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Neuromuscular Changes in Older Adults during the Lateral Step Task

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

NEUROMUSCULAR CHANGES IN OLDER ADULTS DURING THE LATERAL
STEP TASK

A thesis submitted in partial fulfillment of

the requirements for the degree of

MASTER OF SCIENCE

in

BIOMEDICAL ENGINEERING

by

Tatiana Bejarano

2014

To: Dean Amir Mirmiran
College of Engineering and Computing

This thesis, written by Tatiana Bejarano, and entitled Neuromuscular Changes in Older Adults during the Lateral Step Task, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

Denis Brunt

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Date of Defense: November 12, 2014

The thesis of Tatiana Bejarano is approved.

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University Graduate School

Florida International University, 2014

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DEDICATION

For my parents,
To whom I owe the strength, courage,
and dedication to pursue my dreams.

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ABSTRACT OF THE THESIS

NEUROMUSCULAR CHANGES IN OLDER ADULTS DURING THE LATERAL
STEP TASK

by

Tatiana Bejarano

Florida International University, 2014

Miami, Florida

Professor Ranu Jung, Major Professor

Older adults may have trouble when performing activities of daily living due to decrease in physical strength and degradation of neuromotor and musculoskeletal function. Motor activation patterns during Lateral Step Down and Step Up from 4-inch and 8-inch step heights was assessed in younger (n=8, 24.4 years) and older adults (n=8, 58.9 years) using joint angle kinematics and electromyography of lower extremity muscles. Ground reaction forces were used to ascertain the loading, stabilization and unloading phases of the tasks. Older adults had an altered muscle activation sequence and significantly longer muscle bursts during loading for the tibialis anterior, gastrocnemius, vastus medialis, bicep femoris, gluteus medius and gluteus maximus muscles of the stationary leg. They also demonstrated a significantly larger swing time (579.1 ms vs. 444.8 ms) during the step down task for the moving leg. The novel data suggests presence of age-related differences in motor coordination during lateral stepping.

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ABBREVIATIONS AND ACRONYMS

ADL	Activities of Daily Living
BF	Bicep Femoris
EMG	Electromyography
VM	Vastus Medialis
GAS	Gastrocnemius
G _{MAX}	Gluteus Maximus
G _{MED}	Gluteus Medius
GRF	Ground reaction force
LS	Lateral step
TA	Tibialis Anterior

Chapter 1: INTRODUCTION

Older adults may have trouble when performing activities of daily living (ADL) due to age-related decline in physical capabilities and the high demands placed on the muscles of their lower extremities [1]. ADL that require use of the lower extremities include actions such as walking, standing up, and stair climbing. These activities are important since they are necessary for independent living. More than 6.5 million older Medicare recipients have difficulties performing such activities [2]. 76 million individuals born in the United States during the years 1946-1964, the baby boomers, are aging and hence there will be an increasing demographic susceptible to age-related declines in ADL.

Age-related declines in ADL can be due to a variety of reasons including decrease in physical strength and motor function and degradation of neuromotor and musculoskeletal function. Declines in ADL due to decreases in motor function can also occur because of the higher propensity for older individuals to have joint or limb replacement, obesity, osteoarthritis, patellofemoral pain, neuromuscular dysfunction and declined visual performance [3, 4]. Degradation of sensory [5], neurological [6], and musculoskeletal systems [7] that result in impaired motor function [8], may lead to injurious falls which can lead to fractures or even death. Falls are responsible for about one quarter admission to nursing homes and also lead to increased health costs [9-11].

Aging is also associated with loss of muscle tissue, attributed to reduced numbers of both type I fibers, responsible for slow enduring movement, and type II fibers,

responsible for faster movements. The use of electromyography (EMG) methods can be used to demonstrate age-related changes in both duration and amplitude of motor unit action potentials. To assess coordinated movement, kinematic data can be recorded using acquisition systems that track retro reflective markers attached to body segments [12-16] as the subject performs a motor task. To assess postural weight bearing during performance of coordinated motor tasks, kinetic data can be recorded using force plates that measure ground reaction force (equal in magnitude and opposite in direction to the force that the body exerts on the supporting surface through the foot) [17-20].

Stair negotiation is an important ADL used for independent living [1] yet limited studies have evaluated neuromuscular control during this motor task, in young and older adults [21, 22]. Lateral Step (LS) is a form of step negotiation used by clinicians to assess lower extremity performance capabilities. However, few have tested the reliability of the LS task [23].

1.1 Specific Aim and Hypothesis

The aim of this study was to assess coordination of motor patterns during the Lateral Step task in young and older adult individuals by examining joint kinematics and neural activation of lower extremity muscle activity using EMG to test the hypothesis that coordinated motor function, when performing normal daily tasks is altered between younger and older adult subjects.

Specifically, we studied the LS task between two different age groups (young:: 21-35 years and old: 50-65 years old) in order to determine modulation of activity in EMG, kinematic and kinetic patterns between the groups. The activity of the lower limb

muscles was recorded with surface electromyograms. Different phases of the task were identified by use of kinetic data obtained from force plates as the task was performed. Both healthy male and female subjects were enrolled in the two age groups.

1.2 Rationale

The purpose of this study is to determine age-related changes in motor function during ADL living such as the step task. This information could be used in the future to provide evidence-based support for clinical interventions to prevent loading at the joints that can result in joint injury or falls. Older individuals are more likely to fall due to degrading motor coordination therefore it is essential to observe their motor control.

Coordination of movement in this study was analyzed by observation of neural control of different lower-limb muscles and the biomechanics of movement during a lateral step task. It has been suggested that biomechanical analysis of stair negotiation may enhance the understanding of the kinematic requirements of this demanding task and aide in developing suitable clinical interventions to improve performance on stairs [1]. The lateral step task offers excellent inter-tester reliability for measurement of functional lower limb strength [24] and because it requires simultaneous coordination of hip, knee and ankle musculature that are all required for stair-climbing activities.

In this study hip abductor activity was studied in lateral step up and step down tasks since evidence indicates that hip muscle activity plays an important role in controlling movement of the knee in the frontal and transverse plane [25]. Neural activation of the quadriceps, hamstrings, tibialis anterior and gastrocnemius muscles were assessed during the LS task. These muscles are directly responsible for movements of the

knee. Several studies have found that there are changes in muscle activity with association between hamstrings [26-29], quadriceps weakness [30-33], hip abductor activity [13, 34] and knee injury.

1.3 Significance

The study has examined neural control and biomechanics of movement during a common ADL, namely the lateral step task, in healthy younger and older adult subjects. This information could be used in the future to provide evidence-based support for clinical interventions to prevent loading at the joints that can result in joint injury or falls. Forming assessments of meaningful change in a person's ability for stair negotiation (also referred to as the step task) could be useful in clinical practice and research settings to monitor progression of functional decline in aging and determining the efficiency of rehabilitative interventions [35]. The literature indicates that physical training can have a beneficial impact on motor function in older individuals and improvement of motor function can be seen within 4-6 weeks of physical training [36]. Therefore, observation and analysis of muscle activation changes in leg muscles while performing ADL such as the step task could provide guidance for the development of a physical training protocol to aide in improvement of motor function as people age.

Previously, research has been done on stair walking analysis in young adults [37-39], patients with joint disease or injury [3, 14, 20, 25, 34, 37, 38, 40-42], and in older adults [12, 43-46]. However, the lateral step task has been less extensively examined compared to other forms of stepping [23, 47]. This research is innovative because no one has extensively studied the combined activity of muscle groups such as Quadriceps

(vastus medialis (VM)), Hamstrings (biceps femoris (BF)), Tibialis Anterior (TA), Gastrocnemius (GAS), Gluteus Maximus (G_{MAX}) and Gluteus Medius (G_{MED}) and biomechanical changes during the LS task and their correlation with each or assessed changes in these correlations with age-related decline in motor coordination [21, 22, 28]. Since an older person has an increased risk for injury or falls, with over 60% of accidents occurring on stairs [1], measures need to be developed to provide rehabilitation protocols that can aide in strengthening muscles and prevention of injury. Hence, by finding the differences in neuromotor function between younger and older individuals, such as which muscles are more active during the task between the groups, a suggested rehabilitative protocol could be designed.

1.4 Organization of the Thesis

The thesis is divided into five chapters. Chapter 1 provides an introduction to the thesis and presents the hypothesis, specific aims, rationale and significance of the study. Chapter 2 is a background literature review of the activities of daily living, specifically the Lateral Step Task focusing on activity of the muscles acting on the hip and knee during the lateral step task, and the joint angle kinematics. Chapter 3 presents the research methods, experimental protocols utilized to conduct the study and the outcomes of the study. Chapter 4 summarizes the results, discusses lower extremity muscle activity and kinematic patterns in the LS task in older subjects compared to younger subjects. Chapter 5 presents a discussion of the results and offers a conclusion. Finally, Chapter 6 offers direction for future work. The bibliography for the entire thesis is presented at the end.

Chapter 2: BACKGROUND

Activities of daily living (ADL) are referred to as tasks that are done every day as part of an individual's regular routine and include walking, standing, and stair climbing. Due to age-related declines in physical abilities, older adults may have trouble when performing ADL. Declines in the ability to complete ADL can be due to several factors such as decline in neural activation and motor function. Thus by observing and comparing the changes in muscle activity and joint angle kinematics during performance of ADL between younger and older adults, it may be possible to discover if neuromotor function is different in older adults.

2.1 Age-related changes in physical capabilities

As individuals age there is a decline in physical capabilities which may lead to difficulty in performing daily activities [1]. The individuals who have difficulty performing daily activities are limited in their ability to perform in the community [48]. There are several factors that lead to loss of independence in older adults including physical inactivity, decline in motor function and neural activation which may lead to changes in muscle activity and kinematic control of joints.

2.1.1 Physical exercise

Adults who do not remain physically active have reduced ability to do daily routines including dressing, grooming, and housekeeping [49]. Physical activity not only improves the ability to do everyday activities but also has influence over other age-related physiological functions such as metabolism, cardiovascular function and overall

physiologic well-being [50]. Remaining active is key to maintaining functional physical capabilities.

Muscle analysis at the microscopic level has shown evidence of age-related neuropathic changes such as atrophy [51-57]. Physical exercise can increase muscle cross sectional area moderately by 5-10%, leading scientists to believe that exercise could lead to increase in strength of the motor control pathways [58-65]. The loss of contractile material occurs by muscle hypotrophy due to aging-related decline in muscle cross sectional area [66]. Particularly training has been an effective way of improving muscle strength in older adults below 80 years of age [67, 68]. Loss of muscle mass and strength can result in frailty, impaired mobility, loss of independence and quality of life [67-69]. Therefore, increasing muscle strength due to increased muscle mass may leads to better muscle function in older age and could prevent physical disability [50].

2.1.2 Neural Activation

Another reason for age-related decline in ADL can be attributed to impaired neural activation of muscles [67, 70]. Neural activation of motor units, that consist of a single motor neuron and its family of innervated muscle cells, results in muscle contraction [71]. Electromyography (EMG) methods that record muscle activation can be used to demonstrate that age-related changes in both duration and amplitude of motor unit action potentials could cause a decline in coordinated motor function [72-75].

2.1.3. Decline in motor function

Lateral stability and falling may be caused by changes in neuromotor function in older adults. Falls are responsible for about one quarter of the admissions to nursing

homes and lead to increased health costs [9-11]. Decline in motor function can be found in older individuals who are obese, have osteoarthritis, neuromuscular dysfunction, or declined visual performance or may have had joint or limb replacement [3, 4]. Degradation of sensory perception [5], neurological control [6] and musculoskeletal function [7] ,[22], may lead to injurious falls which can lead to fractures or even death. The deterioration of the nervous system has been suggested to cause decreased stability with increased age, and may lead to the slowing of the central integrative mechanisms responsible for postural control [76, 77]. The decrease in stability can lead to increased sway and is thought to indicate a decrease in sensory input within the central nervous system. Increased sway has repeatedly been shown to increase the likelihood of falling with age [4, 47, 78]. It is important to note that associations between visual, peripheral sensation, strength and reaction time measures and performance suggest that these systems are important in maintaining lateral stability [47].

2.1.4. Neuromuscular function

When comparing a younger and older adult population several changes in neuromuscular function and muscle activation have been noted. Muscle movement occurs by brain signals that form action potentials, through the nervous system to the motor neuron that innervates several muscle fibers. The contraction of several muscle fibers at once allows for movement of joints. Lower extremity muscles are responsible for movements of the legs at the hip, knee and ankle joint. Lower extremity muscles such as quadriceps constituted of the rectus femoris, vastus lateralis (VL), vastus medialis (VM), and vastus intermedialis [22, 75, 79-82] and hip muscles such as the gluteus

maximus (G_{MAX}) and gluteus medius (G_{MED}) [1, 30, 32] are important when understanding movement in ADL. Changes in quadricep activity due to aging is apparent [75, 79-81]. Earlier quadricep activation is proposed to occur in order to compensate for the decreased balance and strength of older individuals when executing challenging activities [79]. On the other hand, a decrease in hip abductor and adductor muscle strength has been measured with age [32]. It is clear that research is necessary to understand the effects of aging on human neuromuscular function [71].

2.1.5. Biomechanics at the joint

Several features of the biomechanics of joint control and muscle activation have been reported to be different between healthy younger adults and older adults. Older individuals exhibit decreased concentric and eccentric knee extension strength [33], hip abductor and adductor joint torques [32], and maximal hip strength and movement speed [30]. There can be an age-related decline in isometric peak torques for hip abduction (34%) and adduction (24%) and an even greater decline in peak torque hip abduction (44%) and adduction (56%) [32]. Older individuals produced 16% lower velocities as a function of load and lower maximum power in a fall prevention protocol using a Biodex machine [30]. Additionally, biomechanical analysis shows irregularities in trunk, hip, knee and ankle kinematic during the motor task execution [12].

Lower extremity motion is controlled at the knee joint by several muscles including the quadriceps and hamstrings. The knee has received extensive exploration because of frequency of injury [83]. Knee joint motion and muscles surrounding the knee such as the quadriceps play a vital role in all lower limb tasks, especially those of weight-

bearing nature [79]. Muscle function can be expressed as flexion, decreasing angle between segments, or extension, increasing the angle between two segments. Due to the knee's importance in daily activities, the exact functions of each muscle have been investigated. Knee extensors, quadriceps located on the thigh such as the vastus medialis , are responsible for several ADL including standing up, sitting down, stair climbing and gait (walking) [80]. Muscles such as the gluteus maximus, hip extension, and the gluteus medius , hip abduction are also required for stability and are essential for walking [84]. Additionally, the gastrocnemius an ankle plantarflexor, and tibialis anterior an ankle dorsiflexor, are also known to maintain stability while standing [85].

2.1.6. Importance of age-related declines in physical ability

Age-related declines in physical strength, function, and mental process leading to decreased kinematic and kinetic data can hinder individuals' independence and quality of life. Therefore, it is crucial to understand the age-related and disease-based changes that could influence neuromuscular performance. Knowledge about the effects of aging on the human neuromuscular system is required for effective prevention and treatment programs that seek to maintain high levels of physical function and independence in the rapidly growing population of older adults [71].

2.2 Activity of Daily Living: The Step Task

Activities of Daily Living refers to activities that individuals perform on a daily basis. These activities include but are not limited to standing, walking, sitting to standing, and stepping. Without the ability to perform these tasks, individuals would not be able to maintain posture or perform personal tasks such as cooking, cleaning, and bathing. This

inability to perform ADL can lead to loss of independence and degraded quality of life. ADL have been extensively studied over the years due to their importance in mobility and the ability for changes in motor patterns to be distinguished across tasks.

The ability to perform ADL has proven to be different among different categories such as age and gender. In order to assess age-related changes in motor function during daily activities, specific ADL have been studied, for example, gait (the act of walking) [86-89], sit to stand (the act of going from a seated position to a standing position) [90, 91], stepping [8, 12, 46, 82, 92-95] and posture [8, 26, 76, 96].

Some age-related differences in gait are reduction in peak hip flexion, increased anterior pelvic tilt, and ankle plantarflexor concentric weakness [88, 97]. Older individuals may be limited by hip flexion contracture, joint immobilization due to underuse, and ankle plantarflexor weakness, which may lead to decline in performing ADL. Older adults also experience slower walking velocity, lower cadence, shorter step length, longer stride time, longer double-support time, less heel contact and push-off forces increasing the risk for fall or injury [88]. Age-related differences can be observed in sit to stand as well, where older adults show alterations in strategy by increasing their hip flexion velocity while attempting to increase their stability, taking more time to rise and shortening the distance between their center of mass/base of support while lifting from the chair [90]. This form of sit to stand suggests a more conservative strategy but more difficult, resulting in decreased success in rising from a chair. Additionally, posture and balance is affected as individuals' age. Older adults were found to demonstrate a significantly greater medial inclination angle during the stair-to-floor transition phase when compared to young adults [28]. Age-related degenerations in the elderly could

compromise their ability to regulate body sway during the stair-to-floor transition, which may consequently increase the risk of falling [26]. Finally, biomechanical analysis of the step task in older populations has shown abnormalities of the trunk, hip and ankle kinematics during the motor task such as prolonged double stance phase duration, greater anterior flexion of the trunk, greater flexion of the hip, and reduced dorsiflexion of the ankle which increases the risk for tripping or falling [12].

While gait and sit to stand have been extensively studied, there are fewer studies that have analyzed kinematics, kinetics and neuromuscular function during the step task. The step task should be studied since a large amount of accidents occur on stairs and studying neuromuscular control during the step task would allow assessment of lower extremity performance capabilities.

2.2.1 Step Task

The step task is an ADL. It is defined as the act of stepping down and stepping up, as experienced in stair descent/ascent. The stepping task is also described as stair negotiation, the act of going from one step to another. Stair negotiation is a significant functional activity of independent living [1, 17, 19, 28, 98, 99]. During the step task, movement at the hip, knee and ankle joints is necessary. The hip, knee, and ankle need to flex or extend during frontal stepping, the act of stepping forward onto a step. Lateral stepping, the act of stepping to the side onto a step, requires abduction/adduction of the hip and flexion/extension of the knee. The step task has been used as an indicator of strength and mobility [100-102] and is often used in knee rehabilitation. The stepping task is an appropriate task to assess motor function in older adults because the movement

pattern is similar to that which occurs during stair climbing, the task can be easily performed at home, is relatively safe, and can be adjusted based on height of the step [46].

Stair walking is demanding and one of the most dangerous activities in everyday life and is the cause of several falls and injuries [28, 45, 99]. Stair negotiation is challenging due to several reasons, one of them being that the knee flexion moment during stair ascent has been reported to be three times greater than during walking, causing the knee joint to become unstable. The knee and ankle may be the key joints requiring adequate strength and power for a safe descent [43]. Individuals performing stair descent endure large forces on the lower extremity especially at the knee joint, a weight-bearing joint [28]. Landing on a single leg with the knee abducted results in valgus collapse, increased strain in the medial side of the knee and compression of the lateral side, subsequently increasing the risk of injury [27]. The contraction of both quadriceps and hamstrings allows for a modulated movement and controlled loading at the knee. The knee is an important joint to study because it is responsible for control of the step task. Observing variation in the step movement can be an indicator for need of muscle strengthening or kinematic adjustment of the knee joint.

Traditionally, open kinetic chain (OKC) exercises where the limb is free to move have been used in knee rehabilitation protocols. Consequently, the idea of using closed kinetic chain (CKC) exercises where the weight bearing joint is fixed and remains in contact with an immobile surface has been examined recently and has shown to provide the same if not better results [81, 103, 104]. CKC exercises offers several advantages over OKC exercises such as providing co-contraction of quadriceps and hamstrings by

providing functional recruitment patterns over multi-joint movement. CKC exercises also provide improved stability due to increased joint compressive forces and decreased shear (parallel stress) forces [81, 83].

Due to pain or difficulty of performing the step task, older adults use different techniques to descend steps, compared to young adults [105]. Impaired reactive stepping in older adults can be caused by a decline in musculoskeletal function [106] due to atrophy in the contractile properties of muscles [107] and/or decreases in range of motion within the joints [97] which results in reduced movement proficiency. Individuals with reduced motion or low knee extensor strength compensate by use of their upper extremity to aid in stair negotiation [29]. This compensation can be in the form of lateral (frontal) stepping. Elderly adults also demonstrate faster sway compared to younger adults in stair descent and ascent due to the need for balancing. The sway has been primarily found in the medio-lateral direction according to the center of motion relative to the center of gravity [26]. Instability in the frontal plane for elderly individuals signifies an area in need of further evaluation. Understanding the changes in muscle activity and joint biomechanics helps to determine the possible sources of alterations in motor patterns in older adults when performing ADL.

2.2.2 Lateral Step

The step task can be completed using a variety of different techniques such as step bench, exercise that involves coordination of various steps, forward stepping (FS) or lateral stepping (LS). Specifically, LS is a form of step negotiation used by clinicians to assess lower extremity performance abilities [23]. Few have tested the reliability of the

LS task [23], but one study suggested that LS has excellent inter-tester reliability for measurement of functional lower limb strength [24].

Few studies have been completed examining the muscle activity and biomechanical patterns during LS [22-24, 42, 46, 81-83, 87, 108-111] compared to other ADL. LS requires simultaneous coordination of hip, knee and ankle musculature to mimic stair-climbing activities. The position of the joints affects which muscles are activated. During the LS task, maintaining a hip neutral position is an effective method to increase the activity of the gluteus medius [109]. LS places a greater demand on knee extensors and ankle plantar flexors in older adults due to balance and postural instability [46] since it produces a greater impulse, work, and power at the knee and ankle compared to FS. Additionally, LS requires greater vastus medialis and vastus lateralis recruitment than hamstring and gluteus maximus [111].

After examination of the LS task, some studies show that use of LS based exercise improves the ability of individuals to increase muscle activity [46], [111] while others question the use of such exercise to increase muscle strength [22]. Other methods of step exercise such as crossover step exercise may show larger concentric muscle activation of the G_{MED} compared to LS [112]. These and additional studies that examine neuromechanical control during LS may provide physicians guidelines for prescription of exercise protocols that may be best for targeting and maximally activating a variety of hip and thigh muscles [112]. Therefore, it is necessary to continue to examine the LS task and observe the changes experienced in muscle activation and kinematics and provide evidence of neuromotor alterations control in older adults.

Chapter 3: METHODS

Described below are the study design, experimental protocols, and methods for collecting electromyographic, kinematic, and kinetic data during performance of the lateral stepping task.

3.1 Subject Groups and Recruitment Process

The study involved two age groups: Ages 21-35 with 4 females and 4 males and Ages 50-65 with 4 females and 4 males. Individuals included in this study had the ability to sit, stand, walk, and step up and down without assistance, orthotics, or prosthetics. Individuals were excluded if they had self-reported pain, aching, or stiffness in either knee in the past year or were currently experiencing moderate or severe lumbar, hip, or lower extremity pain, had history of knee surgery, had any neurological disorder that could affect gait, balance or posture, or had any other co-morbid conditions that might interfere with the ability to perform the study tests. Pregnancy was also an exclusion criteria.

The number of subjects in each group were calculated based on a power analysis conducted on data obtained from a pilot study to determine the most active muscles in the lateral step task. The pilot study included electromyography from quadriceps (Vastus Medialis, Rectus Femoris, Vastus Lateralis), hamstring (Bicep Femoris and Semitendinosus), Gastrocnemius and Tibialis Anterior. The results from this pilot study underwent power analysis by comparing muscle activation duration to determine the appropriate number of subjects per group to achieve 90 % power and 5% significance level between age groups.

Study participants were recruited through flyers (Appendix) posted around Florida International University (FIU) Campuses (Modesto A. Madique and the Engineering Center), and senior centers and clinics in the Miami area surrounding FIU. Flyers were also emailed through several departments at FIU including Biomedical Engineering, Physical Therapy, Psychology, Occupational Therapy and Nursing. Participants, at the point of initial contact with the investigator, were asked a series of preliminary questions as part of the inclusion/exclusion criteria to determine if they were suitable for the study and they were briefly explained the experiment protocol. If they met the inclusion criteria and were interested, then a convenient appointment was scheduled for the participant and the laboratory personnel. Participants were instructed about proper attire (shorts and sleeveless shirt, and athletic shoes) that they would be required to wear during the study and provided directions to the FIU Physical Therapy Department Human Performance Laboratory. On the appointment date, prior to data collection, the entire procedure was explained to the participant in detail. They were given the opportunity to review and sign the Institutional Review Board (IRB) Consent Form and complete a Race and Ethnicity Form. The investigator kept track of all contact with each potential participant in a log. All study records utilized a participant code number.

Testing was conducted at the Human Performance Laboratory, Department of Physical Therapy, Florida International University, Miami, FL. All testing was completed in one session lasting approximately 1.5-2 hours.

3.2 Lateral Step Task Protocol

The procedure for conducting the Lateral Step task and the protocol are illustrated in Figure 1. The trial began with the subjects standing on top of two 4-inch platforms placed on separate force plates (Figure 1B). The protocol for conducting the step down task is illustrated in Figure 1A. The subjects were instructed to step down (SD) laterally using their non-dominant leg after hearing a beep that occurred 2 seconds after recording started. Following the cue, the step-down task took approximately 3 seconds. After completion of the step-down task, once they had both feet on the platforms, they were then required to remain still for approximately 2 seconds. After hearing another beep, the subjects performed the step-up (SU) task back to their original foot position for about 3 second, ending with 2 seconds of no movement at the end. The dominant leg remained stationary for the entire task which in total took 12 seconds. EMG, kinematics, and kinetic data were recorded for a total of 12 seconds. Each task (Step Down/ Step Up) was 6 seconds long. This included 2 seconds before start of the task, approximately 3 seconds of movement and 1 second after the end of the step down/step task. Then, the same task was repeated using two 8-inch platforms. All but one subject was right dominant, therefore except for that subject, the right leg remained stationary on Force Plate 1, and the left leg was the moving leg on Force Plate 2.

FIGURE 1. The Lateral Step Task Protocol. A) The subject initially stands on the platforms with each leg on a separate force plate. On hearing a beep (cue), the subject performs a lateral step down with their non-dominant leg from the platform onto the force plate and holds the position for 2 seconds. On hearing a second beep (cue) the subject steps up with their non-dominant leg to return to the original position, B) Right dominant subject standing on top of platforms on force plates located underneath the platforms. Electrodes used to record EMG are positioned on the BF, VM, TA, GAS, G_{MED} , and G_{MAX} muscles. Kinematic markers were placed on anatomical landmarks of the hip, knee, and ankle. C) Frontal view of a Visual 3D computer software generated generalized

model utilized to calculate kinematic measures for each subject using the kinematic markers. This image shows the force platforms and Lab Axes (X: Left/Right, Y: Forward/Back) for the lateral step task.

3.3 Data Acquisition

The participant was given practice trials prior to obtaining a minimum of five lateral step task trials of which three were utilized for data analysis. One-minute rest was given between trials. Data recorded included EMG, kinetic, and kinematic measures.

EMG data was recorded from the vastus medialis, the bicep femoris, the tibialis anterior, the gastrocnemius, the gluteus maximus and the gluteus medius. The recorded force data from the force plates (AMTI) plates, FP1- right (dominant) and FP2- left (non-dominant) legs, was transported into Visual 3D (C-Motion Inc, MD). Visual 3D also held the recorded kinematic marker positions which were used to create a generalized model as seen in Figure 1C. The kinematic markers and the 3-D model were then used to calculate kinematic measures such as hip, knee, and ankle angles and torque.

In order to assess neural activation of the muscles during the LS task, electromyograms were collected from multiple muscles of the lower extremities using surface electrodes. The electrodes provided pre-amplification of the skin surface with internal protection preventing radio frequency interference and electrical static damage. The electrode contacts were made from medical grade stainless steel. Each electrode had two 12mm disk sensor contacts and a 12 x 3mm bar reference contact separating the sensors. Table 1 lists the muscles and the function they contribute to. Prior to electrode placement on the muscle, the skin surface was cleansed/shaved. Manual muscle testing

was used and the muscle surface was felt and EMG visually seen on screen to locate the area of the muscle belly with the most activity. Surface tethered EMG electrodes (Motion Lab Corp) were placed on the muscle belly and EMG activity was recorded with an 8-channel EMG system (Motion Lab Corp) sampled at 1000 Hz. The EMG activity was full-wave rectified and band-pass filtered using a second order Butterworth filter with a 20-500 Hz cut-off.

In order to relate the EMG activity of the different muscles to the different phases of movement during the LS task, kinematic and kinetic data were collected. EMG, kinematic, and force plate data were recorded at 120 Hz, with 12 seconds worth of data leading to 1440 frames. The hip, knee, and ankle joint-angle kinematics were obtained in three dimensions using a Qualisys Motion Capture (Qualisys AB, SE) system. 23 reflective markers, and 6 marker clusters (each with 4 markers on each) were placed on anatomical landmarks on the trunk, pelvis, and lower extremity. Specifically, individual markers were placed on the knee joints, sacrum, pelvis, sternum, 7th cervical/1st thoracic spinous processes, and 8th thoracic spinous process. Clusters were placed on the dorsum of the foot (above shoes in the midline over the metatarsal area), lateral shanks of both legs (just distal to the knee joint), and lateral thigh of both legs (proximal to the knee joint). 9 motion capture cameras (Figure 2) were placed around the laboratory to record the marker positions. The height (m) and weight (kg) of each participant were collected using DETECTO, a digital clinical scale that uses weight and height measurements for calculation of body mass index and entered into Visual 3D to build the skeletal model to analyze the kinematics of the lower extremity. The ground reaction force (GRF) during the tasks was recorded using 2 dual AMTI force plates (Motion Lab Corp) from 3-axes.

TABLE 1. Lower limb muscles and their function.

Muscle	Function (major)
VM: Vastus Medialis	Knee Extensor, Hip Flexor
BF: Bicep Femoris	Knee Flexor, Hip Extensor
G _{MED} : Gluteus Medius	Hip Abductor
G _{MAX} : Gluteus Maximus	Hip Extensor
TA: Tibialis Anterior	Ankle Flexor (Dorsi- Flexor)
GAS: Gastrocnemius	Ankle Extensor (Plantar Flexor)

FIGURE 2. Setup for kinematic and kinetic data collection. 9 Infrared cameras that capture the kinematic marker movements are placed around the platform on which the subject stands. Two force platforms under each foot record the GRF data.

3.4 Data Analysis

EMG data collected was used to evaluate the active muscle activity throughout the lateral step task and to understand timing of activation and role of the muscle throughout the task. EMG was also used to determine muscle burst duration of each muscle recorded. Muscle burst duration was calculated as the onset and offset of muscle activity. EMG data were analyzed for the ankle muscles, TA (ankle dorsiflexor), and GAS, ankle plantar flexor from both the legs (stationary and moving) during the Step task. These muscles were chosen after a pilot study that indicated these were the most active throughout the lateral step task. EMG onset of each muscle was identified for each individual trial. A computer algorithm identified onset of activity at the point where the EMG signal reached a threshold of 3 standard deviations above the baseline activity for that muscle. Each trial was visually inspected to assure the algorithm identified the correct onset. Each muscle activation length was recorded.

Kinematic angle data was imported directly from Visual 3D, and calculated using one segment in relation to another using the coordinate system, with no further processing involved. Ground reaction force was used to determine the phases of the task as well as swing time. Swing time was calculated by finding the time in-between the red dotted lines in Fig. 3, the time where Force plate 2 is zero signifying the time the non-dominant moving leg is in the air when performing the step task. Finally kinematic angle data was calculated for hip, knee and ankle joints to determine the change in angle position throughout the task.

The start of step down was the first frame when Force plate 2 data reached zero, i.e. the non-dominant leg was in the swing phase. The end of step down was the last

frame where Force plate 2 data was at zero. Phases of movement can be seen in Figure 3. As mentioned, each trial was aligned based on the start of the task. The beginning of the task was identified (beginning of swing time) and used to synchronize data because muscles don't activate at the same time.

Using the GRF data to distinguish start and end of the step task allowed the phases to be noted. The lateral step task has step down and step up phases. The complete step cycle is comprised from 0-100% and includes both step down (0-50%) and step up (50-100%). Step down/Step up is divided into three phases: loading phase, stabilization phase, and unloading phase. The loading phase can be described as the time prior to the dotted lines indicating the start of the task as indicated in Fig. 3. The stabilization phase lies in-between the dotted lines signifying the start and end of the task, where most of the muscle activation occurs. The unloading phase, after the task, is where muscle activation decreases.

After all EMG, kinematic and kinetic data was processed using Visual 3D, data was exported to MATLAB software (Math Works Inc, MA). Trials 2-4 were chosen unless there was an issue with incorrect motion or markers falling and placed in a matrix within MATLAB. MATLAB was used to find the duration in seconds to perform the task (swing time) for each trial and placed in a matrix within MATLAB. Another MATLAB program for EMG was created to find a threshold value of 3 standard deviations above/below the mean baseline data for burst duration, and placed in a matrix within MATLAB. The average for each task Step Down/Step Up for 4-inch and 8-inch tasks was calculated for both swing time and muscle burst duration and exported to an excel sheet.

FIGURE 3. Phases of Movement for Dominant and Non-Dominant Leg. A) Stationary (Dominant) Leg Ground Reaction Force data showing the cue signifying to the participant to start movement for Step Down/Step Up. B) Moving (Non-Dominant) Leg Ground Reaction Force data showing the cue signifying to the participant to start movement for Step Down/Step up. Start/End of tasks are labeled with dotted red lines. Swing time is the time within the dotted red lines, when moving leg is at 0 N.

Statistical analysis was conducted using SPSS (SPSS, Inc) by two-way (2x2) ANOVA for each task comparing step height (4inch, 8inch) and age (young, old). Swing time and muscle burst duration averages in the MS Excel worksheet were imported into an SPSS (SPSS Inc, IL) worksheet and restricted so the average of all the interested variables were entered group wise (younger/older, 4inch/8inch). Subjects were categorized based on age, which is one of the most common risk factors for joint injury and falls [11, 92, 107]. Prior to analysis, data was reviewed to ensure whether data was normally distributed for all variables in each of the groups. Determining skewness and Q-Q plot distribution validated normal distribution [113]. Muscle burst duration for tibialis anterior and gastrocnemius for dominant/non-dominant legs and swing time was compared across groups.

Chapter 4: RESULTS

4.1 Participant Demographics

Participants were chosen using the criteria explained in section 3.1. The mean demographic information is given in Table 2.

TABLE 2. Participant Demographics.

	Age (years)	Weight (kg)	Height (m)	Gender (M/F)
Younger Adult (n=8)	24.4 ($\pm$3.1)	71.4 ($\pm$13)	1.7 ($\pm$0.1)	4/4
Older Adult (n=8)	58.9 ($\pm$5.1)	69.1 ($\pm$14)	1.7 ($\pm$0.1)	4/4

4.2 Kinetic, Kinematic and Electromyographic data

Fig. 4 illustrates the typical kinetic, kinematic and electromyogram data obtained from a younger subject when performing the lateral step down and step up task from a 4-inch height. The external angles shown in Fig. 4-5 show hip, knee, and ankle angles while performing the step task. The blue line represents flexion (+) / extension (-) (x-axis), the green line represents abduction (+) / adduction(-) (y-axis), and the red line represents longitudinal rotation (z-axis). The knee, hip, and ankle begin at 0 degrees of flexion in the standing position. Each task has a peak flexion and is easily comparable between age groups. This peak occurs once the moving leg has gone through a step down (SD) process from platform to floor or a step up (SU) process from floor to platform. The 8-inch task uses a larger hip (40°) and knee (90°) joint angle excursion compared to the 4-inch task hip (20°) and knee (70°) angle excursions.

Across trials, the mean (and standard deviation) angle excursions of the joints in younger adults for the step task were hip (20° (8.2)), knee (50° (10)), ankle (26.7° (5.2)), while those for the joints in older adults for the step task were hip (25° (12.9)), knee (55°

(10)), ankle (20 (0)). Qualitatively it can be observed that there was a 5° difference in joint angle excursions between younger and older adults while performing the step task: an increase in hip and knee angle while a decrease in ankle angle, in older adults,. The most noticeable difference was in the peak hip flexion value.

As seen in Fig. 4.2, the ground reaction force of the dominant stable leg is constant with a brief unloading prior to the initiation of the swing movement of the non-dominant moving leg during the step down task and an increased loading during the swing phase.. The cycle repeats again with the step up task and ends with stabilization of the dominant standing leg. Observation of the forces produced by both the dominant standing (Fig. 4A) and non-dominant moving (Fig. 4B) legs indicates that while one leg is undergoing loading the other is unloading. The force plate was zeroed with the platform on top. When the GRF reaches zero, in this case negative (due to the platform lifting off the floor) for the FP2-moving leg, it means that there is no GRF and the leg is mid air. There is a difference in the amount of ground reaction force exerted on each leg depending on the height of the platform. For instance, while performing the step-down task from a 4-inch step (Fig 4) there is a larger peak GRF (940 N) under FP1-standing leg than when the task is performed from an 8-inch step (860 N) (Fig. 4 vs. Fig.5). Peak GRF for the FP2 -moving leg was 1000 N for the 8-inch step task compared to 790N for the 4-inch step task (Fig. 4 vs. Fig. 5).

Neural activation of the muscles can be observed as a burst of muscle activity (Fig. 4 and 5.) Figs. 4 and 5 demonstrate a baseline (no activity) and then a burst of activity, where the blue signal is raw data and red is filtered data for the muscle graphs (G_{MED} , G_{MAX} VM, GAS, TA, TA2, GAS2). Activation of muscle activity is observed as

increased amplitude from the baseline activity, for example, G_{MED} activity between 2.5 and 3 seconds in Fig. 4A during step down.

FIGURE 4. Kinetic, Kinematic and Electromyographic data for a single younger adult subject for the 4-inch Lateral Step Task. Muscles from the dominant (right) leg include G_{MED} : Gluteus Medius, G_{MAX} : Gluteus Maximus, VM: Vastus Medialis, BF: Biceps Femoris, TA: Tibialis Anterior, GAS: Gastrocnemius. Muscles from the non-dominant (left) leg include TA2: Tibialis Anterior and GAS2: Gastrocnemius. Step up: 1-6 seconds, step down: 6-12 seconds. Data represented for stable dominant leg (left column) and moving leg (right column). Cue, purple line, instructs the individual to

perform the task. The first and second pair of dashed lines in each column demarcates the start and end of the lateral step down and step up tasks respectively for the swinging non-dominant leg. Boxes represent muscle burst activity. The EMG data (G_{MED} , G_{MAX} , VM, BF, TA, GAS, TAS2, GAS2) shows: blue signal as the raw EMG data and red signal as the filtered data. Kinematic data (hip, knee, ankle) has blue line represents flexion (+) / extension (-) (x-axis), green line represents abduction (+) / adduction (-) (y-axis), and red line represents longitudinal rotation (z-axis).

FIGURE 5. Kinetic, Kinematic and Electromyographic data for a single younger adult for the 8-inch Lateral Step Task. Muscles from the dominant (right) leg include G_{MED}: Gluteus Medius, G_{MAX}: Gluteus Maximus, VM: Vastus Medialis, BF: Biceps Femoris, TA: Tibialis Anterior, GAS: Gastrocnemius. Muscles from the non-dominant (left) leg include TA2: Tibialis Anterior and GAS2: Gastrocnemius. Step up: 1-6 seconds, step down: 6-12 seconds. Data represented for stable dominant leg (left column) and moving leg (right column). Cue, purple line, instructs the individual to perform the task. The first and second pair of dashed lines in each column demarcates the start and end of the lateral step down and step up tasks respectively indicating the swing time for the swinging non-dominant leg. Boxes represent muscle burst activity. The EMG data (G_{MED},

G_{MAX}, VM, BF, TA, GAS, TAS2, GAS2) shows: blue signal as the raw EMG data and red signal as the filtered data. Kinematic data (hip, knee, ankle) has blue line represents flexion (+) / extension (-) (x-axis), green line represents abduction (+) / adduction (-) (y-axis), and red line represents longitudinal rotation (z-axis).

4.3 Coordinated Muscle Movement Patterns

In order to see the coordination of muscle movement patterns it was beneficial to plot the average muscle activation and compare against age groups. Averages were taken first across each person per trials, and then averaged across age groups. Movement can be divided into three phases per step down and step up: loading, stabilization and unloading seen in figure 6.

In the loading phase, muscle activation is seen for most of the recorded muscles in both dominant and non-dominant legs. This occurs as the leg is preparing or bracing for the task prior to movement of the non-dominant leg. The dominant leg muscles are preparing to stabilize the leg on the platform as the non-dominant leg is swung laterally into the air. For younger adults during the 4-inch step down task muscle activation is seen in all muscles (BF, G_{MED}, G_{MAX}, TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) except VM. During step up muscle activation is seen all muscles (VM, BF, G_{MED}, G_{MAX}, TA, GAS- dominant leg; TA2, GAS2- non-dominant leg). For older adults during the 4-inch step down task muscle activation is seen in all muscles (VM, BF, G_{MED}, G_{MAX}, TA, GAS- dominant leg; TA2, GAS2- non-dominant leg). During step up muscle activation is seen in VM, BF, G_{MED}, G_{MAX}, TA in dominant leg and TA2 in the non-dominant leg. For the 8-inch step down task muscle activation for younger adults is seen

in BF, G_{MED} , G_{MAX} , GAS of the dominant leg and TA2, GAS2 of the non-dominant leg. In the step up task, muscle activation in the younger adults is seen in G_{MED} , G_{MAX} , TA, GAS of the dominant leg and TA and GAS of the non-dominant leg. In older adults muscle activation is seen during step down for all muscles (VM, BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2, GAS2- non-dominant leg). During step up muscle activation is also seen in all muscles (VM, BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2, GAS2- non-dominant leg).

During the stabilization phase of the LS tasks (step down and step up) the muscle activation per muscle varies. G_{MED} is responsible for the hip abducting, and eccentrically contracting to allow the standing leg to remain straight while lowering the moving leg (Fig. 1A). G_{MAX} a hip extensor also has a higher burst of activity throughout the same phase frame. On the other hand, the knee extensor, VM, is active during step down start to end, in all except the 8-inch step down step up tasks performed by younger adults. The knee flexor, BF, is active during the step down task and during the step up task and in between the two tasks. The ankle dorsiflexor, TA, and plantar flexor, GAS, are both active during the step down task.

Younger adults stepping down from the 4-inch step (Fig. 6A) show activation of BF, TA and GAS in the dominant leg and TA2, GAS2 in the non-dominant leg. Step up activation is seen in VM, BF, TA and GAS muscles of the dominant leg and TA2, GAS2 muscles of the non-dominant leg. Older Adults performing the 4-inch step down task (Fig. 6B) show activation of VM, TA, GAS of the dominant leg, and TA2, GAS2 of the non-dominant leg. During step up activity is seen in BF, TA, GAS of the dominant leg and TA2, GAS2 of the non-dominant leg. The 8-inch task (Fig. 6C, 6D) shows different

activation patterns between the two age groups with younger adults showing activation in all muscles (BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) except VM in step down/up and older adults showing all muscles active simultaneously (VM, BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) in step down and step up.

The unloading phase shows that younger adults performing the 4-inch step down task (Fig 6A) show muscle activations for VM, BF, TA, GAS in the dominant leg and TA2, GAS2 of non-dominant leg. In step up the active muscles were VM, BF, and GAS of dominant leg. Older adults performing the 4-inch step down (Fig. 6B) show muscle activation in VM, TA of dominant leg and TA2, GAS2 of non-dominant leg, while in the step up task muscle activation of BF, TA, GAS of the dominant leg and TA2, GAS2 of the non-dominant leg were observed. Contrarily for the 8-inch step down task (Fig. 6C), young adults show activation of all muscles (VM, BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) and for the step up task muscle activation of VM, BF, and GAS in the dominant leg is observed. Older Adults in step down (Fig. 6D) show activation of all muscles (VM, BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) while step up shows muscle activation of all (VM, BF, G_{MED} , G_{MAX} , TA, GAS- dominant leg; TA2 non-dominant leg) except GAS of non-dominant leg.

Further inspection can show that there is indeed some coordination between muscle groups during the step task, which can be observed group wise. Younger adults during the loading phase activate G_{MED} and G_{MAX} of the dominant leg first during the 4-inch step down task (Fig. 6A), shortly followed by GAS of the dominant leg and TA2 of the non-dominant leg. Then, BF of the dominant leg and GAS2 of the non-dominant leg

are activated. The stabilization phase shows a consistent activation of BF, TA, and GAS of the dominant leg and TA2 and GAS2 of the non-dominant leg with VM becoming active towards the end. Lastly, during the unloading phase activation of GAS of the dominant leg ends first, followed by TA of the dominant leg, then BF and finally VM of the dominant leg, and lastly TA2, GAS2 of the non-dominant leg. Almost the same process occurs in older adults with the exception of TA2, GAS2 having a shorter unloading activation, and BF activation ending right after stabilization begins.

In the 4-inch step up task, during the loading phase TA2 and GAS2 of the non-dominant leg are active first, followed by almost simultaneous activation of the G_{MED} and G_{MAX} of the dominant leg, followed by TA then GAS of the dominant leg, and BF then VM. During the stabilization phase, VM, BF, GAS of the dominant leg, and TA2 of the non-dominant leg remain active while GAS2 of non-dominant leg become inactive prior to the end of the phase. Finally, in the unloading phase TA2 of the non-dominant leg becomes inactive first, followed by GAS of the dominant leg then VM and lastly BF of the dominant leg. Older adults for the 4-inch step up loading phase show a very different coordination of muscles as G_{MAX} of dominant leg is active first, followed by G_{MED} then BF, then VM, then TA of the dominant leg and finally TA2 of the non-dominant leg. The stabilization phase has VM becoming inactive mid-way through, while GAS of the dominant leg becomes active mid-way through, BF of the dominant leg, TA2 and GAS2 of the non-dominant leg remain active throughout. The unloading phase is similar to that of younger adults but VM is not active in this phase as it was in younger adults.

Next, looking at the 8-inch task for step down, young adults have an almost simultaneous muscle activation of all muscles with GAS of dominant leg, and TA2 of

non-dominant leg activating first (Fig. 6C), followed by GAS2 of the non-dominant leg, then almost all together BF, G_{MED}, G_{MAX} of the non-dominant leg. Older Adults show BF, G_{MAX} and GAS of the dominant leg activating together (Fig. 6D), followed by G_{MED}, TA of dominant leg and TA2 of non-dominant leg activating together. Both age groups show similar activation during the loading phase as all muscles (BF, G_{MED}, G_{MAX}, TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) with the exception of VM in younger adults. In the loading phase, all muscles are active in younger adults (VM, BF, G_{MED}, G_{MAX}, TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) with G_{MED}, G_{MAX}, GAS of dominant leg becoming inactive first, then GAS2 of non-dominant leg, followed by BF, TA, TA2 together and finally VM. Older adults show a similar pattern with the exception of TA becoming inactive last instead of VM.

In the 8-inch step up task, the loading phase in younger adults (Fig. 6C) shows TA2 of non-dominant leg activating first, followed by GAS2 of non-dominant leg, then TA of dominant leg, lastly G_{MED} and G_{MAX} activate simultaneously. In older adults (Fig. 6D), first TA of the dominant leg activates then TA2 of the dominant leg, followed by GAS2 of the non-dominant leg, and G_{MED}, G_{MAX} together, finally VM, BF, GAS of the dominant leg.

The stabilization phase has several differences age wise. Young adults show consistent activation of and GAS of the dominant leg and TA2 of the non-dominant leg, with BF becoming active mid-way through. On the contrary, older adults show that all muscles (VM, BF, G_{MED}, G_{MAX}, TA, GAS- dominant leg; TA2, GAS2- non-dominant leg) are active throughout this phase. The unloading phase also has differences between age groups. Young adults show GAS becoming inactive first, followed by BF and VM active

simultaneously. VM becomes active only during this phase. Older adults show a different pattern, with TA of dominant leg and TA2 of non-dominant leg becoming inactive first, followed by G_{MAX} , then G_{MED} , and VM, next GAS and finally BF.

Overall it is observed that hip abductor (G_{MED}) and extensors (G_{MAX}) activate together and there is a coordination between ankle dorsiflexor (TA) and ankle plantar flexor (GAS) muscles, while knee flexor (BF) and knee extensor (VM) muscles work counter to each other activating at different times. Almost all muscle activation occurs in the loading phase prior to stabilization, and usually in one swift effort to get the body off the ground and ready for stabilization onto the dominant leg. VM is the only muscle that does not activate in some instances during the loading phase, and activates last in all tasks. From figure 6 it is clear that coordinated muscle movement patterns between age groups is not the same. Although there are similarities in the phases when muscles become active, the duration and moment of activation within phases is not consistent between age groups.

FIGURE 6. Muscle Activation Burst Durations during Step Down and Step Up tasks for a complete step cycle. A-B) 4-inch step tasks for younger and older adults respectively; C-D) 8-inch step tasks for younger and older adults respectively. The step down task occurs in the first half of the step cycle while the step up task occurs primarily in the latter half of the step cycle. The relative initiation and termination of the burst activity indicates the temporal coordination amongst different muscle groups. Phases of movement for each task include Loading, Stabilization and Unloading of the dominant stationary leg. Dashed lines signify the time the moving leg is in the air (swinging), and the force plate is at zero. See text for abbreviations.

4.4 Burst Duration of Muscle Activity

Table 3 and Fig. 7 summarize the mean values and standard deviations of burst duration for muscles (TA & GAS) in the standing and moving leg during the two-step tasks for 4-inch and 8-inch step heights for all of the subjects. The ankle flexors, TA and GAS were compared in younger and older adults. The TA muscle burst duration in the moving leg was significantly different between the two age groups during both 4-inch Step Down (Younger: 1.2 sec, Older: 1.7 sec) and Step Up (Younger: 1.1 sec, Older: 1.8 sec); $p < 0.05$. GAS muscle burst duration was found to be significantly different between age groups (Younger: 0.7 sec, Older: 1.5 sec) for only the 4-inch Step Up task. Burst durations of the EMG recorded from TA and GAS of the standing leg were not found to be significant for either 4-inch or 8-inch Step Tasks.

Table 4 and Fig. 8 summarize the mean values and standard deviations of burst duration for leg muscles (VM, BF, G_{MED} , G_{MAX}) in the standing (dominant) leg during the two-step tasks for 4-inch and 8-inch step heights for all of the subjects. The knee flexor/extensor, BF and VM, hip abductor, G_{MED} and hip extensor G_{MAX} were compared in younger and older adults. The VM muscle burst duration in the standing dominant leg was significantly different between the two age groups during the 8-inch Step Down (Younger: 1.7 sec, Older: 2.8 sec) and Step Up (Younger: 1.4 sec, Older: 1.8 sec); $p < 0.05$. BF muscle burst duration of standing dominant leg was found to be significantly different between age groups during Step Down of 4-inch (Younger: 1.9 sec, Older: 1.3 sec) and Step Down of 8-inch (Younger: 2.8 sec, Older: 2.7 sec). G_{MED} muscle burst duration of standing dominant leg was found to be significantly different between age groups during both Step Down 8-inch (Younger: 1.7 sec, Older: 2.1 sec) and Step Up 4-inch (Younger:

1.7 sec, Older: 0.7 sec) and Step Up 8-inch (Younger: 1.8 sec, Older: 2.5 sec). G_{MAX} muscle burst duration of the standing dominant leg was found to be significantly different between age groups during both Step Down 8-inch (Younger: 1.8 sec, Older: 2.3 sec) and Step Up 4-inch (Younger: 1.4 sec, Older: 0.7 sec), and Step Up 8-inch (Younger: 1.9 sec, Older: 2.1 sec) tasks. These results indicate a difference in neural activation depending on the task and muscle between age groups.

TABLE 3. Length of Burst Duration (sec) for ankle muscles.

	Step Down	Step Up	Step Down	Step Up	Step Down	Step Up	Step Down	Step Up
	TA _{standing}		GAS _{standing}		TA _{Moving}		GAS _{Moving}	
	4 Inch							
Young Adult (n=8)	1.9 (0.5)	1.6 (0.5)	1.5 (0.5)	1.6 (0.3)	1.2 (0.2)	1.1 (0.2)	1.0 (0.5)	0.7 (0.2)
Old Adult (n=8)	2.1 (0.9)	1.9 (0.9)	1.8 (1.1)	1.6 (0.4)	1.7 (0.5)	1.8 (0.6)	1.7 (0.8)	1.5 (0.6)
P-value	0.75	0.38	0.45	0.89	0.04*	0.01*	0.08	0.01*
	8 Inch							
Young Adult (n=8)	2.3 (0.7)	1.7 (0.7)	1.7 (0.4)	2.0 (0.3)	1.7 (0.3)	1.8 (0.3)	1.2 (0.4)	0.8 (0.4)
Old Adult (n=8)	2.3 (1.2)	2.2 (1.0)	1.9 (0.5)	2.2 (0.5)	2.1 (0.9)	1.7 (0.3)	1.7 (1.0)	1.1 (0.7)
P-value	0.64	0.23	0.42	0.71	0.11	0.78	0.08	0.31

Mean (SD). TA: Tibialis anterior for standing (dominant) leg and moving (non-dominant) leg; GAS: Gastrocnemius for standing (dominant) leg and moving (non-dominant) leg.

*Represents significant differences between Age groups ($p \leq 0.05$).

FIGURE 7. Muscle Burst Duration for the TA and GAS muscles in younger and older adults during the Step Down and Step Up tasks. TA: Tibialis anterior for standing dominant (TA-S) leg and moving non-dominant (TA-M) leg; GAS: Gastrocnemius for standing dominant (GAS-S) and moving non-dominant (GAS-M) leg. Muscle burst duration was compared between the age groups. White bars represent younger adults; black bars represent older adults. Black stars represent significant differences between age groups (* $p \leq 0.05$).

TABLE 4. Length of Burst Duration (sec) for leg muscles.

	Step Down	Step Up	Step Down	Step Up	Step Down	Step Up	Step Down	Step Up
	VM		BF		G _{MED}		G _{MAX}	
4 Inch								
Young Adult (n=8)	1.8 (0.6)	1.3 (0.5)	1.9 (1.1)	2.5 (1.3)	1.3 (0.8)	1.7 (1.3)	1.5 (1.0)	1.4 (1.1)
Old Adult (n=8)	1.8 (0.5)	1.3 (0.4)	1.3 (0.2)	2.0 (0.3)	0.9 (0.2)	0.7 (0.4)	1.1 (0.2)	0.7 (0.2)
P-value	0.79	0.86	0.01*	0.45	0.19	0.05*	0.48	0.02*
8 Inch								
Young Adult (n=8)	1.7 (1.4)	1.4 (1.4)	2.8 (2.1)	2.5 (1.4)	1.7 (1.6)	1.8 (1.7)	1.8 (1.7)	1.9 (2.0)
Old Adult (n=8)	2.8 (2.2)	1.8 (0.6)	2.7 (0.8)	2.6 (0.7)	2.1 (0.9)	2.5 (1.4)	2.3 (0.8)	2.1 (1.1)
P-value	0.01*	0.01*	0.04*	0.2	0.01*	0.01*	0.01*	.02*

Mean (SD). VM: Vastus Medialis for standing (dominant) leg; BF: Bicep Femoris for standing (dominant) leg; G_{MED}: Gluteus Medius for standing (dominant) leg; G_{MAX}: Gluteus Maximus for standing (dominant) leg. *Represents significant differences between age groups ($p \leq 0.05$).

FIGURE 8. Muscle Burst Duration for the VM, BF, G_{MED} , G_{MAX} for in younger and older adults during the Step Up and Step Down tasks. VM: Vastus Medialis for standing (dominant) leg; BF: Bicep Femoris for standing (dominant) leg; G_{MED} : Gluteus Medius for standing (dominant) leg; G_{MAX} : Gluteus Maximus for standing (dominant) leg. Muscle burst duration was compared between age groups. White bars represent younger adults; black bars represent older adults. Black stars represent significant differences between age groups ($p \leq 0.05$).

4.5 Swing Time Duration for the Step Tasks

Swing time of the moving leg is characterized between the dotted lines in Fig. 4B force plots. Table 5,6 and Fig. 9 display mean value and standard deviations for swing

time in younger and older adults during the Step Task from two different step heights. Swing time for the 4-inch Step Down task was found to be significantly different ($p=0.024$) between the two age groups (Younger: 444.8 ms, Older: 579.1 ms). Swing time for the 4-inch Step Up, and the 8-inch Step Down and step up were not significantly different between the two age groups. While, swing time for the younger subjects was also found to be significantly different between the two step heights (4-inch: 444.8 ms, 8-inch: 620.8) for both Step Down ($p=0.01$) and Step up ($p=0.01$), no significant differences were found for the older adult subjects. The swing time results indicate that older adults require more swing time to complete the step task. Additionally, there is a swing time difference in younger adults indicating that the 8-inch task requires more swing time.

TABLE 5. Swing Time (ms) for the Step Task.

	4 Inch		8 Inch	
	Step Down	Step Up	Step Down	Step Up
Younger Adult (n=8)	444.8 (75.3)	436.5 (61.9)	620.8 (125.9)	607.9 (139.1)
Older Adult (n=8)	579.1 (119.9)	504.6 (78.5)	712.0 (148.9)	562.5 (114.2)
P-value	0.02*	0.09	0.28	0.55

*Represents significant differences between age groups ($p \leq 0.05$)

TABLE 6. Swing Time (ms) for the Step Task comparing Step Height.

	Younger Adult (n=8)		Older Adult (n=8)	
	Step Down	Step Up	Step Down	Step Up
4 Inch Step	444.8 (75.4)	436.5 (61.9)	579.2 (119.9)	504.6 (78.5)
8 Inch Step	620.8 (125.8)	607.9 (139.1)	712.0 (148.9)	562.5 (114.2)
P-value	0.01*	0.01*	0.28	0.55

*Represents significant differences between age groups ($p \leq 0.05$)

FIGURE 9. Swing Time for the Step Task. A-B) Comparison of swing time for step down and step up tasks from a 4 inch step height (A) and 8-inch step height (B). White bars represent younger adults; black bars represent older adults. C-D) Comparison of swing time in younger (C) and older (D) adults. Older Adults require longer Swing Time in 8-inch than in 4-inch Step Tasks. Light grey bars represent 4-inch step tasks and dark grey represent 8-inch step tasks. Black stars represent significant differences between Age groups ($p \leq 0.05$).

Chapter 5: DISCUSSION & CONCLUSIONS

The aim of this study was to assess coordinated motor pattern during ADLs, specifically the Lateral Step (LS) task, in young and older adult individuals using joint angle kinematics and electromyograms of lower extremity muscles to test the hypothesis that coordinated motor function, when performing normal daily tasks, is altered between younger and older adult subjects. We studied the LS task between two different gender-matched age groups of healthy adults. The activity of the lower limb muscles was recorded with surface electromyograms. Changes in the joint angles of the hip, knee and ankle were assessed using kinematics and the different phases of the task were identified by use of kinetic data. Thus, by evaluating the biomechanical patterns of movement and changes in weight bearing during the LS task the study has provided us a better understanding of the control of movement as people age.

The study included male and female participants. In side-step cutting maneuvers during sports activities such as soccer, or recovery from lateral falls a gender difference has been noted [114-117]. Hence, to minimize the effect of gender on the lateral-step task the two groups had the same proportion of male and female participants (4 each). The average height of the two groups were also similar although the younger adults weighed slightly more.

Ground reaction force has been used previously as a useful means to determine phase changes throughout a task [118] and temporal parameters of the stepping movement can be calculated from the vertical ground reaction forces. The onset of weight shift is a common indicator used to distinguish between phases of movement. In this study, force data was used to separate the start and end of each task (step down and step

up). As previously described in section 3.6, the start of the step down/step up task was indicated when the force generated by the moving leg (force plate 2) reached zero, and the end of the task was the last frame the force was at zero. The onset and offset of muscle activation was considered with respect to the phases of the movement. A weight shift occurs from the moving-leg to the standing leg when the lateral step task is commenced.

Qualitatively it was observed that during the step task there is a 5° joint angle excursion difference between younger and older adults: older adults had an increase in hip and knee joint angle excursion compared to younger adults, while older adults had a decrease in ankle joint angle excursion compared to younger adults. The most noticeable difference was in the peak hip flexion value but the average hip, knee, and ankle angles between younger and older were not significantly different. This is a new observation and in contrast to a previous study that suggested lateral stepping places a greater demand on knee extensors and ankle plantar flexors in older adults due to balance and postural instability [46] since it produces a greater impulse, work, and power at the knee and ankle compared to frontal stepping. It is a possibility that since there were minor changes in hip, knee, and ankle angles that lateral stepping could potentially place a higher demand at the joints for older adults, but this conclusion is not supported since a large difference in angles was not seen.

It has been suggested that age-related decline in ADLs is attributable to impaired neural activation of muscles [67, 70]. Neural activity in the spinal cord results in recruitment of groups of motor units (a motor unit is a motor neuron and the muscle cells it innervates) to activate a muscle contraction resulting in generation of force. The

electrical activity of the motor neurons can be measured using electromyograms (EMG). EMG can be used to assess changes in both duration and amplitude of motor unit action potentials and relative activation of different muscles during a task cycle and thus determine if there is a decline in coordinated motor function with aging [72-75]. Aging shows loss of motor neurons which leads to decreased muscle activation and EMG has shown reductions in duration and amplitude of motor unit action potentials in older individuals [119].

The lateral step task requires loading and unloading the moving limb. Muscles acting at the ankle, knee and hip joints have to be activated to complete the task. Muscles responsible for ankle plantar flexion (tibialis anterior) and dorsiflexion (gastrocnemius) activate prior to the start of step down (during the loading phase) in preparation for the leg to move off the platform. During the loading phase, the gluteus maximus and the gluteus minimus have the important task of hip extension and hip abduction, which allows the leg to move away laterally and back from the platform. The gluts work in conjunction with activation of the knee flexors, and extensors, specifically vastus medialis and bicep femoris respectively. When comparing age groups, it was observed that there is difference in the timing of muscle activation. There did seem to be an anticipatory muscle activation prior to the beginning of the step task in the loading phase. The process occurs in opposite order when the leg is on the floor and preparing/performing the step up task.

In our study, the most noticeable difference in EMG while the two groups of adults performed the LS task was in the muscle burst duration during the task. Older individuals required more time to perform the step down or step up tasks but muscle

activation was held for different periods of time depending on the muscle, thereby signifying a difference in neural activation. It appears that older individuals require longer muscle activation time, depending on the muscle, in order to maintain stability, suggesting that aging is associated with decreased postural stability [80]. The gastrocnemius, an ankle plantarflexor, and tibialis anterior, an ankle dorsiflexor are known to play an important role in maintaining stability while standing [85]. In our study there were significant differences in TA and GAS muscle burst duration between the age groups. Muscles such as gluteus maximus, hip extension, and gluteus medius, hip abduction are also required for stability and are essential for walking [84] and significant differences in G_{MAX} and G_{MED} were muscle burst duration between the age groups. Due to the function of specific muscles such as the ankle and hip muscles in stabilization, it is interesting to find that the duration of activation of these muscles were almost all statistically different between age groups, supporting the fact that stability is an important factor affected by aging.

There was a clear difference in swing time duration between the age groups during performance of the step down and step up tasks. In respect to swing time, older individuals took longer to perform the task and were stabilized on one leg for longer time period than younger adults for the 4-inch step down and step up and 8-inch step down tasks. A general observation between swing time and muscle burst duration can be made from the collected data. Older Individuals took longer to perform the 4-inch step down and step up tasks but had shorter muscle burst durations for the leg muscles (BF, G_{MED} , G_{MAX}) yet longer ankle muscle (TA, GAS, TA2, GAS2) burst durations. Older individuals took longer to perform 8-inch step down and had longer leg (VM, BF, G_{MED} , G_{MAX}) and

ankle (TA, GAS, TA2, GAS2) muscle burst which is different from 8-inch step up where it took older individuals less time to perform the task and muscle durations for leg (BF) and ankle muscle (TA, GAS, TA2, GAS2) were still larger compared to younger individuals. While on the 4-inch step, older individuals are closer to the ground and activate leg muscles (VM, BF, G_{MED} , G_{MAX}) quicker but keep the ankle muscle (TA, GAS, TA2, GAS2) contracted to support them when landing. In 8-inch all muscle activation is longer in leg muscles (VM, BF, G_{MED} , G_{MAX}) and ankle muscles (TA, GAS, TA2, GAS2) signifying it takes the older adults longer to perform the task and muscle activation is longer to maintain the stability since they are farther from the ground. The increased time of step movement indicates a risk for fall or injury as was explained that older adults experience decreased speed in performing activities [88]. This supports accounts that there are age-related changes in motor function during daily activities [8, 12, 26, 46, 76, 82, 86-96].

5.1 Limitations

The two age groups were matched in height but not weight. This could have unforeseen deviations in the results. It has been shown that not only aging but also weight [120, 121] affects ADLs. Therefore, it is important to note that even though there was not a great difference in the mean weight between age groups it could very well have skewed the data.

During the step down task, participants were asked to put their hands crossed on their upper chest to prevent covering the lower extremity markers. This may have resulted in an alteration in the normal stepping down and stepping up procedure. It is also

a possibility that the attached markers and/or awareness of the existence of force plates under the stepping platform could have affected the participants' step task.

The recording of data occurred at any given time during the day. It is possible that individuals who came to the laboratory later in the day could be more fatigued than individuals who came in the early morning. Additionally, the placement of markers and electrodes on the skin is a long and tedious process, which could cause participant fatigue particularly if the bony landmark or muscle belly are not found quickly and proficiently. Thus the preparatory phase for this study could have also influenced the development of muscle fatigue.

The lower extremity has several muscles that contribute to the step task including hip adductor and abductor, and knee and ankle flexor and extensors. The data recorded in this thesis were chosen because they were the most active in the pilot study but it is known that other muscles like the quadriceps and hamstrings [75, 79, 80, 82, 121-123] are essential in the movement of the knee during the step task. These additional muscles could have provided additional or different results than those obtained in this thesis.

5.2 Conclusion

Decline in motor function and neural activation may lead to changes in muscle activity and kinematic control of joints and the loss of independence in older adults including physical inactivity and increase risk of falls or injury.

- Electromyography: Coordinated muscle movement patterns between age groups are not the same. Although there are similarities at the phases when muscles become active, the duration and moment of activation within

phases is not consistent between age groups.

- Muscle Burst Duration: Older individuals required more time to perform activities yet muscle activation varies depending on muscle and task signifying a difference in neural activation.
- Swing time: There was a difference in swing time duration between the age groups. Older individuals took longer to perform the task and were stabilized on one leg for longer time period than younger adults.
- Kinematic Measures: Qualitatively it can be observed that there is a 5° a joint angle excursion difference between younger and older adults while performing the step task: an increase in hip and knee angle in older adults, while a decrease in ankle angle. Peak hip flexion was noticeably higher but the average hip, knee, ankle between younger and older were not significantly different.

The data provides novel information on the activity of lower extremity muscle groups actively involved in performance of Step Down and Step Up tasks. The findings suggest age-related differences in motor function.

Chapter 6: FUTURE STUDIES

Future work should involve further investigation of age-related changes in different populations such as individuals with neuromuscular or degenerative diseases that may lead to injury or falls. Several features of biomechanics of joint control and muscle activation have been reported to be different between healthy adults and adults with neuromuscular disorders [124-126]. It has been shown that activities of daily living (ADLs) can be altered in older individuals because of physical disability associated with neuromuscular diseases such as knee osteoarthritis, hip fractures, and lower back pain [127]. Motor activity can be influenced by musculoskeletal pain and has been shown to produce increases/decreases in muscle activity, variations in posture and movement patterns [125]. Individuals suffering from neuromuscular diseases often experience pain, which leads to decreased muscle activation and limited velocity and range of motion (ROM) [124]. Several injuries and neuromuscular diseases occur at the knee joint of which anterior cruciate ligament (ACL) injuries [128-130], patellofemoral pain, and osteoarthritis [131-135] are among the most common. Muscle activity surrounding the hip joint such as hip abductors has been of interest in lower extremity muscles [136-139]. Muscle weakness in the hip abductors has been observed in patients with patellofemoral pain syndrome [25, 138], ACL injuries [140], and knee osteoarthritis [132] and can be an area of further evaluation and possible comparison with the data presented in this thesis.

Neuromuscular diseases such as ACL injuries occur most commonly by cutting, pivoting, or immediately landing from a jump [141]. It has also been noticed that gender specific risk factors such as anatomical, hormonal, or biomechanical can increase the risk

of these injuries [129]. From these risk factors, the biomechanical area has received much review [142-144]. There is two to eight time greater likelihood of an ACL injury in females than for males [128-130, 145]. Therefore, gender modulation provides another area of exploration when observing knee biomechanics in ADLs.

The long-term goal is to provide evidence-based support for clinical interventions such as novel balance strategies and rehabilitation techniques on how to prevent loading at the joints, which may lead to injury or falls. Therefore, it may be useful to look at swaying of the torso, center of gravity or center of pressure, which are known to fluctuate and lead to a higher probability of injury or falls. Clinical interventions may include physical therapy or exercises structured to help individuals with balance and muscle strengthening. Additionally, it would prove useful to gather data from studies conducted to test the proposed balance strategies and rehabilitation techniques.

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