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Foot Clearance for Different Methods of Stair Ascent

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ABSTRACT

One of the leading causes of injury in the elderly population is falls, which commonly take place on stairs. While previous studies have examined activity level and medication history on the ability of the elderly to climb stairs, and evaluated the biomechanics of climbing stairs while multitasking, no studies to date have evaluated the influence of different methods of climbing stairs. This study examined the mechanics of different methods of ascending stairs. Specifically, subjects ascended stairs using different techniques: 1) one foot on a step at a time, 2) stepping sideways, with both feet on a step before moving to the next, and 3) stepping sideways with both hands holding a railing. Foot clearance during each of these techniques was measured as well as the associated ground reaction forces. This study recruited six healthy subjects with a mean age of 21.9 ± 1.16 years old. Motion analysis and force data were collected during the three different techniques of stair ascent. It was found that there was no significant difference in minimum foot clearance values between the methods of stair ascent, although the time to clear a stair edge was shorter for the one on a step method compared with the other two methods. However, peak vertical ground reaction forces in the forwards condition were significantly greater than in the sideways with handrail condition. These results provide initial evidence that ascending a staircase sideways while using a handrail may be the safest way to negotiate stairs for the elderly.

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Chapter 1

Introduction

1.1 Introduction

Injuries due to falls account for 10-15% of all emergency department visits in the United States, as falls are the leading cause of unintentional injuries amongst adults (Gelbard et al., 2016). Falls that do not occur on ground level, such as on stairs, result in a greater burden of injury compared with falls that occur on ground level (Gelbard et al., 2016). Staircase falls are an indicator of functional decline in older adults, with those who are predisposed to falling exhibiting diminished balance and weakened muscle strength (Woolley et al., 1997). There are several changes in gait that come with the aging process, further placing older adults at risk of falling (Buchner et al., 1996). Gait speed is used as a primary indicator of gait function in older adults, as walking speed slows with aging due to prolonged loss of muscle strength and aerobic capacity (Buchner et al., 1996). Gait speed decreases by 1% each year after the age of 60 and this decline is correlated with higher risk of hospitalization, and with impairment of activities of daily living (Cruz-Jimenez, 2017). Diminished function of the musculoskeletal system that comes with aging can lead to postural changes (Cruz-Jimenez, 2017). These postural changes can further worsen the normal gait functioning of older adults, causing them to adopt unnatural walking patterns (Cruz-Jimenez, 2017).

The functioning of the lower extremity joints is also important to analyze when assessing gait function in older adults. Resultant joint moments of the lower extremity are typically smaller with aging, which is an indicator that older adults cannot produce as much muscular force from their leg musculature during walking (Jung et al., 2016). This also means older adults have less stability during challenging tasks, such as walking at faster speeds or negotiating stairs (Judge et al., 1994). The resultant joint moments of the lower extremity joints can be algebraically summed to provide a value known as the lower extremity support moment (Winter, 1980). The lower extremity support moment establishes a relationship between the hip, knee, and ankle, indicating that the three joints work together to support the body during gait (Winter, 1980). Environmentally challenging tasks can provide greater lower extremity support moment values which means that the tasks are more biomechanically demanding of the legs (Shih & Ho, 2023). The characteristic gait pattern that is produced by the lower extremity joints working together is especially important when determining toe clearance (Winter, 1992). Minimum toe clearance is another critical walking factor when considering fall prevention (Winter, 1992). Increased incidence of trips occurs when toe clearance is at its minimum, especially in the case of negotiating stairs (Ullauri et al., 2019).

Older adults are three times more likely to sustain severe injuries when falls occur on the stairs opposed to walking on level surfaces (Jacobs, 2016). Decline in stair negotiation ability in the elderly is an indicator of overall functional decline and stair negotiation is among the top five most difficult activities of daily living for older adults (Oh-Park et al., 2011; Startzell et al., 2000). Older adults operate closer to their maximum muscular capabilities during stair ascent and stair descent (Reeves et al., 2009; Reeves et al., 2008). Peak lower extremity support moment values are greater for older adults during stair negotiation when normalized with respect to their maximum lower extremity support moment capabilities (Reeves et al., 2009; Reeves et al., 2008). Other factors that hinder older adults' stair negotiation abilities include vision loss, postural changes, and overall stability (Foster et al., 2015; Bosse et al., 2012; Mian et al., 2007). It may be difficult for older adults to overcome age-related changes of stair negotiation function (Mian et al., 2007), thus it is important to assess the best adaptations for the elderly to employ during stair negotiation to decrease the biomechanical demand of their lower extremity joints.

1.2 Specific Aims

Previous studies by Mustafaoğlu et al. (2015) and Vallabhajosula et al. (2015) have evaluated the physical activity level on the ability of the elderly to ascend stairs, and the biomechanics of stair ascent while multitasking, respectively. However, there are no studies that evaluate different methods of stair ascent with respect to foot clearance of a stair. Foot clearance magnitude is a key determinant of the likelihood of a fall. This study will evaluate three different stair ascent conditions that are:

1) stair ascent with one foot after the other, one foot on a step at a time,
2) sideways stair ascent with both feet meeting on a step before ascending to the next, with both hands on the handrail,
3) sideways stair ascent with both feet meeting on a step before ascending to the next, without their hands on the handrail.

The aims of this study are:

1) for a group of subjects to measure the ground reaction forces across different conditions of stair ascent,
2) for a group of subjects to measure foot clearance as they ascend the stairs.

1.3 Hypotheses

Three hypotheses were tested. They were,

Hypothesis I – The peak vertical ground reaction force will be greater for the sideways ascent without handrail use compared with sideways ascent with handrail use.

Hypothesis II – the time for the foot to clear a step will be shortest for the more familiar task (stair ascent with one foot after the other) compared with the two sideways ascent methods.

Hypothesis III – the minimum foot clearance for a step will be lowest for the more familiar task (stair ascent with one foot after the other) compared with the two sideways ascent methods.

1.4 Study Overview

This study will determine the biomechanical effort of the lower extremity across three separate conditions of stair ascent. The study recruited six healthy young adults between the ages of 18 and 35 years old. Motion analysis and force data were collected during the three conditions of stair ascent. Kinematic data was collected to measure foot stair clearance values, which will be compared to determine which condition has the greatest risk of tripping via the foot potentially skimming the steps. Force data was normalized to subject body weight, allowing for the relative loads to be determined through comparison of normalized ground reaction forces between stair ascent conditions. In addition, kinematic data was collected to determine the ascent time for each of the conditions.

1.5 Overview of Chapters

The following chapters will go into further detail about current literature surrounding the areas of this study, as well as the methods, results, and discussion of the study itself. Chapter 2 is a literature review concerning falls in the elderly, gait changes due to aging and biomechanical variables that accompany these changes, and stair negotiation, including stair ascent and stair descent. Chapter 3 will provide information regarding the methods used in the study. Subsections that discuss the subjects, equipment, data collection and processing, and statistical methods of the study are included in this chapter. The results of the study will be presented in Chapter 4 and the discussion and implications of these results will be described in Chapter 5.

Chapter 2

Literature Review

2.1 Introduction

This chapter will review literature concerning falls, walking gait, and stair negotiation in the elderly. The second section will discuss incidences of falls in the elderly, as well as the causes of falls and the injuries that result. Specifically, falls on stairs will be discussed. The third section will assess studies on changes in gait function that occur with aging. Changes in gait, such as self-selected walking speed and gait patterns will be the primary focus. Within this section, four subsections will be dedicated to specific biomechanical components of gait that diminish with aging. These subsections highlight: the kinematics of gait, differences in resultant joint moments of the lower extremity between older and younger adults, the lower extremity support moment, and the effects of toe clearance on falls and the changes that occur with aging. The fourth section of this chapter will focus on stair negotiation differences between younger and older adults. Biomechanical causes of worsened stair negotiation function in older adults will be discussed in this section. These causes will be related to the subsections of section three. Stair ascent and stair descent will be individually analyzed in their own separate subsections.

2.2 Falls in the Elderly

The leading cause of unintentional injury in The United States amongst adults is falls (Gelbard et al., 2016). This is especially the case for those over the age of 65, with falls accounting for 62.9% of emergency department visits for older adults (Gelbard et al., 2016).

Injuries due to falls, therefore, account for 10-15% of all emergency department visits. These visits are not only a reflection of physical trauma due to falls, but they are also a major contributing factor to the cost of healthcare that comes from injury treatment; the annual cost of healthcare expenditure related to falls was estimated in 2016 to be around $20 billion in The United States (Gelbard et al., 2016). A growing elderly population in The United States has led to more falls and resulted in more injuries and greater healthcare costs. In addition, the elderly population is becoming more physically active compared to previous generations (Gelbard et al., 2016). Older adults are more frequently engaging in activities that have a greater physical demand compared with standing or walking (Gelbard et al., 2016). These activities include climbing stairs or ladders, and walking around public spaces with environmentally challenging surfaces or obstacles (Gelbard et al., 2016).

Gelbard et al. (2016) classifies falls that take place on level surface as ground-level falls (GLF) and falls that occur on elevated surfaces, such as stairs, as non-GLF. Gelbard et al. (2016) reviewed the fall records of patients admitted to University of Southern California Medical Center between January 2009 and December 2010. Of the 3,885 patients, 86% were admitted due to GLF and 14% due to non-GLF. Those who had non-GLF had greater burden of injury compared to the GLF group, with 50% of their falls occurring on the stairs. Older adults who are at greater risk of falling tend to spend more time at home, which is reflected by the data that majority of falls (82%) occurred in residential locations (Gelbard et al., 2016).

Falls on stairs are an indicator of functional performance issues in the elderly (Woolley et al., 1997). Performance-oriented falls were examined by Woolley et al. (1997) who conducted a study that analyzed functional activity performance between fallers and non-fallers. The functional activities included a static balance task and dynamic tasks, which were ground-level walking and stair descent. The subjects classified as fallers were found to have significantly reduced balance compared to the non-fallers, allowing them to be more easily perturbed when put under challenging conditions. The fallers also showed greater difficulty walking and completing stair descent compared with the non-fallers (Woolley et al., 1997). The fallers modified their stair descent by having double foot contacts on each step, which limited their single support time on each step (Woolley et al., 1997). This allowed the fallers to have less time with their center of mass outside their base of support when descending the steps, a cause of falls on the stairs. There was a greater difference in performances between groups during the dynamic tasks compared with the static task. Their isometric quadricep strength was found to be similar between the fallers and non-fallers, which had little effect on their static task performances. However, a difference in quadricep strength became present during challenging tasks, such as stair descent, with the non-fallers exhibiting greater strength (Woolley et al., 1997).

Jacobs (2016) analyzed the typical causes for stairway falls. He noted that falls on the stairs often coincide with having distracted attention. People climbing stairs are often multitasking through carrying objects, talking on the phone, or changing handrail use. Of falls that occur on stairs, 41% happen while partaking in these behaviors, and 91% of younger adults and 57% of older adults report that they find themselves multitasking when negotiating stairs. Jacobs (2016) states that it is important to have a sound strategy for negotiating stairs before partaking in multitasking or risky behaviors. The author called for more studies that analyze the sensorimotor mechanisms involved in negotiating stairs. He also suggested examining topics such as age-related physical impairments and the best way to negotiate stairs in order to overcome these impairments (Jacobs, 2016).

2.3 Gait Changes due to Aging

Gait speed is one of the major indicators of gait function and mobility performance in older adults (Buchner et al., 1996). Gait speed slows in old age, and is associated with fitness, physical health status, and/or cognitive and depressive symptoms of older adults (Buchner et al., 1996). A study by Buchner et al. (1996) assessed the individual influences of physical and mental health on self-selected gait speed to determine which factor was the greatest contributor to gait speed decline. The study was comprised of 109 older adults between 68 and 85 years old. The subjects had below average knee extensor strength compared with older adults of similar heights and masses. One group underwent an exercise intervention consisting of endurance and resistance training for six months, while the control group had no intervention. The exercise group was found to have a 2% increase in gait speed at the end of their intervention, which the authors indicated was not a large enough change to resemble a clinically meaningful improvement (Buchner et al., 1996). Through the authors' research, they found that prolonged loss of strength and aerobic capacity in older adults leads to a nonlinear reduction in gait speed with respect to age (Buchner et al., 1996). While there was no intervention to determine the influence of depression on gait speed, the authors found a strong correlation between slower gait speed with depressive symptoms and worsened health status. The authors conclude that the physiological capacity of older adults determines maximum performance of gait speed, and that psychosocial factors, such as depression, modulate a person's given performance within their physiological range (Buchner et al., 1996).

Overall gait and mobility are altered in the elderly due to changes in posture and typical walking movement patterns (Cruz-Jimenez, 2017). Gait speed is impacted the most, decreasing by 1% each year after the age of 60. Decline in gait speed is related to a higher risk of mortality, hospitalization, and impairment in activities of daily living (Cruz-Jimenez, 2017). Other gait disorders are prevalent in older adults, such as shuffling, cautious walking, and walking with a broad base of support. Of adults over the age of 70, 35% have walking disorders in addition to slowed gait speed (Cruz-Jimenez, 2017).

Postural changes accelerate in older adults after the age of 60 years old, contributing to gait changes (Cruz-Jimenez, 2017). Change in posture naturally changes the position of whole-body center of mass. This in turn changes the position of the center of mass in relation to the person's base of support, therefore the individual must compensate by adopting an atypical gait pattern to avoid falling due to the new center of mass position. Atypical gait patterns increase the risk of falls and walking disabilities, as well as diminishing quality of life. Fear of falling is also a valid concern in older adults, which can cause people to further modify their gait patterns and speed in a more atypical fashion (Cruz-Jimenez, 2017)

Another physiological aspect of aging that changes gait patterns and speed is reduced muscle strength (Cruz-Jimenez, 2017). Weakened muscles lead to limited range of motion of the joints they cross. Greater mechanical work expenditures are employed to compensate for this limited range of motion. Not only does this lead to an unnatural gait pattern, but it also requires more energy expenditure. The typical daily energy cost due to physical activity is 15-30% of all energy expenditure. This percentage increases when other muscles are needed to produce movement due to weakened muscles in other parts of the body (Cruz-Jimenez, 2017).

Jayakody et al. (2021) references the theory that accelerated self-selected gait speed decline precedes cognitive decline and can even be an indicator of cognitive decline to come. Jayakody et al. (2021) determined the rates of gait speed decline between single-task walking (STW) and walking while tasking (WWT) conditions. Their study was a longitudinal study over

12 years, with the mean age of subjects across the study being 75 years old. Once a year, the subjects would complete either a STW or WWT task with their gait speeds measured each time. The STW group simply had to walk in a straight line across an 8.5-meter walkway and the WWT did the same while reciting alternate letters of the alphabet (Jayakody et al., 2021). The authors found that STW-speed declines at a greater rate with aging compared with WWT-speed (Jayakody et al., 2021). STW-speed was also found to start rapidly declining before the age of 73, along with WWT-speed. The WWT group was observed to adopt slower walking speeds due to the cognitive demands of their task, but these speeds and cognitive performances remained at a consistent level across the 12-year span. The STW group, however, walked at much quicker speeds at the beginning of the study than at the end. While the STW group had a greater margin to decrease their gait speed compared to the WWT group, each subject had a similar trend of speed decline with aging. The results of this study support the theory that self-selected gait speed and function declines because it is a task that requires increased cognitive engagement (Jayakody et al., 2021).

2.3.1 Kinematics

Speed is not the only component of gait that changes in the elderly. The kinematics of gait and lower extremity kinetics are important variables to consider when analyzing gait in older adults. Hageman & Blanke (1986) conducted one of the first studies that provided direct comparison between older and younger adults in terms of gait variables. The authors recruited 13 younger women between the ages of 20 and 35 years old, and 13 women 60 years old and above. The subjects were matched for height, mass, leg length, and body fat percentage to account for any potential confounding variables. High-speed stereo-photogrammetry was used to record the subjects' gait patterns as the subjects completed a 14-meter walk at a normal pace (Hageman & Blanke, 1986). The younger group was found to have longer step and stride lengths, as well as increased ankle range of motion (Hageman & Blanke, 1986). Younger women were measured to have an ankle range of motion of 31° and older women's was measured to be 24°. The range of motion at the hip and knee had similar values between the groups, indicating that the extrinsic and intrinsic foot muscles are impacted the most by aging (Hageman & Blanke, 1986).

A study by Protopapadaki et al. (2007) analyzed the biomechanics of stair negotiation in healthy adults. At the time of their publication, most studies of gait kinematics had focused on level walking, with few studies analyzing the biomechanics of stair negotiation. The authors recruited 33 healthy adults between the ages of 18 and 39 years old to complete trials of stair ascent and descent. Motion tracking markers were placed on the lower extremities of the subjects to measure sagittal plane movements of the hip, knee, and ankle. Stair ascent proved to be the more biomechanically demanding task compared with stair descent. This was measured by the joint moments and ranges of motion produced at the lower extremity joints. Greater hip and knee flexion and ankle dorsiflexion angles were measured during stair ascent compared with ground ground-level gait, with maximum lower extremity joint moments occurring during stair ascent (Protopapadaki et al., 2007).

The results of Protopapadaki et al. (2007) relate to the findings of Hageman & Blanke (1986) with respect to ankle range of motion. As previously mentioned, ankle range of motion decreases the most with age, while hip and knee range of motion remain relatively constant (Hageman & Blanke, 1986). With stair negotiation being a common everyday task for older adults, the range of motion in their lower extremity joints is a vital component of assessing their ability to ascend and descend stairs. Older adults experience age-related reduction in ankle range of motion, and with the study by Protopapadaki et al. (2007) concluding the ankle has a large range of motion during stair ascent, older adults may be unable to meet the necessary ankle range of motion requirements to effectively ascend stairs.

Joint range of motion is an age-related kinematic change that affects gait, which is due to the weakening of the lower extremity muscles that occurs with aging (Liang et al., 2022). Compensation strategies with altered muscle recruitment often occur as a result of this weakening, further altering gait patterns in older adults. These are age-related changes in gait. However, there are kinematic gait components that remain unchanged in older adults. If these non-age-related features were to be altered, then normal gait functioning would be severely affected. A study by Liang et al. (2022) sought out to determine which kinematic gait components are non-age-related by comparing eight healthy elderly subjects and twelve healthy young adults during barefoot walking. Joint moments of the hip, knee, and ankle were measured to be identical between age groups, regardless of differences in range of motion and muscular changes. These results allowed the authors to conclude that non-age-related features of gait kinematics are the joint moments of the lower extremity joints (Liang et al., 2022).

2.3.2 Resultant Joint Moments

Resultant joint moments are another kinetic variable of interest when analyzing gait. They reflect the net effect of the muscles crossing a joint. Judge et al. (1994) conducted a study which examined the resultant joint moments of the lower extremity joints during normal walking, and high-speed walking. The study employed older subjects, with a mean age of 79 years old, and younger subjects, with a mean age of 26 years old. While the primary goal of the study was to determine the greatest power-generating joint during walking, the authors also examined joint moment data (Judge et al., 1994). Joint moments were calculated by combining segmental kinematics, estimates of body segmental intertial properties, and ground reaction force data collected from force plates (Judge et al., 1994). It was found that the greatest changes in kinematic and kinetic measures during high-speed walking occurred at the hip for older adults. The hip flexor moment increased by 25% and hip extension moment increased by 44% for the subjects when walking at high speeds compared with their normal pace. There was little change in the ankle and knee moments between walking speeds. Through their analyses, the authors were able to conclude that the hip has the greatest change between normal and high-speed walking for joint moments (Judge et al., 1994).

Direct comparison of resultant joint moments between younger and older adults during walking has been analyzed by Winter et al. (1990). The young group and elderly groups were asked to walk at a comfortable pace while the researchers collected motion analysis and force plate data. The resultant joint moments at the hip and the knee were determined to act in opposite directions, with the hip producing a positive moment at the same instance the knee produces a negative moment. This trade-off is referred to as the index of dynamic balance, which is a key determinant of an individual's ability to balance while walking. There was a slightly reduced index of dynamic balance in the older adults during normal walking, suggesting that there is an age-related deterioration of the balance control system during gait. Despite differences in the index of dynamic balance between age groups, the overall pattern and cadence of resultant joint moments remained the same (Winter et al., 1990).

The results from Winter et al. (1990) support the findings of Judge et al. (1994) that the hip is an especially vital joint for walking. The hips are responsible for stabilizing the weight of the HAT (head, arms, trunk) while standing and walking. Resultant joint moment time profiles of the hips had greater variance than any other joints during the stance phase of gait. This reflects the continuously changing balancing act that occurs during gait, for which the hips need to account for (Winter et al., 1990).

As previously discussed, gait speed and step length are major indicators of motor ability during aging. Another important gait phase to analyze is gait termination (Jung et al., 2016). Gait termination alters gait patterns and therefore potentially threatens the elderly's stability as a result. This is due to the increased braking force required of the leg muscles during the final supporting phase of gait. This is an issue for those with reduced muscle strength, which is an occurring phenomenon in the elderly population. A study by Jung et al. (2016) analyzed the resultant joint moments of the lower extremity joints during gait termination between groups of 10 younger adults (mean age of 45 years old) and 10 older adults (mean age of 73 years old). The plantar flexion moments of the ankle, and the extension moment of the knee were much smaller in the older adults. The resultant joint moments at the knee are also responsible for stopping the body in a rapid, effective, and safe manner (Jung et al., 2016). Weakened muscles of the ankles and knees result in the hips needing to work harder in order to support and move the body during gait. This idea was supported by the finding of the elderly group having a greater hip extension moment compared with the younger group. All three joints of the lower extremity work together, and when one or two are dysfunctional, the remaining joint(s) must compensate for the deficit (Jung et al., 2016).

2.3.3 Lower Extremity Support Moment

Resultant joint moments of the hip, knee, and ankle are critical components of gait analysis. These joint moments can be summed together to provide the lower extremity support moment (Winter, 1980). With knee extension moment acting in the counterclockwise (positive) direction and hip and ankle extension acting in the clockwise (negative) direction, the support moment can be calculated with Ms = Mk – Ma – Mh, where Ms represents the support moment, with Mk, Ma, and Mh representing the moments at the knee, ankle, and hip, respectively. Winter (1980) explains how collapse of the legs occurs with simultaneous hip, knee, and ankle flexion, so the extension moments of these three joints are summed to provide the lower extremity support. It is important that the lower extremity support moment is calculated and analyzed during the stance phase of gait (Winter, 1980). This is because the function of the lower limb during stance is to resist resist collapse and provide extension for appropriate push-off (Winter, 1980).

Winter (1980) compared the support moment between 12 subjects during normal walking via segmental kinematics and force plate data. Support moment data were analyzed for the duration of the stance phase. Each subject had a similar support moment profile, regardless of differences in individual resultant joint moments. For example, a 73-year-old subject with knee replacement had a negative knee moment, indicating that the knee was flexing and therefore collapsing during their stance phase. To compensate for this, their hip and ankle extension moments were much greater than normal. These compensations allowed for the subject to maintain a typical support moment pattern. Based on these results, it can be concluded that walking control involves a total lower limb pattern rather than individual joint patterns (Winter, 1980).

A limitation of Winter's support moment model is that there is no discrimination in which parts of the joint moments contribute to support versus forward progression generation (Kepple et al., 1996). The lower extremity is responsible for generating two types of acceleration; horizontal and vertical. Horizontal acceleration allows for forward progression of the body during gait and vertical acceleration resists gravity, providing support. A study conducted by Kepple et al. (1996) consisted of five subjects between the ages of 25 and 40 years old who were asked to walk at a normal pace. Motion analysis and force data were collected to calculate resultant joint moments and lower extremity support moments (Kepple et al., 1996). Each major joint of the lower extremity showed a contribution to bodily support, while horizontal acceleration was primarily due to ankle plantar flexors. This data shows that Winter's support moment model can be used to understand vertical acceleration/support, but not horizontal acceleration/forward progression (Kepple et al., 1996).

Lower extremity support moment is commonly considered during normal gait tasks, such as walking and running on level ground (Shih & Ho, 2023). There is less literature on the lower extremity support moment during more environmentally challenging tasks. Shih & Ho (2023) sought out to compare lower extremity support moments between upslope, level slope, and down slope running. The authors recruited 20 recreational runners between the ages of 21 and 40 years old to run on a treadmill set to a 6° upslope and down slope gradients, as well as a 0° level gradient. The subjects ran for three minutes under each condition at a relatively comfortable jogging pace of 2.3 m/s (Shih & Ho, 2023). Values of the lower extremity support moment varied across the three conditions (Shih & Ho, 2023). Down slope running had the lowest calculated lower extremity support moment value while upslope running had the greatest, indicating that upslope running has the greatest biomechanical demand of the lower extremities.

The authors noted that it is important to consider the slopes for runners based on possible musculoskeletal conditions, that may occur due to aging. These results indicate that different environmental conditions require different lower extremity support moments and biomechanical demand. It is important to further analyze these demands in different environmental settings (Shih & Ho, 2023).

2.3.4 Toe Clearance

With falls in the elderly being a major health concern in the United States, fall prevention factors should be understood. A critical walking factor for fall prevention is minimum toe clearance (Winter, 1992). Minimum toe clearance (MTC) occurs during mid-swing phase of the gait cycle when the ankle is plantar flexed with the toe pointing towards the ground. At the instant of MTC, the body is at its greatest velocity during the gait cycle. The body's center of mass is also anterior to its base of support at this instance. This combination of forward momentum and center of mass positioning makes it nearly impossible for the support limb to recover balance if a trip were to occur during the swing phase. The only possible safe recovery technique would be appropriate placement and action of the swing limb itself, which can be a difficult task for older adults (Winter, 1992).

As previously mentioned, the joints of the lower extremity work together to produce rhythmic gait patterns. This remains true in the case of toe clearance, with each lower extremity joint playing a role in the distance the toes are from the ground (Winter, 1992). To determine the roles that lower extremity joints and their actions play in toe clearance, Winter (1992) analyzed normal gait in 11 young adults. The data from this study revealed that MTC occurs during the mid-swing phase of the gait cycle, with the subjects having an average MTC of 1.29 cm. Maximum toe clearance was recorded just before heel contact, with an average of 15 cm. Each joint of the stance and swing limbs (hip, knee, and ankle) were found to cause about 0.5 cm of toe clearance variability, revealing that small angular changes of these joints lead to large changes in toe clearance measurements. These findings reinforce Winter's support moment model (1980), with certain subjects who had below-knee problems having increased knee flexion and hip abduction in their support limb to compensate for ankle deficits (Winter, 1992).

To further assess lower extremity joint involvement in MTC, Ullauri et al. (2019) conducted a study that simulated age-related muscle weakness in the legs. Muscle Activity Restriction Taping Technique (MARTT) is an aging simulation technique that limits joint range of motion by placing tape on the transversal area of muscle bellies, limiting the length change capacity of the muscle. Ullauri et al. (2019) recruited 10 male subjects with an average age of 22 years old to be randomly assigned to two groups. The first group had MARTT applied to their shank to restrict their anterior tibialis and gastrocnemius activity. The second group had MARTT applied to their shank and thigh, restricting their rectus femoris and vastus lateralis activity as well. The subjects were tasked with six walking trials at slower and normal paces (Ullauri et al., 2019). Greater MTC reduction was seen across both groups when walking at normal speed compared with slower speed walking (Ullauri et al., 2019). The shank and thigh group saw the greatest reduction in MTC, with hip flexion and ankle dorsiflexion activity restricted. This restriction led to the subjects employing greater knee flexion than average. Their reduced MTC resulted in their toes contacting the ground more frequently because their toes were unable to be in the air for long during the gait cycle. Their toe ground contacts were five times as frequent as those for normal gait patterns. The shank group had a less profound change in performance, with only their ankle dorsiflexion activity being restricted. This resulted in less reduction in MTC compared to the shank and thigh group, and twice the frequency of toe ground contacts compared with normal gait patterns (Ullauri et al., 2019). Both groups exhibited MTC values similar to older adults, indicating that the results from this study can be applied to the elderly (Ullauri et al., 2019). Toe ground contact is more frequent in the elderly due to reduced MTC, which is a direct result of weakened muscle strength (Ullauri et al., 2019). Variability of MTC values is also limited in the elderly due to their diminished musculoskeletal activity. This does not permit for easy adjustment of toe clearance when navigating more challenging environments, such as uneven terrain, stairs, and surfaces with obstacles (Ullauri et al., 2019).

There is an increased risk and incidence of trips when toe clearance is at its minimum, with obstacles on walking surfaces causing additional issues due to the demands of increased toe clearance to overcome them (Schulz, 2011). Ground height variations and visibility of them alter MTC, and Schulz (2011) sought to determine which joints are responsible for these changes. Subjects walked at three speeds (slow, normal, fast) in three separate conditions. These conditions were no obstacles, visible obstacles (white obstacles on a black surface), and hidden obstacles (black on black). The obstacles were 10 cm long and 13 mm high (Schulz, 2011). MTC increased with gait speed across all three surfaces (Schulz, 2011). This is a natural adaptation of the body to reduce trip risk during more hazardous gait conditions, such as walking at increased speeds. The alterations of floor surfaces resulted in significant effects on MTC and joint kinematics, regardless of gait speed. There was an increase in ankle dorsiflexion, and hip and knee flexion during the visible obstacle conditions. These adjustments resulted in MTC doubling compared with normal walking surfaces. Hidden obstacle conditions magnified these adaptations even more. During the normal walking surface, subjects had an average of 11 mm MTC. The subjects would not have been able to clear the 13 mm obstacle heights had they not been made aware of the obstacles' presence. The results of this study show that trips and potential injury can be caused when people are not aware of challenges in their walking environment because of their normal MTC (Schulz, 2011).

2.4 Negotiating Stairs

The most common location of falls is on stairs, with 30% of all falls occurring on the stairs (Jacobs, 2016). These falls result in a disproportionate risk of death or severe injury compared to falls that occur on level ground. Severe injuries due to falls on the stairs include traumatic brain injury and hip fracture (Jacobs, 2016). Older adults are three times more likely to sustain traumatic brain injury when falls occur on the stairs as opposed to normal walking (Jacobs, 2016). There are several reasons as to why falls on stairs are more frequent than falls on level ground, these will be outlined in the following paragraphs.

Stair use generates greater coefficients of friction compared to level-ground walking, which are variable depending on the individual or the staircase. These values can reach a maximum of 0.7, increasing the risk of falls due to the high surface-friction demands. Older adults also have smaller and less variable toe clearance values, which therefore poses a challenge for them when trying to clear stairs during ascent or descent (Jacobs, 2016). Negotiating stairs causes the body's center of mass to be horizontally displaced more frequently than during normal walking, and older adults have larger and faster displacement of their center of mass (Jacobs, 2016). Combining the physical demands of stairs with older adults' predisposition to falls leads to further complications when negotiating stairs. These physical demands can be reduced with several methods such as slower walking, contacting each step with both feet, and maintaining contact with a handrail (Jacobs, 2016).

Other factors of aging that affect decline in stair negotiation function include weakened muscular function, joint disease and surgery, and somatosensory issues (Startzell et al., 2000). Visual factors also play an important role in stair negotiation, with more than half of individuals involved in stair falls reporting that they did not look at the stairs when approaching them (Startzell et al., 2000). Older adults often experience aging complications that affect their ability to negotiate stairs without realizing this declined functioning. Having unawareness of a functional decline combined with not putting thought into negotiating stairs is what often leads to falls and injuries for older adults. Physical therapy and strength training can be utilized to maintain muscular function during aging. They have proven to be effective methods of reintroducing stair walking after disease or accident, as well as improving overall stair negotiation function (Startzell et al., 2000).

Stair negotiation is among the top five most difficult activities of daily living (ADL) for adults over the age of 60 years old (Startzell et al., 2000). When older adults are faced with difficult ADL, they tend to engage in the activities less often (Startzell et al., 2000). However, the older and younger adult populations use the stairs the same amount during their everyday lives (Startzell et al., 2000). A study by Oh-Park et al. (2011) analyzed the relationship between stair negotiation and functional decline of other ADL. The authors recruited 513 residents of a retirement community with a mean age of 81 years old. The residents' ADL were assessed every two to three months via a number scale asking how difficult certain tasks were and how often the residents completed the tasks. Functional decline was defined as a decreased increment of one point or more in any of the ADL (Oh-Park et al., 2011). Stair negotiation performance was determined by timing the residents during stair ascent and descent of three steps (Oh-Park et al., 2011). The authors predicted that stair negotiation times would increase with age because of the weakened knee extensors of older adults. Younger adults employ 54% of their maximum knee extensor moment during stair ascent, while older adults use 78% of their capacity. Stair descent requires the greatest effort of older adults, who use 88% of their maximum knee extensor moment compared to younger adults' 42%. Stair ascent and descent times were greater for older subjects as well. Difficulty in stair negotiation was directly related to difficulty with other ADL, with the stair negotiation times increasing as other ADL scores decreased. Older adults often exhibited diminished stair negotiation function before other ADL were negatively impacted. This leads to the conclusion that stair negotiation difficulty is a predictive factor of functional decline in older adults (Oh-Park et al., 2011).

2.4.1 Stair Ascent

Due to the muscular weakness that comes with aging, older adults tend to operate closer to their maximum muscular capabilities compared with younger adults when ascending stairs (Reeves et al., 2009). Stair ascent requires primarily concentric strength of the knee extensors, and with concentric strength declining more than eccentric strength during aging, stair ascent can be a greater challenge for older adults (Reeves et al., 2009). A study by Reeves et al. (2009) identified resultant joint moments and range of motion requirements for older and younger adults during stair ascent. Through their study, they were able to establish the demands of this task relative to the age groups' maximum capabilities (Reeves et al., 2009). Knee joint moments peaked right at the beginning of single leg support phase during stair ascent, which is when one foot remains on a step while the other one moves to the next (Reeves et al., 2009). The older adults' knee joint moments peaked at 75% of their maximum capacity while the younger adults peaked at 53%. Even though the older adults used a greater capacity of their peak knee joint moments, their recorded joint moment values were less than the younger adults'. Generating lower peak knee joint moments allowed for the elderly to maintain a knee joint moment reserve, which could serve as a safety mechanism in the event of balance loss (Reeves et al., 2009). Both the older and younger adults produced peak ankle joint moments that were at 93% of their maximum capacity (Reeves et al., 2009). This indicates that the ankle is a critical joint for stair ascent. Similar to the knee joint moments, the older adults' peak ankle joint moment values were less compared with the younger adults. The age groups experienced the same normalized ground reaction forces during stair ascent, so a lower ankle joint moment can be attributed to a smaller moment arm of the force relative to the ankle joint center. A smaller moment arm about the ankle is seen in the elderly because their center of pressure is positioned closer to their ankle joint center. There is a smaller separation between center of pressure and center of mass during stair ascent for older adults, which is a cautious strategy to maintain postural stability. Another alternative strategy seen in the elderly is putting more relative effort into their ankle activity compared to their knee (Reeves et al., 2009). These moment patterns were reflected in the EMG signals used to measure lower extremity muscle activity during stair ascent (Reeves et al., 2009).

Vision loss is another aspect of aging that older adults need to work around when ascending stairs (Foster et al., 2015). Increasing toe clearance is a common strategy used when stepping onto raised surfaces for those with visual impairments. This is a safety mechanism used to limit the risk of trips and falls for the elderly. Foster et al. (2015) conducted a study to determine whether increased toe clearance could be induced by changing the visual appearance of stairs rather than their physical height. The authors recruited 25 older adults with a mean age of 69 years old to ascend a three-step staircase in different horizontal-vertical (HV) illusion conditions. Toe clearance was recorded for a condition with no HV illusion component, and four HV illusion conditions with different black-and-white stripe patterns across them. An increase in toe clearance was observed across all four HV illusion conditions, with a 17.5% increase in each condition compared with the normal visual condition. Despite differences in toe clearance, single-limb support duration and stair ascent duration were the same across all conditions. This indicates that an increase in toe clearance increases safety during stair ascent and does not have any influenes on other key gait parameters. Not having a large enough toe clearance is a common reason why older adults trip while ascending stairs, and including HV illusions in staircases can be beneficial for older adults. This is because the HV illusions provide an extra margin of safety without hindering the adults' ability to ascend stairs (Foster et al., 2015).

Leg length inequalities (LLI) are another condition that can affect how older adults ascend stairs (Siebers et al., 2022). LLI are a common orthopedic condition that can have a great impact on older adults, such as gait issues and general pain (Siebers et al., 2022). Siebers et al. (2022) simulated the effect of LLI on stair ascent by using different shoe heights between legs. Subjects in their study wore a regular shoe on one foot and a shoe with a platform on the other, ranging from one to three centimeters in additional leg length. LLI had a significant impact on all major lower extremity joints, with hip and knee flexion and ankle plantar and dorsiflexion being affected. During stair ascent, the subjects' longer legs were functionally shortened due to increased hip and knee flexion. The shorter leg was lengthened through decreased dorsiflexion and increased plantar flexion. These natural compensation patterns can lead to further functional and orthopedic issues later in life, resulting in another factor that can impact the elderly's ability to ascend stairs (Siebers et al., 2022).

2.4.2 Stair Descent

Of the falls that occur on stairs, about 75% take place during stair descent (Reeves et al., 2008). Ground reaction forces are greater during stair descent than they are during level-surface walking, indicating that stair descent is a physically demanding task. Greater ground reaction forces suggests that there can be greater joint moment requirements. Reeves et al. (2008) conducted a study to determine baseline values of lower extremity joint moments and ranges of motion in older and younger adults. Similar to the Reeves et al. (2009) stair ascent study, the authors' goal was to establish kinematic demands relative to the maximal capabilities for both age groups during stair descent. The study recruited 15 older adults and 17 younger adults for the simple task of stair descent while holding onto handrails. Knee joint moment values were similar between groups, but the older adults functioned at a higher percentage when this data was normalized to their maximal eccentric knee extensor moment. The range of motion values were similar between age groups at both the knee and ankle. These values were also greater for the older adults when normalized to their maximal range of motion capacities (Reeves et al., 2008). In contrast, the peak ankle joint moment values were greater for the younger adults compared with those of the older adults (Reeves et al., 2008). This indicates a different distribution of joint moments in the older adults' lower extremity joints during stair descent compared with the younger adults'. If the elderly generated similar ankle joint moments to the younger adults, they would be at about 90% of the elderly's maximal capacity. Stair descent would become a much more dangerous task if this were the case, disposing the elderly to a greater risk of falling if they were unable to meet their ankle joint moment demands. The difference between ankle joint moment values can be attributed to the moment arm about the ankle. Both age groups experienced the same ground reaction forces during stair descent, meaning that the elderly needed to have a smaller moment arm to result in a smaller ankle joint moment. There was less displacement of the elderly's center of pressure from their ankle joint center compared with the younger adults, providing a smaller moment arm (Reeves et al., 2009).

Bosse et al. (2012) further elaborated on differences in center of pressure, center of mass, and base of support during stair descent between older and younger adults. Older adults descend stairs with altered control strategies to reduce the demand on their knee extensors. One of these strategies includes spending a prolonged time looking at the next step before descending to it. This shifted gaze requires a flexed trunk posture, which results in an anterior shift of whole-body center of mass. A shift in center of mass creates a separation from the base of support and causes greater difficulty with postural control. This separation between the center of mass and base of support is what the authors refer to as dynamic stability. During normal walking, the center of mass and base of support can both be altered to adjust dynamic stability. However, descending stairs requires the feet to be in a specific position to fit on the steps, providing a fixed base of support. This means that dynamic stability during stair descent depends on the position of whole-body center of mass (Bosse et al., 2012).

Through a study by Bosse et al. (2012), older adults were found to have greater anterior center of mass velocity during stair descent. This led to a more displaced center of mass and therefore a lower margin of dynamic stability by 33%. Older adults have less control of their body while stepping down, indicated by lower joint moments of their leading leg compared with those of younger adults. This requires more effort from the support leg, which is an issue for older adults because of their decreased muscle strength. Lack of control is a direct cause of greater anterior velocity and displacement of center of mass and therefore less dynamic stability. The diminished margin of dynamic stability seen in older adults during stair descent predisposes them to a greater risk of falling (Bosse et al., 2012).

Falling during stair descent results in injury three times more frequently than falling while ascending stairs (Mian, 2007). Another factor that puts older adults at a greater risk of falling while descending stairs is the demands placed on knee strength and range of motion. Greater knee flexion is needed during stair descent compared to normal walking in order to lower the body to the next step. A study conducted by Mian et al. (2007) showed that older adults had a smaller peak knee flexion angle compared with younger adults while descending stairs. This range of motion reduction led to a slower time of stair descent and increased hip-pelvis motion in the frontal plane. Greater frontal plane motion was related to greater lower extremity instability in older adults, further increasing the time it took to descend stairs. Another contributing factor to increased frontal plane motion is the weakened hip abductor strength that comes with aging. This results in greater hip adduction action and motion. Mian et al. (2007) also placed some of their elderly subjects in a 12-month exercise program to see if there was a reduction in stair descent times. There was little-to-no difference in range of motion and muscular function between the control and exercise groups, with no increase in speed and reductions in stair descent time as a result. These results indicate that it may be difficult for older adults to overcome the age-related challenges of stair descent (Mian et al., 2007).

2.5 Summary

This chapter explored the literature regarding falls, walking gait, and stair negotiation in older adults. The second section examined instances of falls in the elderly, along with the underlying causes and resulting injuries. The third section evaluated research on age-related changes in gait function, with a primary focus on alterations in gait such as self-selected walking speed and gait patterns. This section comprised of four subsections, which concentrated on specific biomechanical aspects of gait that change with age. These subsections covered the kinematics of gait, variations in resultant joint moments of the lower extremity between older and younger adults, the lower extremity support moment, the impacts of toe clearance on falls and the associated changes with aging. The fourth section of this chapter centered on differences in stair negotiation between younger and older adults. The biomechanical factors outlined in the previous four subsections highlight compromised stair negotiation function in older adults.

Chapter 3

Methods

3.1 Introduction

This chapter will cover the methodology used in the study. The second section will outline how the subjects are recruited, the inclusion and exclusion criteria for their participation, and their basic demographic information. The third section will explain the laboratory equipment that will be used for the study and includes details of the instrumented staircase. Data collection and processing information will be discussed in the fourth section, including the study protocol explaining the specific stair ascent conditions the subjects will complete. The fifth section of this chapter will describe the statistical analyses used to interpret and compare the data.

3.2 Subjects

Subjects of the study were recruited through word-of-mouth. Each of these subjects met the inclusion criteria for the study and therefore participated in this study. The inclusion criteria for the study were:

- Between the ages of 18 and 35 years old
- No history of lower extremity surgeries
- No lower extremity injuries within the past six weeks.
- No diagnosed neurological disorders.

The subjects each came into the laboratory for a single visit. Their visit began with reviewing and signing a consent form approved by the Institutional Review Board (Appendix A).

Height, mass, age, and leg dominance were recorded after the subjects signed the consent form. For the subjects who did not know their leg dominance, it was tested as outlined by van Melick et al. (2017). It included alternating between standing on one leg, alternating between jumping on one leg, and kicking a ball with both legs. These methods were selected because of the high agreement between observed performance and the subjects' self-reported dominant leg (van Melick et al., 2017). Performance of both legs was assessed for the subjects during the tasks, with the leg exhibiting the greatest natural functioning to be considered the dominant leg.

Six subjects were recruited for this study, their details are presented in Table 3.1.

Table 3.1: The demographics of the subjects in the study, mean and (SD).

Height (m)	**Mass (kg)**	**Age (years)**	**Right Leg Dominant**
1.74 (0.09)	71.7 (15.5)	21.9 (1.16)	n = 4

3.3 Equipment

The instrumented staircase used in this study consisted of seven steps with two force plates at stair four and stair six (Figure 3.1). Each step was made of concrete and had a rise of 18 centimeters and a run of 28 centimeters. Kistler force plates (9286B model) were used in the staircase to measure ground reaction forces in the x, y, and z direction. An eight camera Motion Analysis Lab system was used to measure the locations of key body landmarks, predominantly, on the lower limb segments during stair negotiation.

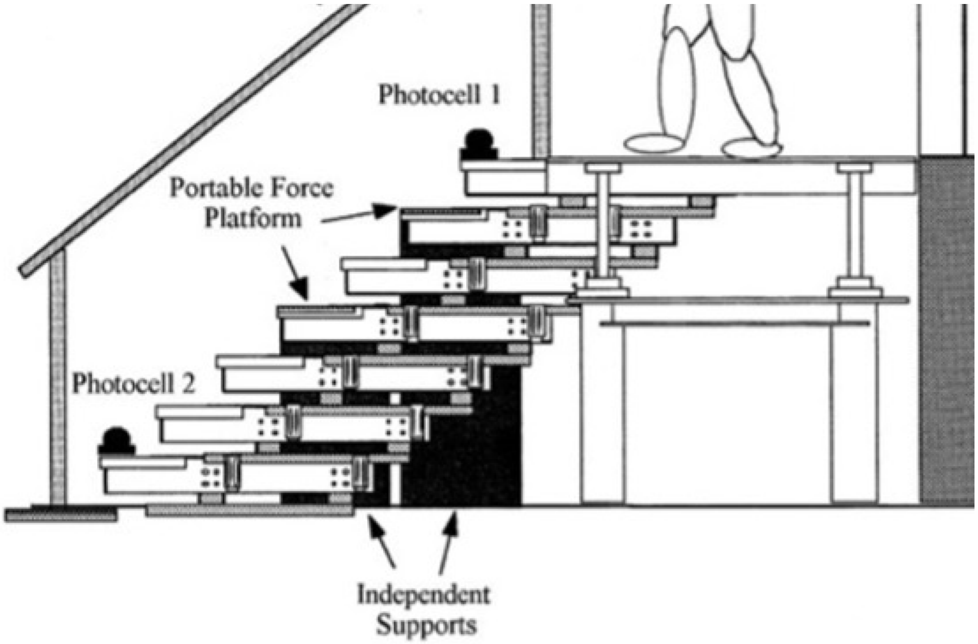

Figure 3.1: Instrumented staircase used in this study (diagram adapted from Christina & Cavanagh, 2002)).

3.4 Data Collection & Processing

Motion tracking markers were placed on both legs of each participant, with a total of 46 markers used. The participants had 20 markers attached to the feet, and 26 markers attached to the other leg segments using athletic wrap and skin-safe tape (Figure 3.1). The lower extremity marker model was created by the principal investigator, including a foot marker model from Davis & Challis (2022).

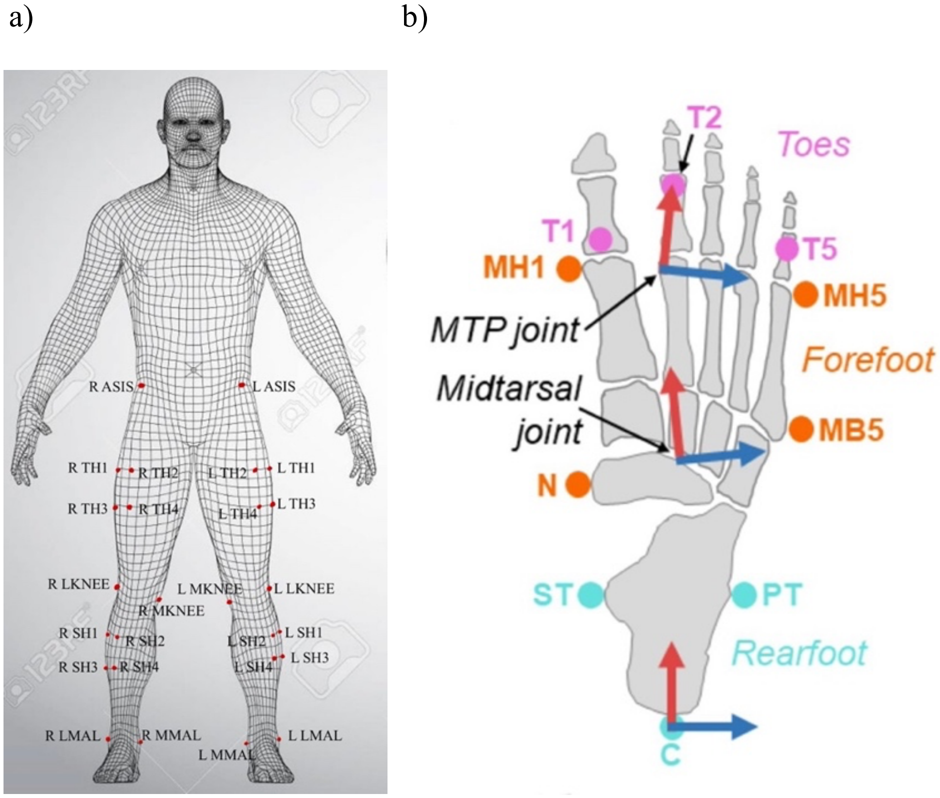

Figure 3.2: The location of markers on the lower limb, a) thigh and shank, and b) the foot. See Table 3.2 for the definitions of the marker names.

The subjects completed stair ascent of a seven-step staircase at their preferred walking speed under three conditions:

Condition 1 - stair ascent with one foot after the other, one foot on a step at a time.

Condition 2 - sideways stair ascent with both feet meeting on a step before ascending to the next, with both hands on the handrail.

Condition 3 - sideways stair ascent with both feet meeting on a step before ascending to the next, without their hands on the handrail.

Table 3.2: The key landmarks identified by a marker.

Marker ID	Location	Marker ID	Location
ASIS	Anterior superior iliac spine	C	Calcaneus
TH1	Posterior superior thigh	ST	Sustentaculum tali
TH2	Anterior superior thigh	PT	Peroneal tubercle
TH3	Posterior inferior thigh	N	Navicular
TH4	Anterior inferior thigh	MH1	Metatarsal head 1
LKNEE	Lateral knee	MH5	Metatarsal head 5
MKNEE	Medial knee	MB5	Metatarsal base 5
SH1	Posterior superior shank	T1	Toe 1
SH2	Anterior superior shank	T2	Toe 2
SH3	Posterior inferior shank	T5	Toe 5
SH4	Anterior inferior shank		
LMAL	Lateral malleolus		
MMAL	Medial malleolus		

The order of the conditions was randomized between each subject, and each condition consisted of three trials. Ground reaction forces were collected at a rate of 1000 Hz from the force plates, and lower extremity kinematic data was collected at a rate of 100 Hz by the Motion Analysis system. The analysis focused on the stair between the two force plates. On this stair two markers were placed on the stair to define the stair edges. The following variables were determined,

Step Speed – the speed taken to move from the first step with a force plate, to the second step with a force plate. Measurement made in steps/second.

Contact Time – for both force plates the duration of contact was measured. Measurements made in seconds.

Peak Force – for both plates the peak vertical ground reaction force was measurements. Measurements are expressed in bodyweights.

Clearance Time – the time from when the foot was first at the edge of the stair until the foot had first cleared the stair. Measurements made in seconds.

Minimum Foot Clearance – during the clearance time the distance from the foot to the stair edge was determined, the minimum value is reported. Measurements made in meters (m).

It should be noted that Minimum Foot Clearance was determined for all of the foot. Often analyses focuses on toe clearance only but due to the analysis two novel stair ascent methods (sideways stair ascent with and without handrail use). In these novel methods it was not known *a priori* for the subjects which part of the foot would pass closest to the stair edge.

All data were filtered prior to analysis using a low-pass Butterworth filter with a 5 Hz cut-off (Challis, 2021). All data analysis was performed in MATLAB.

3.5 Statistics

The variables of interest in this study were: Step Speed, Contact Time, Peak Force, Clearance Time, and Minimum Foot Clearance. For all metrics means and standard deviations were computed. In addition, for Peak Force, Clearance Time, and Minimum Foot Clearance comparisons were made between conditions. These comparisons were made via a two factor repeated measure analysis of variance. When necessary post-hoc comparisons were performed using Tukey's HSD (honestly significant difference) test.

3.6 Summary

This chapter discussed the methodology of the study, including the subjects recruited, equipment used, data collection and processing, and statistical analysis methods. The second subsection described the inclusion and exclusion criteria for subject participation, along with leg dominance testing process and heigh, mass, and characteristics of the subjects. The third subsection elaborated on the laboratory equipment utilized in the study and a diagram of the instrumented staircase used. The fourth subsection presented information on data collection and processing. Study protocol outlining the stair ascent conditions was included in this subsection as well. Statistical analysis of the data was explained in the fifth subsection, providing a basis for data comparison and interpretation.

Chapter 4

Results

4.1 Introduction

This chapter will cover the results of the study. The results presented in this chapter will consist of Step Speed, Contact Time, Peak Vertical Ground Reaction Force, Clearance Time, and Minimum Foot Clearance. The next three sections will be dedicated to each condition of stair ascent: normal, sideways without using the handrail, and sideways with the handrail. Mean and standard deviation values for individual subjects and mean values across all subjects will both be reported in these sections. One table in each section will present the individual mean values for Peak Force, Clearance Time, and Foot Clearance. The final section will compare these three variables between each condition:

- Peak Vertical Ground Reaction Force
- Clearance Time
- Minimum Foot Clearance

4.2 Normal Stair Ascent

Normal stair ascent in this study was characterized by walking up the steps forwards, with one foot placed on each step. Step Speed is represented in the units of steps/second, and the mean values for Subjects 1-6 were 2.68 ± 0.17 steps/sec, 3.48 ± 0.12 steps/sec, 3.47 ± 0.08 steps/sec, 3.38 ± 0.12 steps/sec, 3.85 ± 0.05 steps/sec, and 2.98 ± 0.01 steps/sec, respectively. The mean Step Speed in the forward condition across all subjects was 3.31 ± 0.09 steps/sec.

Contact Times for the subjects in this condition were 1.11 ± 0.12 s, 0.85 ± 0.04 s, 0.81 ± 0.01 s, 0.89 ± 0.02 s, 0.77 ± 0.02 s, and 0.99 ± 0.01 s, providing a mean value of 0.90 ± 0.03 s across all subjects. Each subject had a mean Peak Vertical Ground Reaction Force (vGRF) of just over one times their body weight, with Subject 5 having the greatest value of 1.19 ± 0.02 Bw. The mean Peak vGRF across all subjects was 1.11 ± 0.03 Bw. Individual mean Peak vGRF values are presented in Table 4.1. The following figure (Figure 4.1) presents the Peak vGRF profile across both force plates for Subject 1.

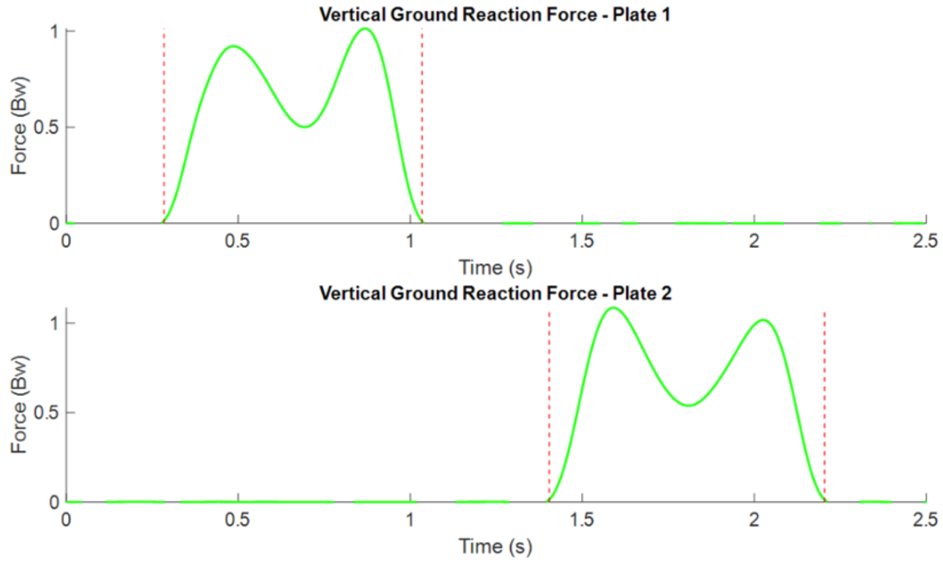

Figure 4.1: The vertical ground reaction forces for contact with the first and second force plates during stair ascent during normal stair walking. Note the vertical red lines correspond to the start and end of contact. Forces have been normalized with respect to subject body weight (Bw).

Mean Clearance Time and MFC values across all subjects were 0.07 ± 0.03 s and 0.018 ± 0.006 m, respectively. Refer to Table 4.1 for individual mean values for Peak vGRF, Clearance Time, and MFC.

Table 4.1: Individual values for normal stair ascent, mean and (SD), (vGRF – refers to Vertical Ground Reaction Forces, MFC – refers to Minimum Foot Clearance).

Subject	**Peak vGRF (Bw)**	**Clearance Time (s)**	**MFC (m)**
1	1.02 (0.03)	0.08 (0)	0.011 (0.002)
2	1.12 (0.06)	0.06 (0)	0.016 (0.006)
3	1.12 (0.02)	0.06 (0)	0.019 (0.001)
4	1.08 (0.03)	0.08 (0)	0.024 (0.001)
5	1.19 (0.02)	0.05 (0)	0.012 (0.003)
6	1.11 (0.03)	0.08 (0.01)	0.027 (0.001)
Group	1.11 (0.03)	0.07 (0.01)	0.018 (0.006)

4.3 Sideways Stair Ascent

This condition had the subjects ascend the staircase sideways with two feet meeting on a step before ascending to the next. The subjects led with their right foot to ascend to the next step. Mean Step Speed for the subjects 1, 2, 3, 4, 5, and 6 was 1.54 ± 0.11 steps/sec, 1.43 ± 0.15 steps/sec, 1.54 ± 0.08 steps/sec, 1.90 ± 0.07 steps/sec, 2.04 ± 0.02 steps/sec, and 1.64 ± 0.06 steps/sec, respectively. The mean Step Speed for this condition across all subjects was 1.68 ± 0.08 steps/sec. The individual mean Contact Time on the steps was 1.73 ± 0.15 s, 1.87 ± 0.23 s, 1.68 ± 0.11 s, 1.38 ± 0.07 s, 1.30 ± 0.02 s, and 1.49 ± 0.42 s for each subject. These values were averaged to produce a mean Contact Time of 1.58 ± 0.17 s across all subjects. Individual mean Peak vGRF, Clearance Time, and MFC values are presented in Table 4.2. The mean value across all subjects for these variables were 1.08 ± 0.03 Bw, 0.11 ± 0.02 s, and 0.032 ± 0.008 m, respectively. A visual for MFC is provided in Figure 4.2 as it shows the trajectory of a foot marker between steps.

Table 4.2: Individual values for sideways stair ascent, mean and (SD), (vGRF – refers to Vertical Ground Reaction Forces, MFC – refers to Minimum Foot Clearance).

Subject	**Peak vGRF (Bw)**	**Clearance Time (s)**	**MFC (m)**
1	1.03 (0.02)	0.11 (0.01)	0.019 (0.017)
2	1.09 (0.02)	0.10 (0.01)	0.022 (0.003)
3	1.05 (0.05)	0.11 (0.01)	0.038 (0.003)
4	1.07 (0.03)	0.10 (0.01)	0.033 (0.010)
5	1.17 (0.02)	0.10 (0.01)	0.042 (0.003)
6	1.07 (0.03)	0.11 (0.01)	0.035 (0.009)
Group	1.08 (0.03)	0.11 (0.02)	0.32 (0.008)

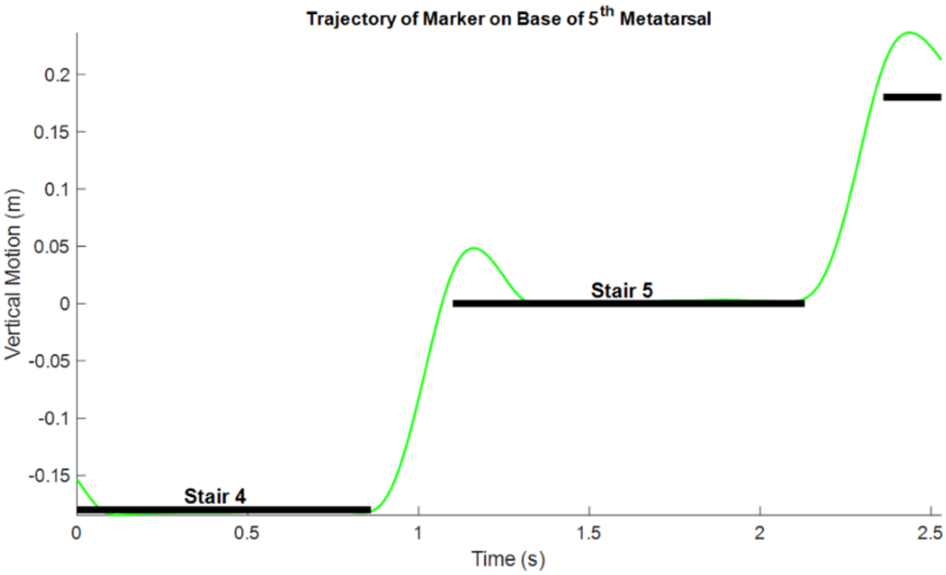

Figure 4.2: The vertical motion of a marker on the foot as it moves from stair 4 to stair 5, for sideways stair ascent without rail condition.

4.4 Sideways Stair Ascent with Handrail

For this condition, subjects ascended the staircase the same way as the previous condition but were holding onto the handrailing for the duration of the ascent. Individual mean values for Step Speed for subjects 1-6 were 1.59 ± 0.11 steps/sec, 1.67 ± 0.05 steps/sec, 1.78 ± 0.03 steps/sec, 1.74 ± 0.04 steps/sec, 1.88 ± 0.08 steps/sec, and 1.72 ± 0.03 steps/sec, respectively. The mean Step Speed across all subjects was 1.73 ± 0.06 steps/sec. Mean Contact Times for each subject in this condition were 1.78 ± 0.11 s, 1.59 ± 0.09 s, 1.48 ± 0.01 s, 1.58 ± 0.03 s, 1.40 ± 0.06 s, and 1.61 ± 0.05 s, providing a mean Contact Time of 1.56 ± 0.10 s across all subjects. Mean Peak vGRF, Clearance Time, and MFC values across all subjects were 1.06 ± 0.03 Bw, 0.11 ± 0.01 s, and 0.026 ± 0.008 m, respectively. Refer to Table 4.3 for individual mean values for these variables.

Table 4.3: Individual values for sideways stair ascent with handrail, mean and (SD), (vGRF – refers to Vertical Ground Reaction Forces, MFC – refers to Minimum Foot Clearance).

Subject	**Peak vGRF (Bw)**	**Clearance Time (s)**	**MFC (m)**
1	1.07 (0.02)	0.12 (0.01)	0.014 (0.010)
2	1.09 (0.02)	0.10 (0.01)	0.021 (0.014)
3	1.04 (0.03)	0.11 (0.01)	0.027 (0.004)
4	1.00 (0.04)	0.11 (0.02)	0.036 (0.009)
5	1.09 (0.03)	0.11 (0.01)	0.038 (0.002)
6	1.04 (0.04)	0.12 (0.02)	0.022 (0.011)
Group	1.06 (0.03)	0.11 (0.01)	0.026 (0.008)

4.5 Comparison Between Conditions

In this sub-section the results from the three conditions are compared using a two factor (trial and condition) repeat measures analysis of variance. When necessary paired conditions were compared using a post-hoc Tukey HSD test. The results are summarized in Table 4.4.

Table 4.4: Comparison of variables across conditions, mean and (SD), (vGRF – refers to Vertical Ground Reaction Forces, MFC – refers to Minimum Foot Clearance).

Condition	**Peak vGRF (Bw)**	**Clearance Time (s)**	**MFC (m)**
Forwards	1.11 (0.03)	0.07 (0.01)	0.018 (0.006)
Sideways (No Railing)	1.08 (0.03)	0.11 (0.02) *	0.032 (0.008)
Sideways (With Railing)	1.06 (0.03) *	0.11 (0.01) *	0.026 (0.008)

* Denotes a significant difference ($p < 0.05$) between the condition and the forward condition.

The repeat measures ANOVA revealed no effect of trial ($p = 0.56$) on the magnitude of the Peak vGRF, but did reveal a difference due to condition ($p = 0.03$), Figure 4.3. A post-hoc Tukey HSD test indicated that Peak vGRF was smaller for the sideways with railing condition compared with the forwards condition ($p < 0.01$), there was no indication of a difference between the forward and sideways without railing conditions ($p=0.19$), nor between either of the sideways conditions ($p = 0.16$).

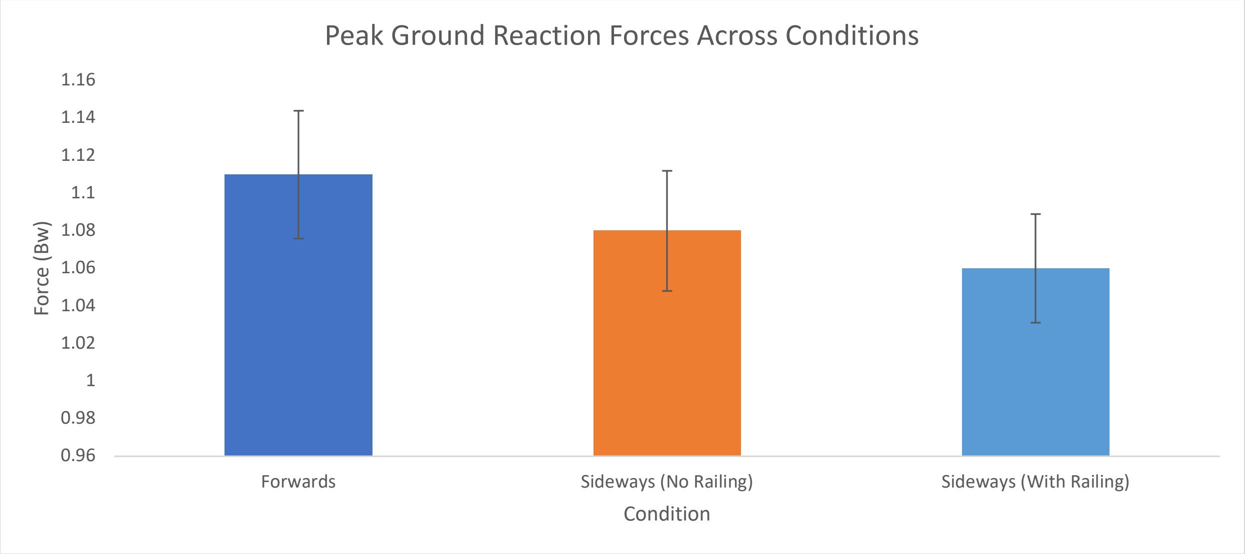

Figure 4.3: Comparison of Peak Vertical Ground Reaction Forces across conditions. Forces have been normalized with respect to subject body weight (Bw).

The repeat measures ANOVA revealed no effect of trial ($p = 0.10$) on the magnitude of the Clearance Time, but did reveal a difference due to condition ($p < 0.01$), Figure 4.4. A post-hoc Tukey HSD test indicated that the Clearance Time was shorter for the forwards condition compared with the sideways without railing condition ($p < 0.01$), and shorter for the forwards compared with sideways with railing condition ($p < 0.01$), but there was no difference between the two sideways conditions ($p = 0.31$).

Figure 4.4: Comparison of Clearance Time across conditions.

The repeat measures ANOVA revealed no effect of trial ($p = 0.33$) on the Minimum Foot Clearance, nor for the effect of condition ($p < 0.33$), Figure 4.5.

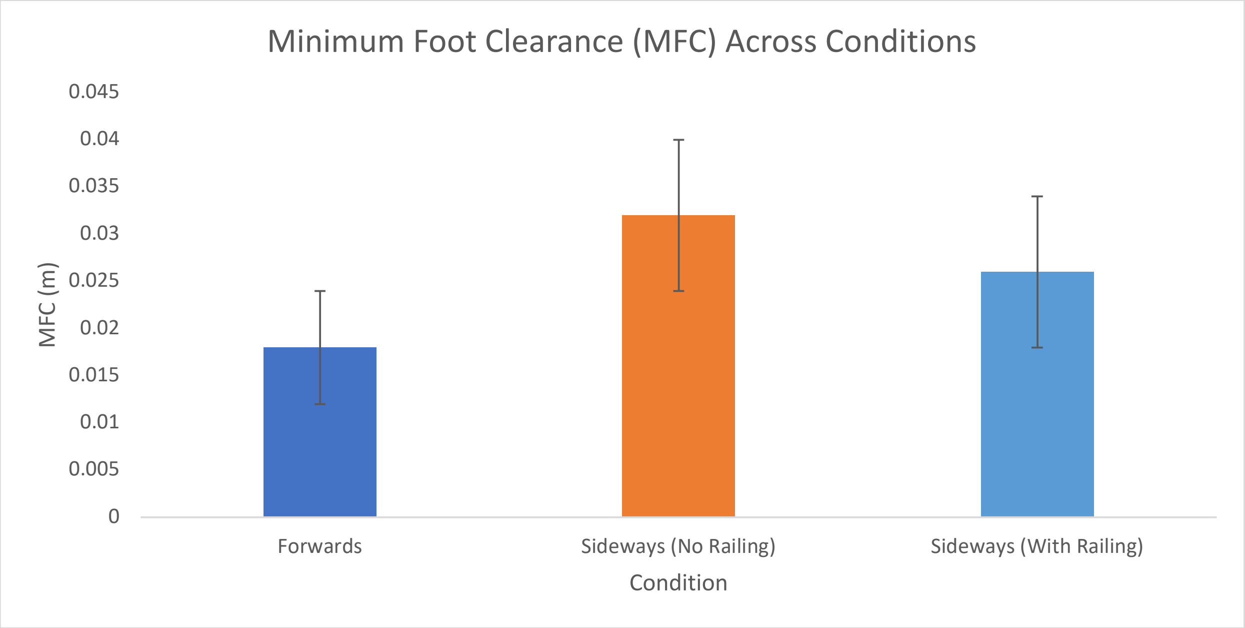

Figure 4.5: Comparison of Minimum Foot Clearance across conditions.

4.6 Summary

This chapter presented the results of the study. The variables of interest were Step Speed, Contact Time, Peak Vertical Ground Reaction Force (vGRF), Clearance Time, and Minimum Foot Clearance (MFC). There were three sections dedicated to forwards, sideways with no handrail, and sideways with handrail conditions, and one section that compared the variables across these three conditions. One table in each section presented the mean values of variables used for statistical analysis: Peak vGRF, Clearance Time, and MFC. Both individual mean and group mean values were presented in these tables. Through repeated measure analysis of variance and post-hoc Tukey HSD tests, it was found that there was a significant difference in Peak vGRF values between the forwards condition and the sideways with handrail condition. No significant difference in Peak vGRF was found between the forwards and sideways with no handrail condition, nor either of the sideways conditions. For Clearance Time, there were significant differences between the forwards and sideways (without and with handrail) conditions, but none between the two sideways conditions themselves. No significant differences were found in MFC between any of the conditions.

Chapter 5

Discussion

5.1 Overview

This chapter will discuss the results from the study, providing insight and critiques of the study where appropriate. The second section will address the findings of the study and will interpret the results from Chapter 4 - Results. The third section will discuss how the findings of the study can apply to the elderly in terms of the best way to ascend stairs. Study limitations will be presented in the fourth section, with the following section building off these limitations for recommendations of future studies. Conclusions from the study will be summarized in the final section of this chapter.

5.2 Findings

The three hypotheses of this study were:

Hypothesis I – The peak vertical ground reaction force will be greater for the sideways ascent without handrail use compared with sideways ascent with handrail use.

Hypothesis II – the time for the foot to clear a step will be shortest for the more familiar task (stair ascent with one foot after the other) compared with the two sideways ascent methods.

Hypothesis III – the minimum foot clearance for a step will be lowest for the more familiar task (stair ascent with one foot after the other) compared with the two sideways ascent methods.

With regards to Hypothesis I, there was evidence of a reduction in the Peak Vertical Ground Reaction Force (vGRF) comparing stair ascent with one foot after the other with sideways ascent using the handrail, but using the handrail did not produce a measurable difference between the sideways stepping with and without the handrail. Therefore, the hypothesis that the Peak vGRF for sideways stair ascent without the handrail will be greater than sideways stair ascent with the handrail is rejected. This shows that there is less force transmitted through the legs during this sideways stair ascent when using the handrail, implying that there may be reduced joint moments required when ascending stairs sideways with the handrail.

Hypothesis II is supported through the results of the study because of the significant differences between the forwards stair ascent and sideways stair ascent conditions. There was a significantly smaller Clearance Time for the forwards stair ascent condition, which makes sense considering it is the more familiar task. Sideways stepping took longer for the foot to clear the stairs because of the relatively unnatural movement required for the task. These results should be considered in the context that the profile of the foot which has to clear the stair edge was greater for the forwards stair ascent compared with the sideways ascent.

The results do not support Hypothesis III because there were no significant differences in Minimum Foot Clearance (MFC) values between all three conditions. It seems that the less practiced sideways stepping is as safe from a tripping perspective as the normal way of ascending stairs, as MFC values were no different. Given that the sideways stepping was a relatively novel task this result was not anticipated. MFC during normal, ground-level walking is about 0.01 m (Schulz, 2011). The results show that mean MFC during stair ascent can be up to three times as large during stair ascent compared with ground-level walking, demonstrating that stair ascent is a more biomechanically challenging task.

5.3 Implications

The results of this study can be used to help older adults more safely ascend stairs. Weakened muscular strength is a common age-related change that affects MFC, predisposing the elderly to falls on the stairs (Cruz-Jimenez, 2017; Jacobs, 2016; Ullauri et al., 2019). The study provides insight into the MFC values across different methods of stair ascent, which are not significantly different. This implies that there is no difference in the risk of falls during stair ascent caused by the foot skimming the steps. There is, however, a difference in the Peak vGRF experienced between forwards and sideways stair ascent using the handrail. Having a greater Peak vGRF during forwards stair ascent for older adults may place excess demand on their weakened musculoskeletal system. Having weaker leg muscles may increase the risk of falls during an environmentally challenging task such as stair ascent (Startzell et al., 2000). Increased Time Clearance in the sideways conditions may be beneficial for older adults as well, as more caution and attention to stepping is exhibited. This could further help limit the incidence of falls, as falls on the stairs are often caused due to distracted attention (Jacobs, 2016). Placing more attention on the task of stair ascent could help draw attention away from other distracting tasks for the elderly, allowing them to navigate the stairs more safely.

5.4 Study Limitations

A limitation of this study is its small sample size (n = 6). Having a greater number of subjects could provide greater statistical power, where power is the probability that a test of significance will pick up on an effect that is present. Another study limitation was not having the participants leading with the same foot during forwards stair ascent. For example, one subject could have placed their right foot on the first step while another placed their left foot on the first step, and so on. For the sideways stair ascent subjects always lead with their right foot. While this factor would likely not have impacted the results obtained, standardizing this aspect of the study would confirm this assumption.

5.5 Future Studies

To further understand the muscular activity required from the legs during stair ascent, future studies should focus on quantifying the joint moments and the lower extremity support moment (Jung et al., 2016; Winter, 1980). While the peak vGRF was able to indicate mechanical load to an extent, joint moments would provide a better understanding of the demand placed on the legs during different methods of stair ascent. There is limited literature on the lower extremity support moment during environmentally challenging tasks (Shih & Ho, 2023). Analyzing the support moment under different stair ascent conditions would strengthen this field of research, and potentially provide guidance on for the elderly on how to better negotiate stairs based on their musculoskeletal capacities. These results could be directly applied to the elderly because the overall pattern and cadence of resultant joint moments remain the same with age

(Winter et al., 1990). Once a study computing resultant joint moments in the young subjects has been completed, this could segue to a study in the elderly.

5.6 Conclusion

The specific aims of this study were:

1) for a group of subjects to measure the ground reaction forces across different conditions of stair ascent,

2) for a group of subjects to measure foot clearance as they ascend the stairs.

Through the findings of the study, it may be recommended for older adults to ascend stairs in a sideways manner while using the handrail. While MFC was no different between the method of stair ascent, Peak vGRF and Clearance Time values favor sideways stair ascent in limiting the risk of falls. In addition, both feet are placed on each stair during sideways ascent which is inherently more stable than ascending the stairs with one foot after the other where only one foot is placed on each step. Future studies should be conducted to further understand the biomechanical demand placed on the lower extremity during stair ascent. These findings could further support the conclusion of this study or provide a new biomechanical perspective on the safest way for the elderly to ascend stairs.

Appendix A

Informed Consent Form

CONSENT FOR RESEARCH
The Pennsylvania State University

Title of Project: Comparison of Lower Extremity Support Moments Between Methods of Ascending Stairs in Healthy Adults

Principal Investigator: Curtis Walter

Address: Biomechanics Laboratory, 29K Recreation Building, The Pennsylvania State University, University Park, PA, 16802

Telephone Numbers: Weekdays: 8:00 a.m. to 5:00 p.m. (814) 308-4373

Faculty Advisor Telephone Number: (814) 863-3675 – (John H Challis)

Subject's Printed Name: ____________________________

We are asking you to be in a research study.

Whether or not you take part is up to you. You can choose not to take part. You can agree to take part and later change your mind. Your decision will not be held against you, and there will be no penalty or loss of benefits to which you are entitled.

This form gives you information about the research. Please ask questions about anything that is unclear to you and take your time to make your choice.

KEY INFORMATION

The following is a short summary of this study to help you decide whether or not to be a part of this research. More detailed information is provided later in this form. If you have any questions, be sure to ask the study team.

Why am I being invited to take part in this research study?

We are asking you to take part in this voluntary research study because you are a healthy adult within the ages of 18 to 35 years old. You also have no neurological disorders, and no history of lower extremity surgeries. In addition, you should have had no lower extremity injuries within the past 6 weeks.

What is the purpose of this research study?

The purpose of this voluntary research study is to determine the way to go up a set of stairs with the least mechanical demand on the lower extremity (hips, knees, ankles).

How long will the research study last?

The research study will consist of a single visit to the Biomechanics Lab that will last for 1 - 2 hours.

What will I need to do?

Your leg dominance will first be tested through a short series of activities (e.g., kicking a ball and standing on one leg). You will then have 23 motion tracking markers placed on each leg, attached to your body with skin-safe (hypoallergenic) tape and athletic wrap. These markers will be directly attached to your skin, so we ask that you wear shorts. We will not shave any areas of your legs that have hair or make any other modifications to your skin.

You will complete a task of ascending a seven-step staircase in three different conditions.
Condition 1 - you will walk up the stairs in a normal, casual fashion (one foot after the other up the stairs) without holding onto the attached handrails.
Condition 2 - you will walk up the staircase sideways, with both feet meeting on a step before ascending to the next one. Both of your hands will be placed on the handrail.
Condition 3 - you will walk up the staircase sideways, with both feet meeting on a step before ascending to the next one. You will not use the handrail.

Each condition will have three trials of repeated stair ascent. For all conditions, you will be able to descend the stairs in the way you perceive to be the most comfortable and safe.

What are the main risks of taking part in the study?

For this study, the main risks to know about are: falling on the steps while either ascending or descending them and potential skin reactions to the marker tape or athletic wrap. There are no increased risks when walking up or down the experimental stairs compared to a typical staircase.

What are the possible benefits to me that may reasonably be expected from being in the research?

There are no benefits to you from taking part in this research. Results of the study may benefit other people in the future by helping us learn more about the method of ascending stairs that requires the least amount of mechanical effort from the body.

What happens if I do not want to be in this research?

Participation in research is completely voluntary. You can decide to participate or not to participate. You may choose not to take part in this research study. You are free to withdraw from the study at any time.

DETAILED INFORMATION

The following is more detailed information about this study in addition to the information listed above.

1. Why is this research study being done?

This research is being done to find out the method of ascending stairs that requires the least amount of mechanical effort from the body.

Approximately 12 people will take part in this research study at Penn State.

2. What will happen in this research study?

Body Measurements – we will measure your mass and height.
Leg Dominance – this will be tested through a series of activities. First you will be asked stand on one leg for 10 seconds. Then I will ask you to perform three jumps on one leg. After these tasks, you will stand and kick a ball. Finally, you will be asked to simulate stomping out a fire.
Marker Placement - 23 motion tracking markers will be placed on key landmarks on each of your legs. They will be placed using skin-safe (hypoallergenic) tape and athletic wrap.
System Calibration – to calibrate the motion tracking system, I will ask you to stand still in a number of balanced standing positions.
Data Collection – you will walk up a 7-step staircase in three different ways: normal, a typical fashion (one foot after the other with one foot on a step at a time). side-stepping while using the handrail, and side-stepping without using the handrail. Once you reach the top of the steps, you may descend in the way you feel most comfortable and safe. You will repeat each condition three times. The order of condtions will be randomized, and you can rest between trials for as long as you require.

3. What are the risks and possible discomforts from being in this research study?
The risks and possible discomforts from being in this research study are:

- Falling when ascending or descending the stairs
- Discomfort or skin reaction to the markers/tape/athletic wrap

There is a risk of loss of confidentiality if your information or your identity is obtained by someone other than the investigators, but precautions will be taken to prevent this from happening. The confidentiality of your electronic data created by you or by the researchers will be maintained as required by applicable law and to the degree permitted by the technology used. Absolute confidentiality cannot be guaranteed.

4. What are the possible benefits from being in this research study?

4a. What are the possible benefits to me?
You will not benefit from this research study.

4b. What are the possible benefits to others?
The results of this research may gain further understanding of the way of ascending stairs that has the least mechanical demand of the lower extremity. The results of this study will be applied to the elderly population with the goal of limiting falls and injuries on the stairs.

5. What other options are available instead of being in this research study?
You may choose not to be in this research study.

6. How long will I take part in this research study?
If you agree to take part, it will take you about 1-2 hours to complete this research study. You will be asked to visit the research site only this one time.

7. How will you protect my privacy and confidentiality if I decide to take part in this research study?

7a. What happens to the information collected for the research?

Efforts will be made to limit the use and sharing of your personal research information to people who have a need to review this information. Reasonable efforts will be made to keep the personal information in your research record private. However, absolute confidentiality cannot be guaranteed, and there may be situations where disclosure is required by law.

- A list that matches your name with your code number will be kept in a locked file in Dr. Challis' office.
- Your research records will be labeled with your code number, only. Your initials and your date of birth, which will be collected if you consent to the study, will be kept in a safe area in Dr. Challis' research office.

In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared.

We will do our best to keep your participation in this research study confidential to the extent permitted by law. However, the following people/groups may check and copy records about this research.

- The Office for Human Research Protections in the U. S. Department of Health and Human Services
- The Penn State Institutional Review Board (a committee that reviews and approves human research studies) and the Penn State Human Research Protection Program
- The investigator, Penn State study staff, and other Penn State professionals who may be evaluating the study or need this information to do their jobs (such as for treatment, payment (billing), or health care operations)

Sometimes a Principal Investigator or other researcher moves to a different institution. If this happens, your identifiable information and samples may be shared with that new institution and their oversight offices. Data will be shared securely and under a legal agreement, if applicable, to ensure it continues to be used under the terms of this consent and authorization.

7b. What will happen to my research information after the study is completed?

Researchers can do studies that are more powerful when they share with each other the data or information they get from research studies. They share this information with each other by putting it into scientific databases. Your research information may be put in one or more databases and used for future research. Your information stored in these databases will not include any identifying information. While we will collect your date of birth information for our own records, this information will not be included in the databases that contain the study information. Your research data will only be available to researchers who have received approval from the scientific database and/or Institutional Review Boards. Some of these databases are maintained by Penn State, some are maintained by the federal government, and some are maintained by private companies and other institutions.

8. What are the costs of taking part in this research study?

Nothing, it is completely free for you to participate.

8a. What happens if I am injured as a result of taking part in this research study?

It is possible that you could develop complications or injuries as a result of being in this research study. If you experience a side effect or injury and emergency medical treatment is required, seek treatment immediately at any medical facility. If you experience a side effect or injury and you believe that emergency treatment is not necessary, you should contact the principal investigator listed on the first page of this consent form as soon as possible and the principal investigator will arrange for medical treatment. You should also let any health care provider who treats you know that you are in a research study.

<u>Penn State compensation for injury</u>

- There are no plans for Penn State to provide financial compensation or free medical treatment for research-related injury.
- If an injury occurs, medical treatment is available at the usual charge.
- Costs will be charged to your insurance carrier or to you.
- Some insurance companies may not cover costs associated with research injuries.
- If these costs are not covered by your insurance, they will be your responsibility.

When you sign this form you are not giving up any legal right to seek compensation for injury.

9. Will I be paid to take part in this research study?

You will receive $25 for your participation in this research study. If you do not complete the study for any reason, you will be paid.

10. Who is paying for this research study?

Funds from the Penn State Department of Kinesiology will be used to support this research.

11. What are my rights if I take part in this research study?

Taking part in this research study is voluntary.

- You do not have to be in this research.
- If you choose to be in this research, you have the right to stop at any time.
- If you decide not to be in this research or if you decide to stop at a later date, there will be no penalty or loss of benefits to which you are entitled.

If you choose to withdraw from this study, your collected data will not be used for the study. During the course of the research you will be provided with any new information that may affect your health, welfare or your decision to continue participating in this research.

12. If I have questions or concerns about this research study, whom should I call?

Please call the head of the research study John Challis at (814) 863-3675

You may also contact the Penn State Human Research Protection Program (HRPP) at (814) 865-1775 or visit the HRPP website at https://www.research.psu.edu/irb/participants if you:

- Have questions or want information regarding your rights as a person in a research study.
- Have concerns, complaints or general questions about the research.
- You may also call this number if you cannot reach the research team or wish to offer input or to talk to someone else about any concerns related to the research.

INFORMED CONSENT TO TAKE PART IN RESEARCH

Signature of Person Obtaining Informed Consent

Your signature below means that you have explained the research to the subject or subject representative, provided the subject or subject representative an opportunity to discuss and consider whether or not to participate in the research, and have answered any questions about the research.

______________________________	__________	______	___________________
Signature of person who explained this research	Date	Time	Printed Name

(Only approved investigators for this research may explain the research and obtain informed consent.)

Signature of Person Giving Informed Consent and Authorization

Before making the decision about being in this research you should have:

- Discussed this research study with an investigator,
- Read the information in this form, and
- Had the opportunity to ask any questions you may have.

Your signature below means that you have received this information, have asked the questions you currently have about the research and those questions have been answered. You will receive a copy of the signed and dated form to keep for future reference.

Signature of Subject

By signing this consent form, you indicate that you voluntarily choose to be in this research and authorize your information to be used and shared as described above.

___________________________	__________	______	__________________________
Signature of Subject	Date	Time	Printed Name

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ACADEMIC VITA

Education

Bachelor of Science – Kinesiology
Pennsylvania State University
07/2020 – 05/2024

- Minor in psychology
- Schreyer Honor's College scholar
- College of Health and Human Development Dean's List Honoree (each semester)
- Community outreach chair of Kinesiology Club (2022-2023)

Study Abroad Program
Brunel University & Pennsylvania State University
06/2022

- Took a course that analyzed aspects of sport and physical activity, such psychology of exercise, sport policy, and how to tailor exercise to specialized populations
- Became immersed in the London culture and learned how to navigate a foreign country

Experience

Undergraduate Research Principal Investigator – Biomechanics Laboratory
Pennsylvania State University
08/2023 – 04/2024

- Developed study in collaboration with John Challis that assessed the biomechanical demand of stair ascent on the legs
- Recruited subjects for the study
- Wrote an accepted grant proposal outlining the study
- Collected data and performed biomechanical analyses

Undergraduate Research Assistant – Biomechanics Laboratory
Pennsylvania State University
01/2023 – 04/2023

- Collected and analyzed data for research study that assesses the force production of the gastrocnemius and soleus muscles based on varying lengths of the Achilles tendon
- Collected and analyzed data for research study that assesses the biomechanics of regaining balance after partaking in rotational movements

Undergraduate Research Assistant – Athletic Training/Exercise Physiology Laboratory
Pennsylvania State University
01/2022 - 09/2022

- Collected and analyzed data for blood flow restriction research study
- Assessed the effects of restricting blood flow to the lower extremities during exercise, with the goal of determining if the intervention improves muscular efficiency and strength
- Established and maintained proper laboratory conditions