

THESIS

EFFECTS OF PACE ON STABILIZATION AFTER RISING FROM  
A CHAIR IN YOUNG AND OLDER ADULTS

Submitted by

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## ABSTRACT

### EFFECTS OF PACE ON STABILIZATION AFTER RISING FROM A CHAIR IN YOUNG AND OLDER ADULTS

Falls are of significant concern for an aging population, and with 14% of falls thought to occur during the transition from sitting to standing this is a task that could be further assessed. Looking at a relatively new phase of the task, the stabilization phase could provide insight into movement and allow for better evaluation of those at risk. The purpose of the study was to determine the effect of chair rising speed on stabilization phase stability in young and older adults.

Twenty healthy older adults (between the ages of 65-80 yrs) and 20 young adults (ages 18-33 yrs) performed the task of rising from a chair after a series of functional tests were performed. Four single repetitions of the task were performed at a comfortable pace (CSTS) along with four repetitions at a maximal fast pace (FSTS) in a randomized block design. Measurements of the ground reaction forces and moments were recorded during the task and for at least 15 seconds following completion so that the movement phase, length of the stabilization period and events within the stabilization phase could be examined.

The older adults exhibited lower five time sit-to-stand, short physical performance battery (SPPB), grip strength, and Activities Specific Balance Confidence (ABC) survey scores compared with the young adults. The movement time (MT) decreased between the comfortable and fast condition. However, duration of the stabilization phase was significantly greater in the between pace conditions only in the anterior-posterior direction. The older adults did not

produce significantly longer stabilization phase lengths compared to the young. The older adults did see significantly greater movement regarding the center of pressure (COP) movement within the first 2s of stabilization. The older adults also exhibited significantly greater trial-to-trial variability in the COP variables. The GRFv variables were correlated between the CSTS and FSTS amongst the older adults, but this was not the case for they young, nor for the COP variables in both groups. The event just prior to the stabilization phase the rising phase minimum (GRFv RPmin) had the greatest correlation with events in the first 2s of the stabilization for the older adults during the FSTS, although this relationship was not seen for the young adult or during CSTS in both groups.

The older adults exhibited greater between trial variability further displaying the common effects of aging. The correlation between movement phase variables and events of the stabilization phase were greater in the older adults, with the events prior to reaching standing posture and within the first 2s of the stabilization phase revealing differences among age and condition. Considering the lack of correlations between the COP variables in the CSTS and the FSTS indicates that both conditions are unique and warrant further research. Performing the CSTS along does not tell the complete story relative to dynamic stability. It would appear that a short window of the stabilization phase may be more revealing than determining the duration of the stabilization phase. The functional differences displayed between our young and older adults and the differences noticed within the stabilization phase reveal that varying pace may be an appropriate means to assess function and could identify those at greater risk of falling.

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## CHAPTER I

### INTRODUCTION

Falls are the leading cause of non-fatal injuries among older U.S. adults [4]. In a one year period, one in three adults over the age of 65 will experience a fall [4, 5]. Falls typically occur during dynamic movement, where a transfer of weight occurs due to a change in ones center of gravity [6]. An example of this would be the task of rising from a chair. The rising motion can be defined as a transition requiring movement in the forward and vertical direction, allowing one to achieve a standing posture. Fourteen percent of falls that occur in older adults are thought to be linked to an inability to successfully rise from a chair [2, 6]. Common injuries associated with falls are bruises, lacerations, fractures, and concussions. People over the age of 75 yrs are four to five times more likely than those 65 to 74 yrs to be admitted to a long-term care facility, for a year or longer [7], highlighting how fallers risk loss of independence and eventual institutionalization [8, 9].

The ability to rise from a chair requires adequate lower extremity muscle strength, power and postural control [10-12]. To rise successfully the individual must exert enough force to lift the body's center of mass, transfer the mass in an upward and forward direction, then be able to stop the movement and end in a stable standing position [1]. The effort required to complete this task varies among older and young adults, requiring older adults to work at 80-100% of their maximal strength capacity compared to the 40% of their young counterparts [13]. The coordinated efforts result in a stabilization phase where vertical and horizontal momentum must be controlled to stabilize the body [1]. The stabilization phase is typically considered the time

between reaching an upright posture and achieving a stable position similar to quiet stance. Yoshida and colleagues have shown that it can take up to two seconds longer for older adults to reach stabilization compared to their young counterparts when rising at a self-selected comfortable pace [14].

The task of rising from a chair has been used as a method of assessment determining one's functional capabilities with daily activities [15]. The typical chair rise test has the subject complete 5 repetitions of sit-to-stand as quickly as possible (5xSTS). The 5xSTS was originally used as a physical performance measure meant to find associations with mortality and disabilities [16]. Additionally, it has been used as an outcome measure for surgery, therapy, and strength training intervention success [17]. The 5xSTS has been shown to be predictive of recurrent falls in healthy older adults, with those who take longer than 15 seconds to complete the task having 74% greater risk of falling [18]. The 5xSTS test may reveal the likelihood of falling and can be indicative of decreased muscle strength and balance disorders. However, it does not reveal what deficit(s) exist, and it is not representative of real life situations. The potential difficulties associated with teasing out individual deficits are demonstrated in the work by Mong *et al.* (2010). Mong and colleagues found the 5xSTS to be reliable for determining knee flexor muscle strength but not for balance ability [17].

A single repetition of STS, monitored until maintenance of quiet stance, could be an assessment tool that not only reflects real-world daily requirements but also quantitatively measures dynamic control of balance. Furthermore, assessment of the stabilization phase when the STS is performed at both a comfortable and fast pace may provide additional information relative to dynamic balance control compared with performing the task only at a comfortable pace. At a comfortable pace older adults rise more slowly than their young counterparts [2].

The slower speed for older adults may be an adaptation of reduced dynamic balance, or may be due to reduced strength and/or power associated with increasing age. If truly due to strength and power losses, balance may not be significantly challenged during comfortable rising. Therefore, rising at a maximal pace may be a better assessment of dynamic balance. A faster pace may challenge dynamic balance more than using differing foot positions or seat heights. To our knowledge no research has combined altering the speed of the STS when looking at stabilization phase. This is an area that could be benefitted with further research to aid in understanding more about balance and differences associated with age.

The goal of this investigation was to examine the stabilization phase of comfortable-paced and fast-paced single repetitions of chair rising in older and young adults. We hypothesize that the maximal paced task will result in a longer stabilization phase than self-paced, for both the older and young adults. Additionally, we predict that older adults will take longer to stabilize, both at a comfortable and maximal pace compared with the young adults. The expectation is based on the loss of muscular function and nervous system control of stability that typically accompany human aging [19]. We also expect older adults to have more trial-to-trial variability when completing both tasks, which may be related to dynamic balance and the risk of falling. Therefore, in addition to assessing average parameter values, it is also important to assess within subject variability. Additionally, it is believed that when looking at the relationship of the comfortable and fast pace for each individual age group they will be correlated. Along with the prediction that variables prior to the movement phase will be correlated to events within and durations of the stabilization phase. This information helps to better understand the postural requirements necessary to rise from a chair, in order to benefit clinical practices and improve therapeutic interventions designed to improve ambulatory abilities.

## CHAPTER II

### REVIEW OF THE LITERATURE

#### **A. Introduction**

Maintaining independence during the aging process can be difficult due to decreases in muscle strength, power, and motor control [20, 21]. These factors are important for successfully completing daily activities, such as rising from a chair, which has been reported to occur up to 70 times a day [22]. Of falls among elderly adults, 14% are thought to occur during a transition to standing [6]. During a rising motion, stability can become compromised in the hip lift-off and knee-hip joint extension movements, because of the transfer of weight resulting in a change in ones center of gravity in both a vertical and horizontal direction [6, 23]. When unable to meet changing balance demands the success of daily activities can be jeopardized and result in a fall [24].

Further research looking at postural stability after completion of a functional task could provide more information on fall risk and functional ability. To better understand the stabilization phase of the STS task, we need to first look at the prior research associated with the STS task and how its performance is thought to change with age. It is also necessary to understand neuromuscular changes that occur with age and those that have been linked to falls. Topics that will be explored in more detail are falls in the elderly, neuromuscular changes associated with age, current methods to assess dynamic balance, and the STS task itself.

## **B. Falls in the Elderly**

### *Cost to Society*

One of the fastest growing segments of our U.S. population are those reaching 90+ years of age [25]. Advancing age in individuals and populations is associated with increased medical care costs, but helping aging populations to maintain mobility and independence longer could reduce some of those expenses. In 2010, falls accounted for an estimated medical cost of \$30 billion [26]. This cost represents the 2.3 million non-fatal fall injuries among older adults who had to be treated in emergency departments, 662,000 of which required further hospitalization [5]. Emotional injury as a result of a fall can be detrimental to an individual's confidence, but 20-30% of falls also result in physical injuries like lacerations, bone fractures, and head trauma [27, 28]. In addition to emotional and physical injuries sustained, deaths as the result of a fall have increased in both men and women over the last decade [5]. Of falls in the Canadian population, deaths due to a fall for those 80 years of age and older is higher than motor vehicle accidents deaths for 15-29 year olds, 185.6 per 100,000 and 21.5 per 100,000, respectively [29]. Falls are therefore extremely costly to society.

### *Cost to the Individual*

Certain aspects of aging are inevitable, but isolation and loss of independence does not have to be one of them. Falls and the resulting injuries are one of the major reasons for a loss of independence. Up to 40% of nursing home admissions are preceded by a fall or instability [30]. Then once in a nursing home, or in an extended hospital stay, falls account for the largest category of incident reports [31]. With 5% of falls resulting in a fracture, and an additional 5-

11% resulting in more serious injury, injuries sustained from falls have become the leading cause of death for adults over the age of 65 years [32]. Falls among the older adult population have become an increasingly important public health concern [26].

Rising to a standing position from a seated one is a necessity for the mobility requirements of daily life and a prerequisite for maintaining physical independence [1], which can be of major concern for an aging population. When activities of daily living diminish, individuals can lose their functional independence, subsequently increasing their risk of falls and eventual institutionalization [9]. As a result of the diminished functional ability, many older adults experience a fall, or multiple falls. Those who fall, whether it resulted in an injury or not, often develop a fear of falling [33]. The fear of falling can result in a cascade, or cycle, of events (Figure 2.1 – adapted from [34]). This fear can be debilitating, causing individuals to alter or limit their daily activities subsequently reducing mobility and physical activity, which in turn can then further increase their actual risk of falling [34]. Any loss in physical function, as well as a fear of falling, can all influence an individual’s quality of life and negatively impact their ability to maintain independence.



**Figure 2.1 Fear of Falling Cycle**

A fear of falling can be debilitating both to those who have experienced a fall, and those who have never experienced a fall [35]. The consequences of this fear can have a psychological impact on the individual amounting to a loss of self-efficacy, activity avoidance and loss of self-confidence [36]. The common risk factors of a fear of falling have been cited as a previous fall, being female, and increasing age [35]. A developed fear of falling impacts different components of the individuals' life, such as their physical functioning, psychological well-being and social contact. This fear can have negative consequences and further perpetuate the cycle, and lead to a diminished quality of life. Knowledge of this fear and the associated risk factors can be used to help create multidimensional programs to combat these problems. The most identifiable risk factor that is modifiable is eliminating a previous fall. Early identification of those at the greatest risk of falling in combination with prevention programming may be the solution to this risk factor. Once identified as at risk, steps can be taken to improve quality of life and independence for the individual.

### *Cause of Falls in an Elderly Population*

The increased likelihood of falling is not just related to age, there can be many underlying risk factors that are linked both to a fall and increasing age. The greater the number of risk factors one person has the greater the likelihood of falling, as those with no risk factors have a 12% risk of falling and those with three (specifically hip weakness, unstable balance, and taking more than four medications) have a 100% risk [37]. Personal risk factors that have been linked to falls are both intrinsic and extrinsic in nature. Intrinsic risk factors are a loss in strength, power, and neural capacity, medication use, visual impairment, and overall general health (e.g. a diagnosis of a chronic disease) [38]. Strength and power deficits are a natural part of aging,

associated with a decrease in muscle mass and muscle performance [39]. Neural losses can be seen in the emergence of balance and gait disorders, slower reflexes and reaction time, sensory dysfunction, and cognitive problems [38, 40].

In both independent living and institutionalized elderly, falls due to environmental hazards (also known as extrinsic risk factors) are a necessary concern. Extrinsic risk factors and environmental hazards that can cause a fall are poor lighting, stairs and/or elevation changes, improper footwear, obstacles in one's path, lack of the proper equipment (e.g. canes and hand rails) [41], slippery/wet floors, and low toilet seats [42, 43]. Outdoor hazards can include broken/uneven stairs or walkways, poorly marked curbs and weather related concerns (i.e. rain or snow). Spirduso (1995) noted that many falls could have been prevented with the proper and habitual use of prescription glasses, which would make these environmental hazards more visible [44]. It was also reported that 60% of falls by independently living elders were associated with not paying proper attention and taking part in hazardous activities [45].

Environmental hazards are a serious risk and should be acted upon to help reduce the likelihood of falls, but environmental risks are still less predictive than personal risk factors of falls and accidents [44]. Looking at 4,862 institutionalized patients who had experienced a fall or accident, major risk factors found were not environmental, but rather more highly associated with a patient's health history. Those who experienced dizziness, anxiety and confusion, and impaired balance experienced a 33%, 21% and 16%, respectively, increased likelihood of an accident or fall compared to those without these conditions [46]. Highlighting how intervention programs aimed at benefiting the individual rather than making environmental changes could serve to be more effective at preventing a fall. Effectively and simply being able to evaluate functional capacity could turn out to be more predictive and better aid in preventing future falls.



Of intrinsic and extrinsic risk factors, intrinsic risk factors are more commonly identified as the reason for a fall in those over 80 years of age [47]. Those over 65 years of age are at an increased likelihood of falling, as 30% will fall each year [4], and those who have already fallen are two to three times more likely to fall again within a year of their first fall [48]. Healthy older adults experience an increased risk of falling compared to their young counterparts, but older adults with frailty experience an increased risk of falling compared to their healthy older peers [49]. Frailty is defined as a clinical syndrome of which three or more of the following criteria are present: unintentional weight loss, self-reported exhaustion, weakness, slow walking speed, and low physical activity [50]. Those diagnosed with frailty are believed to struggle more with activities of daily living, likely due to weakness and fatigability, which only enhances the individuals likelihood of falling. A fear of falling, or risk of falling, does not only occur in an aging population. It can also affect special and clinical populations.

### *Special Populations*

Maintenance of independence is important to healthy older adults, functionally limited older adults, and those elders with a clinical diagnosis. Many can fall under the umbrella of a special populations such as stroke, Parkinson's disease, osteoarthritis, joint replacement, hip fracture, multiple sclerosis, peripheral neuropathy, and countless other diseases that affect the ability to perform daily tasks independently. The benefits from further research regarding dynamic balance could be extended to any one of these populations, with the knowledge gained potentially altering treatment and rehabilitation programs.

Many similarities can be drawn between aging and special populations, therefore the knowledge gained from studying one population could aid the other. This is not an exhaustive list of populations that could stand to benefit, but rather represents the idea of knowledge gained extending to many different people. The goal for most individuals would be to function in a manner that promotes independence and allows for healthy aging, regardless of a disease diagnosis.

### *Stroke Patients*

Stroke patients are at an increased risk of falling compared to non-stroke patients due to their pathological condition effecting physiological processes [51]. Cheng (1998) and others have been able to conclude that most falls occur in stroke patients during activities that result in change of position and transfer of center of mass (COM) [51, 52]. As the STS movement requires both of those components stroke patients can struggle with successful completion of the task, subsequently resulting in a fall. Strokes have become the third most common cause of death in the Western world, while also serving as a major cause for elderly patient disability [53].

There is a lack of appropriate rehabilitation services for this population [54]. Therefore determining the characteristics, within healthy young and older adults, in how they are able to reach and maintain postural stability could serve to better help clinical populations making treatment and rehabilitation methods more effective. Evaluating postural stability could also shed light on sorting those (whether in a special population or not) who are at risk of falling, allowing medical staff to create better prevention and treatment applications for both fallers and non-fallers.

### *Parkinson's disease Patients*

Patients with Parkinson's disease (PD), often experience difficulty starting a task as well as stopping motion once started. When surveying 101 individuals with PD, 81% reported difficulty in being able to rise from a chair [55]. It was speculated that some difficulties experienced may be due to differences in anticipatory postural control of COM [56]. Inkster *et al.* (2004) demonstrated that subjects with mild PD displayed no quantitative differences in controls for the STS performance [56]. Even though no differences were seen it is important to understand why patients with PD experience difficulty when rising from a chair as well as performing other activities of daily living in order to provide better interventions. Further research is needed to better identify other compensatory mechanisms used by PD patients to successfully achieve and maintain a standing position in order to better their medical treatment.

### *Joint Repair and Bone Fracture Patients*

After an initial hip fracture, due to a fall, up to 53.3% of patients will report another fall within the first six months post hospital discharge [57]. Studies have been able to show that a range of 25-75% of hip fracture patients are able to achieve normal functioning post fracture [58]. With respect to STS, total knee repair patients have been shown to shift torque loads from the knees up to the hips by altering their upper body kinematics in order to generate greater momentum [59]. This could serve as a potential problem in the ability to reach a state of stability after rising from a chair and thus increase risk of falling.

## *Summary*

The increased likelihood of falls for older adults is a concern for many as a fall can have deleterious effects. The consequences of falls can impact both the individual and society. Several of the intrinsic and extrinsic risk factors can be combated, but many are associated with the natural aging process. In particular are neuromuscular changes associated with age, which may be able to be slowed but appear to be inevitable. However, a more thorough understanding of how the neuromuscular system changes with age is necessary to design interventions that may slow the downward progression and add quality years to the lifespan.

### **C. Neuromuscular Changes Associated with Age**

Maintaining balance requires rapid and precise integration of multiple neural inputs from muscle mechanoreceptors, joint proprioceptors, somatosensory systems, and vestibular systems [60]. In the aging process these systems can degrade causing daily activities to become more difficult [2]; placing limitations on an individual's movement abilities [61]. Functional decreases in mobility can also be seen due to decreased regular physical activity. As a result, there is often a loss of crucial balance and motor control functions with age.

When rising from a chair, it is necessary to maintain the body's COM within the boundaries of the base of support. Lower extremity weakness and balance impairment produce some functional limitations on this ability, with muscle strength being the better predictor of success [62]. Several efforts have been made to determine the contributions of muscle strength during the STS movement [63-67]. Despite these studies, little is known about the relative

contributions of strength and balance during the stabilization phase of the STS for an aging population.

Balance and posture are maintained through the integration of three sensory systems: vision, vestibular, and somatosensory [29]. To avoid objects and plan movements, we utilize our vision. We use the vestibular system to sense linear and angular accelerations of the head and provide a sense of spatial orientation. In combination we use the somatosensory system to evaluate body position and velocity using sensors (mechanoreceptors) to guide our movements and interactions with external objects. The integration of these systems allows individuals to move about during functional activities. In an older adult population, declines in motor function, loss of fine motor skills, osteoarthritis, and declines in visual abilities all occur [68, 69]. The losses and declines in older adults are thought to contribute to an increased likelihood of falling. To better understand the neuromuscular changes associated with age we will look at the changes to muscles, tendons, the peripheral nervous system, and the central nervous system.

### *Muscle*

In the aging process the force-generating capacity (strength) and power of skeletal muscles are reduced [70-73]. As a result, many older adults will experience difficulty when performing daily tasks [74]. Research has indicated that this loss is due to a combination of muscle fiber loss and atrophy leading to loss of muscle mass, and impairment of the ability to activate the muscle by the nervous system [75-77]. Sarcopenia, the degenerative loss of skeletal muscle mass (of either fiber size, fiber number, or a combination of the two) is a major contributing factor to a loss of independence and reduced mobility [78], and can be exacerbated

by inactivity or immobilizing injuries. The overt morphological consequences of sarcopenia can also be observed as a decrease in the cross-sectional area (CSA) of skeletal muscle with age [75]. In addition to the decrease of overall skeletal muscle CSA, it has been demonstrated that the muscles of older adults (aged 65-83 yrs) contain less contractile tissue and more non-contractile tissue when compared to young adults (aged 26-44 yrs) [77]. The non-contractile tissues, composed of fat and connective tissue, when seen in higher percentages results in a decreased force production capability [79]. When trying to determine a cause for skeletal muscle atrophy in older adults, some researchers have looked to see if there are effects on fiber type within the muscle during the aging process [74, 80, 81]. In comparisons of young and older adults, type II fibers were smaller in the older adults, while the size of type I fibers were much less affected [82]. Thus, the atrophy and decrease in muscle CSA is likely due to a reduction in both the number of both types of fibers and a preferential atrophy of type II fibers [82].

To perform tasks effectively and efficiently, the ability to control muscle force and movement is critical. The amplitude and timing of the activation of both the agonist and antagonist muscle groups must be optimal [83]. These coordinated efforts come from voluntary and reflexive muscle contractions that are the result of conscious and unconscious neural activation, respectively, stemming from the brain, brainstem, and spinal cord [84]. A signal sent from the brain, in the form of patterned trains of action potentials traveling down vast tracts of descending neurons, excite lower (alpha) motor neurons in the spinal cord, which directly innervate muscle fibers. A motor unit is defined as a single motor neuron and its innervated muscle fibers. A single muscle can have ~100 to several thousand motor units devoted to it [85]. The muscle contraction occurs due to the signal sent from the brain, and the subsequent electrical activation of muscle fibers. The electrical activation leads to calcium influx into the cytosol of

the cell, which drives the interaction of the myosin and actin filaments via myosin-actin cross bridge cycling. The physical interaction and translation of the filaments past each other produces a pulling force which is ultimately transmitted via the connective tissue to tendons.

To generate a muscle contraction, motor neurons receive information from the CNS [86]. The signal sent in the form of an action potential travels down the motor neuron which innervate several muscle fibers [87]. When the action potential is sent the cell membrane is triggered to depolarize. The depolarization of the membrane results in a dramatic increase in the concentration of cytosolic calcium [88]. The elevated calcium initiates calcium-sensitive contractile proteins which use adenosine triphosphate (ATP) to cause sarcomere and fiber shortening through the interaction of the myosin and actin cross-bridge [89]. The process that links nerve stimulation to muscle contraction, is known as excitation-contraction coupling. This process involves many steps that have to proceed in a specific manner. Part of the observed age-related decrease in muscle function may be due to dysfunction in excitation-contraction coupling. [90]. For example, the decrease in  $\text{Na}^+/\text{K}^+$ -ATPase concentration in aging muscle fibers that causes increases in fatigability [91], can contribute to muscle fibers generating less force [92, 93].

A decline in muscle force in aging has clearly been described, but it has also been suggested that force produced per volume of muscle tissue (muscle quality) declines with age as well [94]. Delbono *et al.* (1995) was able to show that the tension developed by a single muscle fiber depends on the cross-section of the fiber and the age of the experimental animal [94].

The size of muscles clearly changes with age. These changes are accompanied by changes in function such as motor unit firing rate [79]. Runge *et al.* (2004) identified peak

power to be more informative of aging deficits than CSA [95]. They found that peak power as opposed to CSA was correlated with chair rising performance, and that peak power output decreases with age [95]. They attributed these findings to sarcopenia that was regionally variable and also to loss of functional properties of the muscle and tendon [95]. The end result of these changes is impaired force production and muscle function. However, there is substantial evidence that both strength and endurance training can reduce some of the physiological effects observed in aging skeletal muscle [79]. As power is the product of force and velocity (also known as the rate of doing work), the loss of type II muscle fibers can significantly affect power. Type II fibers (fast twitch), reach their peak force faster than type I fibers, resulting in a faster shortening velocity than type I fibers [96]. Action potentials tend to also reach type II fibers faster than type I fibers because they are travelling on larger diameter motor neurons [96]. Therefore, the preferential loss of type II fibers with age has a compound effect on power by not only reducing the maximum force capacity of the muscle, but also the maximum shortening velocity capacity.

An additional explanation for the loss of balance and stability in aging is the observed co-contractions in agonist and antagonist muscles around a particular joint. The relationship of agonist and antagonist muscle contractions is important because it helps with precise movements and provides a level of protection during rapid contractions. Muscle activation when assessed by the twitch interpolation was found to be less in older compared to young individuals [97]. Co-activation levels measured by surface electromyography (EMG) were reported as higher in old age [98] meaning that with advancing age there is a decrease in activation of the agonist and an increase in co-contraction activation of the antagonist [99]. This decrease in activation can result in reduced balance and stability, because higher agonist forces are associated with better control



of joint motion [100]. The changes in activation levels signify neural regulation changes that decrease the ability to regulate the simultaneous contraction of agonist and antagonist muscles acting on a common joint which generally aids in joint stability [101].

### *Tendon*

Tendons transmit muscle force produced by the muscles to bones. The stiffness of the tendon is important to its function [102]. The muscle tendon unit (MTU) is comprised of the skeletal muscle and the tendon(s) that connect the muscle to bone. The tendon acts as a spring-like structure, exhibiting both stiffness and elasticity that contributes to the quality of movement and performance [103, 104].

Tendons are capable of being stretched, which occurs when the molecular structure resists the stretch and exert an elastic force on the skeleton causing movement. In the case of tendons, stretch is caused by either a passive increase in the joint angle, or by active shortening of muscle fibers [104]. Tendons will vary by thickness and length, with those that experience a higher magnitude of physiological loads generally being stiffer, like the Achilles tendon compared to extensor carpi radialis brevis tendon [104]. The ability of tendons to stretch, their stiffness and thickness all influence the properties of the tendon and allow for a capacity to store elastic energy.

The material properties of tendons can decline with disuse and increased age [105]. As humans reach about the age of 40-50 yrs the connection between tendons and bones become weaker due to more cross-links making the tissue potentially less compliant [105]. Research has been mixed regarding the effect age has on the mechanical properties of tendons with results

demonstrating stiffer and stronger tendons with age [106] and the opposite [107]. A reduction in stiffness associated with aging could have functional implications like an older tendon stretching more during a muscle contraction, reducing force [108]. Force of the muscle is generated both by the length of the muscle and the shortening velocity. As the muscle and tendon work together in the MTU if these components are altered for the tendon it affects the whole unit. A greater stretch in the tendon reduces force because the muscle is now in a less favorable location on both its force-length and force-velocity curves, with the muscle shortening faster at a reduced length compared to a stiffer tendon. Muscles generate the greatest force when they are at their resting length, stretching (or shortening) from this point decreases force [109]. As stated above power is the product of force and velocity, therefore when the muscle is shortening faster, velocity is increasing and force production will decrease. Depending on which attribute changes more it will dictate if power is maintained or lost in this process. Additionally, a more compliant tendon (which has been associated with age) requires a longer time period to be stretched, reducing the ability to react quickly [108]. Enhancing the notion that older tendons are less capable than young tendons of quickly transmitting force from muscle to bone, affecting reaction time and fall avoidance [108].

### *Peripheral Nervous System*

At its simplest level the flow of information from peripheral nervous system (PNS) to the central nervous system (CNS) and back can be thought of as input, evaluation and output. Signals start with afferent neurons which convey sensory information to the CNS concerning stimuli from the surroundings [104]. Afferent signals are considered the input signal and enter the CNS, synapsing on interneurons, that convey the information centrally. Interneurons act as

the evaluation method and modulate the interaction between input and output signals [104]. Once a response has been decided (in the form of excitation or inhibition) efferent neurons transmit the output signal from the CNS to the effector muscle [104].

With an increase in chronological age, physical inactivity also increases [110] subsequently contributing to further muscle wasting and weakness, placing elderly persons at an elevated risk of falling [88]. The possible reasons for a fall are numerous, but causes can often be pinpointed to impairments and loss of control of power and strength in the musculature of the lower extremity [111]. Older adults display a reduced ability to control force, as measured by increased motor output variability, when compared to younger adults [87]. Motor output variability is the unintentional variation in the output of voluntary contractions that can be seen between and within trials [112]. Older adults display a greater motor output variability that is thought to be associated with an inability to move as accurately [113]. The variability of these contractions in older adults has been linked to altered activation of muscles involved in the movement likely due to structural and neural changes in CNS possibly resulting from the death of cortical neurons [114].

Signals and their corresponding responses are also slowed in the aging process as opposed to just being inappropriately interpreted. The PNS can be implicated for age-dependent disorders as functional deficits may be the result of structural and biochemical changes that result in the slow progressive loss of neurons and nerve fibers [115]. These losses are not compensated in older adults like younger adults because of decreased regeneration and innervating abilities of nerve fibers with age [115]. The lack of compensation demonstrates how the signal and response can be slowed, and thus effecting reaction time and fall prevention. Possible reasons for slower information processing are due to lower nerve conduction velocity as myelin sheaths degrade,

and motor recruitment and firing frequency decreases with age [116]. This slower conduction at peripheral nerve endings leads to decreased sensations and slower reaction time [116].

Neurological changes associated with age are the degeneration of tissue in the peripheral nervous system, which reduces the quality of afferent sensory signals [117]. The deterioration of balance control is likely due to an inability of the CNS to no longer adapt and compensate for functional losses [29]. The ability of the CNS to adapt also makes it hard to know when systems are beginning to decline, as problems may not become apparent until well after the damage has been done. As a result the loss may not be seen until compensatory mechanisms are exposed and/or removed.

### *Central Nervous System*

As the vestibular system and joint proprioception are a part of the communication network between the PNS and CNS, their changes associated with age also need to be evaluated. The vestibular system, which contributes to balance and movement by providing a sense of spatial orientation, does exhibit structural deterioration during aging [118]. This deterioration may contribute to postural reflex insufficiencies and dizziness [118]. Although not all older adults experience the same losses, the CNS is able to compensate up to a point. Thus deterioration beyond the ability of the CNS to compensate could produce physiological consequences that have emotional effects like a loss of balance confidence and independence [118]. The deterioration of the vestibular system can be attributed to some cell loss in neuronal and sensory cells [119]. These are highly differentiated cells that are not capable of reproducing during adulthood, and must maintain their structural organization to function properly [120].

The vestibular system has also been shown to have mediating influences over joint proprioception input [119].

Proprioception is the sense of body and joint position provided by the collective sum of neural input to the CNS from specialized nerve endings called mechanoreceptors [121]. The proprioceptive sense is important for producing smooth and coordinated movements and adequate postural stability [122]. It was found that among differing age groups more reliance is placed on proprioception than vision for balance maintenance, implicating a decline in proprioception as a contributing factor to falls [121, 123]. With advancing age there is believed to be a decrease in joint position sense (JPS – a subject's ability to sense a joint angle and replicate it) and an increase in movement detection threshold (length of time it takes a subject to recognize a change in movement) [121]. Possible mechanisms from one study revealed anatomical and physiological age-related changes to the muscle spindles [121]. A decrease in the number of muscle spindles is a problem, as muscle spindles are sensory receptors within the belly of a muscle which convey information to the CNS helping to determine body position. Muscle spindles aid in the regulation of muscle contractions, and when there are fewer muscle spindles available less signals can be sent. When less signals are sent it leaves an individual susceptible to instability due to a lack of accurate assessment capabilities of where their body is within space. Aging can affect both the PNS and CNS, resulting in declines in proprioception [121].

From a movement perspective, the CNS can be thought of as a control center meant to evaluate incoming sensory information in order to govern the control of muscles. There are natural changes that the brain and spinal cord undergo as a part of aging, some with more detrimental effects than others. Changes associated with age are not universal in experience or

severity, but with age there is the potential for degradation in components of the PNS and CNS, contributing to reduced senses or reflexes. A decrease or loss of senses and reflexes can affect the ability to generate appropriate targeted movements, further increasing the likelihood of episodes of instability and falls.

### *Asymmetries Associated with Age*

The literature on lower extremity symmetry (or lack thereof) during tasks like the STS movement has been mixed. Functional asymmetry refers to side-to-side variances in the kinetics and kinematics during the performance of tasks otherwise thought to be completed symmetrically [124]. There are instances when asymmetries are to be expected, but those are generally thought to be related to injury or physical impairment. Although measurable asymmetries have been documented in healthy subjects, there are some explanations for asymmetry such as differences in strength, anthropometry, neural control and potential flexibility, but age should be considered on the list of potential explanations for asymmetries.

Hesse and colleagues (1996) found that weight distribution in healthy subjects between the right and left leg, and the medial-lateral displacement of the COM, before and after rising from a chair were significantly different across subjects 19-40 years of age [125]. They also found clear preferential dominance of one limb when standing. Prior to standing only one subject showed preference for the right limb, but after lift-off nine of 20 subjects placed more weight on one limb over the other [125]. They found that healthy subjects were better able to control for any combination of limb preference without losing balance [125].

In a comparison of young and older adults during a quiet stance under varying conditions of eyes opened and eyes closed, older adults were found to have greater limb load asymmetries in both conditions [126]. Under the eyes closed condition there was a significant increase in the distribution of body weight asymmetry in the older adults that was not seen in the young population. In the eyes open task, mean load asymmetries were 1.08 and 1.12 (calculated as the ratio of body weight fraction put on the more loaded limb to the less loaded limb, perfect limb loading symmetry would result in a value of 1.0) for young and older adults, respectively. In the eyes closed condition the asymmetry did not change much for the young adults with a mean of 1.09, whereas the mean increased to 1.19 for the older adults under the same condition [126]. The eyes closed condition displays the effect vision has on asymmetries in older versus young subjects. The differences seen between these populations is possibly due to aging, and the progressive decline of postural control, with the nervous system requiring more time to make postural adjustments [126].

### *Summary*

With advancing age there are some expected reductions or losses to occur in the communication of information to CNS. The consequences of this error in communication could produce a fall. In order to determine if and when these losses occur we need to have optimal assessment methods. Better assessments will increase the quality of the information about the effect of age on functional performance. Is less power produced, less force generated, is reaction time slowed? If more than one, which is the most important to be targeted with preventive therapy? Both static and dynamic balance assessment method can determine these outcomes and reveal how the problem is affecting daily functioning and possibly interfering with a person's

quality of life. Knowing the problem can then help to create better solutions providing insight for patient prevention and treatment.

#### **D. Current Methods to Assess Dynamic Balance**

##### *Fall Risk Assessment*

Although training and intervention programs have been implemented to help prevent falls, before these can even take place the first step is to evaluate who is at risk of falling [127]. Fall risk assessments are the means by which this evaluation is completed, and are meant to identify those of the population at the highest risk of falling. There are three main types of assessments pertinent to evaluating falls and mobility: 1) comprehensive medical assessments (generally performed by appropriate medical professionals), 2) nursing fall risk assessments (performed in a hospital or nursing home environment), and 3) functional mobility assessments (completed in the outpatient setting) [127]. For the purposes of this work our focus will be on the third type of assessment, functional mobility.

##### *Static Postural Sway*

As bipeds capable of locomotion the movements of the human body create balance demands that the body must respond to, or a fall could be the result [29]. These demands also arise when standing and both feet are in contact with the ground. Even when standing quietly the body naturally sways over its base of support [44]. This natural movement is termed postural sway, often determined by measuring the location and change in position of total vertical force



vectors projected onto a horizontal plane (also known as center of pressure - COP) [44]. Placing an individual in a standing position is inherently unstable unless there is continuous control applied to the system [29]. Postural sway during a standing position among older adults has been documented to increase [128-130] generating links between greater postural sway and an increased risk of falling [86]. When measuring recovery time from perturbation during a quiet stance older adults took longer than their young counterparts to recover [131]. Postural sway is functionally relevant for its relation to a risk of falling. Thought to be a process under automatic control, greater conscious effort is required during postural sway for the elderly [44]. As there are losses in neuromuscular feedback with age, older adults have to focus greater attention to make up for deficits [44].

Postural sway is a measure of interest believed to identify those at a greater risk of falling. As well as, recognize those whom could benefit from training and intervention programs meant to prevent falls. A relationship between increasing postural sway and increasing age has been demonstrated [132, 133]. Although, the results do not always demonstrate as close of a relationship at predicting future falls as is desired for fall risk identification. In one double-blind study of institutionalized elderly, those who had already fallen once had a significantly greater average speed of postural sway than those who had not fallen [134]. Yet, there was no correlation seen for an increase in postural sway and an increased frequency of falls [134].

Standing quietly is also generally not when an individual falls. Patla *et al.* (1990) made the point that measuring natural posture sway during a quiet stance was not necessarily an appropriate measure for a lack of balance control [135]. Healthy older adults may not be challenged in a normal stance. Although, it is generally believed that larger deviations in COP are commonly interpreted as a reflection of poor balance control [135], patients with

neurological disorders, like Parkinson's disease, have a normal or reduced postural sway, possible due their increased muscle stiffness [136]. As a whole, although predictive to a certain degree, the literature suggests that quiet stance may not be the best method of evaluation to discriminate between those at low or high risk of falling. Rather tasks of a greater dynamic nature may be more revealing of balance deficits and identify individuals at a heightened risk of falling [135].

### *Necessity for New Balance Assessment Methods*

Functional assessments have become more common for their ability to be completed in an outpatient setting. These types of assessments include the Berg Balance Test, Dynamic Gait Index, Sit-to-stand tasks and more, all of which are meant to focus on limitations in balance and gait [127]. Depending on the environment and reasons for the assessment, many of these tests are performed together, which can become tiring and time consuming to the individual subject [127]. Despite copious methods of evaluation there are still gaps in the assessment process. It is hard to determine both intrinsic risks and functional limitations from a single test, along with being difficult to make comparisons between tests, as the current assessments are not standardized [127]. In order to determine that a new method of assessment is warranted, current methods of dynamic balance assessment should be evaluated. Our discussion will focus on tether releases, sliding platforms, gait assessments, and the five time sit-to-stand (5xSTS) before presenting an alternative method of assessment.

A commonly used method to study balance recovery in older adults involves the simulation of an anterior or posterior loss of balance. By tilting the participant into a static

forward lean using a horizontal tether, the tether can be released at random requiring the individual to recover their balance, likely by taking one or two rapid steps [137]. When assessing the value and use of such a method it is important to consider the practicality, limitations, and repeatability.

Practicality and limitations can be compromised with a tether release system as it requires a lot of equipment. The set-up can be very intricate and requires several additional safety measures, as researchers should only want to simulate a fall, not cause one. Subjects are required to wear a harness and be hooked up to a cable system that may be uncomfortable. This is not an assessment that could be performed in most clinical or outpatient settings. As far as repeatability, one study revealed there to be a learning effect when completing tether release assessments [137]. In previous studies, subjects were often repeatedly exposed to the tether release and have been shown to alter their recovery strategy [138, 139]. When looking at older adults stability during balance recovery, stability increased following repeated exposures, within a single test session [137]. Demonstrating learning effects based on the motor learning theory, that an individual's own neuromuscular and reflexive protective mechanisms can be developed and improved through repeated perturbations [140]. As falls occur unexpectedly performing multiple trials of a tether release seems unnecessary [137], yet multiple trials of a single event may be necessary in order to understand individual movement rather than recovery strategies. Although recovery strategies involving muscle and joint movement can be learned, tether release systems do not appear to offer a method of assessment that is time efficient, cost efficient, potentially portable, and easy to use for a large number of participants.

Other devices used to simulate balance perturbations are treadmills, sliding platforms, or pivot platforms. A motorized treadmill can pose balance demands by simulating trips (causing

one to fall forward), and slips (causing one to fall backward). A reason for using treadmills is to determine if reactions are of the same biomechanical nature on the treadmill as they would be during an actual fall [141]. Treadmill devices can be used for both standing and walking perturbations, with either acceleration or deceleration of the treadmill [142]. Treadmills may also exhibit split-belts to elicit balance challenges. Training effects have also been seen in treadmill protocols evaluating slips [143], but these protocols and treadmill use does have limitations. Research using these methods still needs to be evaluated further for how transferrable the perturbation training is to real life slips [143]. An additional drawback is the time to train both clinicians and subjects for proper use and safety, along with the cost. Treadmills can be a relatively inexpensive item with many applications, but the additional safety equipment can be costly and take up large amounts of space. The safety harness can influence human behavior, and in one study subjects grabbed the harness, while others simply chose to fall into the harness rather than step to avoid a fall [144]. With the additional equipment it is hard not to affect individual movement, as well as differentiate between voluntary and involuntary falls [144], making some of these purposefully perturbing assessments undesirable.

Sliding platforms were initially built to force movement and elicit a postural response during standing [145]. The platforms have become more advanced and are capable of assessment and aiming to improve balance strategies to perturbation [146]. Yet it is unclear whether the slipping/fall created by the sliding platforms is similar to how a natural slip affects individual stability and balance [147]. Additionally sliding platforms are similar assessment method to treadmills and would likely have the same drawbacks. Making this method of assessment not preferable since it may not be representative of natural falls.

Pivot platforms and other traditional balance boards are meant to challenge balance through the creation of an unsteady surface [148]. When standing on a balance board the subjects center of gravity (COG) and COP may move outside the boundary of the axis about which the board pivots, which causes the board to tilt [148]. At which point the subject must react to maintain equilibrium of balance, or a fall could occur. Over the years pivot platforms have become more sophisticated to allow for greater methods of measurement to determine the subjects COP and COG. Resulting in such measurements as the average COP movement during the performance of a balance task [148]. Such devices are often used by physical therapists for rehabilitation means to progressively challenge the subject and improve balance. As such they do not provide a method of assessment for separating individuals based on fall risk.

Commercially available machines from Cybex™, NeuroCom™, and Bertec™ are meant to increase outpatient methods of assessment and rehabilitation. These assessments may be termed as pseudo-dynamic, in that there are perturbations, but the base moves slowly. Wobble boards like those incorporated in the Cybex™ system, have been previously used for rehabilitation purposes and for athletes, with very little work done looking at training and older adults [149]. Other limitations to their use are that not all boards are the same, and some only allow for anterior-posterior tilt, while others allowing for both anterior-posterior and medial-lateral tilt. Use of these boards also required supervision for frail older adults provided by a physical therapist [149]. The use of such equipment would not be ideal in all outpatient settings or for at home use if supervision is required. The EquiTest™ from NeuroCom™, along with their other devices are meant to assess balance control, but these devices are large and have extensive additional measurement equipment, like dual force platforms, rotation capabilities, and moveable visual equipment [150]. Dynamic assessments have been considered an accurate tool

for measuring motor and sensory contributions in balance control, but a drawback to these methods are the high cost, time for training, time for testing, and space requirements [151].

Other non-perturbation methods of dynamic assessment are gait analysis and the 5xSTS task. These tests require very little additional equipment and mimic common activities of daily living. Gait analysis can now be performed and interpreted by experienced individuals in clinical settings [152]. Although it is not often used for diagnostic purposes it has provided insight to quantitative information that can be helpful for treatment and exercise prescription [152]. A draw back to gait analysis is that it has proven to be of the greatest clinical value for individuals with central nervous system disorders related to spasticity (stiff and/or rigid muscles) [152]. Not all balance disorders are related to spasticity, therefore gait analysis may not be an effective form of evaluation for both healthy older adults and those with balance disorders. For gait analysis variability, inaccuracy and a lack of reproducibility have all come into question, and are often related to technical factors [152]. Other issues arise with functional subject variability, which can be different from step-to-step, demonstrating that gait studies may not be representative of everyday walking patterns [153].

The 5xSTS has been looked at as a clinical measurement for balance disorders. It was found to be a valid measure, however, the assessments it was compared to, the Activities-specific Balance Confidence Scale (ABC) and Dynamic Gait Index (DGI), were better able to discriminate between those with and without balance disorders [154]. The 5xSTS test has been widely used as it is considered easy to administer, and it is a relatively quick assessment [154]. However, it appears there are alternative methods that are more sensitive and better able to distinguish between varying functional levels of ability. Meaning that if the 5xSTS is not as

sensitive of a test there may be better methods that require less time and effort, and better mimic activities of daily life.

As the 5xSTS is meant to be quickly administered there are other tests or tasks that have been created under the pretenses of being a simple and quick method of assessment. Such tests range from the Romberg test, Standing Reach test, and 4-Square Step Test. The Romberg test (Romberg Maneuver) is meant to be a neurological examination where the subject stands with their feet together and eyes closed [155]. A positive test is indicated by the subject stumbling or falling [155]. This particular test has been shown to have poor sensitivity [156]. The Standing Reach test (Functional Reach test) is measured as the maximal distance one can reach forward beyond arm's length, while maintaining a fixed base of support in the standing position [157]. It is dynamic in nature as it requires the individual to maintain balance during movement [157]. Meant to be an easy test both to administer and participate in it still leaves more to be desired for evaluation. In one study the test was found to be a weak measure of stability limits, revealing low correlations between the distance achieved and displacement of the COP [158]. The 4-Square Step test challenges subjects to step both forward, backward and side-ways, while assessing mobility. Some limitations of this type of exam are it may not be suited for those with cognitive disorders as it requires memorization of the specific order of moves [159], and it may not be as reliable for subjects with vestibular disorders [160].

Although this is not an exhaustive list it is clear that there are many current methods to assess balance in both a dynamic and static way. However, many of these alternative methods require expensive equipment, have limited portability, significant time to set up, and trained individuals to administer. There is still a void that can be filled with a simple, quick and effective method to assess dynamic balance to be used in clinical practices.

### *The Single Repetition Sit-to-Stand Task: An Alternative Method of Balance Assessment*

When seated, rising to a standing position must occur before further ambulatory processes [22]. The ability to rise from a chair unassisted can be compromised with age and other pathological conditions. When a person loses the ability to complete the task his or her functional independence can become diminished [2]. Requirements of the task are sufficient leg strength, power, adequate coordination, balance, and mobility, in order for ones weight to be transferred from a more stable three-point base of support to an erect position with a two-point base of support [161].

The STS movement has been deemed one of the most taxing activities of daily mechanical functioning [162]. It requires a greater peak hip joint moment than other daily activities like walking or stair climbing [163]. While also producing higher peak hip joint contact pressure than either walking, jogging or jumping [164]. The mechanical demand of the activity lends itself to being used to test indicators of functional ability in a variety of different manners like repeated tasks, foot position, speed variances, and postural adjustments preceding the task (which will be discussed in greater detail during the analysis of the movement). The majority of these analyses have examined the rising phase. Only a few have examined the ensuing stabilization phase. Of those that have examined the stabilization phase, effect of task speed has not been assessed.

Assessing speed may prove to be a better assessment of dynamic stability when compared to having the individual rise at their comfortable pace. One study determined that the speed at which a task is performed may affect the consistency of the results [165]. During upper limb movement as the speed increased the accuracy of the limb movement decreased [165]. It was determined that a decrease in movement time of 100 ms caused a 20% decrease in



movement accuracy [166]. It is likely that the same relationship exists during lower limb movement of a STS task. The same study concluded that tests meant to assess dynamic balance should be more representative of activities of daily living, rather than creating novel forms of evaluation [165]. Additionally, assessing the STS task at varying speeds could be more revealing of compensatory mechanism used during the task.

Akram and McIlroy (2011) believed that learning more about the moments after completion of a STS task could reveal better indicators for measuring functional ability and help predict fall risk [2]. They proposed that measuring the COP during the stabilization period would help to elucidate methods to determine dynamic instability [2]. The advantaged gained would be to create better individualized care in both the prevention and treatment of falls in an aging population.

The question about what the reason, or reasons, is/are for compromised abilities to stabilize quickly following STS still remains. Is it the strength, power, or timing of the event that act as an explanation for differences [1]? Understanding the contributing factors better could improve STS performance in older adults, particularly those who have experienced a loss of functional performance [1].

Although previously the importance of strength, speed, and balance during the STS movement were noted, they were only able to offer an explanation for  $\leq 47\%$  of the differences in STS performance [62]. Therefore, we believe that looking at both the STS task and the stabilization phase to follow may be more revealing than the rising alone. It allows for the evaluation of a dynamic task (reflective of daily living) to occur first before assessing stability. It is an evaluation that can also be done after a single event rather than repeated tasks, requiring

less time and effort for the subject. Performing the task at varying speeds could be reflective of real life situations in which balance may be challenged.

The STS test is a useful and practical test that can be reflective of an individual's level of functioning [167], it is very representative of tasks that are necessary to maintain functional independence, like getting out of bed, out of a car, and rising from a chair in order to walk. Therefore, being able to rise from a chair in a faster and more controlled manner may be representative of a higher level of functioning. While at the same time a test that accurately predicts falls in combination with assessment of one's functional levels is still needed [15].

To assess both static and dynamic movements a force platform instrument is commonly utilized for its ability to measure the ground reaction force (GRF) and COP at the foot-ground interface. These measured variables provide the opportunity to calculate other variables of interest, like the length a time and in what direction a force was moving. The growing use of force platforms in a clinical setting advocates that the platforms are relatively easy to use, becoming more affordable and more readily available [89]. Continuing to promote the use of force platforms, and other functional assessment methods, aids in our understanding of how daily tasks and our abilities to perform them change with age. Additionally, effectively being able to evaluate older adults' functional abilities aids in determining individual needs. Thus, providing the opportunity to assist these individuals with the means to achieve healthy and successful aging.

## *Summary*

Evaluating movement and those particularly related to the maintenance of balance have been of interest and researched for both young and aging populations. Many of the current assessment methods require extensive and expensive equipment, training time, and time to administer the test. These aspects make the methods undesirable in a clinical or other outpatient settings, and leave room for new and alternative methods. A single repetition STS task at varying speeds could fill the void by providing a quick and easy assessment of balance. In order to determine the effectiveness of the STS task as a valid assessment it needs to be further evaluated by biomechanical means.

### **E. Sit-to-stand**

When seated, the motion of rising from a chair is necessary before further ambulatory processes can occur. With the frequency in which the movement is performed, the demands of the task are often forgotten until limitations arise that prevent successful completion. Once the transition can no longer be made as efficiently and effectively, aspects like individual quality of life may begin to deteriorate due to a loss of independence. To understand the requirements and demands of the task, further analysis is needed from a biomechanical standpoint. This includes dissecting the movement into phases, how the task is altered with changing requirements, how attributes of the task affect the ensuing stabilization phase, and what affect age has on completion of the task.

### *Single Repetition versus Repeated Repetitions*

The STS can be looked at in the form of single repetition trials or repeated repetition trials. As a repeated task, the 5xSTS has been used as a practical measure to predict recurrent falls in healthy older adults living within a community [18]. The 5xSTS was intended to be used as a physical performance measure identifying associations between mortality and disability [16]. It has been shown that those who took longer than 15 seconds to complete the 5xSTS were at 74% greater risk for recurrent falls than those who completed it in under 15 seconds, when looking at those greater than 65 years of age [18]. Those who take longer in the task are thought to have less postural control, or greater muscle weakness, indicating why they would be at a greater risk for falling. The 5xSTS has proven to be a useful tool for determining changes made after surgery, therapy, or a program intervention [17]. However, potential difficulties are associated with teasing out individual deficits, as the 5xSTS has been more reliable for determining weaknesses in knee flexor muscle strength rather than weaknesses in balance ability [17]. In a separate study the 5xSTS was able to identify people with balance disorders, but the ABC survey was the best tool utilized to discriminate between who had a balance disorder and who did not [154]. These results demonstrate that there are inconsistencies in the measurement and outcomes of the 5xSTS. Additionally, to our knowledge studies utilizing the 5xSTS have not looked at the stabilization phase of the STS movement, but are instead concerned with the time to complete the 5 repetitions. Thus a single STS looking at the whole task may provide more insight to distinguish those with balance disorders. The most common evaluation method of singling out the stabilization phase of the STS is a onetime movement over separate repeated trials [1, 2].

### *Biomechanical Analysis and Phases of the Sit-to-stand*

When healthy, normal weight individuals rise from a chair most initiate by flexing their hips to lean forward, while keeping their feet in the same position on the floor [168]. The movement encompasses a transfer of weight that requires exerting enough force to raise the body's COM through extension of the hips and knees, with simultaneous plantar flexion of the ankles. When in a sitting position the body's COM is maintained over a larger base of support that when standing becomes smaller and is moved in an anterior direction. Thus, leg muscles have to be adequately developed and maintained in order to produce the appropriate strength and power required for lifting the body [1]. Power, the product of force and velocity has also been cited to be more important than strength when performing daily activities [169]. In addition, there has to be a level of balance and control to ensure that rising from a chair ends in stable standing position [1].

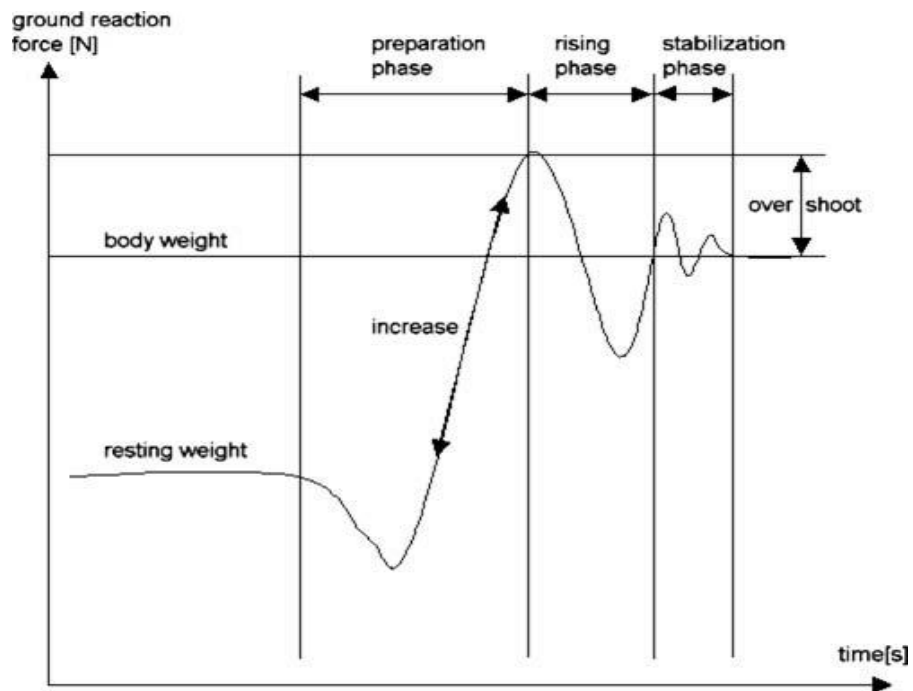
To follow the movement patterns of the STS task it is often divided into multiple phases. Lindemann *et al.* (2007) made the division into three phases, the preparation phase, rising phase and stabilization phase [1]. There is a sequential manner to the movement, in which during the preparation phase forward momentum is generated to initiate the movement, followed by seat unloading and vertical acceleration [56]. In order to accelerate in the vertical direction leg extensor strength (both the hips and knees) and a wide range of motion in the hip joint are required [67, 170, 171]. Movement in the forward and upward direction during the rising phase has to then be slowed in order to stop the movement in a standing position. Slowing begins during the rising phase when the GRFv drops below body weight. Halting the motion continues during the stabilization phase [1] in order to prevent a continuing forward motion, establish

stability, and prevent a fall. The mechanical demand placed on the body is what makes this task one of the most difficult daily activities, and one necessary for maintaining independence [162].

When dividing the STS into multiple phases, depending on the analysis there can be some debate about the exact timing that precise movements occur. Phases can be defined based on the joint motions, GRF, or a combination of the two. Using the GRFv to define the phases is one of the most common, since not all studies include joint motion data. The task starts with the preparation phase characterized by unloading of the feet caused by hip flexion (equal and opposite moments at the hip that causes the feet to slightly unload the ground), the resting weight determined when sitting quietly in the chair decreases during unloading to see a dip in the GRFv (Figure 2.2)). Characteristics of this stage include the first decrease in GRFv from resting weight [1]. The phase continues until seat lift-off when GRFv at the feet peaks [170] and enough force is generated to raise the body at which point the rising phase begins.

The rising phase sees extension beginning after the seat lift off. Hip lift-off, the point when there is no longer contact between the subject and the chair, and the appearance of the peak GRFv are thought to occur relatively close together. Some cite the peak GRFv just before hip lift off [172], and others cite a peak in GRFv just after lift-off [173]. The peak in GRFv is followed by a brief deceleration to correct for the over-shoot of GRFv past the subjects body weight. The GRFv decreases to a second minimum before again increasing back toward body weight. The time from the peak GRFv until increasing back to body weight marks the duration of the rising phase, at which point there is full extension at the hip and knee joint [170]. During the preparation and rising phase is when we see the largest movement of the COP during the STS task, with sway back and forth during the stabilization phase.

When the subject's GRFv curve passes body weight for the third time the stabilization phase has started [1, 2]. The stabilization phase is characterized by the GRFv curve oscillating around body weight until a point of stability is determined using either the GRFv or COP fluctuations, compared to a normal quiet stance [1, 169]. Postural control is likely achieved with contractions of the ankle muscles [174]. For stability to be achieved, one has to end in a standing position above their new base of support, meaning that to rise from a seated position forces have to be applied at the appropriate time and in the correct magnitude [1].

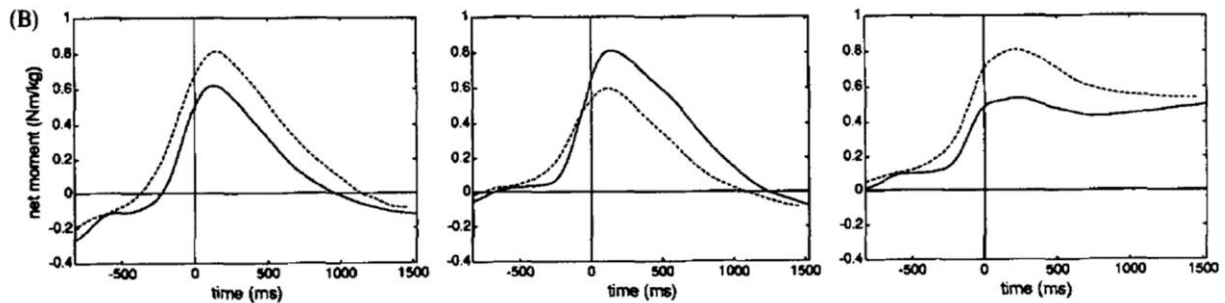


**Figure 2.2:** Phases of the Sit-to-stand displayed on vertical ground reaction force curve [1]

The stabilization phase is an area of the task that could be explored further to uncover possible relationships between functional tasks, postural stability and a risk of falling. Being able to control ones stability at the end of a STS task is linked with an ability to control dynamic movement regarding the COM, mainly controlling for the forward motion to preserve the

anterior-posterior stability [2]. However, stability must also be achieved in the medial-lateral direction as well.

When minimizing energy expenditure those with normal neuromuscular control move in such a pattern to produce small joint moments to reduce muscle force, but the transfer from sitting to standing requires large moments, mainly from the hip and knee joints [175]. Figure 2.3 displays joint moments at the hip, knee, and ankle during the STS.

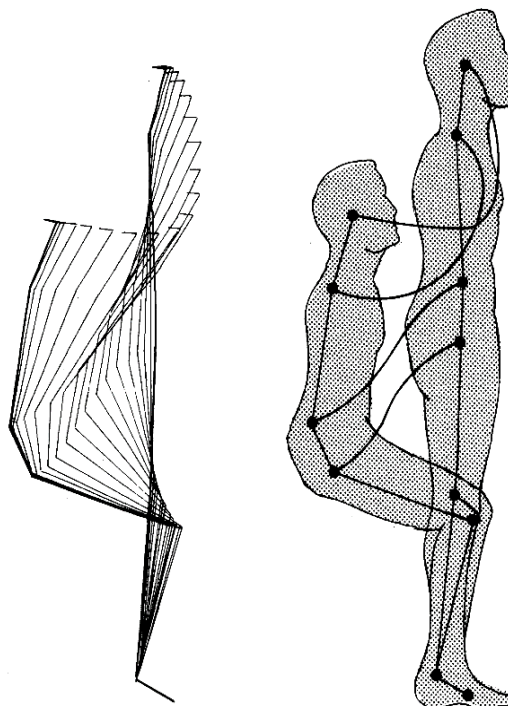


**Figure 2.3:** Joint moment at the hip, knee and ankle during a normal STS.

When looking at the biomechanics of the movement some have divided it into two distinct phases; a forward-thrust (FT) phase and extension phase (EXT) [176]. Breaking down the movement we see trunk flexion that corresponds to a hip flexor joint moment, which results in low back loading meant to minimize the extensor torque on the knee joint [168]. For about the first 40% of the activity the hip remains flexed and becomes extended during the progression of movement after lift-off has occurred [3]. The knee begins to change angles slightly from its initial flexed position to start extending, and the thigh moves forward and upward from the chair [176]. The pelvis, which started in an anterior tilt will rotate posteriorly during standing to end in an upright position. When muscle weakness, or other limitations, inhibit the movement, there



are many different alternative patterns that can be applied to reduce hip and knee movement to allowing stronger muscles to do the work [175]. The hip flexion moment at the beginning of the FT reaches ~50% of its peak values while the knee flexion moment stays near zero. Hip and ankle flexion increases reaching their maximum activity at the end of the FT phase. The EXT phase is set to begin, and the body continues to move in an upward position. Hip and knee angles go through extension with the knee rapidly extending [176]. Hip moments that were flexing now decrease to approximately zero, and knee moments reverse extending the joint to the end of the EXT phase. The ankles will progress through dorsiflexion during the first portion and then move through plantar flexion until the task is complete [3]. Horizontal and vertical displacement of joint positions has to occur, as there is movement through space to end in an erect standing posture (Figure 2.4).



**Figure 2.4** Diagram depicting the movement pattern from initial position to final position. Left diagram is a projected sampling rate of movement. Right diagram is of movement trajectories at different joints [3].

The influence and assessment of power during the STS task has been of interest. A decline in leg power among older adults can be related to mobility difficulties, and reduce STS performance [177]. One study using older adults over the age of 70 had participants complete a STS at a comfortable and fast pace [178]. It was determined that a fast pace elicited higher peak power demonstrating that there are differences among pace conditions [178]. Others were able to find differences between young and older adults when looking at lower limb muscle power during the STS movement. Young adults were able to produce a significantly higher maximal lower limb muscle power of  $9.05 \pm 3.66$  W/kg compared to the  $5.50 \pm 2.02$  W/kg of the older adults when rising at a comfortable pace [179]. There was also a significant difference between maximal GRFv of  $138.79 \pm 24.2$  N/BW, and  $117.51 \pm 8.5$  N/BW, in young and older adults respectively. The differences reveal that decreases are to be expected and associated with performance variation during the STS when comparing young and older adults.

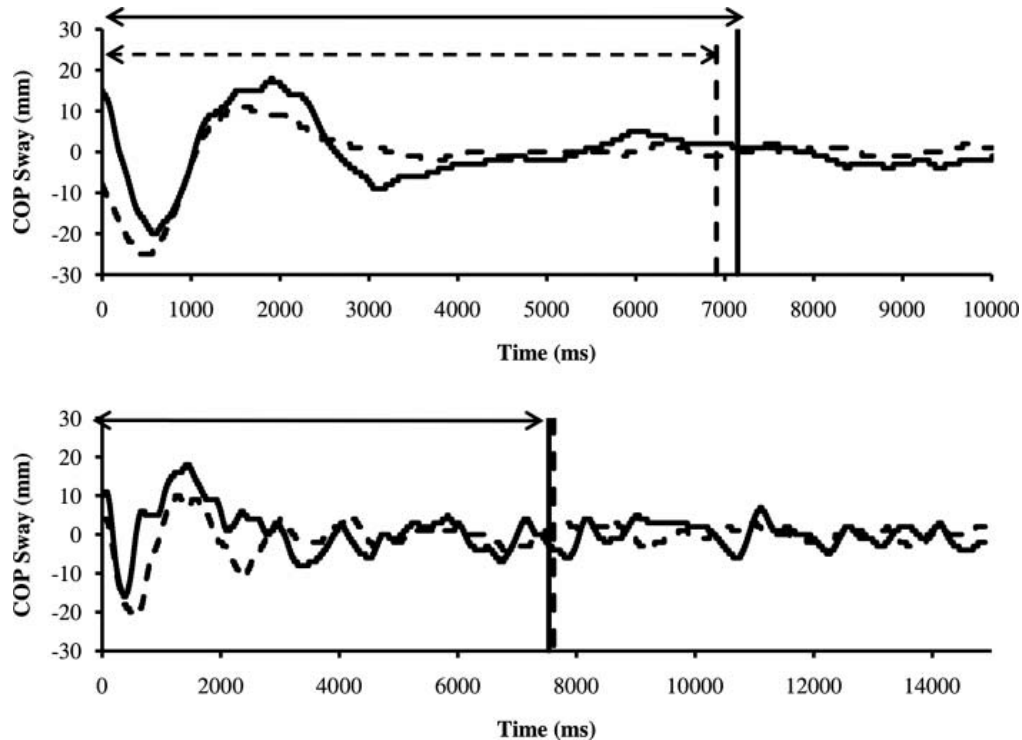
### *Stabilization Phase*

As the stabilization phase is of relatively new interest there are few studies that provide an in depth look at the characteristics of the stabilization phase. In one study the foot position relative to the seat was used to alter and determine characteristics of the stabilization phase when rising at a self-selected pace [2]. Subjects were 11 healthy young and 11 healthy older adults (average age 23 and 74 years respectively). They used two different task conditions of placing the feet further away or close to the chair. They then calculated the COP in both an anterior-posterior (ap) and medial-lateral (ml) direction. They defined three stages of the task 1) the preparation phase: the beginning of the STS movement until the force plate under the chair was unloaded, 2) the movement phase: from seat lift off until the hip joint reached full extension, 3)

the stabilization phase: from the time of full hip extension until the magnitude of the COP movement fell within the range of natural sway during quiet stance [2]. Average time of the stabilization phase in the ap direction was 6847 ms and 7037 ms, close and far respectively in the young adults [2]. Average time in the same direction was 8812 ms and 8738 ms, for close and far respectively in older adults [2]. Older adults took longer to stabilize in both the ap and ml direction than their young counterparts, though there was no interaction between foot placement and age [2]. It is thought that the older adults may have had a speed and accuracy trade-off, a strategy meant to ensure safety [2]. The difference in MT between conditions was larger in the older adults with a longer MT during the far condition, but they stabilized faster. However, it was determined that altering foot placement may not be the appropriate means to increase the intensity of rising from a chair to determine deficits. As there was no significant interaction between age and condition when altering foot placement.

To determine when COP was within the range of a normal quiet stance they quantified COP during the last two seconds of the trial that lasted at least 15s, when individuals were in their most stable stance. From the point of full hip extension the standard deviation of the COP sway was determined for consecutive 2s intervals. The time point at which the calculated COP sway fell within the 95% confidence interval of normal COP sway signified the duration of the stabilization phase (Figure 2.5). Determining when the COP fell within 2.5% window was done separately for both the ap and ml COP sway. In addition to duration they also assessed the total path traveled by the COP in the first second of the stabilization phase for both ap and ml directions. The young saw a path length in the ap direction of 22 and 23 mm, close and far respectively, and in the ml direction 25 and 36 mm close and far respectively. The older adults

recorded path lengths in the ap 20 and 32 mm, and in the ml 40 and 44 mm, close and far respectively.



**Figure 2.5:** Stabilization phase with depiction of the COP in the ap (dashed lines) and ml (solid lines) directions for young adults (top panel) and older adults (bottom panel). Single trial of participant during far condition, from the end of the movement phase to the end of the trial. The vertical line indicated the time when COP sway falls within the range of natural sway during a quiet stance in ap (dashed line) and ml (solid line) directions [2].

An alternate method of evaluation for the stabilization phase performed by Lindemann and colleagues was to look at the GRFv [1]. In their study participants were asked to stand as fast as possible with their feet on two separate force platforms. They assessed time to stand up, power, maximum GRFv, increase in GRFv and overshoot of GRFv over body weight. The use of force platforms allowed for the generation of a GRFv curve to be displayed over a function of time (Figure 2.2). The analysis of the curve took place in two phases, the preparation/rising

phase and the stabilization phase. The stabilization phase was determined to start when GRFv reached body weight after decreasing and increasing after peak force, and was set to end GRFv fluctuates in the corridor of 2.5% body weight [1]. Lindemann *et al* looked at the stabilization phase from the perspective of events that occur during the rising motion [1]. Using regression analysis of power, maximum GRFv, increase in GRF, and time of stabilization as independent variables they were able to explain 81% of the variance of the total time to stand up [1]. Note, the total time to stand included the stabilization phase. The regression analysis of total time to stand revealed that power and the increase of the GRFv (both adjusted to BMI), were negatively associated while max GRF and time to stabilization were positively correlated. Displaying how it is important to analyze both the stabilization phase and what comes before it, as the characteristics prior to the stabilization phase may be telling of the stabilization phase success, particularly the peak force. Total time was found to be 1.82s with a range of 0.82-4.72s, with the time of stabilization being the strongest predictor of total time [1]. The length of time to stabilization averaged to be 0.38s for in this study [1]. Lindemann *et al.* (2007) used participants with an average age of 82.5 years, and instructed participants to rise as fast as possible [1].

Few others had identified the stabilization phase but did not report results on it to help define the characteristics. Lindemann *et al.* (2003) defined the last phase of the STS as the stabilization when the GRF oscillates around body weight [169]. They speculated that the phase is related to a balance capacity since balance plays a role in rising [62]. Total time of the STS was recorded at 1.2 s with the stabilization phase consuming 0.12 s or 10% of the movement [169]. Schenkman *et al.* (1999) also outlined the stabilization phase as beginning just after hip-extension velocity reached 0%/sec [180]. But the end of the stabilization phase was not easily determined at the time and not used for the analysis of the study. With little research on the

stabilization phase further analysis is warranted. From these few works the stabilization phase has yet to be directly associate to balance or fall risk in older adults.

### *Evaluation Criteria of the Sit-to-Stand*

As the STS task has been used as a measure of physical function there are certain criteria that account for the success or failure of the task. Riley *et al.* (1997) determined two types of STS failures, the first a “sit-back” failure and the second a “step” failure [181]. In the first instance the subject would rise slightly from the chair and then immediately sit back down unable to make it to a full standing position. In the second, the individual is able to successfully stand up, but is unable to finish the task in a stable position (i.e. taking a step, or falling). Both failures are the result of a loss in balance control, and possibly strength, and in real life situations could easily produce a fall [181].

In the first scenario there are many explanations for why the task was unable to successfully be completed. There could have been muscle weakness from inactivity in the lower extremity [181] or an injury/disease, thus preventing an individual from being able to lift their own body weight. Without the proper strength the movements of flexion and extension could have been inhibited at different joints, resulting in the sit-back [181]. Flexibility may also be an issue limiting the adequate range of motion. An impairment in proprioception and balance may also prevent a person from rising without falling backwards. Whatever the cause of the failure, it is most often believed to be related back to an inability to generate enough momentum to carry through with the movement [181].

The second type of STS failure, the step failure, is of particular interest when looking at the stabilization phase, because wherever the failure may have actually occurred the result was seen in this phase. It was determined a STS movement that resulted in a step failure was still able to produce enough energy to permit rising, but the terminal rise was poorly controlled [181]. The failure was not due to excessive momentum generation as was previously thought, because most steps were taken in a lateral or posterior direction, rather than anteriorly [181]. Meaning it was not just a lack of control in correcting for overshoot of excessive momentum at the end of the movement, but rather a lack of control throughout the movement to meet the energetic demands. Therefore the failure occurred in the initiation of the task rather than during the stabilization phase. But by studying the movement phase and stabilization phase we can learn more about where adjustments should be made to prevent moments of instability.

No matter the type of failure, evaluation of the task will likely depend on the expected outcomes of the research. There are different methods of evaluation from using force platforms to record forces and moments to determine GRF and COP characteristics of the movement. Or, the research may utilize direct observation, or video/sensor recordings to gather kinematic information. If both force platforms and kinematics are collected, inverse dynamics may be performed to examine the muscular kinetics. The theory of the varying evaluation techniques is to provide an idea of how the subject is moving through space and time. Output measures are important to be able to track the progression of the movement and see where errors may be occurring. Being able to follow the movement of one individual and compare it to others results in patterns and trends that signify what is expected during the movement. Events that do not fall in line with the general pattern will hopefully be able to lead to the identification of where the problem is originating.

Of the different methods of evaluation there are advantages to each and a combination of the methods may prove to be the best method of evaluation. Using GRFv curves allows us to see changes in forces over time. The evaluation of COP provides insight for movement in both the ap and ml directions. Stabilization in both directions cannot be assumed to occur at the same time, and difference seen based on direction may allow for more specific intervention programs to help individuals. Looking at the first second of the stabilization phase like Akram and McIlroy could also be helpful for individuals who cannot stand for 15-20s [2]. If there are markers within the first few seconds of the stabilization phase that are just as revealing of deficits it can allow for shorter and less physically taxing test to evaluate balance and physical functioning.

#### *Effect of Speed/Pace on Sit-to-Stand*

To test the influence speed has on the completion of rising from a chair, researchers have used a variety of methods from a self-selected pace, to a controlled paced determined by a metronome, to rising as fast as possible. What was seen from increasing the speed of the movement was an increase in the magnitude of the hip flexion, knee extension and ankle dorsiflexion joint moments [182]. Pai (1990) was also able to determine that a faster STS movement effects peak vertical momentum but peak horizontal momentum is unchanged [183]. The flexion and momentum-transfer phases were reported as being shorter during faster tasks [184]. Yet, looking at elderly adults under normal and fast conditions, researchers were able to determine a decrease in hip flexion (the amount of forward lean to initiate movement) at the moment of seat lift off, when rising rapidly [66], and that these same individuals were less able to increase their speed of the movement compared to younger adults.



With an increase in the speed of execution of the task there is an assumed decrease in time spent during the different phases of the task. What's more is that if we know there is a decrease in signals and processing of the central nervous system with age, then the ability for adults over the age of 65 years to complete the task as fast as their young counterparts cannot be assumed. Increasing the pace of rising from a chair is also thought to increase the intensity of the movement making it more fatiguing and taxing on the individual. Evaluating varying speeds of completion is important as it represents how the task may be completed in daily life. There are instances when individuals feel hurried or pressured to complete the task faster. From a rehabilitation perspective it would be worthwhile to consider both comfortable pace and fast pace tasks to meet the demands of daily life.

When evaluating the STS task, time to completion has been associated with standing and leaning balance, and mobility [16]. Although we propose looking at both comfortable and fast pace conditions, slow STS times have previously been used to predict disability [185] and falls [186-188]. Demonstrating that performance of a STS at a comfortable pace is able to discriminate between those who perform slower being at greater risk than those who perform faster. As associations can be determined with a slow pace can these same or alternative relationships be found when performing at a maximal pace? Although there is a broad range of measurements available during the STS to be used as predictors of success much of the variance is still unexplained [189]. Meaning other important factors that may be learned from completing the task faster could provide additional information on STS performance. Faster conditions may require greater effort for balance and proprioceptive abilities than can be seen during a comfortable pace. When rising comfortably the balance system may not be challenged, and the increased speed could identify deficits not normally observed.

One study using healthy older adults did compare a normal STS to a fast STS, specifically looking at peak power before and after an intervention [178]. Prior to the intervention program normal and fast STS produced similar maximal acceleration (11.22 and 11.86 m/s<sup>2</sup>, respectively), and maximal velocity (0.52 and 0.70 m/s, respectively) [178]. Peak power was greater in the fast condition (423.4 and 585.5 W, respectively) both pre and post intervention [178]; both demonstrating the notion that there may be more to learn from speed difference between age groups, as well as within the same age group.

#### *Alternative Variables Effect on Sit-to-Stand*

The STS task has been evaluated from a variety of different standpoints, using modified aspects of the task to look at how they affect the movement. There have been modifications made to chair related determinants of the task like seat height, armrests, backrests and chair type. Other researches have modified strategy related variables, trunk position, arm movement, knee position, fixed joints, attention, terminal constraints, training, and lighting during the task. Those found to have some of the greatest influence on performance of the task were seat height, armrests and foot position [190]. Although there are multiple variables of influence our focus will be on those determined to have a significant effect on how the task is completed.

Seat height can be altered either by raising or lowering the seat. A change in either direction changes the biomechanical demands and the approach of the task [190]. Consensus acknowledges that a decrease in chair height requires greater momentum generation. Resulting in greater hip and knee flexion and displacement, to cover the larger distance traveled in a vertical direction [191]. Hip and knee moments can increase by 50% and 60%, respectively,

compared to that of a normal chair height. Standard chair height is considered to be 46 cm [2]. A lower seat requires greater momentum, and higher seat position is believed to decrease the demands of the task and result in lower moments at the hip and knee. If greater momentum is required the task difficulty increases and can thereby increase one's effort level for completion. Thus placing the chair at an optimal height for the individual could yield the best results for successful completion. As height varies across individuals and many chairs are a fixed height rehabilitation programs should focus on rising from a standard chair height to have the greatest universal effect on improving daily functioning. While decreasing chair height may be a potential way to alter STS performance, potentially placing increased demand on the stabilization phase when dissipating the initial momentum, it may exclude some older adults from being able to perform the task. If they do not have the adequate strength or range of motion to perform the task, how it is executed cannot be analyzed. Similarly, using an elevated chair height might make the task too easy for some.

When armrests were used to rise from a chair they were reported to decrease moments at the knee and hip, by about 50% [192]. This is likely due to the use of upper extremity muscle groups, taking away some of the burden of the lower extremity. The use of armrests allows for compensatory mechanisms to achieve a standing posture that could be masking real deficits in functional capacity. Although, armrests decrease some of the demand of the task having people always rely on them could hinder their movements when armrests are unavailable, or require them to use an unstable object for support. The use of one's hands or upper extremity can occur during STS even without the use of armrests. Individuals may be able to use their thighs, help from other people or by freely moving their hands. When comparing hand placement on the thigh versus across the chest, the latter produced significantly shorter 5xSTS times [193]. This

position might help to shift the COG forward more efficiently [193]. As few studies have evaluated varying hand positions further analysis is needed. For comparison across studies a consistent hand position of arms placed across the chest should be considered as it does not allow for mechanical compensation from the upper extremity when rising. Along with defining clear parameters for foot and hand position at the start of a STS task, trunk position should also be part of the definition. This will allow for a standardized starting position from head to toe and make for better comparisons across studies.

### *Summary*

The motion of rising from a chair is important for the maintenance of daily functioning. In order to be able to walk, and carry out further ambulatory processes one has to first be able to rise from a seated to a standing position. This movement encompasses biomechanical demands placed on the body, in order to move the bodies COM. Successful completion of the task requires adequate strength, power and maintenance of balance to help the body produce smaller joint moments making the task less taxing on the individual.

The STS task has been assessed based on varying parameters like foot position, seat height, and age of the participants, all of which can affect the movement pattern of rising from a chair. The STS task has also been evaluated from multiple viewpoints based on GRFv, COP in varying directions, and through kinematic sensors. Using a combination of methods may be the most revealing of the movement, and where problems are occurring, the examination of variables captured with force platforms has been the most common method. Variables found to be different among young and older adults that may be indicators of compromised balance are

maximal GRFv, peak power, rising time, and time to stabilization. Further evaluation of the stabilization phase is warranted for the potential use in determining the influential factors over dynamic balance and force control. Using varying speeds to assess and expose deficits is necessary. The evaluation of speed is an under studied area of the literature between age groups and within the same age group. It is important to assess speed difference across age groups, because with advancing chronological age functional limitations and decreases are probable. The efficiency and precision of familiar tasks can become degraded as more attention and effort has to be applied. As previously discussed there are neuromuscular changes associated with the aging process effecting both muscle movement and neural control, thereby affecting such tasks as rising from a chair.

## **F. Conclusion**

Falls are a serious issue and concern for many aging individuals. Falls do not only affect the individual, but society as a whole. The health care costs associated with falls and fall related injuries should make them a primary public health care concern. As people age systems and functioning within the human body can begin to deteriorate placing individuals at a heightened risk of falling. It is important to identify these individuals so as to best be able to help them.

Our current methods of static and dynamic balance assessment as they relate to falls and fall prediction have some room for improvement. Methods are limited by an ability to truly evaluate a functional task that is representative of daily movement and can pinpoint where failures or errors are occurring within the movement. A single repeated trial of the STS looking at the whole of the task, with particular focus on the stabilization phase may fill the void in

assessment and better evaluate a person's ability to perform functional movements for the importance of maintaining independence. Requiring the task to be performed at varying speeds, both a comfortable and fast pace, may be a more realistic adjustment and more appropriate than seat height or foot positions.

Therefore the goals of this investigation are to examine the stabilization phase of comfortable and fast paced single repetitions of rising from a chair in both older and young adults. We believe that older adults will take longer to stabilize than their young counterparts, and that the stabilization time will be longer for the fast paced repetition compared to the comfortable for both older and young adults. It is believed that the events in the preparation phase and rising phase prior to the stabilization phase will be correlated to the duration of the stabilization phase. In addition to assessing average parameter values, it is also important to assess individual coefficient of variation. As we also expect older adults to have more trial-to-trial variability when completing both tasks, which may be related to dynamic balance and the risk of falling. This study aids in the better understanding of the task of rising from a chair and the balance necessary, while also benefitting clinical practices to better assist in therapeutic interventions set out to improve daily functional abilities.

## CHAPTER III

### METHODS AND PROCEDURES

#### Participants

The performances of forty subjects were evaluated during a variety of balance and functional tasks for the purpose of this study. Subjects were categorized into two groups based on age (young and older adults). Young adults were within the age range of 18-33 years, and older adults were between the ages of 65-80 years. Each age group was comprised of equal numbers of men and women.

All participants over the age of 65 were approved by a physician to participate in light exercise within a 12 month period prior to the study. All subjects were considered to be in good health based on inclusion and exclusion criteria. Participants were free of any neurological, musculoskeletal, and vestibular impairments, in addition to having no prior history of unexplained falls within the last year, as determined by self-report. For each subject height and weight were measured and recorded, in addition to determining body mass index (BMI). All subjects reported participating in one to four days of physical activity regularly each week, for a period greater than four months. In addition to exercising at a low to moderate intensity when physically active, all participants were non-smokers, lived in a private residence and were able to rise from a chair unassisted. All subjects were free of lower extremity joint replacements and not currently taking any medications affecting their balance ability. Those who did not meet these

criteria were excluded from the study. A screening form used for all subjects is provided in Appendix A.

Volunteers for the study were recruited from the Colorado State University (CSU) student population, community of Fort Collins, and from the CSU Adult Fitness Program. Signatures indicating informed consent were obtained from all participants prior to participation in any aspect of the study, and after a thorough explanation of the experimental purpose and protocol (a copy of the informed consent is provided in Appendix B). The experimental protocol used in this study was approved by the CSU Institutional Review Board (approval form provided in Appendix C).

#### Experimental Design & Methods

This study was completed in the manner of a cross-sectional investigation. Subjects completed two surveys, the first of which was the Activities-Specific Balance Confidence (ABC) [194], where subjects indicated their level of confidence that balance could be maintained during a variety of activities, on a 0-100% scale. Increasing values towards 100% indicate greater confidence in performing the task safely and successfully without losing their balance. The second survey was the Survey of Activities and Fear of Falling in the Elderly (SAFE) [195], where participants specified how worried they were of falling during varying tasks, on a four point scale (0-3). Increasing values above zero indicate an increasing fear of falling. All subjects then completed the Short Physical Performance Battery (SPPB) [16] involving 3 10s standing balance measures, a timed 5x Sit-to-Stand (STS), and a timed gait assessment of comfortable pace over 4m. Subjects were then instructed to complete a series of stances



performed on a portable force platform (Advanced Mechanical Technology Inc., AccuSway model #ACS-PLUS, Watertown, MA) with an iPod Touch 5<sup>th</sup> Generation (Apple Inc., Cupertino, CA) attached at the point of their right greater trochanter using a Velcro strap, from which the data collected was not used for the purpose of this study. Next, a set of single repetition STS tasks were performed on a force platform at two speeds (a comfortable and fast pace) for four trials each, which were the main focus of the analysis. Finally, a grip strength assessment was performed for three trials on all participants, using their dominant (or strongest if any pre-existing condition) hand.

For the STS trials, the same iPod used during the standing activities was placed at 60% femur length (distance from the palpated greater trochanter to the center of rotation of the knee) using a Velcro strap on the right thigh. All subjects wore shorts during the data collection, with the iPod strapped over the bare upper leg during STS activities. The measurements recorded from the iPod were not analyzed for this study. It is believed that the placement of the iPod did not interfere with the ability to successfully complete any of the required movements.

For the STS task subjects were instructed to start seated in a standard chair (seat height of 46 cm) [1], which was placed on top of a wood platform built to match the dimensions of the force platform. Participants performed all tasks in stocking feet, and placed their feet at the marked heel-to-heel distance of 10% body height on the force platform. When seated, subjects were positioned to allow for vertical alignment of the lower leg, as close to a 90 degree internal knee angle as possible, and at 90 degree hip internal angle. Subjects sat with an erect trunk (not using the back rest), arms folded across their chest with hands resting on their shoulders. Subject position was checked at the start of every trial of the STS task. Once in place and sitting quietly, subjects were given a verbal cue to initiate movement and rise from the seated position to a full

standing position, and remain standing as still as possible for not less than 20 seconds. Subjects performed four trials of a STS at a comfortable self-pace (CSTS), and four trials of a STS at a maximal fast pace (FSTS), for a total of eight trials. To prevent fatigue, subjects were allotted resting time between each trial. Individuals were instructed to rise unassisted (without use of their own upper extremity or the research staff), and asked not to take a step after having reached a standing position. All subjects were asked to keep their feet flat on the platform during all measurement recordings, and if their feet lifted off the platform at any point the trial was redone. The order of the tasks (CSTS or FSTS) performed was randomized, in such a manner that all four trials of the CSTS or FSTS were performed together but in a random order among subjects. Counterbalancing was performed to ensure that half the subjects in each group performed the CSTS followed by the FSTS, and the other half performed FSTS followed by the CSTS. Considering the relative familiarity of the STS task, subjects performed a single practice trial of each before data was collected.

## Measurements

Force ( $F_x$ ,  $F_y$ , and  $F_z$ ), and moments ( $M_x$ ,  $M_y$ , and  $M_z$ ) were recorded at 100 Hz from the force platform from which COP was calculated in the ap and ml directions. Balance Clinic software for AMTI's AccuSway Plus (version 2.02.01, Watertown, MA) was used to collect the data. Collection started ~5s before initiation of the task and continued to record for ~20 seconds after subjects had reached a visible standing position (standing upright and with knees extended).

Data processing was performed using custom MATLAB (Natick, MA) code. Raw force platform data was first low-pass filtered at 15 Hz (4<sup>th</sup> order, reverse Butterworth). The start of

the task was marked at the first sustained decrease of GRFv greater than 2.5% of resting weight [1]. Resting weight (RWT) was a 1s average GRFv calculated prior to giving the initiation signal. The preparation phase (PP) ensued until the maximum GRFv (GRFv max) was reached, followed by the rising phase (RP) and stabilization phase (SP). The RP ended when the GRFv returned to bodyweight (BWT) after a brief unloading period. This also marked the start of the SP. BWT was the 1s average GRFv from 14-15s after triggering data collection. Movement time (MT) was defined as the time to complete the PP and RP. In addition to RWT, BWT, and GRFv max, the minimum GRFv of the PP (GRFv PPmin) and the minimum GRFv of the RP (GRFv RPmin) were also extracted during the movement (Figure 3.1).

The duration of the SP (aka, stabilization time (ST)), was determined using three different methods. Each method used the same starting point based on GRFv as previously described. The end of the SP was determined using the 2s standard deviation (SD) of each parameter calculated from 14-16s after the start of the SP (GRFv, COPml, and COPap postSD), believing that natural sway of quiet stance should be achieved by this time [2]. The end of the SP was then marked when the moving average 2s window of each variable first dropped below two times the postSD (95% confidence band of sway variability) [4]. In this manner there was a ST calculated for the GRFv (GRFv ST) as well as each direction of the COP (COPml ST and COPap ST) (Figure 3.2).

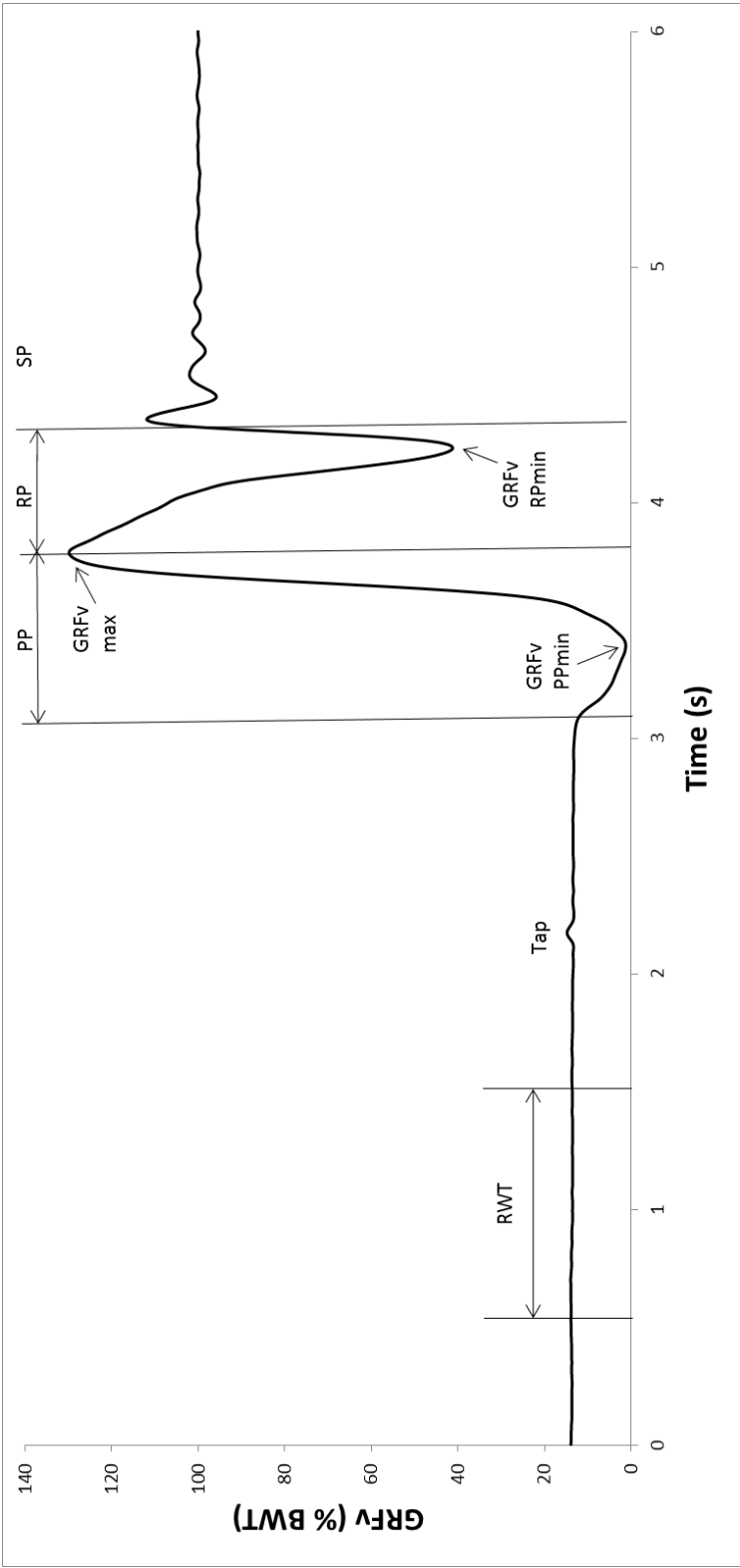
Considering that it may be difficult and time consuming in some situations to have people stand as still as possible for at least 20s after fully rising from a seated position, and that the prior method determines ST relative to their quiet stance postural sway, GRFv and COP fluctuations during the first 2s of stabilization were also assessed. The assessed values were a representation of the maximum minus the minimum value (GRFv, COPml, and COPap 2s $\Delta$ ) as well as the SD

(GRFv, COPml, and COPap 2sSD) (Figure 3.2). The COP path length in both directions (COPml and COPap PL) were also computed during this initial first 2s of the SP. All time variables were calculated in seconds, GRFv variables in percent BWT, and COP in percent standing height.

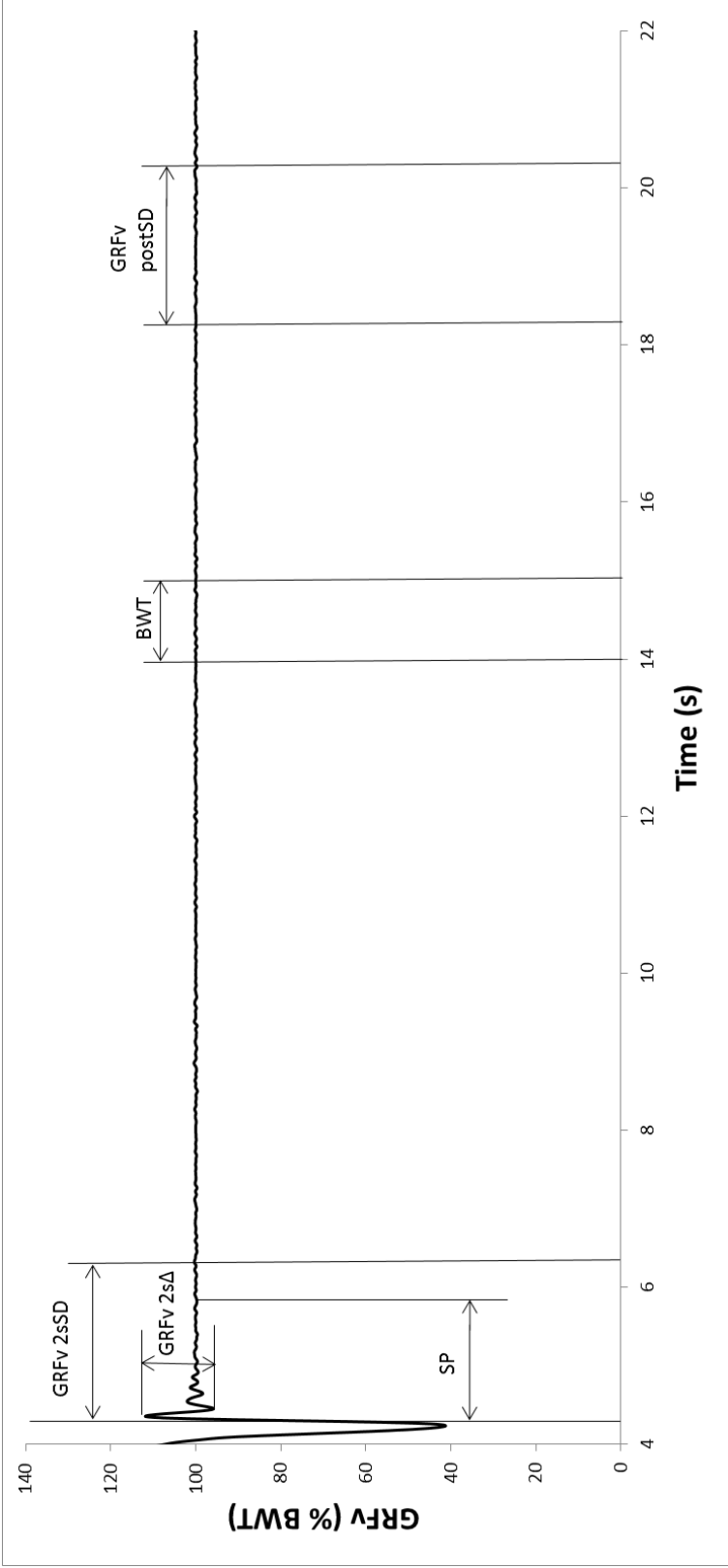
## Statistical Analysis

Mean differences between young and older adult subject characteristics (age, height, body mass, BMI, average foot length, stance width, standing balance measures, 5xSTS, fastest gait, grip strength, ABC composite score, and SAFE composite score) were performed using independent-samples t-tests. The values gathered from each of the four CSTS and four FSTS were averaged to create a representative mean value for each subject. The four trial coefficient of variation (COV) of each variable was also computed to assess between trial variability. The individual subject averages and COV were pooled to create group averages and SD of each and then assessed for differences between groups (young and older adults) and STS pace (comfortable and fast) with 2x2 (group x pace) repeated measures analysis of variance (ANOVA). Post-hoc t-tests were performed if significance was found in the interaction between groups and pace. Pearson correlations were used to examine relationships between CSTS and FSTS, as well as between movement and stabilization phase variables within the young and the older groups. An  $r < 0.500$  was classified as weak, from  $0.500 - 0.799$  classified as moderate, and  $\geq 0.800$  classified as strong. All statistics were performed in IBM SPSS Statistics v 22 (Chicago, IL).  $P < 0.05$  was set for statistical significance.

Prior to any statistical comparisons being performed, each variable was examined for outliers [60]. All extreme outliers using box plot analysis were removed (i.e. those greater than three box lengths from the end of the box). The number of extreme outliers was minimal and when removed never resulted in more than one participants' data points being removed from any single variable. This kept the sample size at 19 or higher for each variable of each group. A total of 11 variables had a single data point removed after outlier analysis, seven from the mean values and four from the COV values. Mean variables in which an outlier was removed were young comfortable pace RWT, young comfortable pace GRFv PPmin, young fast pace RWT, young fast pace GRFv PPmin, young fast pace COPml 2sPL, old comfortable GRFv 2s $\Delta$ , and old comfortable GRFv 2sSD. From the COV variables an outlier was removed from young fast pace COPap 2s $\Delta$ , old comfortable pace BWT, old fast pace GRFv max, and old fast pace COPml 2sPL.



**Figure 3.1** Exemplar GRFv tracing from one older adult subject during a FSTS trial from initiation of data collection through start of stabilization with regions, phases, and instantaneous events labeled. See text for description of events



**Figure 3.2** Exemplar GRFv tracing from one older adult subject during a FSTS trial from start of the stabilization post completion and natural stance with regions and events of interest labeled. Regions and events for COP tracings were determined in the same manner. See test for description of terms.

## CHAPTER IV

### RESULTS

#### Subject Characteristics

A total of 40 subjects completed the data collection. Each of the healthy young and older adult groups consisted of 20 participants, equally balanced with 10 men and 10 women. Besides an increased age, the older adults also possessed a significantly greater BMI. Otherwise, there were no significant differences in anthropometric dimensions between the young and older adults (Table 4.1a). When looking at functional measurements, the older adults performed the 5xSTS significantly slower, possessed significantly lower SPPB standing balance and total scores, had significantly lower ABC survey scores, and had significantly lower grip strength compared to the younger adults (Table 4.1b).

#### STS Time Variables (Average)

Of the time variables, the only statistically significant main effects of the 2x2 ANOVAs with respect to condition (comfortable versus fast) were in MT and COPap ST ( $p \leq 0.001$  and  $p = 0.039$ , respectively). MT was less during FSTS and COPap ST was less during CSTS. There were no significant main effects for condition in GRFv ST or COPml ST ( $p \geq 0.730$ ).

Furthermore, there were no significant main effects for group (young versus older adults) in any



of the time variables ( $p \geq 0.147$ ), nor were there any significant interactions between condition and group ( $p \geq 0.455$ ) (Table 4.2). Graphs of all average results are provided in Appendix D.

#### STS GRFv variables (Average)

Of the 2x2 ANOVAs conducted on the grouped four trial average STS GRFv variables, significant main effects existed for condition in GRFv PPmin, GRFv max, GRFv RPmin, GRFv 2s $\Delta$ , and GRFv 2sSD (all  $p \leq 0.001$ ). GRFv PPmin and GRFv RPmin were both lower in FSTS compared to CSTS. However, GRFv max, GRFv 2s $\Delta$ , and GRFv 2sSD were all greater in FSTS. Main effects for condition were not significant in RWT and GRFv postSD ( $p \geq 0.068$ ) (Table 4.2).

Relative to group (young versus older adults) in the grouped four trial average STS GRFv variables, there were significant main effects in GRFv max ( $p = 0.002$ ), GRFv 2s $\Delta$  ( $p = 0.015$ ), and GRFv 2sSD ( $p = 0.017$ ). GRFv max, GRFv 2s $\Delta$ , and GRFv 2sSD were all greater in the young adults compared to the older adults. No main effects for group were significant in RWT, GRFv PPmin, GRFv RPmin, and GRFv postSD ( $p \geq 0.210$ ) (Table 4.2).

With respect to group by condition interactions in the grouped four trial average GRFv variables, there was significance in GRFv max ( $p \leq 0.001$ ) and GRFv RPmin ( $p = 0.011$ ). Post-hoc tests on GRFv max revealed that while both younger and older adults had higher values in FSTS compared to CSTS, the younger adults produced greater GRFv max than the older adults during FSTS. Post-hoc tests on GRFv RPmin revealed that while both younger and older adults had lower values in FSTS compared to CSTS, the younger adults produced lower GRFv RPmin than the older adults during FSTS. No significant interactions between condition and group

existed for RWT, GRFv PPmin, GRFv postSD, GRFv 2sΔ, and GRFv 2sSD ( $p \geq 0.084$ ) (Table 4.2).

#### STS COP Variables (Average)

Of the 2x2 ANOVAs conducted on the grouped four trial average STS COPml and COPap variables, significant main effects existed for condition in COPml 2sΔ, COPml 2sSD, COPml 2sPL, and COPap 2sΔ, COPap 2sSD, COPap 2sPL (all  $p < 0.001$  except COPml 2sSD  $p = 0.003$ ). All the significant variables were lower in the CSTS compared to the FSTS. Main effects for condition were not significant in COPml post SD or COPap postSD ( $p \geq 0.679$ ) (Table 4.2).

Relative to the group in the grouped four trial average STS COPml and COPap variables, there were significant main effects in all COP variables: COPml postSD ( $p = 0.002$ ), COPml 2sΔ, COPml 2sSD, and COPml 2sPL (all  $p \leq 0.001$ ), COPap postSD and COPap 2sΔ (both  $p < 0.001$ ), COPap 2sSD and COPap 2sPL (both  $p = 0.002$ ). All variables were lower in the young adults compared to the older adults (Table 4.2). There were no significant group by condition interactions in the grouped four trial average of the COP variables ( $p \geq 0.055$ ) (Table 4.2).

#### STS Time Variables (COV)

Of the time variables, there were no statistically significant main effects of the 2x2 ANOVAs with respect to condition (comfortable versus fast) on the grouped COV data ( $p \geq 0.158$ ). There was a statistically significant main effect with respect to group (young versus

older adults) in the COV of COPml ST ( $p = 0.024$ ). The COV of COPml ST was greater in the young adults compared to older adults. There were no significant main effects for group in COV of MT, GRFv ST, or COPap ST ( $p \geq 0.067$ ). Furthermore, there were no significant interactions between condition and group in the COV of the time variables ( $p \geq 0.071$ ) (Table 4.3). Graphs of all COV results are provided in Appendix D.

#### STS GRFv Variables (COV)

Of the 2x2 ANOVAs conducted on the grouped four trial COV of the STS GRFv variables, significant main effects existed for condition in the COV of GRFv PPmin, GRFv RPmin, and GRFv 2sSD ( $p \leq 0.009$ ). The COV of GRFv PPmin, GRFv RPmin, and GRFv 2sSD were all lower in the CSTS compared to the FSTS. Main effects for condition were not significantly different in RWT, GRFv max, GRFv postSD, and GRFv 2s $\Delta$  ( $p \geq 0.056$ ) (Table 4.3).

Relative to group (young versus older adults) in the grouped four trial COV of the STS GRFv variables, there were significant main effects in the COV of GRFv max ( $p < 0.001$ ) and GRFv postSD ( $p = 0.015$ ). The COV of GRFv max was greater in the young adults and GRFv postSD was greater in the older adults. No main effects for group were significant in the COV of GRFv RWT, PPmin, RPmin, 2s $\Delta$ , and 2sSD ( $p \geq 0.051$ ) (Table 4.3). With respect to group by condition interactions in the grouped four trial COV of the GRFv variables, there were no significant variables ( $p \geq 0.134$ ).

## STS COP Variables (COV)

Of the 2x2 ANOVAs conducted on the grouped four trial COV of the STS COPml and COPap variables, a significant main effect existed for condition only in the COV of COPml postSD ( $p = 0.032$ ). The COV of COPml postSD was lower in the FSTS compared to the CSTS. Main effects for condition were not significantly different in the COV of COPap postSD and COPml or COPap 2sSD, 2sPL, and COPap 2s $\Delta$  ( $p \geq 0.358$ ) (Table 4.3).

Relative to group in the grouped four trial COV of the STS COPml and COPap variables, there were significant main effects in every COV variable of COPml and COPap ( $p \leq 0.046$ ). All COV of the COP variables were lower in the young adults compared to the older adults (Table 4.3). With respect to group by condition interactions in the grouped four trial COV of the COPml and COPap variables, none were significant ( $p \geq 0.130$ ) (Table 4.3).

## Correlations

When looking at the relationship between all variables under the comfortable and fast condition for the older adults for the time variables only the MT and GRFv ST were significantly correlated, though weak (Table 4.4). For the GRFv variables, all demonstrated significant moderate to strong correlations between conditions. Only two COP variables were significantly correlated COPap postSD and COPap 2sPL, both at the moderate level. When looking at the young adults and correlations between the comfortable and fast condition the only time variable that displayed a significant correlation was the GRFv ST at the moderate level (Table 4.4). For the GRFv variables RWT, GRFv PPmin and GRFv postSD were significantly correlated at the moderate to strong level between the comfortable and fast condition. Among the COP variables

COPml postSD is the only variable to have a significant correlation between conditions at the moderate level. Table 4.5 provides the correlations between movement phase variables and events of the stabilization phase for the older adults. There were few significant correlations for the comfortable pace between the movement phase variables and the events of the stabilization phase, with most being weak to moderate correlations. No significant correlations existed between the movement phase variables and the COP variables. In the fast condition there were a few weak to moderate correlations between movement phase variables and the time and GRFv variables. More significant correlations existed between movement phase variables and COP variables. More specifically, GRFv max was moderately positively correlated to all three of the COPml 2s variables and the GRFv RPmin was weakly to moderately negatively correlated to five of the six COPml and COPap 2s variables.

Table 4.6 provides the correlations between movement phase variables and the events of the stabilization phase for the young adults. When looking at the comfortable condition a few significant correlations of a weak to moderate level exist, with most correlations being non-significant. The GRFv max has the greatest correlations to stabilization phase events, particularly COP variables. The GRFv RPmin displayed mostly negative correlations to the events of the stabilization phase. When looking at the fast condition a few significant correlations of a weak to moderate level exist, with most correlations being non-significant.

**Table 4.1a Subject Characteristics - Anthropometrics**

	Young Adult		Older Adult		p value*
	Mean	SD	Mean	SD	
Age (yrs)	22.45	(2.72)	71.80	(4.15)	<0.001
Height (cm)	170.66	(8.72)	167.84	(10.68)	0.356
Body Mass (kg)	66.91	(8.05)	77.08	(21.99)	0.060
BMI (kg/m <sup>2</sup> )	23.03	(2.85)	26.89	(5.22)	0.006
Stance Width (cm)	28.38	(2.19)	28.88	(2.88)	0.540
Average Foot Length (cm)	25.21	(1.41)	25.35	(2.42)	0.827

\* between young and older adults

SD = Standard Deviation

BMI = Body Mass Index

**Table 4.1b Subject Characteristics - Functionality**

	Young Adult		Older Adult		p value*
	Mean	SD	Mean	SD	
<b>SPPB Activity</b>					
Side by Side (s)	10.00	(0.00)	10.00	(0.00)	--
Semi-Tandem (s)	10.00	(0.00)	10.00	(0.00)	--
Tandem (s)	10.00	(0.00)	8.85	(2.25)	0.340
4m Gait Fastest (s)	3.19	(0.45)	3.26	(0.59)	0.295
5xSTS (s)	8.40	(1.37)	10.37	(1.98)	0.001
<b>SPPB Score</b>					
Standing Balance	4	(0.00)	3.7	(0.47)	0.010
4m Gait	4.00	(0.00)	3.95	(0.22)	0.324
5xSTS Score	3.95	(0.22)	3.65	(0.67)	0.065
SPPB Total Score	11.95	(0.22)	11.30	(0.80)	0.002
<b>Surveys</b>					
ABC Survey Score (%)	98.41	(2.38)	94.81	(6.91)	0.038
SAFE Survey Score	0.08	(0.12)	0.16	(1.95)	0.119
<b>Other</b>					
Grip Strength (kg)	37.65	(8.46)	30.00	(9.94)	0.013

\* between young and older adults

SD = Standard Deviation

SPPB = Short Physical Performance Battery

5xSTS = 5 times Sit-to-Stand

ABC = Activities-Specific Balance Confidence

SAFE = Survey of Activities and Fear of Falling in the Elderly

**Table 4.2 Average Sit-to-Stand Results**

Time (s)	Comfortable				Fast				Significance
	Young Adult		Older Adult		Young Adult		Older Adult		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
MT (s)	1.98	(0.28)	2.07	(0.47)	1.34	(0.18)	1.49	(0.19)	c
GRFv ST	1.67	(0.48)	1.70	(0.52)	1.72	(0.50)	1.71	(0.47)	
COPml ST	3.61	(1.58)	3.56	(1.14)	3.89	(1.53)	3.38	(0.65)	
COPap ST	2.53	(0.70)	2.87	(1.05)	3.01	(0.87)	3.24	(1.14)	c
GRFv (% BWT)									
RWT	13.54	(2.66)	13.83	(3.56)	13.75	(2.60)	13.51	(3.61)	
GRFv PPmin	6.80	(3.38)	5.82	(3.64)	4.10	(2.09)	3.60	(3.55)	c
GRFv max	122.83 <sup>†</sup>	(6.71)	122.24 <sup>†</sup>	(8.60)	146.78 <sup>*†</sup>	(10.94)	130.75 <sup>*†</sup>	(9.47)	c,g,i
GRFv RPmin	82.87 <sup>†</sup>	(4.72)	81.17 <sup>†</sup>	(8.77)	53.92 <sup>*†</sup>	(13.27)	62.33 <sup>*†</sup>	(11.32)	c,i
GRFv postSD	0.10	(0.02)	0.09	(0.02)	0.11	(0.02)	0.10	(0.03)	
GRFv 2sΔ	3.53	(2.54)	2.34	(0.86)	8.04	(6.51)	4.58	(2.99)	c,g
GRFv 2sSD	0.54	(0.34)	0.38	(0.13)	1.07	(0.81)	0.65	(0.38)	c,g
COP (% Standing Height)									
COPml postSD	0.05	(0.02)	0.07	(0.02)	0.05	(0.02)	0.07	(0.02)	g
COPap postSD	0.08	(0.02)	0.12	(0.03)	0.08	(0.03)	0.11	(0.03)	g
COPml 2sΔ	1.05	(0.34)	1.32	(0.30)	1.29	(0.24)	1.67	(0.49)	c,g
COPml 2sSD	0.27	(0.09)	0.37	(0.10)	0.32	(0.04)	0.45	(0.13)	c,g
COPml 2sPL	2.23	(0.67)	2.99	(0.80)	2.91	(0.60)	3.71	(1.07)	c,g
COPap 2sΔ	1.47	(0.41)	2.23	(0.56)	2.27	(0.65)	2.64	(0.73)	c,g
COPap 2sSD	0.39	(0.13)	0.60	(0.15)	0.61	(0.19)	0.69	(0.20)	c,g
COPap 2sPL	3.14	(0.94)	4.59	(1.24)	4.78	(1.39)	5.74	(1.69)	c,g

c = main effect for condition (comfortable versus fast)

g = main effect for group (young versus older adult)

i = interaction between condition and group

\* post hoc difference between young and old within condition

† post hoc difference between condition within group

**Table 4.3 Coefficient of Variation (%) Sit-to-Stand Results**

Variable	Comfortable				Fast				Significance
	Young Adult		Older Adult		Young Adult		Older Adult		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Time									
MT	9.2	(4.4)	10.5	(4.2)	8.9	(5.2)	9.1	(6.2)	
GRFv ST	25.4	(14.8)	27.0	(11.9)	22.9	(14.4)	24.5	(13.1)	
COPml ST	53.4	(14.7)	52.4	(17.2)	58.6	(20.5)	42.9	(14.1)	g
COPap ST	47.5	(22.4)	55.5	(29.7)	37.1	(20.0)	51.5	(24.6)	
GRFv									
RWT	9.2	(4.8)	11.6	(6.6)	9.2	(6.8)	11.0	(6.5)	
GRFv PPmin	36.8	(31.7)	28.3	(13.7)	61.3	(41.9)	82.6	(82.1)	c
GRFv max	3.4	(1.7)	2.5	(1.6)	4.3	(2.6)	2.1	(1.0)	g
GRFv RPmin	4.4	(2.2)	4.8	(3.1)	15.3	(11.5)	11.2	(6.0)	c
GRFv postSD	12.2	(6.4)	18.0	(6.3)	14.2	(6.1)	17.1	(9.3)	g
GRFv 2sΔ	39.7	(19.7)	45.3	(21.4)	53.6	(20.8)	51.8	(23.8)	
GRFv 2sSD	33.7	(16.9)	37.8	(18.6)	47.5	(18.3)	46.7	(18.5)	c
COP									
COPml postSD	370	(248)	646	(616)	234	(166)	416	(224)	c,g
COPap postSD	276	(144)	508	(431)	224	(197)	444	(328)	g
COPml 2sΔ	239	(129)	366	(259)	256	(272)	390	(195)	g
COPml 2sSD	270	(189)	445	(351)	254	(234)	428	(233)	g
COPml 2sPL	172	(123)	296	(236)	195	(206)	271	(110)	g
COPap 2sΔ	305	(186)	355	(261)	219	(178)	416	(299)	g
COPap 2sSD	296	(188)	416	(280)	236	(191)	456	(299)	g
COPap 2sPL	241	(163)	358	(296)	177	(158)	353	(263)	g

c = main effect for condition (comfortable versus fast)

g = main effect for group (young versus older adult)

no significant condition by group interactions



**Table 4.4 Correlation between Comfortable and Fast Pace in Older and Young Adults**

Older		Young	
Comfortable v. Fast		Comfortable v. Fast	
Time (s)		Time (s)	
MT (s)	0.481*	MT (s)	0.367
GRFv ST	0.486*	GRFv ST	0.625**
COPml ST	-0.291	COPml ST	-0.008
COPap ST	0.088	COPap ST	0.299
GRFv (% BWT)		GRFv (% BWT)	
RWT	0.937**	RWT	0.814**
GRFv PPmin	0.785**	GRFv PPmin	0.773**
GRFv max	0.823**	GRFv max	0.188
GRFv RPmin	0.576**	GRFv RPmin	0.137
GRFv postSD	0.775*	GRFv postSD	0.796**
GRFv 2sΔ	0.560*	GRFv 2sΔ	0.411
GRFv 2sSD	0.546*	GRFv 2sSD	0.401
COP (% Standing Height)		COP (% Standing Height)	
COPml postSD	0.286	COPml postSD	0.720**
COPap postSD	0.514*	COPap postSD	0.410
COPml 2sΔ	0.074	COPml 2sΔ	0.161
COPml 2sSD	0.137	COPml 2sSD	0.290
COPml 2sPL	0.369	COPml 2sPL	0.285
COPap 2sΔ	0.081	COPap 2sΔ	0.311
COPap 2sSD	0.279	COPap 2sSD	0.375
COPap 2sPL	0.598**	COPap 2sPL	0.438

\* Correlation is significant at the 0.05 level (2-tailed)

\*\* Correlation is significant at the 0.01 level (2-tailed)

**Table 4.5 Correlation between Movement Time and Stabilization Phase Variables in Comfortable and Fast Pace**

		Older			
		Comfortable		Fast	
		MT	GRFv PPmin	GRFv max	GRFv RPmin
Time (s)					
	Time (s)				
MT	MT	1.000	0.227	-0.556*	0.686**
GRFv ST	GRFv ST	-0.026	-0.032	0.149	-0.084
COPml ST	COPml ST	0.194	0.211	-0.268	0.234
COPap ST	COPap ST	-0.001	0.023	0.478*	-0.515*
% BWT	% BWT				
RWT	RWT	-0.297	0.643**	0.504*	-0.303
GRFv PPmin	GRFv PPmin	0.227	1.000	-0.047	0.172
GRFv max	GRFv max	-0.556*	-0.047	1.000	-0.738**
GRFv RPmin	GRFv RPmin	0.686**	0.172	-0.783**	1.000
GRFv postSD	GRFv postSD	0.190	-0.245	0.046	0.003
GRFv 2sΔ	GRFv 2sΔ	0.215	-0.251	0.268	-0.285
GRFv 2sSD	GRFv 2sSD	0.374	-0.185	0.157	-0.112
% Standing Height	% Standing Height				
COPml postSD	COPml postSD	0.094	-0.392	0.100	-0.129
COPap postSD	COPap postSD	-0.023	0.007	-0.385	0.191
COPml 2sΔ	COPml 2sΔ	-0.009	-0.085	0.181	0.101
COPml 2sSD	COPml 2sSD	0.318	-0.168	-0.051	0.198
COPml 2sPL	COPml 2sPL	0.269	-0.220	0.164	0.129
COPap 2sΔ	COPap 2sΔ	0.083	-0.075	0.080	-0.013
COPap 2sSD	COPap 2sSD	0.149	-0.048	-0.013	0.000
COPap 2sPL	COPap 2sPL	0.114	-0.261	0.228	-0.149

\* Correlation is significant at the 0.05 leve (2-tailed)

\*\* Correlation is significant at the 0.01 leve (2-tailed)

\* Correlation is significant at the 0.05 leve (2-tailed)

\*\* Correlation is significant at the 0.01 leve (2-tailed)

**Table 4.6 Correlation between Movement Time and Stabilization Phase Variables in Comfortable and Fast Pace**

		Young							
		Comfortable			Fast				
		MT	GRFv PPmin	GRFv max	GRFv RPmin	MT	GRFv PPmin	GRFv max	GRFv RPmin
Time (s)									
MT		1.000	0.327	-0.314	0.649**	1.000	0.041	-0.163	0.470*
GRFv ST		-0.507*	-0.006	0.403	-0.486*	-0.223	-0.134	0.080	-0.232
COPml ST		-0.193	-0.172	-0.019	-0.232	-0.387	0.044	0.069	-0.188
COPap ST		-0.320	-0.309	0.631**	-0.315	-0.067	0.480*	0.234	-0.152
% BWT									
RWT		0.049	0.861**	0.050	-0.039	-0.130	0.681**	0.103	0.004
GRFv PPmin		0.327	1.000	-0.162	0.120	0.041	1.000	0.291	-0.103
GRFv max		-0.314	-0.162	1.000	-0.308	-0.163	0.291	1.000	-0.869**
GRFv RPmin		0.649**	0.120	-0.308	1.000	0.470*	-0.103	-0.869**	1.000
GRFv postSD		-0.019	0.181	-0.072	-0.181	-0.108	0.516*	0.575**	-0.395
GRFv 2sΔ		-0.645**	-0.286	0.265	-0.536*	-0.444*	-0.033	0.482*	-0.722**
GRFv 2sSD		-0.703**	-0.276	0.350	-0.597*	-0.447*	-0.044	0.486*	-0.699**
% Standing Height									
COPml postSD		0.285	0.237	-0.102	0.027	-0.028	0.171	0.126	-0.096
COPap postSD		-0.179	-0.142	-0.119	-0.270	-0.340	-0.002	0.129	-0.294
COPml 2sΔ		-0.214	-0.146	0.527*	-0.298	-0.197	0.158	0.380	-0.425
COPml 2sSD		-0.180	-0.101	0.479*	-0.300	-0.126	0.349	0.113	-0.198
COPml 2sPL		-0.325	-0.125	0.555*	-0.388	-0.294	0.290	0.495*	-0.555*
COPap 2sΔ		-0.321	-0.443	0.206	-0.382	-0.386	0.002	0.215	-0.383
COPap 2sSD		-0.096	-0.372	0.146	-0.268	-0.356	-0.058	0.277	-0.392
COPap 2sPL		-0.542*	-0.311	0.488*	-0.549*	-0.415	0.091	0.481*	-0.615**

\* Correlation is significant at the 0.05 level (2-tailed)

\*\* Correlation is significant at the 0.01 level (2-tailed)

## CHAPTER V

### DISCUSSION

The main focus of this study was to examine the stabilization phase after performing a STS task at a comfortable (CSTS) and fast (FSTS) pace in both healthy young and older adults. We hypothesized that the FSTS condition would produce longer stabilization phases. We also hypothesized that older adults would exhibit longer stabilization phases in both task conditions relative to the young. In addition to the time duration of the stabilization phases, we hypothesized that older adults would have greater trial-to-trial variability in both task conditions. Furthermore, we hypothesized that comfortable and fast conditions will be correlated within age groups. Lastly we hypothesized that variables during the movement phase would be correlated to stabilization phase variables in both young and older adults in both task conditions. Overall, our hypotheses were partially supported. The movement time was shorter during FSTS, but only the duration of stabilization phase in the anterior-posterior direction (COPap ST) was greater during FSTS with no significant differences between the young and older groups. However, during the initial 2s of the stabilization phase there were significant differences in all variables both between conditions and between groups with the older adults and fast condition almost always producing higher values. For the trial-to-trial variability, none of the stabilization variables were significantly different between task conditions, though the older adults were almost always more variable between trials than the younger adults. When correlating the FSTS and CSTS within age the older adults exhibited greater correlation between GRFv variables but a

lack of correlations was seen in the young olds or in COP variables. When correlating the movement phase with the stabilization phase significant correlations only consistently exist in the older adults during the first 2s of stabilization adjustments particularly for COP variables and of both a positive and negative nature.

### Subject Characteristics

Aside from age the only significant characteristic difference between our young and older adults was their BMI. The older adults had a significantly greater BMI than the young adults, and although their height was similar their body mass trended toward a significant difference (Table 4.1a). This difference in BMI may point to differences seen not being purely due to age. The younger were stronger (according to grip strength), and had a lower BMI, the older adults with a great mass and less strength will make the task more challenging to move and stabilize. However considering the mass was not significant between each group it suggests this effect was mostly likely relatively small. The older adults were of a high functional status, but the older adults were starting to show signs of aging as functional scores were not perfectly matched. More specifically, there were significant differences in the direction of reduced function in the older adults compared to the younger adults in the 5xSTS times to completion, the SPPB standing balance and total scores, as well as the ABC survey score and grip strength (Table 4.1b).

Our results do confirm what was found by Regterschot *et al.* (2014) who examined independently living participants over the age of 70 yrs while performing the STS activity. We reported similar MT values for our older adults at both a comfortable and fast pace compared to

their older subjects [178]. The average age of our young and older participants (22.5 and 71.8 yrs) were similar to some studies that examined differences in stabilization after STS [2, 15], but our older adults were younger than those of Lindemann *et al.* [1]. Similar to the subjects of Akram and McIlroy (2011) our subjects were free of neurological, vestibular, and musculoskeletal disorders, and had no recent falls (within at least six months) [2]. Others who have examined the stabilization phase did not report quantitative functional ability for their subjects; therefore it is not clear if our older adults are fully comparable to this small niche of published literature. Based on the similarities between our young and older adults, it is possible that our older adults may have been more functionally intact than those previously examined. This is underscored by the fact that our subjects did exercise on a regular basis, something that does not appear to exist in the older adults previously examined, nor in the general population. Therefore, larger differences between young and older adults as well as between CSTS and FSTS may have been observed if the older adults were not as functionally able. However, since differences did exist between the groups it appears to be an adequate comparison between young healthy adults and older adults that are just starting to show a loss of functional capacity. Studying older adults who are just starting to show decrements in function is critically important, since this is the group where interventions should be initiated to prevent further decline.

#### Comfortable vs. Fast STS

Altering the performance speed of the STS did result in some significant differences between conditions. The MT decreased from the comfortable to fast condition and a main effect was found, signifying that participants in both groups did indeed rise faster allowing for variable comparisons between conditions (Table 4.2). These results are supported by Hanke (1995) who

examined young adults and also found shorter transfer movement times when increasing speed [184]. The only other main effect for condition of the time variables was for COPap ST. The length of time to stabilization was greater in the fast condition, demonstrating that speed could affect balance control after rising in the ap direction. The finding that the ap direction is most sensitive to changes in speed is reasonable considering that the ap base of support is shorter than the ml, the ankles are less stable in the ap direction, and the COM is displaced considerably more in the ap direction during the STS movement. This finding that the ap direction took longer to stabilize was also shown by Akram and McIlroy for both young and elderly adults who rose at a self-selected pace [2]. However, it was anticipated that moving faster would pose stabilization challenges of greater duration in the vertical and ml directions as well, but this does not appear to be the case in healthy adults with reasonable functional capacities. Thus the results only partially support our hypothesis that time to stabilization would increase with faster movement time.

For the GRFv variables (% body weight) we found that under greater speed requirements there were lower minimum and higher maximum forces generated (Table 4.2). Both the GRFv PPmin and RPmin were lower in the fast condition, while the GRFv max was greater in the fast condition. The greater extremes in force produced mean there was a wider range of movement that did not result in longer stabilization phase durations, except for in the COPap direction. The fluctuations in forces makes sense as Pai (1991) determined faster movement times also increased the magnitude of joint moments at the hip, knee, and ankle [182]. Since vertical force is directly related to vertical acceleration, it makes sense that the faster movement produced higher fluctuations in force. The greater acceleration might suggest that power measurements are the next step of analysis. It is anticipated that greater accelerations would lead to greater

velocities. Power is the product of force and velocity, both of which seem to be affected by pace of the STS.

From a control perspective when performing a STS faster, greater corrections for balance are likely required not only during the movement but potentially that might carry over to the stabilization phase. In fact, within the first 2s of the stabilization phase both the min-max amplitude and the average fluctuations in GRFv (GRFv 2s $\Delta$ , 2sSD) were greater for the fast condition (the correlations between movement phase and stabilization phase variables will be discussed in more detail later, as there were differences between the young and older adults). This finding further emphasizes that when rising faster there is greater overshoot that has to be corrected for to return to a stable stance. As the GRFv ST was not significantly faster it appears that even with a faster rising time, and greater correction required, both our young and older adults are able to stabilize in a similar time frame regardless of speed (with the exception of the COPap ST). The COP (2s $\Delta$ , 2sSD, and 2sP $\Delta$ ) variables for both the ml and ap direction within the first 2s of the stabilization phase were all greater in the fast condition as well (Table 4.2). Emphasizing how greater movement and overshoot during faster STS tasks does not result in greater stabilization times, except in the ap direction.

In looking at the COV (Table 4.3) between CSTS and FSTS the only variables to display a main effect for condition were the minimum GRFv during the PP, minimum during the RP, the standard deviation of GRFv with in the first two seconds of the stabilization phase, and the standard deviation 15s post standing in the COPml direction (GRFv PPmin, GRFv RPmin, GRFv 2sSD, and COPml postSD). The GRFv variables were all found to be greater in the FSTS compared to the CSTS. The greater value signifies that greater between trial variability is occurring when performing the task faster. This high variability is not out of the question as was



found when looking at simple flexion and extension of the elbow. Both agonist and antagonist EMGs displayed greater variability in faster, practiced movement [197]. This relationship of faster times and greater variability relates to what is seen above with GRFv PPmin and GRFv RPmin producing smaller forces requiring greater correction during the fast condition. The high variability of the SD within the first 2s of the stabilization phase also demonstrates that greater variability prior to standing is affecting movement within the first 2s of the stabilization phase. The COPml postSD COV was actually lower in the FSTS compared to the CSTS. The postSD variable is a measurement of the SD at the ~15s mark after standing posture had been achieved. Therefore a smaller COV in this variable suggests a more controlled stance post completion when rising faster, possibly due to greater attention placed to the task when performing it quickly. The general nature of the COV values were high, with the time variables and GRFv variables producing smaller variation than the COP variables. The COP COV values were all greater than 100% (and the preferable range is less than 10%), signifying less control in the ml and ap directions in the stabilization phase. From a repeatability standpoint, COP percentages of this magnitude suggest that a relatively large number of trials must be performed in order to obtain a representative value for a subject. We are aware of no other studies examining trial-to-trial repeatability during the STS task. This is an aspect that should be further explored to ensure that accurate conclusions are drawn.

### Young vs. Older Adults

Comparing healthy young and older adults completing a STS task there were some significant differences for the main effect of group (age) (Table 4.2). There was no significant difference between groups for the time variables (both movement and stabilization). However,

COPml and COPap postSD were greater in the older adults. This indicates that when standing still the older adults were less stable than the young adults and that the older adults did not have to be as stable on an absolute scale for their stabilization phase to be completed. However, these increased postSD values do not affect the variables computed with the first two seconds of stabilization, since they are not factored into these values in any manner.

While the stabilization phases were defined similar to Akram and McIlroy, ours were shorter with no differences between young and older adults. Both studies determined the end of the stabilization as the time the sway fell within two times the SD of the quantifying variable (body weight, COPml, and COPap) which represents a 95% confidence interval. However, it is possible that ours was the very first time it fell to this level while Akram and McIlroy may have determined the phase end as the point when the COP sway fell within the same window and stayed there for the remainder of the trial. It is not clear from their description within the article if this is the case. If that were the case, this may explain some differences seen. However, it may also be explained by our highly functioning older adults. Although the older adult subjects may have been different, the younger should have been similar and our stabilization phase lengths were longer. Lindemann defined their stabilization phase based on when GRFv fell within a 2.5% body weight corridor, that compared to our methods resulted in stabilization times that were shorter, but we recorded similar movement times [1]. Lindemann did only look at the stabilization phase for GRFv variables, but their range of stabilization time (0.0-3.15 s) is large enough to include our stabilization phase time recordings. We didn't utilize Lindemann's methods based on percent body weight because our subjects did not consistently reach an overshoot greater than 2.5%. Without a 2.5% overshoot the stabilization phase could not be defined. This suggests our subjects may have had greater functional abilities than theirs.

While we found no differences between groups in duration of stabilization phase, we did find differences between groups within the movement phase and the first two seconds of the stabilization phase. The GRFv variables displayed a difference in the GRFv max (fast condition only), GRFv RPmin (fast condition only), GRFv 2s $\Delta$ , and GRFv 2sSD, which were all greater in the young compared to the older adults (Table 4.2). These differences in GRFv again demonstrate the fluctuations in force and likely vertical accelerations that subsequently is affecting balance. As power has been shown to decrease with age [177, 178], and with our highly functioning older adults strength may not have been compromised during the constrained task. Our older adults did display a significant loss in grip strength compared to the young adults which further supports strength was not challenged enough to elicit a change in MT or stabilization. All the COP variables (% standing height) in both the ml and ap direction were significantly greater in the older adults in both conditions. These results suggest that the younger adults more aggressively made adjustments during the movement phase as well as during the initial stages of the stabilization phase even though the time spent in each phase was not different between groups. Considering the differences that existed between groups in the first two seconds of the stabilization phase, if the older adults were not as functional it is reasonable to expect stabilization phase differences between young and older adults. Our findings suggest that when working with highly functional older adults the stabilization phase duration should be determined using an absolute level of stability, or instead of calculating the length of the phase just examine the first two seconds of the phase.

As was hypothesized the older adults did reveal greater variability between trials than the younger adults. Especially with the COP variables in both the ap and ml direction, which the older adults were significantly higher in their COV than the young adults (Table 4.3). The

higher variability of the older adults between trials is to be expected due to the aging process placing limitations on movement abilities and older adults reduced ability to display control [61, 87]. The higher value of such variables as the standard deviation 15s post standing posture had been achieved (GRFv postSD, COPml postSD, and COPap postSD) for the older adults reveal that even 15s after reaching standing posture older adults are more variable. These results confirm the need to examine a reasonably large number of trials in order to accurately determine the representative values for each subject. It also suggests that trial-to-trial variability may prove to be useful when examining risk for falls, although the ideal number of trial is still unknown.

## Correlations

When looking at Pearson's correlations in Table 4.4 the correlations within age group between comfortable and fast conditions display some moderate to strong correlations at least for the older adults in GRFv variables. The GRFv variables reveal all significant positive correlations, while the COP variables show only two significant moderate positive correlations. The lack of significant correlations for COP variables demonstrates that the ability to stabilize when moving at a comfortable speed is not necessarily related to being able to stabilize when moving as fast as possible, especially in older adults. If looking just at the GRFv correlations it would appear that a faster pace is not necessary for analysis if the comfortable and fast pace tasks are related. But the lack of significance of the COP variables for the older adults and for both GRFv and COP variables for the young adults reveal that altering pace is necessary because there are differences in the approach and completion of the STS and stabilization phase. There were far fewer significant correlations between comfortable and fast tasks for the younger adults in the GRFv variables, further demonstrating that faster movements challenge the system much

differently than slower movements and that the older adults are challenged differently than the young. The greater challenge at a faster speed is further supported by the fact that older adults control of movements becomes slower and more variable [196]. The young likely also displayed a greater ability to produce different speeds for the two conditions, while the older adults were not able to make such drastic changes between conditions. Although there were no significant differences in speed between young and older adults the young adults did produce a more dramatic drop in MT demonstrating a greater ability to separate comfortable and fast movements.

Although the stabilization phase length outcomes may not have been what was predicted there were definitely differences between the young and older adults within the first 2s of the stabilization phase. These differences are telling of alterations in movement and outcomes between young and older adults. With the significant negative correlations seen between GRFv RPmin and the COP 2s variables for older adults during the fast condition, and lack thereof for the comfortable and young adults, the FSTS is providing different information compared with the CSTS. The relationship seen between the RPmin and COP 2s variables for the older adults hints that while mechanistically we don't know the differences in approach the fast task condition is producing an alteration in movement. The correlation of movement phase variables reveal that those events just prior to stabilization have the greatest effect on stability and control, at least within the first 2s of the phase. With greater force generated and more overshoot to be corrected for in the fast condition, while the stabilization phase length may not have been significantly different the fact that COP 2s variables were, demonstrates that moving faster altered GRFv variables that translated to differences within the stabilization phase.

The correlations between movement phase variables and stabilization phase variables also reveal differences between the young and older adults. Lindemann also looked at

correlations between time to stabilization and events during rising, but found smaller correlations than our older adults between time to stabilization and maximal GRFv [1]. Both the young and older adults saw a greater number of correlations in their FSTS compared to their CSTS, but the older adults saw the greatest number during the FSTS of any age or condition (Table 4.5 and 4.6). The area of interest is the negative correlation between GRFv RPmin and the COP variables within the first 2s (Table 4.5). This relationship is not seen in the young adults nor the CSTS for the older adults. The fact that a correlation is present during the FSTS reveals that while the cause for the difference may not be known, there is in fact a different approach and completion of the STS for older adults when rising at a maximal pace.

The correlations between movement phase variables and stabilization phase variables do reveal some relationship between movement and stabilization at least within the first 2s. For older adults MT saw a moderate negative correlation to both GRFv 2s $\Delta$  and 2sSD. This demonstrates that faster rising has the ability to affect the stabilization phase more than comfortable rising. When looking at GRFv max during the FSTS and its relationship to COP variables within the first 2s we see a moderate positive correlation to all the COP ml 2s variables (2s $\Delta$ , 2sSD, and 2sPL) for the older adults (Table 4.5). But for GRFv RPmin we see weak to moderate negative correlations to all COP variables both ml and ap, except for COPap 2sSD. With the GRFv max and GRFv RPmin being the last two recorded variables before the start of the stabilization phase, it would appear that the events just prior to stabilization have the greatest impact on stability and control within the first 2s of the stabilization phase for the older adults. In the young adults we see that MT has a weak to moderate negative correlation for GRFv 2s $\Delta$  and 2sSD at both a comfortable and fast pace. We see a weak to moderate positive correlation for GRFv postSD, 2s $\Delta$ , and 2sSD. GRFv RPmin has a moderate negative correlation to GRFv

2s $\Delta$ , GRFv 2sSD, COPml 2sPL, and COPap 2sPL. Again these relationships between the events just prior to stabilization and the first 2s of the stabilization phase reveal that speed does affect postural control during the stabilization phase although it may not effect duration. These results also demonstrate that the stabilization phase provides information above and beyond what can be gleaned from analysis of just the movement phase.

### Limitations

While difference were observed between the young and older adults, the magnitude of the differences was not as high as expected. This have been due to the high level of functioning seen in our older adults, as displayed by their high scores during SPPB balance measures. To be able to determine if balance deficits or functional limitations are affecting the STS movement at varying speeds older individuals who are more frail may be able to see greater differences. Further exploration of the definition of the stabilization phase is also needed in future research. The few studies to define the stabilization phase are inconsistent in their parameters. An additional limitation could be the restricted number of dependent variables. We only utilized a single force platform and had no kinematic or EMG data. Our STS requirements may also have been a limitation. Different results could have been found were subjects able to move their hands, place their feet based on their own preference (both ap and ml relative to the seat), and had we allowed the heels to leave the ground during the transition.

## Alternate Functional Assessment

The STS has been used widely as a functional assessment, but mainly in a 5xSTS format. Adding the dynamic component of the speed variation is new in a single repetition format. The alteration of speed may be a valid new tool. The events that occur during the movement phase and within the first 2s of the stabilization phase could be the most elucidating events. When looking at the averages alone the fast pace may not appear to reveal much more than the comfortable. But when looking at the correlations of transition variables and their relationship to all variables for the older adults in Table 4.5 the COP 2s variables displayed weak to moderate negative correlations to GRFv RPmin. The correlations expose a relationship that was missing from just the average and COV data. The reasoning may not be known but it reveals that the strategy for completing a fast pace STS is different than that of a comfortable pace. The FSTS approach should be further researched to gain a better understanding of the variance in approach and how the outcome variables relate to fall risk. Then the comparison of a comfortable and fast test can be used to differentiate between normal functioning individuals and those who may be at a greater risk of falling or balance disorders. While COV values saw high degrees of variability for both young and older adults the older adults were typically greater than the young. The COV values could also be used to differentiate functional abilities. Those with greater fluctuations between trials could be those showing the greatest sign of loss and interventions may be able to be implemented sooner. For those unable to stand for up to 20s looking at the first 2s could reveal that those with a higher degree of variability are at a greater risk of falling providing a shorter and less taxing exam.

Even though our older adults were not as functionally impaired as those that may have been used in other studies, this is the population that would be used to intervene before dramatic



functional changes occur. When attempting to understand the differences between young and older adults a population as functional as this may not be desirable, but our older adults were starting to show the signs of aging. Individuals that are beginning to show signs of a functional loss are ideal to provide interventions for before drastic declines. The fact that we saw differences within the stabilization phase related to speed and age suggests that this area is worthy of further research. The fact that the most significant findings were in the first 2s of the stabilization phase means that future tests can be terminated earlier allowing more individuals of varying abilities to be tested. A drawback to previous assessment methods was the high cost, time for training, and space requirements [151], all of which could potentially be alleviated with this new assessment method. It requires a single force platform, patients to be familiar with rising from a chair and can take as little as 5-10s to capture the movement and stabilization phase of the STS. Making this new assessment method a likely candidate for future testing with its ease of use and short duration. It is also possible that elements measured here with a force platform could be measured with an accelerometer, making the test accessible to an extremely large number of people.

## Future Research

With little current literature examining the stabilization phase this area of the STS could be further examined to better define the characteristics. Outlining consistent phase definitions and patterns will help with comparisons across studies. Trial-to-trial variability should continue to be monitored, possibly adding on additional trials to better understand individual movement. In addition, determining power and its effects on the stabilization phase appear to be the next

logical step to reveal differences in young and older adults. As well as, with the determined differences noticed by speed variation, continued efforts to vary task conditions should be made.

## Conclusion

The major findings of this study reveal that there are differences within the stabilization phase between young and older adults, particularly at a fast pace. All participants were able to perform the STS faster, but older adults saw the greatest correlation between the events prior to standing and the stabilization phase. The older adults also displayed the greatest trial-to-trial variability, which makes sense knowing that with age there are decreases in control. Our study enhances the current understanding of factors that contribute to the difficulty of the STS task. It provides insight into the role of speed variation on balance control and successful completion of rising from a chair. Further research to determine what causes alternative approaches based on speed could help clinicians with guidelines for safety, training and evaluation of individuals of varying ability levels. Those with motor impairments, mobility limitations or frailty may be able to be identified earlier and more easily before impairments may be seen, as at risk with speed conditions. Implications of a greater understanding could be the development of more effective early identification methods to classify those at risk of falling.

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APPENDIX A

Screening Form

Clinical Biomechanics Lab Health Screening - Coded Cover Sheet

(Separate from the coded screening form, store separately)

Project Title: ***Relationships Between Rising from a Chair, Balance, and Physical Function***

Name (Last, First): \_\_\_\_\_

Address: \_\_\_\_\_

\_\_\_\_\_

Phone number: \_\_\_\_\_

Email: \_\_\_\_\_

Screened by: \_\_\_\_\_

Acceptable Subject:      Yes    or    No

Willing to participate in future research:      Yes    or    No

Notes \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

*- Phone Screening Section-*

Screener's initials: \_\_\_\_\_ Screening date: \_\_\_\_\_ Approved: Y or N  
**Subject ID:** \_\_\_\_\_ **Sex:** O M O F **DOB:** \_\_\_\_\_ **Age:** \_\_\_\_\_

Do you smoke? O Yes O No

Do you have any reservations about participating in light exercise?

O Yes O No

please explain \_\_\_\_\_

Have you been cleared by a physician to participate in light exercise?

O Yes O No

If yes, is documentation available? O Yes O No Date: \_\_\_\_\_

Do you live in a private residence? O Yes O No

please describe: \_\_\_\_\_

Do you normally walk without a cane or walker for assistance? O Yes O No

Can you walk up and down a flight of stairs without assistance? O Yes O No

Can you stand unassisted for at least 5 minutes? O Yes O No

How many unexplained falls have you had in the last year? \_\_\_\_\_

Are you currently pain and injury free?  Yes  No

please explain: \_\_\_\_\_

\_\_\_\_\_

Have all prior injuries healed at least 4 weeks ago?  Yes  No

please explain: \_\_\_\_\_

Do you have any joint replacements or implants?  Yes  No

please list: \_\_\_\_\_

Do you have diabetes?  Yes  No

If Yes, have you lost any feeling in your hands or feet?  Yes  No

Comments: \_\_\_\_\_

Do you have any neurologic disorders, such as peripheral neuropathy or stroke?

Yes  No please list: \_\_\_\_\_

\_\_\_\_\_

Do you have any problems with your vision that is not corrected by glasses?

Yes  No

Comments: \_\_\_\_\_

\_\_\_\_\_

Do you have any inner ear (vestibular) problems that affect your balance?

Yes  No

Comments: \_\_\_\_\_

\_\_\_\_\_



Do you take any medications?  Yes  No

If yes, do any of your medications affect your strength and/or balance?  Yes  No

Comments: \_\_\_\_\_

Women only: Are you on post-menopausal estrogen replacement therapy?  Yes  No

List any medications (may bring list with them at first visit):

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Do you participate in regular physical activity 3-4 times a week?  Yes  No

How long have you participated in regular physical activity?  > 4 months  < 4 months

What do you do, to stay physically active (how long and at what intensity)?

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Are you available for 1 visit between now and mid-June?

Yes  No \_\_\_\_\_

Are you able to provide your own transportation to and from the CSU campus?

Yes  No \_\_\_\_\_

Are you currently involved in any other research studies?  Yes  No

please explain: \_\_\_\_\_

How did you find out about this study? \_\_\_\_\_

## APPENDIX B

### Informed Consent

Consent to Participate in a Research Study  
Colorado State University

**TITLE OF STUDY:** *Relationships Between Rising from a Chair, Balance, and Physical Function*

**PRINCIPAL INVESTIGATORS:** *Raoul F. Reiser II, Ph.D. 491-6958 and Brian L. Tracy, Ph.D. 491-2640*

**WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?** *You are a man or woman between the ages of 18-33 or 65-80 years that is healthy.*

**WHO IS DOING THE STUDY?** *This research is being performed by Raoul F. Reiser II, Ph.D. and Brian L. Tracy, Ph.D. of the Health and Exercise Science Department. Trained graduate students, undergraduate students, and research associates/assistants are helping with the research.*

**WHAT IS THE PURPOSE OF THIS STUDY?** *The purpose of this study is to assess the task of rising from a chair and its relationship to balance and physical function. Force plate and smartphone application technologies will be used to correlate sit-to-stand performance with functional ability and risk of falling.*

**WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?** *This study is being conducted in the main office of Adult Fitness (Glenn Morris Field House) or in the Clinical Biomechanics Laboratory of the Department of Health and Exercise Science on the CSU Campus (221 Moby Arena). The whole research project will take place over a period of approximately four months. However, your part of this study will be a single visit lasting 1 hour.*

**WHAT WILL I BE ASKED TO DO?** *A member of the research team will fully explain each procedure.*

- 1) You will be asked to answer some questions about your health and exercise to determine if you can participate in the study. (~ 15 minutes)*
- 2) For older adults, if not already released by a physician to participate in physical activity, you will be examined briefly by a physician to ensure you are healthy enough to participate. This will occur in the Human Performance Clinical/Research Laboratory in the Department of Health and Exercise on the CSU campus. (~ 10 minutes)*
- 3) You will complete a series of questions about your concerns of falling. (~ 5 minutes)*
- 4) You will perform several simple balance, physical function, and one strength test. These tests include standing in several positions and durations, walking, rising from a chair and testing hand grip strength. (~ 30 minutes)*

*You will be required to wear comfortable, non-restrictive clothing. All testing and training will be performed in stocking feet.*

**ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?**

*If you are not between the ages of 18-33 or 65-80 years of age, or have any injury, disease, or condition that would restrict your ability to participate in a fitness program, you will not be able to participate in the research. You will also need to be a non-sedentary individual who participates in exercise 3-4 times a week, regularly for about an hour at a moderate intensity for at least four months prior to the study. Additional restrictions include:*

- Living in an assisted living home.*
- Any injuries that have not healed prior to the last 4 weeks.*

- Regular use of a cane or walker.
- Diagnosed with a neurologic disorder, such as peripheral neuropathy.
- Taking any medications that affect your balance or strength.
- Any lower body joint replacements.
- Any visual impairments that are not corrected by glasses.
- Being a current smoker.

#### WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

- Health & Demographic Questionnaire – There are no known risks associated with answering health and demographic questions. All information is kept strictly confidential.
- Physical Exam – There are no known risks associated with the physical exam. All information is kept strictly confidential.
- Questions addressing concerns about falling – There is little risk associated with answering these questions. However, some questions can be thought provoking and require some introspection. As such, an emotional response, though unlikely, is possible.
- Balance, Physical Function, and Strength Testing – The risks associated with this test include loss of balance with the potential for falling. However, you will be given practice and closely spotted at all times. These tests have been designed to be safely used with people who have balance disorders. Strength testing has the risk of muscle injury and delayed soreness. You will be provided with a warm-up and practice before performing the strength testing. Furthermore, forces are generated slowly under your control to minimize risks for injury.
- Other - It is not possible to identify all potential risks in research procedures, but the researchers have taken reasonable safeguards to minimize any known and potential, but unknown risks are still possible.

**WILL I BENEFIT FROM TAKING PART IN THIS STUDY?** *There are no direct benefits to you for participating in this study. You may indirectly benefit from information gained through the brief physical exam and performing the selected balance, physical function, and strength tests.*

**DO I HAVE TO TAKE PART IN THE STUDY?** *Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.*

**WHAT WILL IT COST ME TO PARTICIPATE?** *There is no cost to you for participating except that associated with your transportation to our facilities and the time given to fulfill the requirements of the assessments.*

**WHO WILL SEE THE INFORMATION THAT I GIVE?** *We will keep private all research records that identify you, to the extent allowed by law. Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.*

*We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key. You should know, however, that there are some circumstances in which we may have to show your information to*



APPENDIX C

IRB Approval



Research Integrity &  
Compliance  
Review Office  
Office of the Vice  
President for  
Research  
321 General Services Building - Campus Delivery 2011 Fort Collins, CO TEL: (970) 491-1553  
FAX: (970) 491-2293

321 General Services Building - Campus Delivery 2011 Fort Collins, CO TEL: (970) 491-1553

FAX: (970) 491-2293

**NOTICE OF APPROVAL FOR HUMAN RESEARCH**

**DATE:** February 04, 2014  
**TO:** Reiser, Raoul, Health & Exercise Science  
Israel, Richard, Health & Exercise Science, Swiss, Evelyn, RICRO, Burke, Kimberly, 1582  
Dept Hlth & Exer Sci, Tracy, Brian, 1582 Dept Hlth & Exer Sci  
**FROM:** Barker, Janell, Coordinator, CSU IRB 1  
**PROTOCOL TITLE:** Relationships Between Rising from a Chair, Balance, and Physical Function  
**FUNDING SOURCE:** NONE  
**PROTOCOL NUMBER:** 13-4737H  
**APPROVAL PERIOD:** Approval Date: February 04, 2014 Expiration Date: February 03, 2015

The CSU Institutional Review Board (IRB) for the protection of human subjects has reviewed the protocol entitled: Relationships Between Rising from a Chair, Balance, and Physical Function. The project has been approved for the procedures and subjects described in the protocol. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.

If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.

This approval is issued under Colorado State University's Federal Wide Assurance 00000647 with the Office for Human Research Protections (OHRP). If you have any questions regarding your obligations under CSU's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to:

Janell Barker, Senior IRB Coordinator - (970) 491-1655 [Janell.Barker@Colostate.edu](mailto:Janell.Barker@Colostate.edu)  
Evelyn Swiss, IRB Coordinator - (970) 491-1381 [Evelyn.Swiss@Colostate.edu](mailto:Evelyn.Swiss@Colostate.edu)

Barker, Janell

Barker, Janell

Approval is for 45 participants using the approved consent form that is in eP with the IRB approval date added.

**Approval Period:** February 04, 2014 through February 03, 2015  
**Review Type:** EXPEDITED  
**IRB Number:** 00000202

APPENDIX D

