*, 1–14.

Statsenko, Y., Habuza, T., Gorkom, K.-V., Zaki, N., Almansoori, T. M., Al Zahmi, F., Ljubisavljevic, M. R., & Belghali, M. (2021). Proportional changes in cognitive subdomains during normal brain aging. *Frontiers in Aging Neuroscience*, *13*, 673469.

Steffen, T. M., Hacker, T. A., & Mollinger, L. (2002). Age- and gender-related test performance in community-dwelling elderly people: Six-minute walk test, berg balance scale, timed up & go test, and gait speeds. *Physical Therapy*, *82*(2), 128–137.

Sterling, D. A., O'Connor, J. A., & Bonadies, J. (2001). Geriatric falls: Injury severity is high and disproportionate to mechanism. *The Journal of Trauma: Injury, Infection, and Critical Care*, *50*(1), 116–119.

Stevens, J. A., Ballesteros, M. F., Mack, K. A., Rudd, R. A., DeCaro, E., & Adler, G. (2012). Gender differences in seeking care for falls in the aged Medicare population. *American Journal of Preventive Medicine*, *43*(1), 59–62.

Studenski, S. (2011). Gait speed and survival in older adults. *The Journal of the American Medical Association*, *305*(1), 50–58.

Tait, J. L., Duckham, R. L., Milte, C. M., Main, L. C., & Daly, R. M. (2017). Influence of sequential vs. simultaneous dual-task exercise training on cognitive function in older adults. *Frontiers in Aging Neuroscience*, *9*, 368.

Tieland, M., Trouwborst, I., & Clark, B. C. (2017). Skeletal muscle performance and ageing. *Journal of Cachexia, Sarcopenia and Muscle*, *9*(1), 3–19.

Tinetti, M. (2003). Preventing falls in elderly persons. *The New England Journal of Medicine*, *348*(1), 42–49.

Uematsu, A., Hortobágyi, T., Tsuchiya, K., Kadono, N., Kobayashi, H., Ogawa, T., & Suzuki, S. (2018). Lower extremity power training improves healthy old adults' gait biomechanics. *Gait & Posture*, *62*, 303–310.

van Dijk, P. M., Meulenberg, O. M., van de Sande, H. J., & Habbema, J. F. (1993). Falls in dementia patients. *The Gerontologist*, *33*(2), 200–204.

van Schoor, N. M., Smit, J. H., Pluijm, S., Jonker, C., & Lips, P. (2002). Different cognitive functions in relation to falls among older persons. *Journal of Clinical Epidemiology*, *55*(9), 855–862.

Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2003). Interplay between brain-derived neurotrophic factor and signal transduction modulators in the regulation of the effects of exercise on synaptic plasticity. *Neuroscience*, *122*(3), 647–657.

Verghese, J., LeValley, A., Hall, C. B., Katz, M. J., Ambrose, A. F., & Lipton, R. B. (2006). Epidemiology of gait disorders in community-residing older adults. *Journal of the American Geriatrics Society*, *54*(2), 255–261.

Villareal, D. T., Smith, G. I., Sinacore, D. R., Shah, K., & Mittendorfer, B. (2011). Regular multicomponent exercise increases physical fitness and muscle protein anabolism in frail, obese, older adults. *Obesity*, *19*(2), 312–318.

von Haehling, S., Morley, J. E., & Anker, S. D. (2010). An overview of sarcopenia: Facts and numbers on prevalence and clinical impact. *Journal of Cachexia, Sarcopenia and Muscle*, *1*(2), 129–133.

Weinberg, R. S., & Gould, D. (2014). *Foundations of sport and exercise psychology* (6th ed.). Human Kinetics Publishers.

White, D. K., Neogi, T., Nevitt, M. C., Peloquin, C. E., Zhu, Y., Bourdreau, R. M., Cauley, J. A., Ferrucci, L., Harris, T. B., Satterfield, S. M., Simonsick, E. M., Strotmeyer, E. S., & Zhang, Y. (2013). Trajectories of gait speed predict mortality in well-functioning older adults: the health, aging, and body composition study. *The Journals of Gerontology: Series A*, *68*(4), 456–464.

Xiao, T., Yang, L., Smith, L., Loprinzi, P. D., Veronese, N., Yao, J., Zhang, Z., & Yu, J. (2020). Correlation between cognition and balance among middle-aged and older adults observed through a Tai Chi intervention program. *Frontiers in Psychology, 11*, 668.

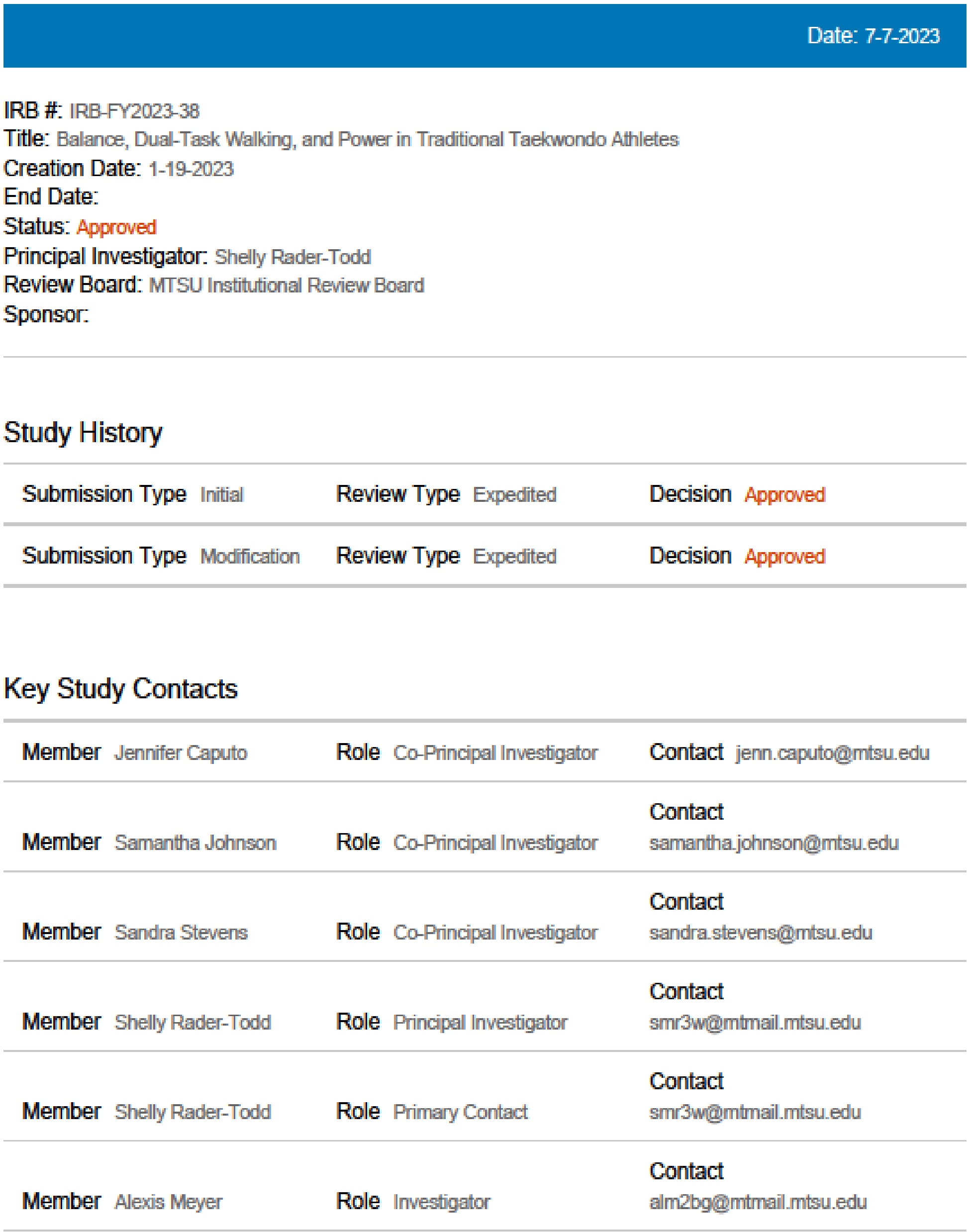
Yang, L., He, C., & Pang, M. (2016). Reliability and validity of dual-task mobility assessments in people with chronic stroke. *PLOS ONE*, *11*(1), e0147833.

Yogev-Seligmann, G., Rotem-Galili, Y., Mirelman, A., Dickstein, R., Giladi, N., Hausdorff, J. M. (2010). How does explicit prioritization alter walking during effects of age and sex on gait speed and variability. *Physical Therapy Rehabilitation Journal*, 90(2), 177-186.

APPENDICES

Appendix A

IRB Letter of Approval



Date: 7-7-2023

IRB #: IRB-FY2023-38
Title: Balance, Dual-Task Walking, and Power in Traditional Taekwondo Athletes
Creation Date: 1-19-2023
End Date:
Status: Approved
Principal Investigator: Shelly Rader-Todd
Review Board: MTSU Institutional Review Board
Sponsor:

Study History

Submission Type	Initial	**Review Type**	Expedited	**Decision**	Approved
Submission Type	Modification	**Review Type**	Expedited	**Decision**	Approved

Key Study Contacts

Member	Jennifer Caputo	**Role**	Co-Principal Investigator	**Contact**	jenn.caputo@mtsu.edu
Member	Samantha Johnson	**Role**	Co-Principal Investigator	**Contact**	samantha.johnson@mtsu.edu
Member	Sandra Stevens	**Role**	Co-Principal Investigator	**Contact**	sandra.stevens@mtsu.edu
Member	Shelly Rader-Todd	**Role**	Principal Investigator	**Contact**	smr3w@mtmail.mtsu.edu
Member	Shelly Rader-Todd	**Role**	Primary Contact	**Contact**	smr3w@mtmail.mtsu.edu
Member	Alexis Meyer	**Role**	Investigator	**Contact**	alm2bg@mtmail.mtsu.edu

Appendix B

Participant Demographics and Data Sheet

Study ID: IRB-FY2023-38

Taekwondo Aging Study

Participant Number ________ Date _________

Please answer the following questions:

1.) What is your Date of Birth (Month/day/year)? __________
2.) What is your Biological Gender (Sex)? _______
3.) What is your current Taekwondo Belt Rank? _______
4.) How many total years have you trained in Taekwondo? _______
5.) Do you participate in weight training? ________

Below area is for administrative use only

Height: _________ **Weight:** _______

Balance - mCTSIB

Standard (Eyes Open/Firm): Path Length (cm) _______ Percentile: _______

Proprioception (Eyes Closed/Firm): Path Length (cm) _______ Percentile: _______

Vision (Eyes Open/Foam): Path Length (cm) _______ Percentile: _______

Vestibular (Eyes Closed/Foam): Path Length (cm) _______ Percentile: _______

Lower Body Power – Vertical Jump Test

Max Jump Height (in) ______ - Base Height (in) _____ = Vertical Jump (in) ______

Walking

Forward Walking: Gait Speed - _______

Forward with Mental Tracking Task: Gait Speed- _______

Responses: ____

Backward Walking: Gait Speed - _______

Backward Walking with a Tracking Task: Gait Speed - _______

Responses: ____