Age dependent differences in attenuation of vertical ground reaction force during a step descent

Nicola Saywell

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Primary supervisor Denise Taylor PhD

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School of Physiotherapy, Faculty of Health and Environmental Sciences

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Confidential Material

All confidential material generated during this project, including written consent forms, photographs and raw data stored on DVD will be stored in a locked filing cabinet in the AUT University Health and Environmental Sciences Office for a period of six years, after which time it will be destroyed.

Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgments), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Candidate: Date:

Abstract

Aim:

The aim of this study was to investigate the differences between older and younger adults in the attenuation of impact during descent from a step. Strategies that have been implicated in reducing either the magnitude of vertical ground reaction force (vertical GRF) or the time taken to reach the maximum vertical GRF in the stepping leg were explored.

Study Design:

The study was an experimental, laboratory based, repeated measures design.

Participants:

Twenty participants took part in this exploratory study. Ten in the older group of 60-80 years, mean 65.3 (SD 5) years and ten in the younger age group of 20-30 years, mean 22.8 (SD 2.5) years.

Main Measures:

The vertical GRF and the time taken to reach maximum vertical GRF were measured to ascertain impact during step descent. Electromyography and kinematic variables were measured to determine the effect they may have on the impact. The variables measured were the maximum joint range of motion of the hip and knee during early stance in step descent. Surface electromyography from four lower limb muscles was recorded to ascertain the magnitude of muscle activity at impact. The relationship in an antero-posterior direction of the upper body and stepping leg at initial contact (IC) was also investigated.

Results:

There was a significant difference in both the amount of knee flexion and the amount of activity of the vastus lateralis muscle during impact between older and younger adults. Older adults had significantly less knee flexion during a step descent activity than younger adults (F(1,18)=5.48; p=.031).Older adults had significantly more vastus lateralis activity during a step descent activity than younger adults (F(1,18)=5.21; p=.035).

Conclusions:

Older and younger adults use different strategies in both muscle activation and joint range of motion around the knee of the leading leg during the step descent. Older adults used more vastus lateralis activity perhaps to increase stiffness in the knee, leading to a reduction in range of motion at impact. Although no change in vertical GRF was detected in this study, both of these strategies have the potential to increase the impact of a step and therefore cause jarring and possible damage. This study recruited healthy active older adults and differences in impact may be observed in an older or less active population, or in those with joint pathology such as osteoarthritis.

2 Introduction

Accurate neural control of muscle activity is vital in all efficient movement. Muscle activation that is not steady, accurate and temporally matched to the task, leads to sub-optimal movement patterns (Patten, 2000). In weight bearing activities a loss of coordination of muscle activity may lead to reduced joint protection by a failure to attenuate impact during sudden loading tasks (Liikavainio et al., 2007; Robbins, Waked, & Krouglicof, 2001).

2.1 Attenuation of Impact

It is well documented that muscle activation, mainly energy absorbing, eccentric muscle activity helps attenuate impact at initial contact of the foot at the start of the stance phase of gait or during descent from a step (Hamel, Okita, Bus, & Cavanagh, 2005; Hinman, Bennell, Metcalf, & Crossley, 2002). A failure of this strategy may increase impact, predisposing the joints to damage (Felson, 2004; Herzog & Longino, 2007). It is the timing of muscle onset and its ability to control the joint through the entire task that is critical to this protective strategy (Hortobagyi & DeVita, 2000). Lower limb muscles are not normally functioning at maximum strength during descent of a step but are required to work with considerable temporal accuracy. It has been demonstrated that a reduction in both the number and size of motor units in older adults, leads not only to a significant decrease in strength but also difficulty with sustaining and modifying submaximal force (Darling, Cooke, & Brown, 1989; Hollmann, Straider, Tagarakis, & King, 2007; Roos, Rice, & Vandervoort, 1997). This may reduce the ability to control the lowering of the stepping leg to the surface below. It may also reduce the efficiency of the muscles of the stepping leg working eccentrically to absorb the kinetic energy of impact.

Muscle weakness and consequent difficulty with control of movement has been reported as a significant clinical feature of osteoarthritis for many years but the suspected cause of the weakness and its relationship to the disease pathogenesis and progression has changed in the last decade (Bennell, Hunt, Wrigley, Lim, & Hinman, 2008; Hurley, 1998). There had been an assumption that muscle weakness was a consequence of pain and disuse in osteoarthritis and therefore predominantly a secondary impairment (Hayes & Falconer, 1992; Hurley &

Newham, 1993; Slemenda et al., 1997). This explanation for the presence of significant weakness in early osteoarthritis has been questioned. The presence of primary weakness and a reduction in neural control, as a precursor to osteoarthritis was initially suggested as a possible theory, based on expert opinion and observation of patients with early osteoarthritis (Becker, Berth, Nehring, & Awiszus, 2004; O'Reilly, Jones, & Doherty, 1997). Recently the theory has been invested by Herzog and Longino (2007). These authors demonstrated that rabbits who were injected with Botulinum type-A toxin (BTX-A) to induce lower limb muscle weakness, developed early signs of joint degeneration in as little as four weeks. Thorstensson, Petersson, Jacobsson, Boegard and Roos (2004) investigated predictors of incidence and progression of knee osteoarthritis in a cohort of adults with knee pain but with no radiographic signs of osteoarthritis. The participants were analysed for the risk factors of age, weight, knee pain and lower limb function. The authors found that when age, weight and knee pain were controlled for, the number of one-leg rises from sitting, predicted development of radiographic osteoarthritic knee changes five years later. The authors concluded that reduced functional performance in the lower limb predicts the development of knee osteoarthritis. These studies have strengthened the theory that muscle weakness is a factor in the pathogenesis of osteoarthritis, especially in weight bearing joints. The incidence of arthritis in the lower limb joints of adults has a rapid increase around the sixth decade of life. The question is whether the loss of accurate neural control of muscles exposes these joints to an increased magnitude or rate of loading and therefore cumulative stress, and whether this stress leads to progressive and permanent joint damage.

Giving weight to the theory that an increase in vertical ground reaction force (vertical GRF) during daily activities such as walking and negotiating steps is a precursor to joint damage is a study by Robbins, Waked and Krouglicof (2001). This study pinpoints the start of a sharp increase in vertical GRF at initial contact (IC) during step descent, to the sixth decade of life. Robbins et al. investigated healthy adults performing a step down activity from a single step on to a force plate. They found that the amplitude of the vertical GRF remained constant across all the age groups of participants until 50 years of age. In people over the age of 50 years the vertical GRF increased significantly by an average of 13.3%, despite none of the participants having any identified pathology that could account for the increase. None of the younger participants showed as high amplitude in vertical GRF as those in the over 50 age group.

The cumulative effect of this greater impact over time was hypothesised to increase the risk of developing osteoarthritis in weight bearing joints. Robbins et al. (2001) suggested that the sudden rise in vertical GRF was caused by a reduction in foot position sense due to a reduction in plantar mechanoreceptor efficiency. However O'Connor and Brandt (1993) maintain that there is little evidence that loss of sensory information is a significant factor in the pathogenesis of osteoarthritis in stable joints. There is a lack of consensus on the role that reduced sensation may have in the protection of joints but it seems likely that sensory impairment and its consequent feed forward role in determining motor output is one of the factors predisposing joints to damage. Robbins et al. did note that the rise in impact occurred at approximately the same age as increased sway, brought about by reduced muscle strength and endurance but that was not measured in their study. However, in the current study the focus is on the motor response as the effector of any protective mechanism, rather than exploring possible sensory system contribution to changes in impact.

In several studies, vertical GRF and surface electromyography (SEMG) of lower limb muscles have been measured to establish whether there is a relationship between muscle activity and vertical GRF (Hinman, Cowan, Crossley, & Bennell, 2005; Hsu, Wei, Yu, & Chang, 2007; Larsen, Puggaard, Hämäläinen, & Aagaard, 2008). However there are inconclusive findings regarding the magnitude of muscle contraction used in the eccentric energy absorbing phase of step descent. Therefore an experiment comparing older and younger participants and recording muscle activity would help to investigate whether a change in magnitude of muscle activation is at least partly responsible for any changes that occur in vertical GRF.

The current study will examine the amount of muscle activity in the main muscle groups implicated in attenuation of impact and investigate any differences that may be found between an older and a younger group of healthy adults. The range of motion in the hip and knee and the relationship between the upper body alignment and the stepping leg during the energy absorption phase will be recorded to see if different movement strategies may also be implicated in the attenuation of impact. Muscle activity will be normalised to the maximum for task, which has been shown to reduce variability between subjects (Winter & Yack, 1987). The peak EMG signal for the ensemble of all trials for each participant will be used as the maximum for task (Yang & Winter, 1984). The mean amplitude of the EMG signal from IC to maximum vertical GRF will be calculated for each muscle and expressed as a percentage of maximum for task.

The potential application of discovering changes in joint range of motion or muscle activation is the implication it may have for rehabilitation. Reversing or at least slowing the progressive loss in accurate neural control of muscles may have benefits in slowing or preventing joint damage. McGibbon, Krebbs and Scarborough (2003) conducted a rehabilitation study with participants who were over 60 years with lower limb osteoarthritis and had a least one impairment and one functional limitation on the SF36 health status measure. The study compared a traditional strengthening exercise programme, with a novel functional training programme that incorporated aspects of accuracy of movement and timing of muscle activity. Both groups had significant gains in muscle strength but the improvement in functional ability happened only in the functionally trained group. The authors maintain that the addition of functionally specific tasks at differing speeds improved coordination and movement control leading to the functionally trained group making greater gains in functional performance through more coordination of muscle power. When looking at the mechanical energy analysis of the lower limb joints in the study, the functionally trained group had regained muscle activation patterns expected to be observed in a younger, healthy population, by increasing the power output of ankle and knee and reducing that in the hip. The coordination of muscle activation patterns had been improved as well as the muscle strength.

2.2 Aim

The aim of this study was to investigate age related differences in vertical GRF and strategies used to attenuate impact during a single step descent task. The study compared older (60-80 years) with younger (20-30 years) adults. Effects on the kinematic and kinetic parameters of the task were analysed using a nine camera three dimensional movement analysis system, a force plate and SEMG from four muscles in each lower limb.

2.3 Delimitations

The following delimitations apply to this study:

- This was a laboratory based study with participants subject to some possible movement constraints. The reflective markers, SEMG leads, central collection belt and trailing lead may all have affected participant's ability to move freely.
- Reflective markers placed on bony landmarks are vulnerable to movement during activity as the skin and adipose tissue moves independently to bone. This can impede the accuracy of the kinematic data.
- Each step down task was undertaken at a self selected speed, therefore some differences may be velocity related more than age related.

2.4 Goals

- To measure peak knee angle between IC and maximum vertical GRF in the sagittal plane.
- To measure peak hip angle between IC and maximum vertical GRF in the frontal plane.
- To determine whether peak vertical GRF after IC is different between older and younger participant groups.

- To determine whether the time from IC to maximum vertical GRF is different between older and younger participant groups.
- To determine, for each of the four muscles on the stepping leg, the magnitude of muscle activity used to attenuate impact between the two age groups.
- To ascertain whether the relationship between the upper body and stepping leg at IC will be different within and between groups.

2.5 Null Hypotheses

1. There will be no difference between older and younger participants in maximum knee angles in the sagittal plane between IC maximum vertical GRF.
2. There will be no difference between older and younger participants in maximum hip angles in the frontal plane between IC and maximum vertical GRF.
3. There will be no difference in magnitude of maximum vertical GRF between older and younger participants.
4. There will be no difference in time taken to reach maximum vertical GRF from IC between older and younger participants.
5. The relative amount of muscle activity used between IC and maximum vertical GRF to attenuate impact will be the same for both older and younger participants.
6. The relationship between upper body and the stepping leg at IC in an antero-posterior direction will remain the same within and between each group of participants.

2.6 Operational Definitions

Initial contact: The point during the step descent task, when the foot of the stepping leg first contacts the forceplate. This was identified by the first signal collected from the forceplate positioned directly below the step.

Vertical GRF: Ground reaction forces are divided into 3 components, describing the forces on the body from its interaction with the support surface. The vertical component describes the forces acting in the vertical direction.

Maximum vertical GRF: The maximum vertical GRF was identified by the first major peak in vertical GRF trace after IC. The early minor peak occasionally observed with adults who have a very heavy heel strike was ignored for the purpose of this study.

Relationship between body segments: the alignment of the upper body on the lower body in an antero-posterior direction. This is measured from mid PSIS to the lateral malleolus of the stepping leg at IC

Net joint moment: when the external and internal moments acting about a joint are equal in magnitude the joint will not move, if the moment is larger in one direction, the net joint moment will determine the direction of the joint movement

3 Literature review

3.1 Introduction

The ability to negotiate steps and stairs is a vital function without which we are extremely limited in our ability to participate in activities of daily living. Most adults require the ability to negotiate steps and stairs frequently during normal activities of daily life (James & Parker, 1989). Stairs are encountered in the workplace, at home and in many public pedestrian areas, such as parks and shopping centres (Beaulieu, Pelland, & Robertson, 2008). Negotiating stairs can be challenging in terms of kinematic and energy requirements and present a significant risk of falls, leading to both injury and death especially to the older population (Beaulieu et al., 2008; Startzell, Owens, Mulfinger, & Cavanagh, 2000). Several studies have identified stair descent as being the most energy costly and dangerous part of stair negotiation (Beaulieu et al., 2008; Cavanagh, Mulfinger, & Owens, 1997) with the majority of the literature focusing on the safety aspects and energy requirements of the task at the time it is being undertaken. Few authors have investigated the cumulative risk of increased impact on lower limb joints during activities such as stair descent. It is suggested that the increased impact found to occur with aging (Robbins et al., 2001) may have detrimental effects on the lower limb joints (Livingston, Stevenson, & Olney, 1991). A change in rate and magnitude of joint loading has been implicated as a factor in the pathogenesis of osteoarthritis with advancing age.

A systematic literature search was conducted between October and December 2007 using Ovid, Evidence Based Medicine Reviews, Allied and Complimentary Medicine, CINAHL, MEDLINE, PsychINFO, and EBSCOhost electronic search engines. The search was repeated in February 2009 to ensure recent literature was retrieved. Key words used were (Step OR Stair) AND (Climb OR Descent), (Impact OR Ground reaction force OR shock absorption) and (Muscle active* OR muscle contract*) AND (lower limb OR leg). A hand search through the references of selected studies was then undertaken to identify any studies that had been overlooked. Eligible studies published from 1975 through to the present day were selected if they evaluated any kinematic or kinetic aspects of stair descent in the older or younger population, but those analysing aspects of stair descent in participants with symptomatic pathology were excluded. The cut off date of 1975 was chosen because the majority of kinematic and kinetic studies have been undertaken since the late 1970's (Livingston et al., 1991). Thirty studies were identified, one study was excluded after reading as it compared different compensatory stair descent patterns and was not relevant to the current project; the remaining 29 included some aspect of normal adults undertaking stair descent activity with a kinetic or kinematic measurement and are included in the review. There were 11 studies that included the above criteria but also *compared* older and younger adults, these were the key studies and are included in Table 3.1 in the literature review.

3.2 Strategies which control impact during stair descent

The two main strategies that allow the rate and magnitude of vertical GRF to be controlled in the descent from a step are:

The ability of the muscles of the stepping leg to eccentrically control the rate of impact and act as a shock absorber.

This will be dependent on temporally accurate muscle activation of sufficient magnitude and will be referred to as the *stepping phase* of the descent task.

The ability of the supporting leg to control the lowering of the body to the stair below.

This will be dependent on the range of motion of the hip, knee and ankle and the strength and control of the muscles of that limb. In the remainder of this thesis this will be referred to as the *controlled lowering phase* of the descent task. Both phases are considered in more detail below.

3.2.1 Requirements of the stepping leg

At IC of the stepping leg in a descent task, the lower limb muscles have a vital role in attenuation of the impact. The rate of loading is controlled by the timing of neuromuscular protective mechanisms and optimal foot placement (Hsu et al., 2007). If the height of the step is misjudged there will be rapid loading, leading to jarring which may cause trauma to articular structures (Hurley, 1999). If the timing of protective muscle activity is disturbed the musculoskeletal system is exposed to repetitive and increased stresses that may, in due course lead to damage to the underlying bone and predispose the individual to osteoarthritis (Liikavainio et al., 2007). The important factors that help determine the attenuation of the impact at each joint will be considered in this section.

Hip Joint of the stepping leg

According to Andriacchi, Andersson, Fermier, Stern and Galante (1980) at IC in step descent the hip joint is in approximately 15° flexion. The external flexor moment is controlled by gluteus maximus but there has been minimal investigation of the muscle activity during stair descent. McFadyen and Winter (1988) did record gluteus maximus SEMG but only reported a mean for the whole task of step descent. From the information reported on mean SEMG for step ascent and descent, gluteus maximus is much less active in step descent than step ascent, but it is not possible to infer a maximum value from the information presented. From graphs, it appears that gluteus maximus has a small activation at IC, which would resist the external flexor moment; it is then active as the body weight is brought onto the stepping leg. The other muscle controlling hip movement during step descent is gluteus medius, controlling the external adductor moment.

In the study by Andriacchi et al. (1980), the mean of the ten participants' maximum external adductor moment recorded for a step down activity was 86Nm (SD± 31.4) which would have been resisted by the internal moment generated by contraction of the hip abductors. This is unable to be quantified because in this study, as previously noted, neither hip muscle activity nor hip movement in the frontal plane was recorded. The role of the knee extensor muscles in the attenuation of impact has been investigated by several researchers (Andriacchi et al., 1980; Chleboun, Harrigal, Odenthal, Shula-Blanchard, & Steed, 2008; Hinman et al., 2005; Hortobagyi & DeVita, 2000; Hsu et al., 2007; James & Parker, 1989; Larsen et al., 2008; Liikavainio et al., 2007; Sheehy, Burdett, Irrgang, & VanSwearingen, 1998) but there has been very little investigation of the hip abductor muscles' role in attenuation of impact during the stepping phase of the descent task. The only study that directly measures gluteus medius activity in the stepping leg during stair descent is by McFadyen and Winter (1988). The authors note that gluteus medius becomes active just prior to initial contact of the foot on the lower surface and continues to be active through the phase between IC and mid stance, when the majority of energy absorption occurs. It is probable that the role of gluteus medius and the degree of external adductor moment generated at IC is rarely commented on because the majority of studies concentrate on movement and moments in the sagittal plane. This may be because both the knee and ankle have significantly more movement in that plane and there is much less variability in measurement than in the frontal plane (Yu, Kienbacher, Growney, Johnson, & An, 1997).

Knee joint of the stepping leg

At IC the knee is fully extended but immediately begins to flex to absorb kinetic energy. Chleboun et al.(2008) report that peak knee flexion in a study of young women was 21° (SD±3). The knee flexion was controlled by eccentric quadriceps contraction which dissipates the load and minimises stress on the joint (Hurley, 1999). Loss of this protective eccentric loading mechanism may lead to an increase in rate or magnitude of loading and consequently a higher risk of damage to underlying bone (Hurley, 1999). In order for this eccentric loading mechanism to occur, quadriceps must be able to contract at the correct time with the correct amount of force. Strength and speed of force generation typically decline with age associated with a process known as sarcopenia (Deschenes, 2004). However depending on the composition of muscle fibres within a muscle, different degrees of decline are reported. It has been noted that decrement in functional ability often exceeds the loss of isometric strength due to the slowing of contractile speed in older adults (Davies, White, &

Young, 1983; Gauchard, Tessier, Jeandel, & Perrin, 2003). The knee extensors have a higher proportion of type II fibres which atrophy more readily than type I with ageing (Lanza, Towse, Caldwell, Wigmore, & Kent-Braun, 2003). This leads to a loss of power (calculated as the product of torque produced and speed of contraction). The reduced capacity to generate force quickly may have significant implications to the ability of the knee to absorb kinetic energy at IC. The difficulty the quadriceps has in activating in a timely manner is illustrated in a study by Hinman, Cowan, Crossley and Bennell (2005) comparing quadriceps onset during a step down task between older (average age 68 years) and younger (average age 25 years) adults. It was shown that despite both groups activating quadriceps prior to impact, older participants activated the muscle 169ms before the younger group which represented a statistically significant difference. This finding was contrary to expectations of slower muscle activation in an older group. This may be a compensatory strategy because of the increased time older adults require to reach maximum activation (Lanza et al., 2003). It has been shown that there is an age related decline in the rate of motor unit discharge and older adults may need to begin activation early to achieve the required torque at impact. The result is that this preactivation or bracing activity that stiffens the limb may increase *impulsive loading*, increasing jarring and vertical GRF. Impulsive loading is the reduction in shock absorption by eccentric muscle contraction, leading to more reliance on the ground to decelerate the participant. Timely and accurate muscle contraction of quadriceps allows control of a larger range of motion and therefore may reduce stress at joints by dissipating kinetic energy and reducing both the rate of increase and magnitude of vertical GRF.

As well as investigation into preactivation of quadriceps, the extent of concurrent agonist and antagonist co-activation has been investigated. In a study by Hsu et al.(2007) it was reported that older men had significantly increased co-activity of the extensors and flexors around the knee. Hortobagyi and DeVita (2000) found that, compared to younger adults, older adults increased muscle co-contraction. When normalised to maximum voluntary contraction, the older adults increased contraction of vastus lateralis and biceps femoris by 140%. Regression analysis revealed that biceps femoris co-activity explained 62% of the variance in leg stiffness between older and younger participants. When normalised, pre-activity of vastus lateralis and biceps femoris was 228% greater in older adults compared to younger during step descent. This finding may help to explain why the rate of initial loading as measured by the rate of change of vertical GRF in body weight/second was higher in the older than in the younger men studied. The co-activation may be another strategy to stiffen the limb to increase stability at impact.

In a study by Hamel, Okita, Bus and Cavanagh (2005) it was found that younger women had significantly larger external flexor moments about the knee at IC, compared with older women. The younger women appeared to have increased their knee flexion and reduced the stiffness of the joint at impact to reduce the rate of vertical GRF. Another study by Chleboun et al. (2008) investigated 33 healthy young women and found that vastus lateralis lengthens continuously from initial contact through the entire first phase of flexion suggesting that the impact is being attenuated during this phase.

Any reduction in strength of the quadriceps muscle may reduce the range of knee flexion a person feels confident to allow. An increase in flexion would increase the external flexor moment the quadriceps had to counteract. The study by Hsu et al. (2007) supports this idea reporting that knee flexion angles were considerably reduced in the older men studied compared with younger men at initial contact.

Ankle joint of the stepping leg

Initial foot placement for stair descent almost always demonstrates forefoot contact (Riener, Rabuffetti, & Frigo, 2002). Consequently the gastrocnemius muscle is the first muscle important for attenuation of impact during a step down activity. The forefoot makes IC with the ground then dorsiflexion of the ankle joint is controlled by eccentric muscle contraction. McFadyen and Winter (1988) found that at IC, the majority of the absorption of energy was undertaken by gastrocnemius. However the main contributor to the absorption of energy is the muscle-tendon complex with some studies actually showing gastrocnemius shortening, rather than lengthening i.e. concentric rather than eccentric muscle contraction. The shortening occurs to increase the dynamic stiffness of the muscle-tendon complex in order that it can achieve the controlled lengthening required (McFadyen & Winter, 1988; Spanjaard, Reeves, van Dieen, Baltzopoulos, & Maganaris, 2008). The properties of the muscle-tendon complex change with age, the tendon exhibiting higher compliance with increasing age, this may complicate the interpretation of EMG related findings during stair descent. Older adults have been found to use tendon elasticity less efficiently than younger subjects and may substitute earlier agonist activation, leading to increased vertical GRF (Hoffren, Ishikawa, & Komi, 2007).

The investigation by Andriacchi et al. (1980) of net joint moments has revealed that both the knee and ankle play a large role in stair descent. Ankle dorsiflexion external moments of 107.5 Nm (SD ±32) were calculated and necessitate plantar flexor muscle forces of a similar magnitude, taking in to consideration other components of the internal moment such as tendon stiffness. However these were not significantly different from levels recorded during level walking whereas knee flexion moments during stair descent 146.6Nm (SD±48) are three times that recorded during level walking. In an earlier study investigating net joint moments and power during step descent, McFadyen and Winter (1988) found that the peak knee and ankle torques occurred at early stance, during weight acceptance and attenuation of impact, and not during the lowering of the body onto the step. This may be because the body's centre of mass is more central to the base of support, during the controlled lowering phase, as opposed to the less stable position of decelerating the body at impact.

3.2.2 Requirements of the supporting leg

The controlled lowering phase of stair descent occurs from approximately mid stance until just prior to the beginning of the swing phase of the same leg (McFadyen & Winter, 1988). This phase of descent is marked by single leg support, enabling the other leg to descend to the stair below. It allows a component of vertical and anterior movement which are constrained by the stair dimensions, both height of stair and depth of tread (Mian, Thom, Narici, & Baltzopoulos, 2007). The important factors at each joint that assist in a controlled lowering are considered below.

Hip joint of the supporting leg

Andriacchi et al. (1980) investigated lower limb biomechanics during normal stair negotiation. Joint angles of the hip knee and ankle were measured during both the stance and swing phases of the task. In the hip joint of the support leg, from mid stance until the foot leaves the step, there is a movement from approximately 10° flexion to near neutral then a return to approximately 20° flexion as the stepping leg lands on the step below (exact range was not recorded in the results but could be seen represented in a graph). During this time the movement of the hip is controlled by the hip extensors offsetting a changing external hip flexion moment. In the frontal plane the hip adducts at mid stance which is produced by an external adduction moment, controlled by the hip abductors. No range of movement for the hip in the frontal plane is reported in this study. The control of the hip movements is stated but not investigated as no recordings from hip muscles were undertaken. It is not possible to give exact ranges of motion for any given phase of the movement because the focus of the study was maximum range required for the whole task; therefore exact range at any given point can be approximated from graphed data only. In a study comparing kinematics of stair negotiation between old and young (Mian, Thom et al., 2007) hip range of movement in the frontal plane was reported. Maximum hip adduction, which occurred at the end of the controlled lowering phase, was 4.7°± 2.2° in young adults and 9.4°±4.3° in older adults. No electromyography was undertaken in this study; unfortunately the authors were unable to report kinetic analyses due to an equipment malfunction.

In Andriacchi et al's. (1980) study, moments about the hip can be approximated from graphed data. The moment about the hip at mid stance changes from about a 15 Nm external flexion moment to a very small extensor moment, as the foot contacts the floor. The external adduction moment is much larger, being about 50 Nm at mid stance, gradually reducing to about 20 Nm as the stepping foot touches the floor. Based on these findings, the important muscle for maintaining stability around the hip at the point of impact of the stepping leg would appear to be gluteus medius. This is supported by McFadyen and Winter (1988) who found that EMG taken from gluteus maximus and gluteus medius showed that only gluteus medius was active after mid stance and during the controlled lowering phase of the step descent task.

A recent study by Hollman et al. (2009) investigated the magnitude of gluteus medius activity during the controlled lowering phase. The subjects were all young women 20-30 years old and the mean gluteus medius activity was 21.9±13.1% of MVC. In contrast the magnitude of gluteus maximus was significantly less than that of gluteus medius at 9.2± 4.1 % of MVC.

McFadyen and Winter (1988) noted that the hip showed large variability in moments and powers calculations during step negotiation. The results from this trial need to be viewed with caution due to the very small numbers (three normal males) and the lack of anthropometric data recorded (weight and height similar to each other but undisclosed). However the authors hypothesised that the observed variability could be explained by the different requirements for the control of balance. Balance requires the centre of mass to be maintained inside the base of support and it is controlled mainly by the hip musculature, especially during single leg support. The most challenging position for balance is when the separation of the centre of mass and the centre of pressure is at its greatest. Increased separation is noted in stair descent, less separation is found during stair ascent (Zachazewski, Riley, & Krebs, 1993). The separation of centre of mass and centre of pressure is of the smallest magnitude during normal gait, which generates less angular torques, requiring smaller internal muscle forces to counteract them. During some phases of normal gait the trunk is vertical, which generates no angular torque but during destabilising phases of gait such as IC and push off, the hip muscles counteract the resultant external flexor or extensor torque to maintain balance (Winter, 1995). In the frontal plane during stair descent the largest separation between centre of mass and centre of pressure occurs just before the stepping leg contacts the stair below. Chang, Mercer, Giuliani and Sloane (2005) support the idea that the variability of hip muscle activity may be explained by the effort to maintain balance under challenging conditions. The authors investigated the rate of force development in gluteus medius during several voluntary balance activities including *one leg stand* and *tandem stand*. Rate of force development (the time taken to go from 10 - 60% of maximum force) was negatively correlated with performance on balance tasks that challenged lateral stability. The more slowly force was developed in gluteus medius the poorer the performance was for the balance task. Descending a step can be considered a challenging single leg task so the degree of variation between moments, may be partly dependent on the individual's stability on each individual trial. However variability of the movement of the centre of mass relative to the centre of pressure has also been observed in adults without any reduction in balance. Protopapadaki, Drechsler, Cramp, Coutts and Scott (2007) found that in a study investigating stair negotiation in healthy younger adults, that there was significant variability in hip moments related to changes in the position of the trunk. Alterations in the position of the centre of mass relative to the centre of pressure resulted in the ground reaction force falling either anterior or posterior to the hip joint, leading respectively to either a flexor or an extensor external moment about the hip of the weight bearing leg. The degree that the centre of mass approaches the vertical axis affects external moments acting about the hip, knee and ankle and therefore the magnitude of the internal moment required to adequately control the movement (Protopapadaki et al., 2007). This study only investigated movement in the sagittal plane so is not directly comparable with studies investigating adductor moments controlled by gluteus medius but does suggest that an altered relationship between centre of mass and centre of pressure is not always due to impairment in balance or strength. In one of the earlier step descent studies by Townsend, Lainhart, Shiavi and Caylor (1978) atypical body positions were noticed when investigating variability amongst healthy and injured young men of differing levels of physical activity. It was noted that the altered strategies seemed to occur in the uninjured as well as the injured and therefore could not be ascribed to any impairments caused by the injury and were part of the normal variation seen during movement. MacKinnon and Winter (1993) investigated different ways the body supports the head, arms and trunk, accounting for significant differences in moments about the hip between participants. This was a study of level walking and may not be completely comparable to step descent however the difference in kinematics seemed to be accounted for by changes around the hip joint. The head arms and trunk were held either in front of the hip joint, leading to an external flexor moment or behind the hip joint leading to an external extensor moment. External moments need to be balanced by opposing internal moments consisting mostly of muscle activation, in order to control movement of a joint. Mian, Narici, Minetti and Baltzopoulos (2007) also investigated the relationship between centre of mass and centre of pressure during stair negotiation comparing a younger and an older group of participants. Both groups were healthy and living independently in the community. No differences between the groups in the relationship between centre of mass and centre of pressure in either the frontal or sagittal planes were found.

Knee joint of the supporting leg

In the study by Andriacchi et al.(1980) investigating stair descent in normal young men, it was discovered that through the controlled lowering phase, the knee joint flexed to a maximum range of 68.9±13.3°. This study selected a step height of 25.5cm, in order to replicate the height of outdoor stairs sometimes encountered. The height of the step may have influenced the knee joint range and is larger than many step heights normally encountered in daily life (Roys, 2001). A study undertaken by Livingston, Stevenson and Olney (1991) investigated healthy women of differing height, negotiating stairs of varying dimensions. The purpose of the study was to describe the kinematic differences between tall, medium and short women negotiating steps of different heights. They found that participants adapted to differing stair dimensions by changing knee range of motion (ROM) before that of the ankle or hip. Joint angles from 83-105˚ of knee flexion were recorded. This implies that knee joint range in particular is very dependent on the task. At the knee during the controlled lowering phase, the maximum external flexion moment recorded by Andriacchi et al. (1980) was 146.6Nm. This is counterbalanced by an internal extension moment produced by eccentric quadriceps, slowing the descent of the body and reducing the impact associated with landing. In this study the muscles found to be active were vastus medialis and rectus femoris, however no muscle recording was taken from the other quadriceps muscles and more recent research implicated vastus lateralis as having a very significant role in stair descent (Chleboun et al., 2008).

The strategy of maintaining weight on the lowering leg for a greater proportion of the controlled lowering phase is one strategy that may be used to reduce impact at initial contact on the stepping leg. A successful use of this strategy means that impact does not necessarily increase under conditions that might be expected to increase it. Spanjaard et al. (2008) investigated the effect of changing step height and body mass on a step descent task in 10 healthy young men. Increased body mass was achieved by the participants wearing weighted jackets during the task. With an increased mass, the vertical ground reaction force at IC did not change, but the joint moments in the supporting leg increased. This implied a change in strategy of the relationship between the upper and lower body segments although there were no measures taken. The participants were possibly keeping their upper body over the support leg and using more eccentric muscle control to ensure that the vertical GRF of the stepping leg at IC did not increase. The strategy of maintaining the weight over the support leg until just prior to impact, to reduce the rate or magnitude of the vertical ground reaction force was employed in the younger population being investigated in this study. This is a strategy that appears to be less successfully implemented in an older population. Hamel, Okita, Bus and Cavanagh (2005) found that older women, despite generating significantly higher internal knee extensor moments than younger women during late stance in step descent, still had .a loading rate at IC that was significantly higher than in the younger women. This may imply that the older women were unable to control the lowering of the stepping leg.

Despite the fact that step descent is normally easily accomplished in young adults, in the older adult the maximum strength available to the individual may not be sufficient to counteract the external torques generated about the knee and ankle (Hortobagyi, Mizelle, Beam, & DeVita, 2003). In the study by Hortobagyi et al. comparing healthy older and younger adults it was found that older adults had reduced maximum quadriceps strength during functional tests; these included, stair negotiation and rising from a seated position. Consequently, relative effort in stair descent was 88% ±43% for older adults, compared with relative effort for the same task in young adults of 42%±20%. Relative effort was measured as the percentage of knee extensor moment during stair descent relative to the maximum knee extensor moment produced when tested on a maximum effort, supine leg press. Reeves, Spanjaard, Mohagheghi, Baltzopoulos and Maganaris (2008) support this finding stating that in absolute measurement, older adults generate similar knee joint moments to younger adults but when compared to maximum isotonic strength, older adults work at a relatively higher level. This study approximated the task undertaken by the knee extensors during the controlled lowering phase by testing eccentric maximum strength, adding weight to the findings of the study by Hortobagyi et al.

Three further factors might hamper the use of the controlled lowering strategy in an older population. Firstly it has been shown that there is a significant co-contraction in biceps femoris and quadriceps femoris measureable during the step down task; however this has generally been measured in the stepping, rather than the supporting leg (Hsu et al., 2007). Minimal investigation of muscle co-activity in the supporting leg has been undertaken, however as co-contraction may be a result of an increase in effort required or a mechanism to improve stability, it is not unreasonable to suggest that such a mechanism is present in the supporting leg. Lark, Buckley, Bennett, Jones and Sargeant (2003) and Rice (2000) both note that there is little research into co-contraction of muscles during sub maximal contraction in the older adults undertaking functional activities and that this is an area requiring further investigation. Secondly during the controlled lowering phase older adults often maintain a flat foot posture for longer than younger adults this is postulated to increase their base of support and facilitate balance. This flat foot action places the body weight on the lowering leg causing the ground reaction force to fall more posteriorly to the knee than in the more usual rise onto the ball of the foot. Therefore the external knee flexion torque is higher in older adults (Lark, Buckley, Jones, & Sargeant, 2004). Thirdly the ability of the neuromuscular system to reliably select appropriate neural pathways for stable and functional movements is compromised in older adults (Kurz & Stergiou, 2003). This may in part be due to the increased motor unit innervation ratio, with each motor neuron innervating more muscle fibres. This occurs as a result of muscle fibres being denervated by the progressive loss of alpha motor neurons from the spinal cord with increasing age. Once denervated a muscle fibre exerts a retrograde trophic signal and is re-innervated by a healthy motor neuron. The denervation-reinnervation process occurs in response to motor neuron death and although it begins in the 3rd decade of life it accelerates rapidly during the 6th decade (Rice, 2000). More muscle fibres units per motor neuron leads to a reduced ability to grade force accurately.

Ankle joint of the supporting leg

Ankle range of motion during the controlled lowering phase of stair descent is dependent on several variables. The variables are the range available, the control of ankle motion, and the height of the step. In an investigation by Lark, Buckley, Bennett, Jones and Sargeant (2003) the range at which peak ankle torque occurred was compared between a group of active older men and a group of healthy younger men during a step. In the older men, at peak torque, dorsiflexion was 21° on a 20cm step, 24.6° on a 25cm step and 24° on a 30cm step. In the younger men peak ankle joint torque was reached at dorsiflexion of 14.7° on a 20cm step, 17° on a 25cm step and 16° on a 30cm step. The older men had a significantly increased range of dorsiflexion before reaching peak torque at heel off. Obviously although step height does have an effect on range of motion, the difference between the two groups suggests that a different strategy was employed in older men to account for these findings. In the ankle joint during the controlled lowering phase, individuals usually rise onto the ball of the foot as they prepare to step to the surface below (Lark et al., 2003). An inability to control this rise onto the ball of the foot may lead to an uncontrolled forward and downward movement and a loss of balance. In this study the authors also investigated the strategy used to lower the body and the ankle joint torque of the stance leg during the lowering phase. Results showed that the absolute time spent in the controlled lowering phase between the older and younger men was similar, however the percentage of that time that older men spent on the ball of their foot was significantly lower than the younger group. The older adults maintained a flat-foot posture for significantly more of the controlled lowering phase. The older men in this trial exceeded the passive movement range that had been tested prior to the stepping task, in a strategy to maintain a flat foot position for longer, possibly because of the balance requirements of the task. Bodyweight produced more force than generated during the manual testing procedure. Due to the increased range and reduced torque, the older men had reduced dynamic stiffness (the measure of resistance to change in joint angle). Dynamic stiffness is one of the factors that is important to facilitate a rapid increase in joint torque to assist in control of movement (Thelen, Schultz, Alexander, & Ashton-Miller, 1996).

Lark et al. (2003) also investigated knee kinematics and stated that the majority of the altered strategies seen in the lowering phase were seen around the foot and ankle rather than the knee. This appears to be in direct contradiction to the study of negotiation of step descent by Livingston et al. (1991) where it was noted that participants altered their knee range of motion in response to altered step height before making changes to ankle or hip range of motion.

However in the study by Livingston et al. the participants were young and would probably have had better knee strength than the participants in Lark et al's. study, as the quadriceps due to their higher proportion of Type II muscle fibres lose strength at an increased rate in the sixth decade of life. The older adults in Lark et al.'s (2003) study may have been compensating for that decline in strength by using more ankle range of motion, which may explain the difference in findings between the two studies.

3.3 Vertical ground reaction force.

The force with which the foot contacts the lower step has been shown to be affected by both the supporting leg, during the controlled lowering phase and the stepping leg during the stepping phase.

Patterns of GRF show a large within person variation during stair descent, compared to the reproducible pattern seen in level gait (Larsen et al., 2008; Stacoff, Diezi, Luder, Stüssi, & Kramers-de Quervain, 2005). There is also a large between person variability, which is so large that a variety of different stair descent strategies are suspected. The normal 'M' shaped pattern of vertical GRF disappears, with the first maximum, corresponding to energy absorption, becoming very dominant and the second maximum, corresponding to push off, often disappearing altogether.

Vertical GRF are highest at the beginning of stance phase of the stepping leg during stair descent (Protopapadaki et al., 2007). The documented value of vertical GRF at initial contact during stair descent varies among authors; 1.52 (SD±0.21) times body weight (Liikavainio et al., 2007), 1.43 times body weight (Riener et al., 2002) 1.6 times body weight (Stacoff et al., 2005) but there is agreement that it is higher than for walking on a flat surface (1.2 times body weight). However the vertical GRF's reported are significantly lower than for many sporting endeavours and the consequential damage reported by some authors, to occur with increasing age, may depend on the frequency of occurrence not just the magnitude of these impulsive forces (Sims, 1999).

Robbins et al. (2001) noted that in a step down task undertaken by healthy adults, grouped by age in decades, vertical GRF remained fairly constant until the 6th decade then rose sharply in response to impulsive loading. Hamel et al. (2005) did find a significant increase in the rate of onset of the vertical GRF for older versus younger participants during stair descent but not an increase in the magnitude of the vertical GRF. Reeves, Spanjaard, Mohagheghi, Baltzopoulos and Maganaris (2008) found that when speed was controlled for older adults did not increase their vertical GRF compared to their younger counterparts. Stacoff et al. (2005) disagree with Robbins et al. about an increase in vertical GRF with increased age, as no significant difference between age groups was found during their study comparing vertical GRF during level walking and stair descent and ascent of different step dimensions. However during the study by Stacoff et al. self selected velocity was used, the authors suggest that a reduction in speed and possible changes in strategy may have led to a reduction in the GRF in the older group. Larsen et al. (2008) in a study of stair negotiation also found no significant difference in vertical ground reaction force between older and younger participants during descent, but as in the previous study the participants used a self selected velocity. In this study the self selected velocity of the older group was 20% lower than their younger counterparts. The authors hypothesised that a reduction in cadence may be a compensation to reduce the vertical GRF. Aging is associated with less certainty in selecting a specific range of motion at both the hip and knee. This may be as a result of the inability to appropriately weight sensory inputs and correlate them with appropriate motor outputs (Kurz & Stergiou, 2003). It is hypothesised that an increase in moderate level impulsive loading may increase the incidence of osteoarthritis, whereas a lower load has been shown to have minimal effect, an increase in impulsive loading in the over 50's could exceed the threshold for damage. A précis of the literature investigating the differences between older and younger adults in step descent kinetics and kinematics can be seen in Table 3.1. Studies which investigated vertical GRF and the variables that may affect either the magnitude or the rate of loading were included. The findings that directly pertain to step descent and the variables measured in the current study are reported.

In a systematic review undertaken to establish the link between activity and osteoarthritis, it was found that sports, recreational activities and activities of daily living all present risk factors for the development of osteoarthritis in the knee. Sports and recreation also present a risk factor for osteoarthritis in the hip (Vignon et al., 2006). The risk correlates with the intensity and duration of the activity. However as this review did not differentiate between older and younger age of onset of the disease it is difficult to establish whether it is the cumulative damage over many years that eventually leads to joint damage, or whether at a certain age the protective mechanisms function less effectively. However a study by Verweij, van Schoor, Deeg, Dekker and Visser (2009) helps to clarify the possible pathogenesis of arthritis in older adults. The authors investigated older adults (55-85 years) with no clinical osteoarthritis and monitored them over a period of 12 years. Incidence of osteoarthritis of the knee during this follow up period was 28%; the results were adjusted for demographics, health status, BMI and early life and current physical activity, including lifetime physical work demands. It was found that a high level of mechanical strain and low muscle strength were correlated with an increased risk of developing osteoarthritis of the knee. Activities of high mechanical strain were defined as including but not exclusively, dancing, tennis and volleyball. All these activities could potentially increase the rate and degree of load on the joint, compared to level walking, which was given as an example of a low mechanical strain activity. It is not clear from the study whether the reduced muscle strength preceded or followed the onset of arthritis because the follow up checks only occurred every three years. More frequent monitoring may have been able to discover more about the role of muscle weakness and dysfunction in the pathogenesis of arthritis.

Table 3.1: Studies investigating the kinetics, kinematics and /or EMG of step descent, comparing older and younger adults

Author	Date	Participants and Method	Main Outcome measures	Results	Main findings
Hortobagyi and DeVita	2000	11 young(20.8) and 12 older (69), healthy sedentary community dwelling women Kinematic and kinetic analysis with EMG data. Ste*p*-down task using right leg, from a platform 20% of body height. approx 32.8cm	Vertical and Horizontal ground reaction forces. Ankle and knee angular position. EMG of VL, BF, Gn(lat) and TA.	Older adults compared to younger used more force, less leg displacement and an increase in leg stiffness during the downward step. Anticipatory muscle activity was increased in the elderly. Muscle activity and coactivity increased at initial loading in older.	Anticipatory muscle activity for postural control may overlap with voluntary muscle activity and degrade the quality of movement. Alteration in preparatory scaling of force at close to that required for the task leads to increased activity. Authors question whether stiffness is a centrally driven compensatory mechanism for ↓ neuromuscular control and loss of type 1 muscle fibres
Robbins et al.	2001	36 male subjects, tested in 6 groups of age matched men. Subjects performed 20 consecutive 'step down' actions from a 4.5cm high step	GRF recorded at each step, calculated vertical impact, forces, moments and centre of force.	Significant correlation between age and impact with a distinct cut off at 50 years. Vertical GRF seems to remain steady until 50 then rises sharply over that age.	Because an increase in moderate level impulsive loading has been shown to increase the incidence of OA, whereas a lower load has been shown to have minimal effect, it may be that the increase in impulsive loading in the over 50's exceeds the threshold for damage.

Author	Date	Participants and Method	Main Outcome measures	Results	Main findings
Christina and Cavanagh	2002	Healthy adults,12 younger (24±3.3),12older (73.3 ±1.9) 7 step staircase, step height 18cm, force plates located on step 2 and step 4. Speed of descent measured. Participants walked down the fight 5x with good lighting and 5x with poor lighting. Body harness used for safety.	First and second peaks of vertical GRF. First and second peaks of anterior GRF Initial loading rate	Double peak for vertical GRF. 1^{st} peak bigger than 2nd. Illumination seemed to have little effect on kinetic variables except low illumination lead to lower 1^{st} peak of GRF trace. Higher loading rates in the elderly compared to young at IC.	GRF patterns in stair walking are very different from level walking, higher peak at IC. Elderly adopt more cautious strategies with push off and braking, but not loading rates. The authors hypothesised this may reflect lack of control at touchdown, or joint stiffness.
Lark et al.	2003	6 younger (mean 23.6), 6 older (mean 67.7) men. Stepping down from one force plate to another. Step heights 200, 250, 300mm. arms crossed during activity.	Passive knee flexion and ankle dorsiflexion. Force plate data (v GRF) Individual net joint torques were calculated.	Max torque values for the elderly at the ankle were lower than for the young.→ reduced ankle stiffness. Max knee torque were similar between older and young	Altered control strategy for stepping down was achieved by the elderly, by altering ankle kinetics leaving foot flat, forcing ankle into dorsiflexion.

Author	Date	Participants and Method	Main Outcome measures	Results	Main findings
Lark et al.	2004	6 younger men (25±1.7) and 6 older men (68±1.4), all healthy and independent. Step down task (x3) from steps of 20, 25, 30, and 33.5cm with arms across chest. Force plate under both the step and landing	Joint kinematics of knee and ankle of the supporting limb and vertical GRF from the landing limb was recorded. Sagittal plane recording was undertaken.	The ROM used in a step down task was represented as a % of available ROM. Older adults utilised 80-100% of available ROM irrespective of step height. Older remained on a flat foot longer during the support phase which increased ROM in ankle.	Old and young use very different strategies for stepping down possibly due to balance requirements. Centre of mass is further behind the knee joint in the lowering phase, which will increase the flexion torque about the knee leading to more work for the quadriceps. However EMG was not recorded.
Hamel et al.	2005	12 healthy young women (24.3±2.5) and 10 healthy older women (73.5±2.6). 7 step staircase18cm height. 5x Stair ascent, descent and level walking. All at a fixed velocity	GRF from 4/7 step from force plate. 5 GRF variables 1st and 2nd peak of vertical GRF, 1st and 2nd peaks of anterior GRF. LR of vertical GRF	1st peak of vertical GRF larger than 2nd in Stair descent. Older women had a higher loading rate of vertical GRF than younger. Younger women had higher flexor moment than old about the knee at IC	Higher loading rate in older women suggestive of loss of control in step down. Older women have higher internal extensor moments about the contra lateral knee during step down, to try to reduce loading rates Young women exhibit reduced knee stiffness at IC.

Author	Date	Participants and Method	Main Outcome measures	Results	Main findings
Stacoff et al.	2005	20 healthy subjects, grouped into young, middle and old. Level walking. Stair ascent and descent	Vertical GRF for 3 age groups level walking, ascent, and descent on 2 consecutive stairs at different heights, 13.3, 17.1 and 20cm	Maximum value for stair descent 1.4-2.0 BW.Stair descent vertical GRF showed no significant higher value between groups. Most variability in step descent, this increases with increased step height.	Stair descent produces the most variability in vGRF. First peak generally larger in stair descent. vGRF pattern changes suggest changes in movement strategy.
Hsu et al.	2007	16 younger men (21.2±0.5) and 16 older men (72.0±4.5) Step 20cm height Staircase of 6 steps force plate was at bottom of stair case. 5x stair descent trials, no arm swing allowed	EMG from RF and BF right leg only, %MVC. Knee ROM measured with an electrogoniometer GRF recorded at bottom of stairs	At impact knee flexion angle was much less in older than younger Loading rate in older was 94% greater than in younger Older adults had 26.55% greater leg stiffness than younger leading to higher loading rate but not significantly higher vertical GRF than younger	Coactivity between knee flexors and extensors is greater in older than younger participants before landing Older adults had no significant increased in vertical GRF. The altered strategies lead to an increased reliance on skeletal system and less on muscular control. Suggests an element of training that involves neural control as well as strength.

Author	Date	Participants and Method	Main Outcome measures	Results	Main findings
Mian et al.	2007	13 young men (23-36) 15 healthy older men (73-84). Looking at the relationship between COM and COP during stair negotiation. Stair negotiation pre-set at 90 steps/minute. Starting descent with left foot. 3-step staircase. Step height 17cm.Five ascent and 5 descent.	9-camera 3D motion analysis. COP recorded from force plates built into stairs. COM calculated from a computer model. Medio-lateral COM range. Peak anterio-posterior and medio-lateral COM-COP separation and velocities.	No significant difference found for any of the measured variables	Authors suggest this study may have been underpowered for finding subtle differences and the men chosen in the older group were above average fitness for their age, the self selected pace was also below the average most chose.
Larsen et al.	2008	11 young and19 community dwelling older women. 9-step staircase with force plate as 5th step 5 stair tasks, step height 16cm: Up at SSS,down At SSS, up at 35 steps /min down at 35steps/min, up at max velocity. No use of handrail.	Vertical GRF was recorded. EMG taken from VL, VM, RF, BF, ST, SOL, Gn(lat) and TA. Of Left leg. Normalised to max EMG No kinematic data recorded	Descent only. No significant difference in vertical GRF between old and young. Increased thigh coactivation and EMG magnitude through entire stance phase in older. Higher unloading vGRF in elderly at 35/min. Reduced initial vGRF in older.	Elderly use a different strategy in stair descent with higher EMG and increased thigh coactivation. When speed was normalised, no significant difference in vertical GRF between old and young but coactivation in thigh remained. Possibly a strategy to increase stability. Older SSS was 20% lower than young.

Author	Date	Participants and Method	Main Outcome measures	Results	Main findings
Reeves et al.	2008	17 young adults,(24.6±4.1) and 15 older adults(74.8±2.8). 3 step staircase, step height 17cm Descent of stair at SSS x3 beginning with R foot	9-camera 3D analysis Eccentric extensor moments tested with an isokinetic dynamometer at 4 angular velocities, 60, 120, 180, and 240˚/s. Passive ROM at ankle, knee and hip. EMG from left leg VL, B F, G M, T A.	No difference in GRF, relationship between COP and COM, or EMG traces between old and young. Old and young had similar knee joint moments but when normalised, older adults working closer to their max. Ankle joint moments lower in old than young but were similar relative to their max. When normalised to max. older operated at a higher relative capacity in ROM.	Joint moment demand for stair descent is similar between young and old therefore as the elderly decrease in strength they will be working at closer to their maximum joint moment limits. GRF similar between old and young but joint moments are distributed differently with the older ankle joint operating at a lower absolute joint moment, to stay at the same relative joint moment as younger. In the knee the elderly have similar absolute joint moments, representing higher relative moment than young.

COM-centre of mass; COP-centre of pressure; GRF- ground reaction force; EMG- electromyography; IC-initial contact; VL-Vastus lateralis; VM-Vastus Medialis; ST-Semitendinosis; Sol- Soleus; RF-Rectus Femoris; Biceps Femoris; Gn-Gastrocnemius; TA-Tibialis Anterior; ROM-range of motion; BW- body weight; Max-maximum; SSS- self selected speed;

3.4 Parameters of the Task

The motor control literature purports that movement is constrained by three interdependent factors, the individual, the task and the environment (Davids, Glazier, Araujo, & Bartlett, 2003; Hong & Newell, 2008). The aim of the current study was to investigate a number of dependent variables in a step descent task. We wanted to replicate as closely as possible situations encountered in everyday life. Therefore the parameters of all three components were considered in light of current literature.

3.4.1 Individual: Type of participants

It has been identified by several authors that sarcopenia and a reduction in neural control of muscle activity increases sharply in the 5^{th} and 6^{th} decade of life (Frontera et al., 2000; Patten, 2000; Rice, 2000). We chose a group of older adults who had reached the age threshold for age related changes, but were community dwelling and free of pathology. Literature identifies that the number of muscle fibres begins to decline late in the 3^{rd} decade of life (Roos et al., 1997), so the younger age range was selected to represent a group who would have experienced minimal age related changes.

3.4.2 Task: Instructions to participants

In order to observe as usual muscle activity as possible the participants were informed which leg to use in time for them to process the instruction (Proteau & Girouard, 1984) and initiate a normal pattern of anticipatory postural adjustment. There has been some evidence that the pattern of anticipatory postural adjustment alters with the proposed task. Gelat and Breniere (2000) investigated postural adjustments, compared those measured during level walking and those measured during a step onto a higher level. Although the current project is investigating a downward step some of the same constraints may apply. The authors noted that a change in the duration of anticipatory postural adjustment occurs with a change in intended forward velocity; this usually happens when a change of task occurs so an alteration in velocity when undertaking a downward step would be expected.

Care was taken not to impose a time constraint on the participants which may have induced a rushed step. Increased rate of stair descent in the over 65 population has been identified as one of the most significant factors in predicting a fall during normal ambulation (Pavol, Owings, Foley, & Grabiner, 2001) and this task had a further level of complexity. No imperative to start was given, just the instruction to “go when ready”.

3.4.3 Task: Step height

The step height was selected as being a common height used in domestic and commercial stairway construction and deemed acceptable by the most number of people regardless of age , gender and stature (Irvine, Snook, & Sparshatt, 1990). It has been demonstrated that dependent variables, such as knee angles and moments (Livingston et al., 1991) and speed of negotiation (Protopapadaki et al., 2007) are affected by the height of the step in a descent task, so a commonly used height would give results the most generalisability to everyday life.

Despite the fact that the older participants were likely to have age related changes in muscular strength compared with their younger counterparts it has been found that eccentric strength is retained at a higher level than either isometric or isotonic muscle strength (Hortobagyi et al., 1995). Consequently as the majority of muscle activity is eccentric during the step descent task the step height was considered to pose no undue risk of injury or loss of balance secondary to inability to control descent.

Buckley et al. (2005) also chose to use a single step model when investigating stair descent in a population that included older adults concluding that it reduced the risks of a fall compared to a staircase, including that of fatigue. We agreed and felt that the parameters we were measuring could be effectively measured during step descent from a single step

3.4.4 Task: Walkway

The study undertaken by Robbins et al.(2001) instructed the participants to land on the stair below, and then remain balanced on the stepping leg for several seconds. The requirement to step down and stop immediately despite the forward momentum generated made this a task not normally encountered in everyday life. We wanted to measure the impact of the stepping leg in a more usual task and therefore instructed the participants to step down and continue walking to the end of the walkway.

3.4.5 Task: Leg used to step

Leg dominance is frequently recorded in participant information data but there have been few studies that specifically examine the kinematic and kinetic variables between the dominant and non-dominant leg during stepping tasks. Much of the research has been more focussed on hand dominance, which may well have larger functional implications. However van der Harst, Gokeler and Hof (2007) investigating the difference in kinematic and kinetic data on healthy young adults undertaking a single leg hop reported significant differences between dominant and non-dominant leg. There was an increase in length of hop for the dominant leg and differences in hip angle. The authors felt that the differences, although statistically significant, probably weren't functionally significant as none of the other variables measured, including force data and joint power calculations were significantly different. Demura, Yamaji, Goshi and Nagasawa (2001) found that although power was not always significantly higher on the dominant leg, the dominant leg was usually significantly better when tested on functional activities. Madigan and Lloyd (2005) also found that in the functional task of recovering from a trip or fall that neither older nor younger adults showed any leg preference. These three studies all had an aspect of activity at maximal capacity but the second two studies did include functional tasks, it was deemed important in view of these findings to ascertain that leg dominance did not produce a main effect during the current study.

3.4.6 Environment

Step and stair negotiation is one of the more difficult activities encountered in daily life for sedentary older adults (Williamson & Fried, 1996). Environmental factors such as distraction, decreased lighting or obstacles, outside the control of the individual can increase the risk associated with step negotiation (Startzell et al., 2000). The risk of falls during step and stair negotiation increases sharply at 65 years (Buckley et al., 2005) with 86% of stair related falls occurring in older adults (Kim, 2009). We needed to ensure that all participants would be able to manage the task while experiencing no ill effects;

consequently environmental factors that have been shown to reduce the risk were considered.

The effect of dual task activity on the ability to retain adequate postural control has been shown to affect older adults more than younger (Rankin, Woollacott, Shumway-Cook, & Brown, 2000). The laboratory was consequently only accessible to the researcher during testing enabling noise and distractions to be kept to a minimum. Older adults experience additional difficulties when performing a complex task and negotiating unpredictable obstacles (Chen et al., 1996) therefore all areas were kept clear of obstacles. The cord which attached the EMG collection port to the computer was a potential hazard and care was taken to move it from the walkway and alert the participants to the need for vigilance.

Christina and Cavanagh (2002) reported three incidents of either slips of trips during investigation of the effect of low lighting in a step descent study. As our study was not investigating illumination as a variable, lights were on at all times to increase safety.

3.5 Section Summary

Two strategies are used to reduce the vertical GRF at initial contact during a step descent task. The primary strategy occurs during the stepping phase when the stepping foot contacts the stair below. This phase is marked by the necessity for muscles to contract eccentrically to control a small range of motion in a temporally accurately manner to absorb the energy generated by the step down. The second strategy occurs during the controlled lowering of the body, slowing the velocity at which the stepping leg contacts the lower stair. Both phases of step descent involve the lower limb muscles around the hip, knee and ankle resisting the moments present about each joint. In the hip the gluteus maximus and gluteus medius resist the small flexion moment and larger adduction moment; around the knee the quadriceps resist the flexion moment and in the ankle gastrocnemius resists the dorsiflexor moment. It has been noted that joint angle range and consequently the moments about each joint vary depending on the task and with increasing age. An alteration in range of motion, strength or neural control of the muscles around the hip, knee or ankle can lead to either of these strategies being less efficient. The consequence of that may be an increase in the magnitude or rate of loading in the vertical GRF and the potential for the jarring of impact to cause cumulative damage. The focus of the current study will be on the stepping phase, measuring the magnitude of joint range of motion at the hip and knee and the muscle activity required to absorb energy between IC and maximum vertical GRF.

Human movement is constrained by the individual, the environment in which the task is undertaken and the parameters of the task itself. In order to increase the generalisability of the results of our study to everyday life, the literature concerning factors that may alter task completion was considered. In any study where the effect of independent variables is being tested on dependent variables there is a need to control for extraneous variables (Grimes & Schulz, 2002). However there is normally occurring variability in performance, which cannot be controlled. The following section will review relevant literature to reduce the extraneous variables that were within our control.

3.6 Measurement of the dependent variables

The following section will evaluate literature regarding the measurement of the variables of interest in this study. A clear rationale for the methods used will include reliability and validity studies where available and will comment on methods used in similar studies.

The measurement of kinetic variables has been found to be more reproducible than kinematic variables during normal stair negotiation (Yu et al., 1997). However McFadyen and Winter (1988) point out that in a biomechanical analysis of normal stair negotiation they encountered significant within subject variation of both kinematic and kinetic variables.

3.6.1 Measurement of kinematic variables

Hip range of motion

The current study, in investigating the role of joint range of motion in attenuation of impact at initial contact, was focused on movement of the hip in the frontal plane. Commenting that kinetic measures are more reproducible than kinematic measures, Yu et al. (1997) noted that kinematic measurement in the sagittal plane was more reproducible than the other two planes and makes particular mention of abduction-adduction as being particularly difficult to measure reliably. Their study did not report on individual joint range of motion, but an amalgam of all ranges at the major lower limb joints, so little can be inferred about the hip motion. Few authors have examined hip ad/abduction and its control by gluteus medius, during stair descent despite the agreement by a number of authors that gluteus medius is a critical muscle of control in all activities that include an element of single leg support (Brindle, Mattacola, & McCrory, 2003; Chang et al., 2005; Kumagai, Shiba, Higuchi, Nishimura, & Inoue, 1997; Winter, 1995). In a study by Growney, Meglan, Johnson, Cahalan and An (1997) investigating the reliability of kinematic measures taken during normal gait noted that frontal plane measures had moderate within test reliability but this reduced significantly for between day reliability.

Monaghan, Delahunt and Caulfield (2007) undertook a study investigating the number of trials required to increase the reliability of 3 dimensional motion analysis, The authors agree with Yu et al. (1997) that the measurement of kinematic variables is less reliable than for kinetic variables but that this can be improved by conducting at least 10 trials. Only general principles can be drawn from this trial as it used active markers (optoelectronic dynamic anthropometer) to increase marker visibility whereas the current study used passive retroreflective markers. The authors include several suggestions to further improve the reliability of 3 dimensional motion analysis They suggest that the use of a larger number of cameras helps prevent 'marker drop out' and that barefoot gait analysis helps reduce errors in variation of footwear. However the authors do note that some variation is simply a consequence of normal variation between trials.

Knee range of motion

Few studies have been undertaken that assess reliability or validity of knee joint angle measurement using a 3 dimensional motion analysis system and only one study was found that has looked at the validity and reliability during a step descent task Selfe (1998).The results of the reliability of repeated measurement of knee joint angle showed consistency, with a mean standard deviation of 1.32°. The authors did point out that accuracy was better at slower movement speed as their camera system had a sampling frequency of 50 Hz. The study we undertook had a camera sampling frequency of 240Hz, which would have overcome that problem. The analysis of the literature that measures knee joint range of motion during step descent revealed that most authors chose to use some form of visual motion analysis system. Of the 14 studies that measured knee range of motion, only two used electrogoniometry, the remainder used some form of camera recording. A single camera system was used in five of the studies but only where recording movement in two dimensions and therefore one plane of movement. Of the studies that undertook 3 dimensional analysis, using multiple cameras there is an increase in sophistication and consequent numbers of cameras and sampling frequency. Earlier studies used two cameras and a sampling rate of 75 Hz (Andriacchi et al., 1980), four cameras and a sampling rate of 100Hz (Riener et al., 2002) and latterly eight cameras and 120Hz (Protopapadaki et al., 2007) and nine cameras and 120Hz (Mian, Thom et al., 2007) with the increase in sampling frequency allowing more accurate data acquisition despite any increase in movement speed (Selfe, 1998).

3.6.2 Measurement of the kinetic variable

Ground reaction force

Force plates were used to measure GRF in many of the studies investigating step negotiation. However many did not report the GRF data directly but used it to calculate stiffness (Hortobagyi & DeVita, 2000), or joint moments (Andriacchi et al., 1980; McFadyen & Winter, 1988; Yu et al., 1997). In the study by Yu et al. (1997) moments about the three joints were amalgamated in to one score and were compared for within subject variability using the coefficient of multiple correlation and reported for different steps. The two descent steps undertaken showed an average magnitude of the coefficient of multiple correlation for joint moments of 0.9, indicating that these steps were highly reproducible. From this information we can infer that the force plate data is reproducible, although it is not explicitly reported.

In another study looking at the reliability of recording kinetic data during stair negotiation, within and between subject reproducibility during stair negotiation was investigated. McFadyen and Winter (1988) compared the data of three men, again force plate data was not directly reported but moments about various joints had been calculated from the recorded data. In this study the hip, knee and ankle were reported separately and coefficients of variation were reported for the three subjects as percentage variation of ensemble averages for all moments about each joint. The percentage of variation for the hip ranged from 41-55%, for the knee from 19.5-29% and for the ankle from 27.5-31%. This obviously shows considerably more within subject variation than the study by Yu et al. (1997) but comparisons are difficult as joint moment were reported separately by McFadyen and Winter (1988) but amalgamated by Yu et al. (1997). Age was also unreported in the study by (McFadyen & Winter, 1988). The final difficulty in comparisons is that almost a decade separates the two studies and the technological advance in kinetic recording may have improved during that time.

Between subject variability was also examined in the study by McFadyen and Winter (1988) and correlation coefficients (r) were reported for stair descent. Hip moment correlation coefficients ranged from 0.6-0.9, knee moments 0.88-0.95 and ankle moments 0.95-0.98. All measurements demonstrate a high level of correlation. The authors suggest that the high level of correlation implies basic patterns of joint moment magnitude that are essential basic requirements of stair negotiation, but the fact that there were only three participants makes such suggestion speculative.

The only study that reported variability of ground reaction force was a study by Stacoff et al. (2005).The authors investigated mean and standard deviation of the coefficient of variation for several distinct parameters on the vertical GRF trace (see Figure 2.1). Stair descent GRF data collection was found to pose significant technical challenges. The detection routine failed to recognise Fz3 (minimum vertical GRF between initial contact and ‘push off’) and Fz4 (maximum vertical GRF at ‘push off’) due to the changes that occur to the trace in descent. The changes in IC during stair descent produce a significant increase in Fz2 (first peak of vertical GRF trace) and difficulty differentiating Fz3 and Fz4 as they are frequently of similar magnitude. The authors also failed to detect loading rate due to the technical difficulties. They reported that compared to level gait and step ascent, step descent showed the highest variability in all parameters measured but due to the technical problems the only parameter for which they could report variation was maximum vertical GRF (Fz2). This parameter showed a large coefficient of variation 7.63 ± 2.03% for left leg and 6.34 ± 1.51 for right leg compared to level gait 4.06±2.82% for left leg and 2.95±1.02 for right leg. The authors reported that compared to level gait and step ascent, standard height step descent showed the highest variability in all parameters.

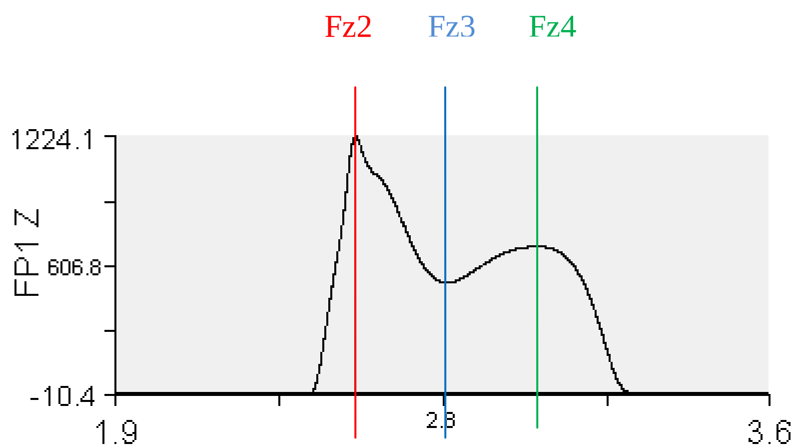

Figure 3.1 Vertical GRF trace identifying the parameters discussed by Stacoff et al. (2005)

3.6.3 Electromyography

Choice of muscles to monitor

In a study by Anderson and Pandy (2003) the contribution of muscle activity to the support of the body during normal gait was measured. They found that muscles make up the largest contribution to the GRF, accounting for between 50-95% of the vertical ground reaction force. Higher values occur when kinetic energy is being absorbed by eccentric muscle contraction at initial contact or generated by concentric muscle contraction at “push off”. Lower values occur when body weight is more directly over the base of support allowing weight to be transmitted directly through the bones. The majority of the muscle contribution to vertical GRF is made by a relatively small number of muscles. These are the dorsiflexors, gluteus maximus, vasti, gluteus medius, soleus and gastrocnemius (Anderson & Pandy, 2003). We selected a representative group of muscles focusing on the muscles that counteracted the largest moments acting about the hip, knee and ankle.

Measuring muscle activity

Muscle activity has been measured using EMG for over 50 years (Winter & Yack, 1987). The method of how the signal is collected, processed and interpreted has been debated over that time. The method of signal collection is usually by surface electrodes placed over the motor point of the muscle which produces a safe yet reliable collection of the signal.

In order for EMG to be a useful tool for measurement of muscle activity it needs to be reliable between trials. In a study by Karamanidis, Arampatzis and Bruggemann (2004) EMG signal parameters from lower limb muscles were investigated and between trial interclass correlation co-efficients (ICC) were calculated. I will comment only on the ICC for the parameters and muscles this study has in common with the current study. For the integral of the signal during contact phase, at a preferred speed, the ICC for vastus lateralis was 0.67, for medial gastrocnemius was 0.86, and for tibialis anterior was also 0.86. For maximal activation the ICC for vastus lateralis was 0.6, for medial gastrocnemius was 0.71 and for tibialis anterior was 0.69. These values did not alter significantly at different velocities and the authors noted that variability seemed to be more dependent on the muscle and the parameter tested than the type of activity being undertaken. Overall there was a significant improvement in ICC values for distal muscles over proximal muscles. This study was a running study but the variability of speeds does give it some application to other ambulation tasks. In a study by Gollhofer, Horstmann, Schmidtbleicher and Schonthal (1990) recording of EMG were taken from lower limb muscles during several tasks involving an increase in vertical GRF, running hopping and jumping. Over repeated tests EMG was found to have good reliability both within and between days. The study concluded that EMG is a reliable method for recording muscle activity in studies of the neuromuscular system.

EMG amplitude reflects motor unit activation (Coburn et al., 2006) but in order for the collected signal to be used to compare both within and between participants, the EMG signal needs to be normalised. A commonly used method of normalising the EMG signal is by expressing the magnitude of the signal as a percentage of the magnitude of the signal collected during a maximum voluntary contraction (MVC). However there is some evidence that normalising to MVC increases intersubject variability (Winter & Yack, 1987). In a study comparing a range of normalization methods, the coefficient of variation (CV) indicating between subject variability was reduced, by 12%-73% when normalization to either the peak ensemble or the mean ensemble was used (Yang & Winter, 1984). Ensemble averages of at least 6 steps for each participant were generated from a fully rectified and smoothed EMG signal, the linear envelope, the signal was then normalised either to the peak or the average of those 6 steps.

Normalising an EMG to MVC had a further limitation if comparison with a functional task is required because the ability to generate a reproducible MVC is angle dependent. Worrell et al (2001) investigated MVC of gluteus maximus and hamstring muscles and found large variation in the ability of participants to produce repeatable maximal contraction at different joint angles. At the knee joint percentage of hamstring MVC varied from at 90° knee flexion 74% (±20) to 0° knee flexion 68% (±20).

Measurement of muscle activity during step descent has been undertaken by several authors (Andriacchi et al., 1980; Hinman et al., 2005; Hortobagyi & DeVita, 2000; Hsu et al., 2007; James & Parker, 1989; Liikavainio et al., 2007; Sheehy et al., 1998) but very little has been written about either intra or intersubject variability. Townsend et al (1978) compared muscle activity between healthy young men with no history of injury and highly trained athletes, half the athletes had a history of knee injury and half did not. The authors when reporting the EMG results for step descent commented that there were primary patterns observed with a high degree of consistency and variants from those patterns occurred in four athletes and one non athlete. The authors suggest that this implies that step descent, like normal gait has some consistent patterns of muscle activity. The participants who differed significantly from those patterns either had knee injury or descended at a significantly increased velocity. No statistical analysis is undertaken and the author describes the analysis as qualitative, although basic patterns of muscle activity are described. James and Parker (1989) similarly describe large variation in biceps femoris and very consistent pattern of activation of tibialis anterior, again this was not analysed statistically. However McFadyen and Winter (1988) did report percentage of coefficients of variation for the three subjects investigated in their study. In all eight muscles were tested but I will focus on the muscle EMG replicated in the current study. Coefficients of variation for ensemble averages of the raw EMG signal were reported. Vastus lateralis showed variation range of 25-37%, gluteus medius 29-36%, gastrocnemius 25-76% and tibialis anterior 50-74%. It can be seen from these results that intra subject variation in EMG recording during stair descent is large. When analysing differences between subjects, a large standard deviation makes it less likely that a statistically significant will be found.

Time period to measure muscle activity

The period chosen to investigate the activity of the muscles of interest was from initial contact to maximum vertical GRF (Fz2). This is a significant part of the time period during which energy absorption to attenuate the impact of step descent takes place. There have been few studies investigating the magnitude of muscle activity during the energy absorption phase, so the decision about the period to monitor was based on kinematic literature. Energy absorption occurs in the period until minimum vertical GRF is reached (this is the trough between the two main peaks in the vertical GRF trace), the second peak is energy generation, caused by the push off phase. However, in many of the subjects there was no obvious minimum between the two peaks so the maximum vertical GRF was chosen to improve the reliability when comparing the two groups. Hortobagyi and DeVita (2000) when investigating the same phase of the step descent task, selected a time frame of 100ms. However when inspecting our collected data the time to maximum vertical ground reaction force trace in several of the younger participants was as high as 170ms so it was felt that the cut off of 100ms might exclude some muscle activity involved in energy absorption. The present study differs in the analysis of EMG from many of the previous step descent studies. There is no separate consideration of the pre activity of the muscle, as this was not one of the measured variables in this study. Measurement of muscle activity will be a sum of any pre activity with additional muscle activity, stimulated by IC.

4 Methods

4.1 Introduction

This chapter will present the method used in the current study to investigate the hypotheses stated in Chapter 1. The study design, participants and ethical and cultural considerations will be outlined. Details of the equipment, pre-experimental set up and data collection will be covered. Finally the step testing procedure will be covered in detail including post experiment data management and statistical analysis.

4.2 Study Design

The study was an experimental, laboratory based, repeated measures design.

The independent and dependent variables are described below

Independent variable is

- age (older or younger)

Dependent variables are

- maximum knee angles in the sagittal plane between initial contact and maximum vertical GRF.
- maximum hip angles in the frontal plane between initial contact and maximum vertical GRF.
- maximum vertical GRF.
- time taken to achieve peak vertical GRF after initial contact.
- the activity of gluteus medius, vastus lateralis, medial gastrocnemius and tibialis anterior between initial contact and maximum vertical GRF measured by SEMG.
- distance between mid PSIS and lateral malleolus of the stepping foot at IC.

4.3 Study Participants

Participants of either sex were invited to join the study if they met the following inclusion/exclusion criteria.

4.3.1 Inclusion Criteria

- able to walk independently with no requirement for walking aids or assistance.
- no significant osteoarthritis, cardiovascular system disease or neurological injury.
- able to descend a step safely over at least 10 trials.
- aged between 20-30 years or 60-80 years.

4.3.2 Exclusion Criteria

- neurological or orthopaedic problems.
- a history of arthritis or falls.

Advertisements were placed on notice boards within the AUT university campus (see appendix A) and older participants were contacted via community groups, posters displayed in a local retirement village and word of mouth.

After contacting the researchers, all potential participants were given or sent an information sheet (see appendix B) and then were contacted one week later by the researcher to answer any questions generated by the information sheet and to check if they were interested in participating in the study.

4.4 Ethical and cultural considerations

The study was approved by the university ethics committee (see Appendix C), participants were informed about the nature, scope and risks of the study and all gave written consent prior to participating (see appendix D).

This project is a laboratory study that does not aim to examine any ethnic differences. Article Three of the Treaty of Waitangi emphasizes the importance of health equivalence between Maori and Pakeha. This project was an exploratory study aiming to add to the body of knowledge around the pathogenesis of osteoarthritis. It is important to note that because Maori life expectancies are improving, more Maori are surviving to reach an age when arthritis becomes a significant risk, meaning this project does have future value for Maori. The results of the study will be accessible to both Maori and non-Maori researchers by being published in a scientific journal. Given that the effect of ethnicity on muscle recruitment is not being examined, and that there is no evidence that this differs across ethnic groups, the need for specific feedback to Maori groups was not warranted.

4.5 Equipment and laboratory set up

4.5.1 Experimental area

The experimental area consisted of a 5m walkway with a step 20cm in height placed at the beginning of the walkway. The step was placed 5cm behind the force plate (see Figure 3.1).

Figure 4.1 Experimental area of walkway and step

4.5.2 Three dimensional motion analysis system

Kinematic and kinetic recordings were collected from a nine-camera, three dimensional motion analysis system (Qualisys Medical AB, Sweden). The cameras were placed at different heights, varying distances from the participant; see Figure 4.2. In the Figure the participant can be seen as a cluster of green markers, stepping on to the white force plate. In Figure 4.3 the plan view of the laboratory shows that the cameras surround the participant in a 360° arc. This allows the most complete capture of the retroreflective markers by the camera system.

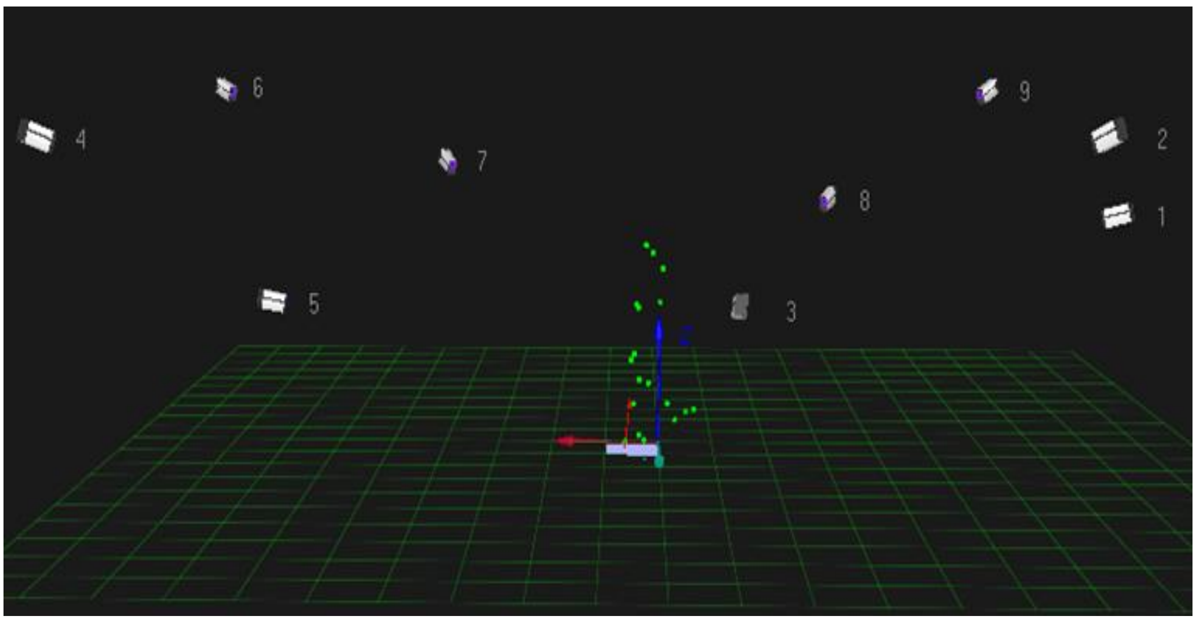

Figure 4.2 Side view of participant in 3D motion analysis laboratory.

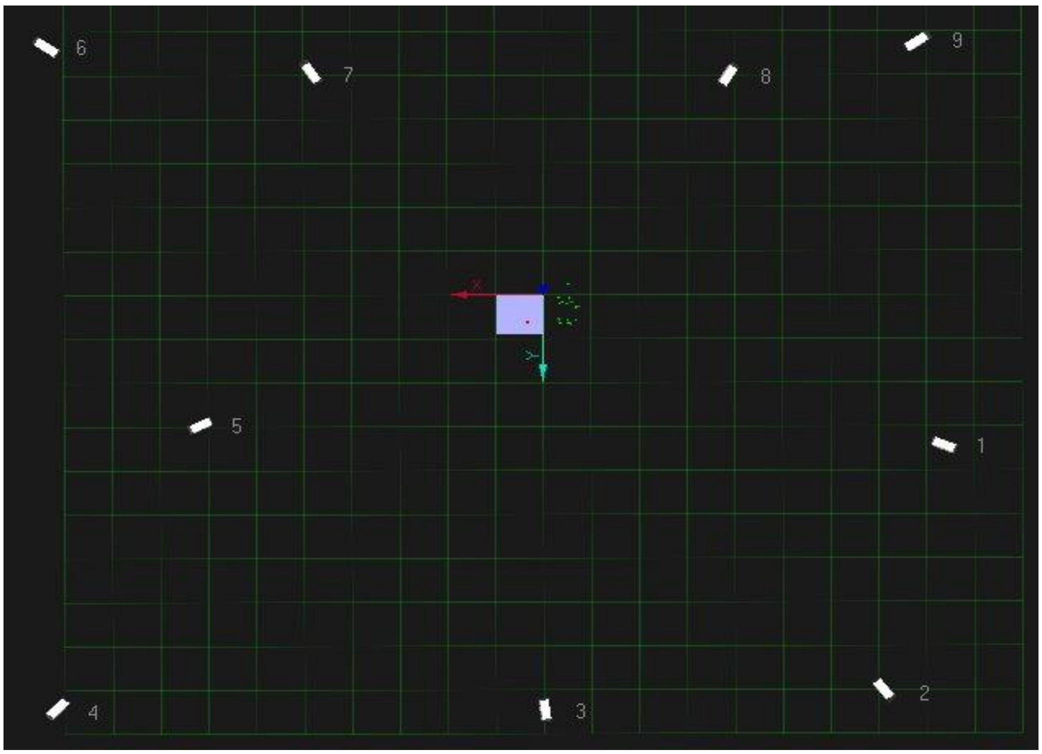

Figure 4.3 Plan of the 3D motion analysis laboratory showing camera placement

4.5.3 *Force plate*

An AMTI (Advanced Mechanical Technology Inc. USA) force plate (Model OR6-7-2000) was used to measure the three force components along XYZ axes. The focus of the current study was on the Z axis (vertical). The force plate consists of a top plate connected to a base plate by four sensing elements. In order for the load to be measured correctly all four sensors must receive the same signal from the load applied to the top plate, this may not happen if there is any rocking of the plate. To ensure stability, the force plate is mounted by being bolted to a concrete base, which also minimises vibration.

When a load is applied to the top plate, a 6-component transducer will measure the three force components and three moment components. The signal is amplified using the AMTI MSA-6 instrument, which is a six channel strain gage amplifier, designed for use with the force plate (Advanced Mechanical Technology, 2003).

4.5.4 *Electromyography*

An eight channel analogue multiplex telemetry system (AMT-8) was used to collect the EMG signal. Electrodes were applied to the skin and the signal was pre-amplified close to electrode placement to minimise noise. The electrode leads were attached to a light weight portable unit secured to the participant via a waist belt. The A single fixed cable transmitted the signal to the main amplifier (Bortec Biomedical Ltd, 2002) and data was then collected in real time on a personal computer using Qualisys software (Qualisys motion capture systems, Qualisys Medical AB, Sweden).

4.5.5 *Digital video*

A digital video camera (Panasonic, USA) collected images in real time. The video camera was synchronised with the 9 camera system and held on a tripod to view the area involved in the step down and one step following. This could be used to verify the collected motion data.

4.6 Procedures

Demographic and anthropometric measurements were taken; age, height and weight. All participants were barefoot and wore shorts and a singlet top to allow reflective markers and SEMG electrodes to be attached to skin.

4.6.1 Three dimensional motion analysis system

Prior to the participant testing, the Qualisys motion analysis system was calibrated as per manufacturer's protocol using a dynamic calibration method. A wand was moved in the space where the participant was to undertake the step descent, while stationary reference markers defined the coordinate set for motion capture.

Preparation for collection of kinematic data

Retroreflective markers, (1.9 cm spheres) were placed on landmarks identified by palpation; see Figure 3.2.

The markers were placed as follows:

- both acromion processes
- bilateral ASIS
- mid PSIS
- T8
- off- set bilateral thigh
- off- set bilateral shin
- bilateral lateral knee joint line
- bilateral medial knee joint line
- bilateral lateral malleoli
- bilateral medial malleoli
- bilateral mid- point between 2^{nd} and 3^{rd} metatarsals,
- bilateral calcaneous at same distance from floor as metatarsal markers.

Collection of kinematic data

The first trial for each participant was a static trial. The data collected from this trial is used as an anatomical template to identify body segments and used to construct a model which can be applied to the movement files. The medial knee and medial malleolar markers were then removed to allow unimpeded movement for the stepping trials. The remaining markers were used to track body segments and define the 6-degrees of freedom of each body segment under investigation. Subsequently 40 step down trials were undertaken.

Figure 4.4 Participant with retroreflective marker placement

4.6.2 Force plate

The step was positioned 5cm behind the force plate to ensure that participants step descent landed within the force plate margins. The force plate was zeroed by using a bridge balancing switch on the strain gage amplifier and calibrated for laboratory position and axis orientation. Participants stepped on to the force plate from the step and GRF data was collected at a rate of 1200Hz and collected via a computer aided data acquisition system.

4.6.3 Surface Electromyography

Skin Preparation

Skin preparation was undertaken by dry shaving the skin directly over the muscle belly of the muscle. The skin was then lightly abraded using skin preparation liquid. To ensure the skin was free of grease or any residue it was then cleaned with an alcohol wipe (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Impedance was measured and was accepted at a level below 5kΩ. Following skin preparation electrodes were placed over each muscle belly of the 8 identified muscles. Each electrode had a small pre-amplifier attached close to the electrode. The pre amplifier was attached to the participant's leg using hypoallergenic tape to reduce the incidence of movement artefacts. The electrode leads were attached to a central collection port which was attached to a belt, placed around the subjects' waist. This was attached to an analog multiplex telemetry system (Bortec Biomedical Ltd. Calgary, AB. Canada) via a long, lightweight lead to enable unimpeded movement of the participant and data was collected through the computer system.

Electrode placement

Bipolar silver/silver chloride surface SEMG electrodes (Norotrode 20) were placed on 4 muscles on each leg and a ground electrode was placed on the left fibula head (see Figure 3.5). Electrodes were placed in line with recommendations by Hermans et.al. (1999).
The muscles selected represent the major muscles implicated by current literature to be important in attenuation of impact at loading response during the stance phase in stair descent.

The muscles were:

- tibialis anterior
- gastrocnemius medialis
- vastus lateralis
- gluteus medius

Figure 4.5 Participant with SEMG electrode placement

4.7 Experimental task

The order of right and left foot step down was randomly assigned, decided by the toss of a coin before the first trial was undertaken. This order was then used for each participant, 20 right and 20 left foot step downs were generated. Participants were instructed which foot to use for the step down, immediately prior to each trial. The instruction was “when you are given the instruction to ‘go’ step down from the step with the identified foot in your own time, then walk to the end of the walkway” The participant was then instructed to return to the step for the next trial. Each participant was offered the opportunity to have a rest after each set of 10 trials and could terminate testing at any point if they so wished.

4.8 Data collection and processing

All data were collected simultaneously on a personal computer using Qualisys software (Qualisys motion capture systems, Qualisys Medical AB, Sweden). At the completion of the data collection all kinetic and kinematic data were stored on a portable hard drive for analysis. The hard drive was stored in a locked cabinet in the principle researcher's office. Confidentiality was maintained by each participant being allocated a unique identifier. The participant's name and number appear together only on a master sheet held in the locked cabinet.

4.8.1 Kinematic data

Kinematic data were collected at a sampling rate 240Hz .The retroreflective markers provided a reference marker set for generation of a model to be used in data analysis. The model was constructed using the biomechanical software programme Visual 3D, C-Motion Inc, USA. Tracking markers were identified, labelled and the static and motion files were exported as C3D files for processing by Visual 3D software (C-motion inc, Germantown, USA). An eight segment, 3D rigid-link dynamic biomechanical model of the trunk, pelvis and lower limbs (right and left foot, lower leg and thigh) was constructed in Visual 3D. Body segments were constructed based on geometric objects (Hanavan 1964) and scaled according to the geometry of the individual. Dempster's (1955) anthropometric data were used as input parameters for calculating the segmental dimensions . The position and orientation of each body segment represented by the geometric object, stemmed directly from the anatomical markers collected during the static and stepping trials. Within the rigid-link model, joints were depicted as hinge joints rotating about fixed axes and joint angles derived according to the relative orientation of the axes of each body segment. Prior to the calculation of joint kinematics body marker traces were smoothed using a second order Butterworth bidirectional low pass filter with a frequency cut off of frequency of 12Hz, to eliminate the noise typically associated with movement artefacts of markers on the skin (Winter, 2005). Angular data were expressed as relative joint angles of knee and hip about the X and Y axes respectively. The anthropometric data of each participant was assigned to the static file to allow body segment parameters to be calculated. The model was then assigned to the motion files. The kinematic and kinetic data was exported as 'ASCII' files and imported into Microsoft Excel programme for statistical analysis.

4.8.2 Kinetic data

Kinetic data was smoothed using a Butterworth low pass filter with a cut off frequency of 70Hz (Boocock, McNair, Cicuttini, Stuart, & Sinclair, 2009), to eliminate high frequency noise from the GRF data, frequently associated with background electrical activity from the force plate. Maximum vertical GRF data was then used for statistical analysis.

4.8.3 Electromyographic data

A full EMG signal using a bandpass filter of 10- 1000Hz was collected. It has been shown in spectral analysis of EMG signals that the majority of the frequencies fall between these two boundaries and filtering at these frequencies is associated with a loss of only about 5% of the original signal (Mello, Oliveira, & Nadal, 2007). For all 20 participants, the maximum EMG signal from the 20 step descents for each leg and each muscle was calculated from the rectified signal during the entire stance phase of the step descent from initial contact to toe off. The rectfied signal was smoothed using a low pass Butterworth filter with a cut off frequency of 6Hz (Arsenault, Winter, & Marteniuk, 1986).

The integral of the maximum signal found over this period was normalised to the period from initial contact to maximum vertical GRF and accepted as the maximum EMG amplitude for the task. The muscle activity from initial contact to maximum vertical GRF for each of the muscles was then expressed as a percentage of the *maximum for task*. Figure 4.6 shows the process undertaken to calculate the maximum for task. The raw signal (see diagram A), was rectified (see diagram B) and then smoothed using the Butterworth filter (see diagram C). The filtered rectified signal, from IC to maximum vertical GRF, shown in blue fill, was calculated as a percentage of the maximum for task, shown in bold red line.

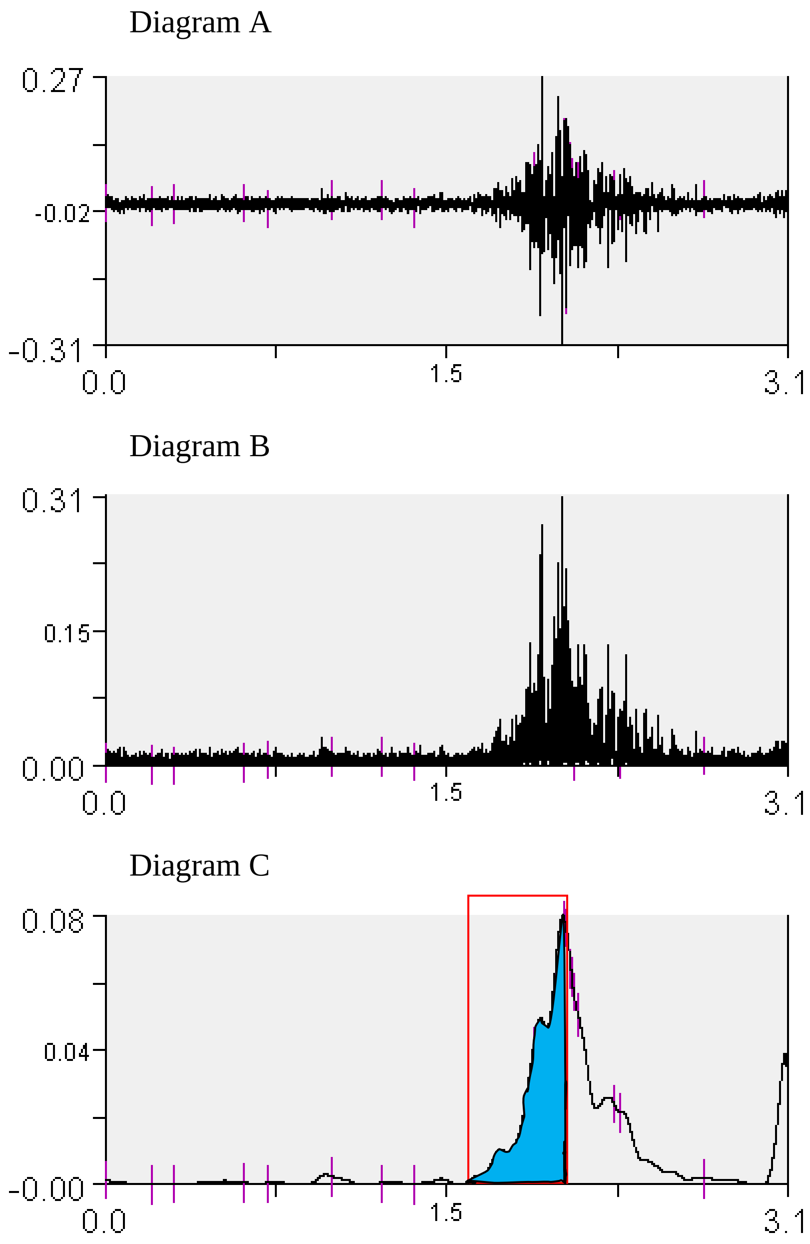

Figure 4.6 EMG signal with the calculated percentage of maximum illustrated.

Diagram A, raw signal; diagram B, wave rectified signal; diagram C, integrated smoothed signal, indicating normalised *maximum for task* (in red), percentage of maximum for task was calculated from the area under the curve (in blue).

4.9 Statistical Analysis

Data will be analysed using SPSS v16.0 for Windows statistical software package (SPSS. Chicago, USA). Initially data will be explored for normal distribution by generating a z score for both skewness and kurtosis. A critical cut off score for these measures is usually 1.96 but as a small sample size was used the cut off score of 2.58 will be accepted to indicate normal distribution. Outliers will be identified using box plot graphs. If the data are found to have a normal distribution a general linear model 2 x 2 repeated measures design will be applied to the individual scores for each trial for the nine dependent variables under investigation. If the data are found not to have normal distribution then suitable nonparametric alternatives will be explored. The main effects of age group and leg respectively will be generated. If using a general linear model, an *F ratio* for the dependent measures will be generated. This compares the variability within the age groups with the variability between the age groups. This ensures that if a significant difference between the age groups is discovered we can have confidence that it is due to the factor in question, not the general variability brought about by individual difference or experimental error. A significance level of $p \leq .05$ will be set for all statistical analysis.

5 Results

5.1 Introduction

The purpose of this exploratory repeated measures study was to ascertain the effect of age on the magnitude of and the time to reach, maximum vertical GRF during a step down activity. We explored the main strategies implicated in the literature in the attenuation of impact. Joint range of motion at the knee and hip, activation of key muscles and the relationship of the upper body segment with the stepping leg were investigated.

There were three occasions where one of the dependent variables was not able to be accurately measured over the course of the 40 trials. There was a technical problem with collection from right gastrocnemius and left tibialis anterior from participant number 13. The fault was traced to the collection point and rectified for subsequent participants. There was a problem with viewing one of the markers around the hip for participant number 12, so the hip angle was unable to be calculated. Apart from these technical difficulties 40 data sets, one for each step down, for all dependent variables were collected from the 20 participants.

The z scores for skewness and kurtosis for all the dependent variables were below 1.96, except for maximum vertical GRF. The z score for both skewness and kurtosis for maximum vertical GRF were below the critical score of 2.58 consequently the data was considered to have normal distribution. Several outliers were identified but analysis of the video footage revealed that the participants undertook the procedure as requested and therefore the differences noted were a variation of normal strategy and as such it was felt they should not be excluded from the analysis. The 2x2 repeated measure analysis was undertaken on the ensemble of the mean score for each variable for the left and right step descent for each participant.

This chapter will report the main findings of the study and as such will be divided into three sections; section 5.2: the participants; section 5.3: the main effects of leg on the dependent variables and section 5.4: the main effects of age group (discussed in relation to each null hypothesis). Bar graphs will be used to illustrate the findings and the results of the statistical analysis will be reported.

5.2 Participants recruited

A total of 20 healthy community dwelling adults volunteered to participate in the study. Ten older (60-80 years) participants were recruited from local and surrounding areas via links with community groups and advertisements placed in public areas. Five males and five females volunteered. The younger (20-30 years) participants were recruited from advertisements placed around the university (See appendix B). Two males and eight females volunteered. Demographic details of the participants are presented in Table 5.1

All volunteers met the inclusion criteria with none having any physical impairments or difficulty with balance that might make them ineligible to join the study. All participants completed 40 trials of the step down task. There were no withdrawals from the trials and only two minor adverse effects reported. Two of the older participants had residual skin irritation for a few days after the study, but both resolved with no intervention required.

Table 5.1 Participant characteristics

	Older group Mean(SD)	Younger group Mean(SD)
Age (years)	65.3(SD 5.0)	22.8(SD 2.5)
Weight (Kg)	67.6(SD 9.37)	66.4(SD 11.88)
Height (m)	1.67(SD 0.06)	1.72(SD 0.09)

In order to establish that the two groups were comparable for the demographic characteristics, an independent samples t test was undertaken to compare the means of weight and height between the age groups. Results for height show t=1.28; p=.2 and for weight t=-0.25; p=.8. No significant difference between the age groups for either weight or height was found.

5.3 Effect of leg

There was a main effect found for leg in only one of the dependent variables, gastrocnemius muscle activity shown in Figure 5.1. The two main muscles implicated in the literature to attenuate impact at IC during step descent are firstly gastrocnemius and then the quadriceps (James & Parker, 1989; McFadyen & Winter, 1988). One of the factors that may be implicated in a right versus left leg difference is leg dominance. The leg dominance of each of the participants is shown in Table 5.2, with the mean percentage of gastrocnemius use for right and left leg. Visual inspection of the data suggests that there is no particular pattern between the amount of muscle activity used for energy absorption and the dominant leg for each participant. This study suggests that leg dominance may not have a significant effect on the ability to control the task of descent from a step, but the number of participants who are left sided dominant are too few to make statistical comparisons meaningful. The statistical difference between legs in the amount of gastrocnemius muscle activity used during the step descent task was $F(1,18)=7.46; p=.014$.

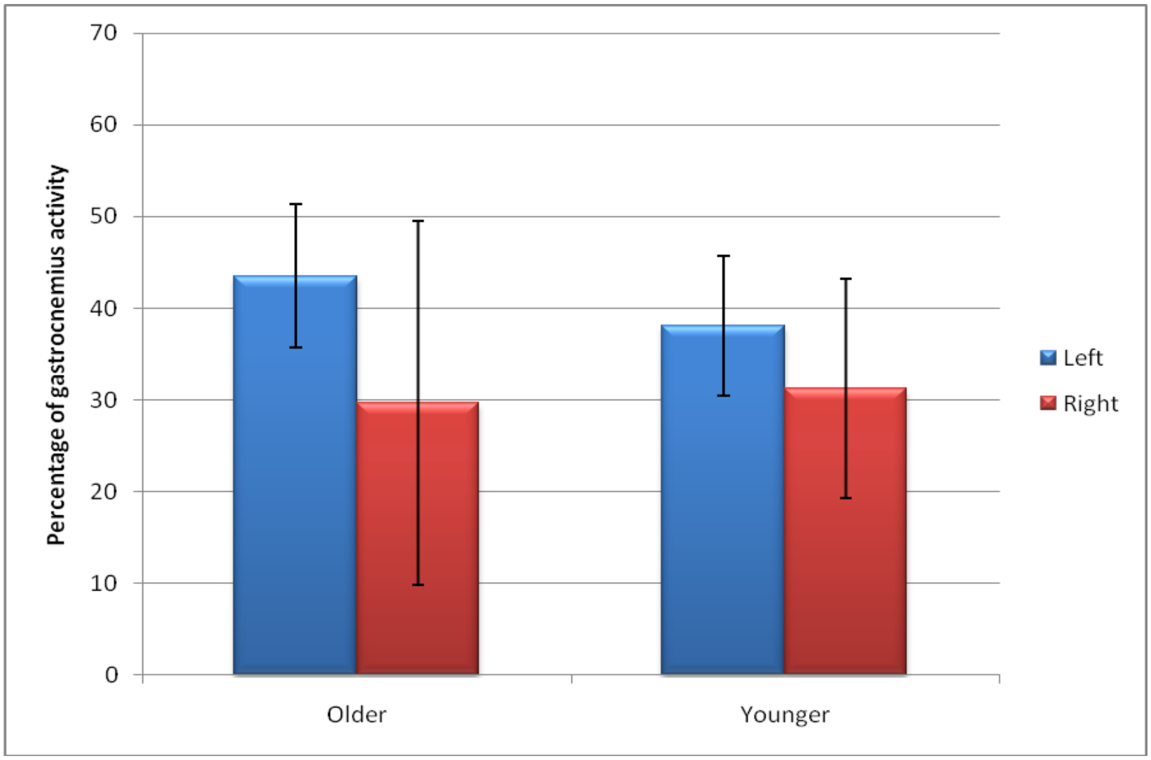

Figure 5.1 Gastrocnemius activity from IC to maximum vertical GFR showing the main effect of leg

Table 5.2 Leg dominance and gastrocnemius muscle activity

Participant number	Age group	Dominant leg	gastrocnemius mean L step *	gastrocnemius mean R step*
1	Y	R	34.5	40.0
2	Y	R	18.9	33.1
3	Y	R	44.0	35.8
4	Y	R	39.8	27.2
5	Y	R	39.6	20.7
6	Y	R	40.8	43.7
7	Y	R	42.2	36.1
8	Y	R	31.3	27.1
9	O	L	45.3	60.7
10	O	L	32.0	33.4
11	O	R	44.3	25.6
12	O	R	49.6	45.5
13	Y	R	40.0	4.6
14	Y	R	43.9	44.2
15	O	R	36.3	13.2
16	O	L	33.7	6.1
17	O	R	40.2	21.0
18	O	R	53.5	3.3
19	O	R	46.0	30.3
20	O	R	53.8	57.1

Y- Younger; O- Older; * percentage of muscle activity used for energy absorption.

5.4 Effect of Age group

There was a main effect for leg in only one of the measured variables. Therefore for the statistical analysis of the other variables, the ensemble means for both legs were combined to investigate the effect of age group. The mean and standard deviation for the variables of the left and right steps are reported and shown separately on the bar graphs.

5.4.1 *Null Hypothesis 1*

> *There will be no difference between older and younger participants in maximum knee angles in the sagittal plane between initial contact and loading response.*

The older participants used less knee flexion between IC and maximum vertical GRF than the younger group; see Figure 5.2 and Table 5.3. The older participants had a mean maximum angle of the left leg of 17.3° (SD 7.8) and of the right leg 18.2° (SD 6.1). The younger participants had a mean maximum angle of the left leg of 25.5° (SD 13.5) and of the right leg 27° (SD 11.6). The difference between the two age groups was statistically significant between older and younger participants in the amount of knee flexion used during the step descent task ($F(1,18)=5.48$; $p=.031$).

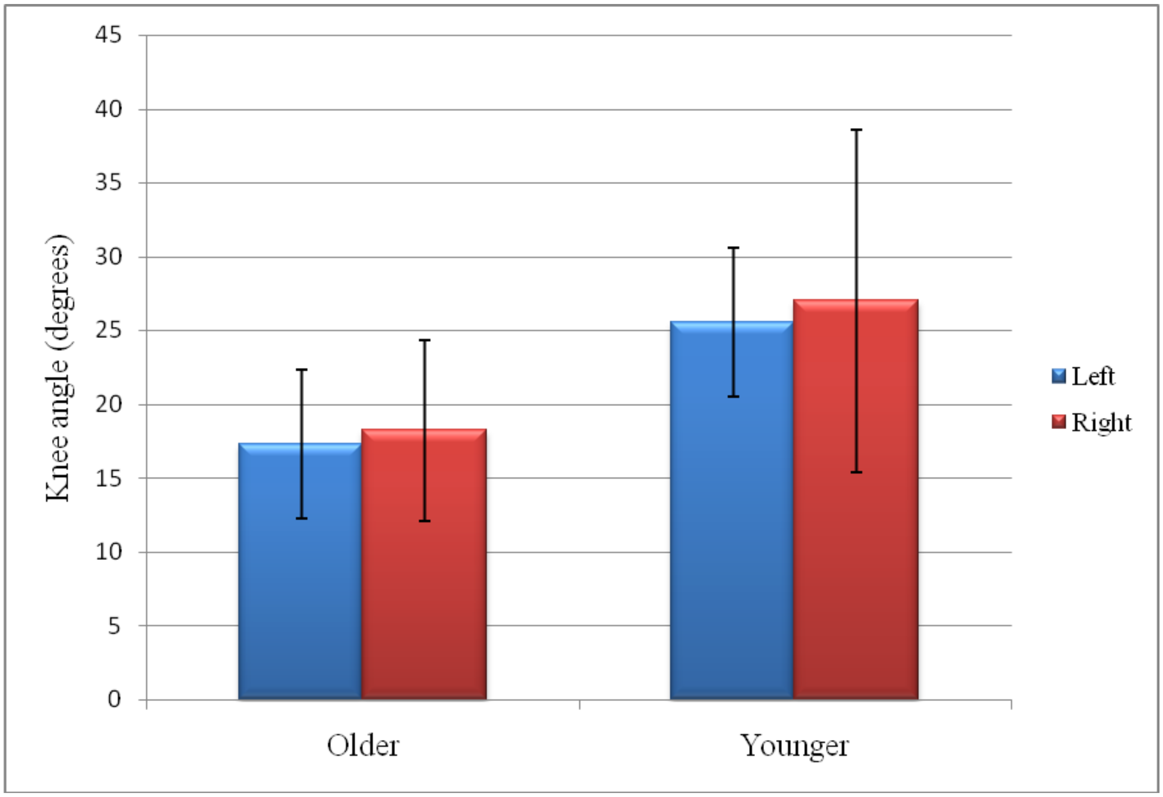

Figure 5.2 Mean maximum knee flexion angles between IC and maximum vertical GRF.

5.4.2 Null Hypothesis 2

There will be no difference between older and younger participants in maximum hip angles in the frontal plane between initial contact and loading response.

The angle of hip adduction between IC and maximum vertical GRF was small in both older and younger participants with a large standard deviation for both groups; see Figure 5.3 and Table 5.3. The older participants had a maximum mean angle of the left leg of 3.15° (SD 2.75) and the right leg of 2.26° (SD 2.58). The younger participants had a maximum mean angle of the left leg of 4.75(SD 3.13) and the right leg of 5.36°(SD 2.05). The hip angle in the frontal plane was not statistically significant different between younger and older participants for the amount of adduction used during the step descent task ($F(1,18)=2.74$; $p=.116$)

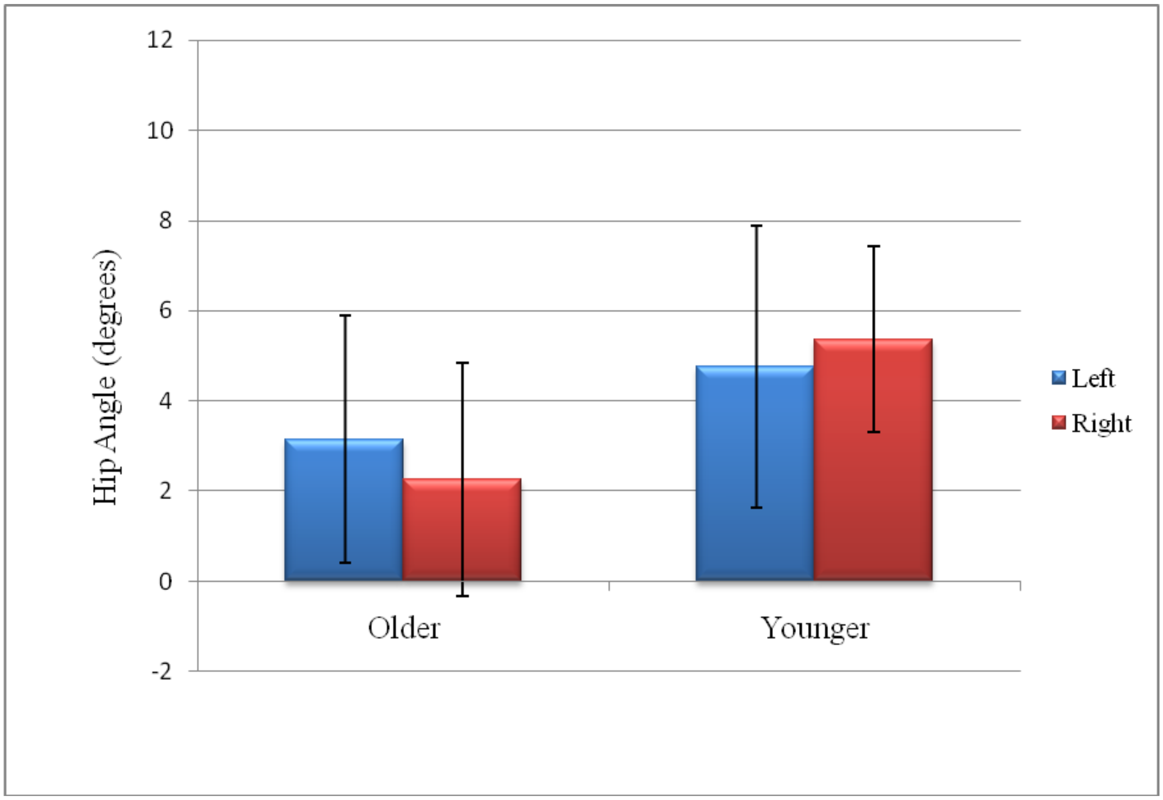

Figure 5.3 Mean maximum hip adduction angles between IC and maximum vertical GRF

The range of movement measured in the frontal plane at the hip joint is of a much smaller magnitude than in the sagittal plane at the knee joint. As already stated in the literature, movement in the frontal plane is harder to quantify and the size of the standard deviation compared to the mean makes this a less reliable measurement. The size of the adduction angle will affect the consequent external moment, although moments were not calculated in this study.

Table 5.3 Ensemble means and standard deviations of joint angles.

	Older				Younger			
	Left		Right		Left		Right	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Knee angle – sagittal plane (°)	17.30	7.82	18.23	6.11	25.55	13.5	27.01	11.59
Hip angle- frontal plane (°)	3.15	2.75	2.26	2.58	4.75	3.13	5.36	2.65

5.4.3 *Null Hypothesis 3*

There will be no difference in magnitude of maximum vertical GRF between older and younger participants.

We first established if there was a significant difference in weight between younger and older participants at baseline. No significant difference was found, so raw data rather than data normalised to body weight was analysed to establish the magnitude of vertical GRF and the loading rate at IC.

It can be seen in Figure 5.4 that there was very little variation between age groups, but the standard deviations for both age groups are moderately large; see Table 5.4. The mean maximum vertical GRF for older participants was, for the left leg 1124.66 N (SD 357.7) and for the right leg 1089.8 N (SD 283.3). For younger participants it was, for the left leg 1021.2N (SD 234) and for the right leg 1029N (SD 215.6). No statistically significant difference was found between younger and older participants for maximum vertical GRF generated by the step descent task ($F(1,18)=0.613$; $p=.444$)

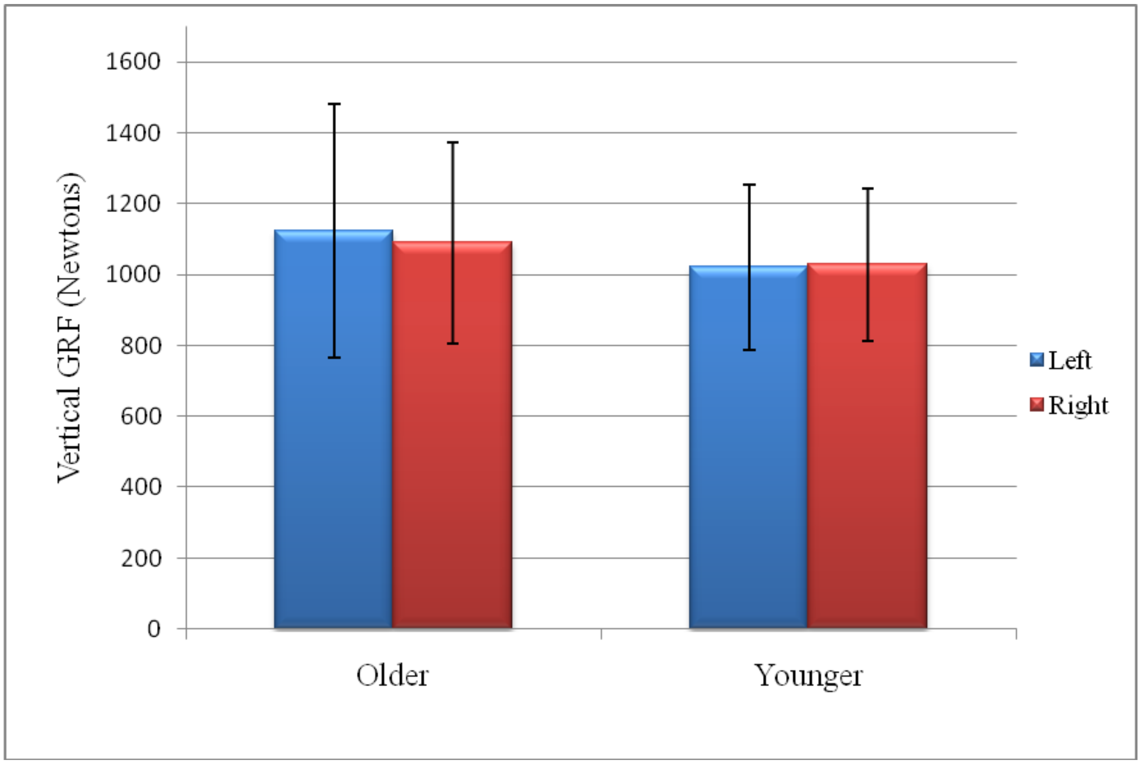

Figure 5.4 Maximum vertical GRF during step descent.

5.4.4 Null Hypothesis 4

There will be no difference in time taken to reach maximum vertical GRF from IC between older and younger participants.

The mean time from IC to maximum vertical GRF, for older adults for the left leg was 0.127sec (SD 0.03) and the right leg was 0.138sec (SD 0.04); see Figure 5.5 and Table 5.4. For younger adults for the left leg it was 0.142 (SD 0.026) and the right leg 0.134sec (SD 0.036). The lowest scores, corresponding to the fastest loading rates were found in the older group, but no significant difference was found between older and younger participants for the time to reach maximum vertical GRF during the step descent task ($F(1,18)=0.268$; $p=.611$).

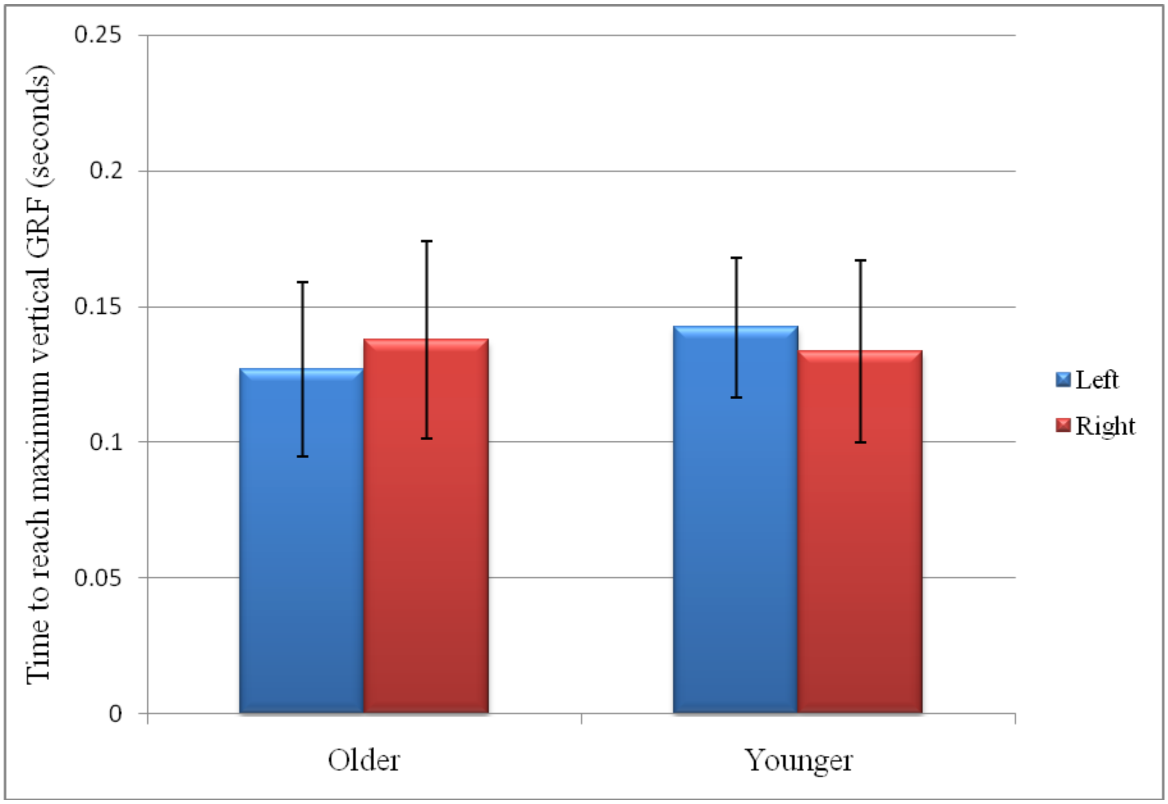

Figure 5.5 Time taken from IC to reach maximum vertical GRF.

Table 5.4 Ensemble means and standard deviations of magnitude and time to maximum vertical GRF.

	Older				Younger			
	Left		Right		Left		Right	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Max vertical GRF(N)	1124.66	357.72	1089.85	283.30	1021.20	234.23	1029.01	215.62
IC to Max vertical GRF (sec)	0.13	0.03	0.14	0.04	0.14	0.03	0.13	0.03

IC-initial contact; N-Newtons

5.4.5 Null Hypothesis 5

The relative amount of muscle activity used at initial contact to attenuate impact will be the same for both older and younger participants.

EMG activity was recorded during the entire step down task; the level of activity for the critical period of energy absorption, from IC to maximum vertical GRF was then calculated as a percentage of the maximum for task, as was illustrated in Figure 4.6.

Gluteus medius

The small adduction range of motion, implies that the muscle activity will have been of a low level. The percentage of maximum for task can be seen in Figure 5.6 and Table 5.5. The older participants used on their left leg a mean of 45.3% (SD 9.9) of maximum and on their right 40.9% (SD 10.7). The younger participants used on their left leg 46.6% (SD 7.7) of maximum and on their right leg 45.4% (SD 8.6).There was no significant difference between older and younger participants in the amount of gluteus medius activity from IC to maximum vertical GRF ($F(1,18)= 0.755$; $p=.396$).

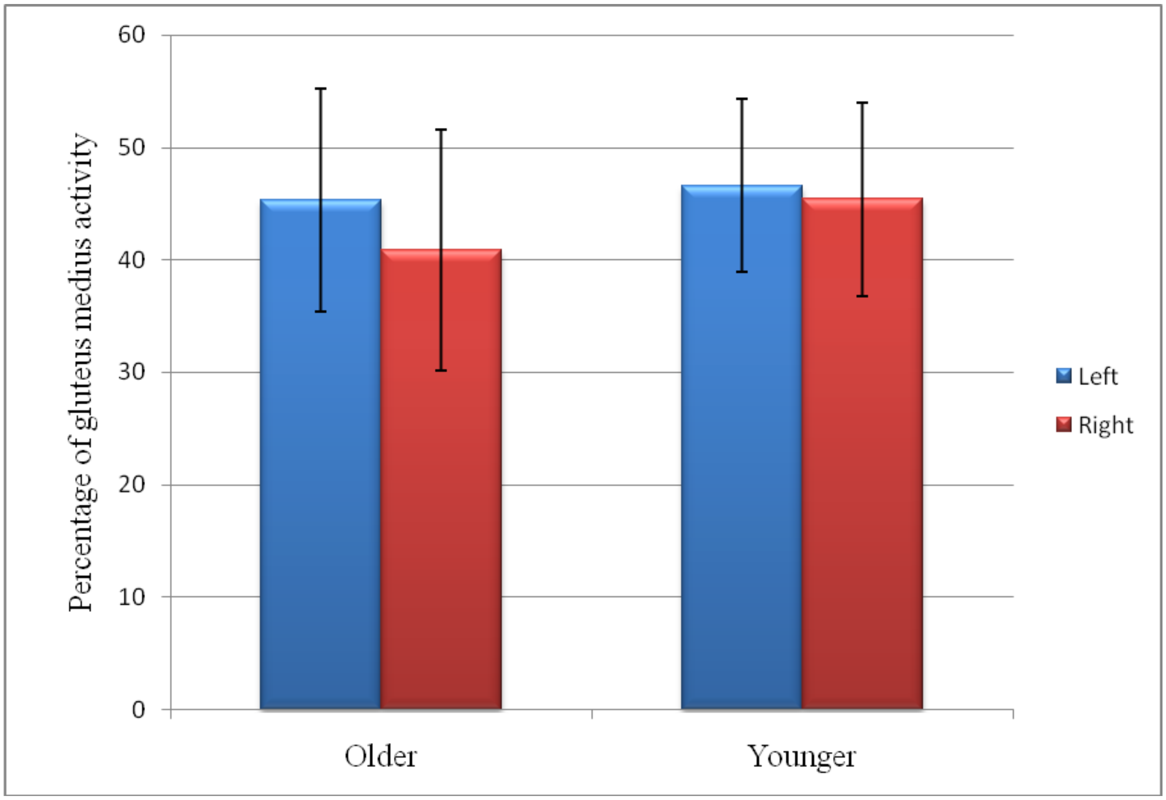

Figure 5.6 Gluteus medius activity from IC to maximum vertical GFR.

Vastus lateralis

There was an increased amount of muscle activity of vastus lateralis during the period from IC to maximum vertical GRF in older compared to younger participants as can be seen in Figure 5.7 and Table 5.5. The older participants on the left leg used a mean of 55.1% (SD 8.9) of the maximum and on the right 50.8 % (SD 10.3). Younger participants used on the left leg 46.7% (SD 8.6) and on the right 44.3% (SD 6.2).There was a significant difference between older and younger participants ($F(1,18)= 5.21$; $p=.035$), with older participants using significantly more muscle activity during this phase of the step down task than the younger participants.

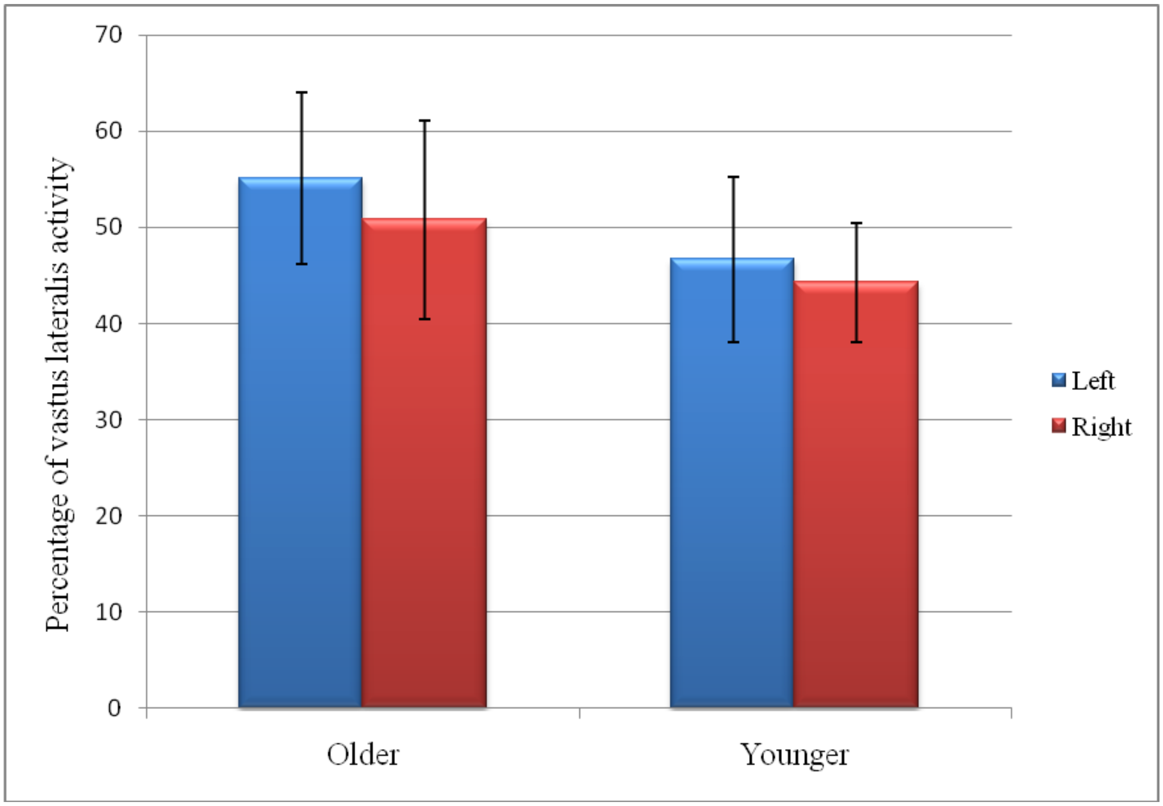

Figure 5.7 Vastus lateralis activity from IC to maximum vertical GFR.

Gastrocnemius

An unusual finding in gastrocnemius was three participants, one younger and two older, used ≤ 5% of maximum for task for 30-40% of their descent trials. See Figure 5.8 for an example of EMG recording from gastrocnemius for a participant with an expected pattern of muscle activity at IC and one where gastrocnemius is inactive at IC. Videotaped footage was reviewed for any alteration in task execution or altered strategy but none was observed. This will have considerably added to the variability of the findings, as can be seen by the large standard deviation, see Figure 5.9 and Table 5.5. Because of the main effect of leg found for gastrocnemius activity in section 5.3, independent t tests were used to analyse right and left legs separately. No significant difference was found between older and younger participants for either leg. Left gastrocnemius activity, $t=-1.73$, $p=.1$; right gastrocnemius activity, $t= 0.22$, $p=.8$.

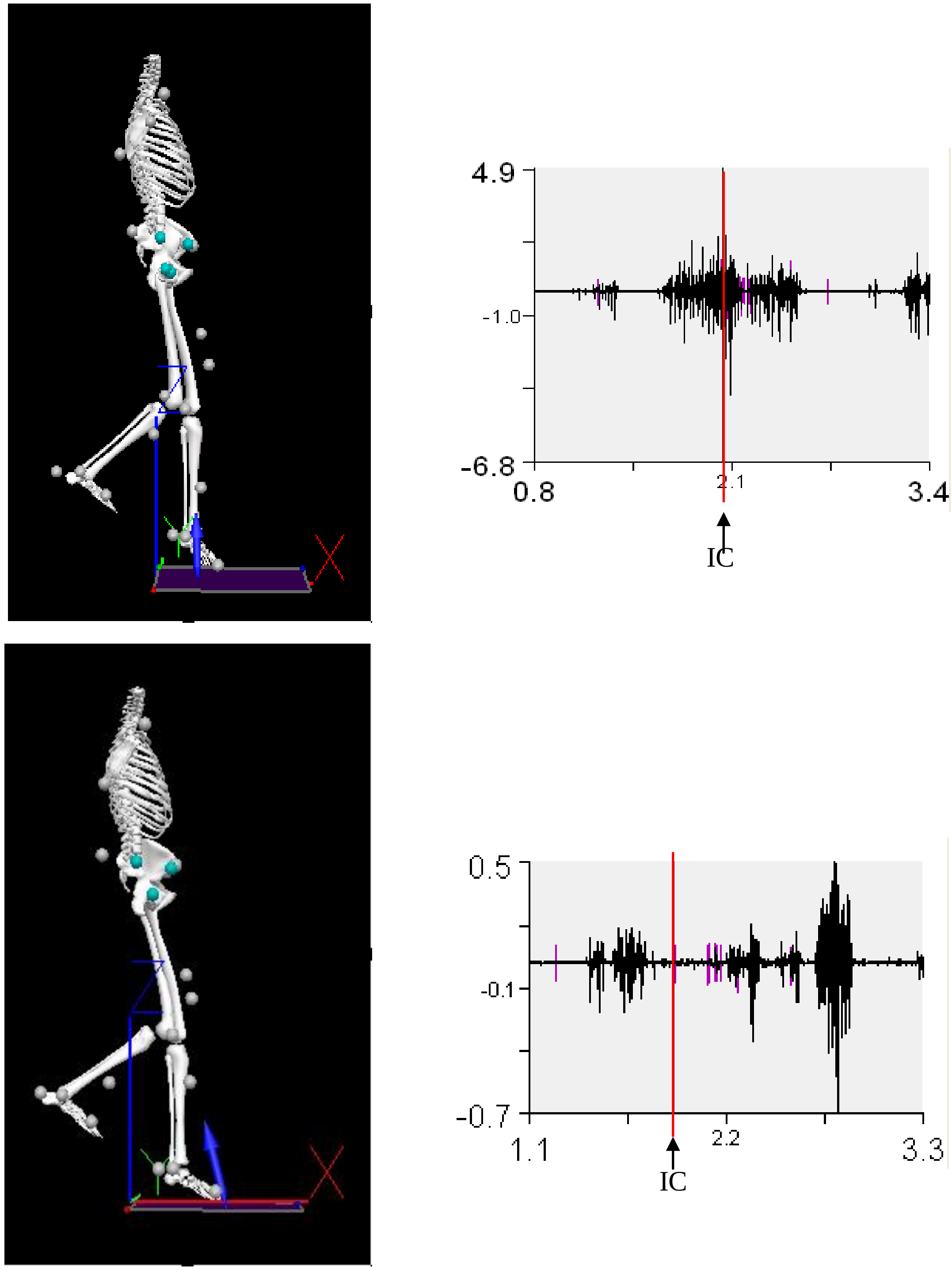

Figure 5.8 Difference in Gastrocnemius activity between participants (top diagram showing IC with gastrocnemius activity as seen in most participants. Bottom diagram showing IC with minimal gastrocnemius activity).

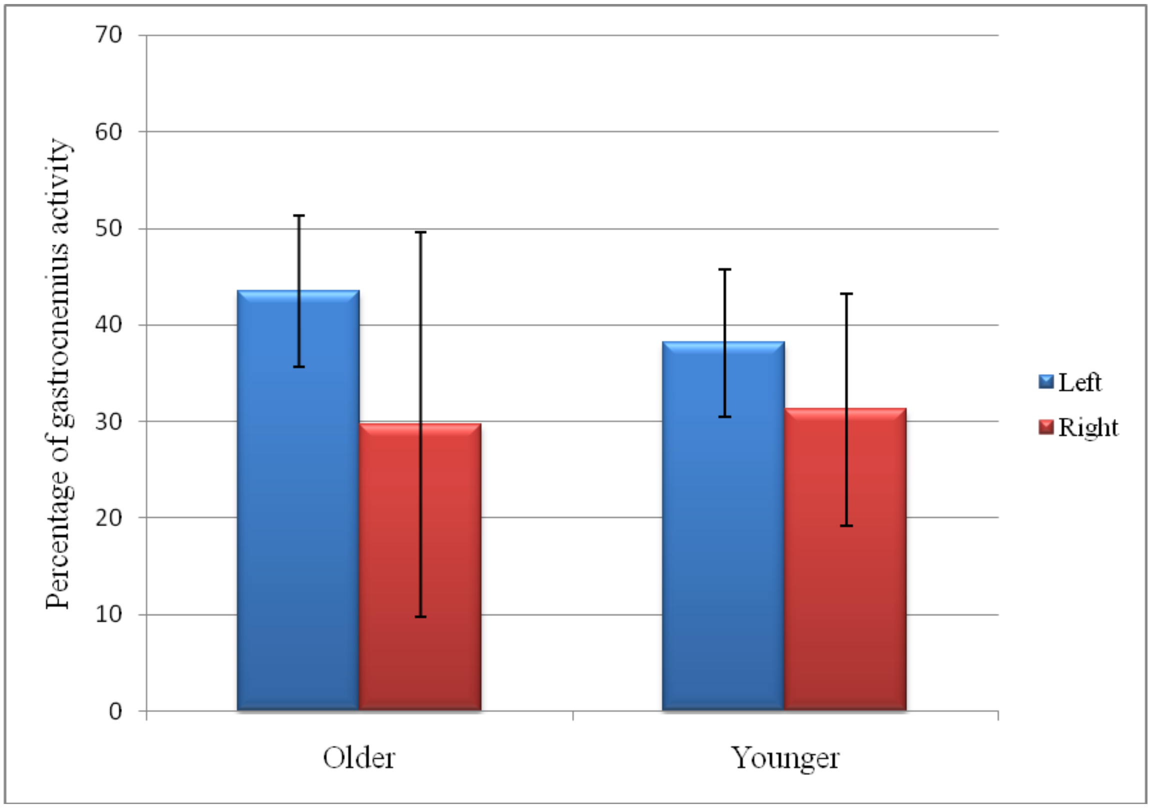

Figure 5.9 Gastrocnemius activity from IC to maximum vertical GFR showing the effect of age group.

Tibialis anterior

As with gastrocnemius, a large standard deviation was measured for both age groups for tibialis anterior activity, see Figure 5.10 and Table 5.5, for a representation of the data. Older participants on the left used a mean maximum of 35.7% (SD 15.4) and on the right 27% (SD 11.4). Younger participants on the left used a mean maximum of 30.5% (SD 10.7) and on the right 26.8% (SD 12.8). There was no significant difference between older and younger participants in the amount of tibialis anterior muscle activity between IC and maximum vertical GRF ($F(1,18)= 0.232$; $p=.636$)

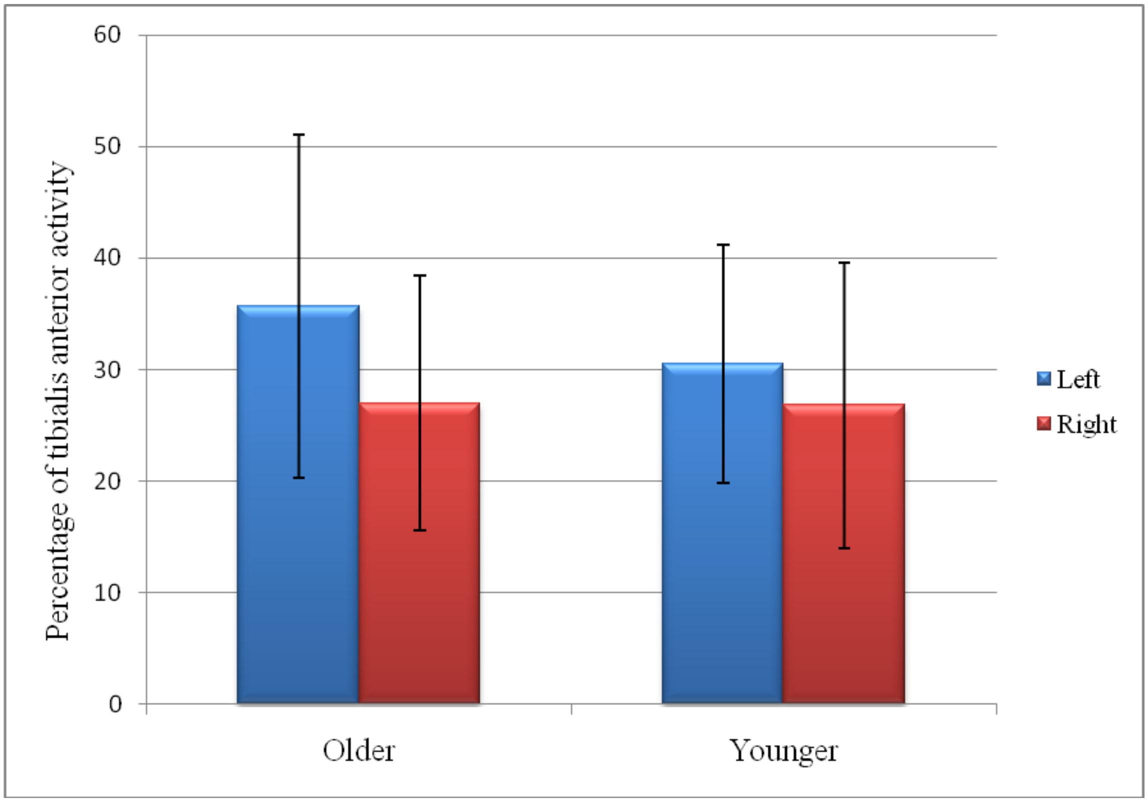

Figure 5.10 Tibialis anterior activity from IC to maximum vertical GFR.

Table 5.5 Ensemble means and standard deviations of muscle activity during energy absorption of a step descent

	Older				Younger			
	Left		Right		Left		Right	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Gluteus medius*	45.3	9.9	40.9	16.7	46.6	7.7	45.4	8.6
Vastus lateralis*	55.1	8.9	50.8	10.3	46.7	8.6	44.3	6.2
Gastrocnemius*	43.49	7.8	29.67	19.9	38.1	7.6	31.2	12
Tibialis anterior*	35.7	15.4	27	11.4	36.5	10.7	26.8	12.8

*All muscle activity is from IC to maximum vertical GRF (% of maximum for task);

5.4.6 Null Hypothesis 6

The relationship between upper body and the stepping leg at IC in an antero-posterior direction will remain the same within and between each group of participants.

This measure, represented in Figure 5.11 and Table 5.6, showed very little variability within or between groups, with a small standard deviation observed for both age groups. The mean distance measured during a left step in older participants was 0.223m (SD 0.021) and during a right step 0.213m (SD 0.03). In younger participants during a left step the distance was 0.247m (SD 0.03) and a right step 0.227 (SD 0.03). There was no significant difference between the older and younger participants in the relationship between the upper body and the stepping leg at IC (F(1,18)=2.28; p=.1480).

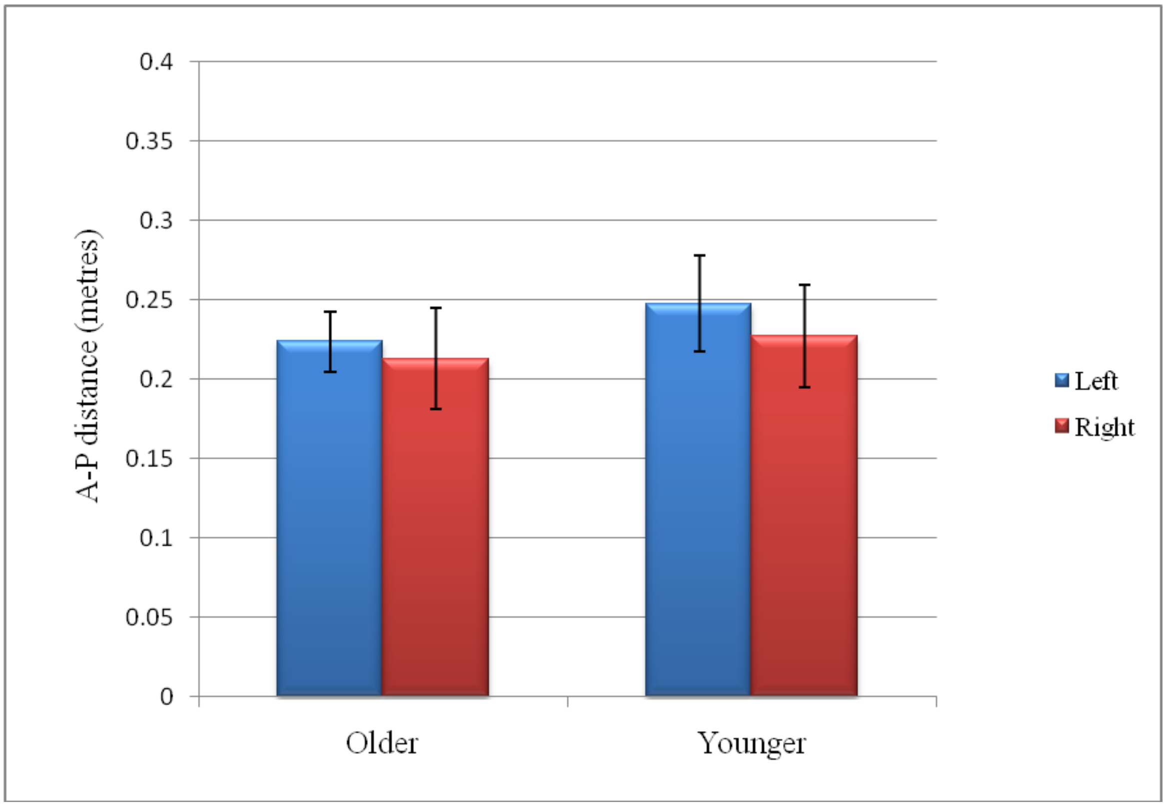

Figure 5.11 The antero-posterior distance between mid PSIS and lateral malleolus of the stepping leg at IC.

Table 5.6 Ensemble mean and standard deviation of distance between upper body and stepping leg at IC.

	Older				Younger			
	Left		Right		Left		Right	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HD between mid PSIS & mall(s) leg (m)	0.22	0.02	0.21	0.03	0.25	0.03	0.23	0.03

HD-horizontal distance; PSIS-posterior superior iliac spine; mal (s)-lateral malleolus of the stepping leg; m-metres

5.4.7 Section summary

The independent variable of interest in this study was age group, either older (60-80 years) or younger (20-30 years). The main effects of age group on the dependent variables are reported under each null hypothesis. The statistical analysis enabled the effect of age group on the nine dependent variables to be established. Age group was found to have had a significant effect on two of the dependent variables; knee angle was significantly reduced in older compared to younger participants; vastus lateralis activity was significantly increased in older compared to younger participants.

6 Discussion

6.1 Introduction

The discussion will examine each null hypothesis in light of the findings of this research. Differences and similarities between the current study and previous research investigating the step descent task will be discussed and addressed. From the findings and conclusions drawn, suggestions will be made for future research direction.

6.2 *Null Hypothesis 1*

There will be no difference between older and younger participants in maximum knee angles in the sagittal plane between initial contact and loading response.

The results of this study show a statistically significant difference between older and younger participants in range of motion at the knee joint during the period of energy absorption in the early stance phase of stair descent.

The magnitude of the range of knee flexion in the stepping leg, which is used to attenuate the vertical GRF at impact was measured in the current study. In many of the other studies investigating the kinematic requirements of step descent the emphasis has been on maximum range of knee flexion for the whole task. The maximum range normally occurs in the support leg as it lowers the stepping leg to the step below and starts the swing phase of stair descent. Lark et al.(2004) and Protopapadaki et al.(2007) compared the maximum knee range available with the range utilised by older adults whilst performing a step descent task. Riener et al.(2002) and Livingston et al.(1991) also investigated the effect of different step heights on maximum range of knee motion in healthy young adults.

Other studies have reported range of motion during the early stance phase of stair descent but in the case of McFadyen and Winter (1988) they did not report the ages of the three participants so no inference about the effect age might have had on the knee angle can be made. Hortobagyi and DeVita (2000) investigated the difference in leg stiffness between older and younger adults at impact during a step down task and found that older adults had significantly increased stiffness. However, stiffness was computed using maximum vertical

GRF divided by leg displacement from IC to the maximum vertical GRF, and no individual measurement of joint range at individual joints was made. There was an assumption that the stiffness was divided between ankle, knee and hip with no measurement of the magnitude in any one joint. This means that any alteration in relative range of motion at joints between the two age groups would have been obscured. Interestingly, despite the substantial increase in limb stiffness, the resultant vertical GRF was not increased in the older group but the maximum was reached more quickly implying an increased rate of loading. Hsu et al. (2007) also compared leg stiffness between older and younger adults in a step descent task. In this study knee angles were measured at impact with the results revealing older adults used 10.6° (SD 14°) knee flexion, whilst younger adults used 19.5° (SD 8.2) knee flexion, this represented a significant difference between the two age groups. In agreement with the previous study, the difference made to vertical GRF was not in magnitude but in the rate of loading. The knee range of motion measured in the current study investigated both legs to account for the possible confounding variable of leg dominance. Knee flexion in older participants for left leg was 17.3° (SD 7.8) and right leg was 18.2° (SD 6). In younger participants, knee flexion for left leg was 25.5° (SD 13.5) and right leg was 27° (SD 11.6). These results show no significant difference between right and left leg for either age group, however as reported in the results, they do show a significant difference between older and younger participants. The amount of knee flexion measured in this study for both age groups is considerably higher than in the study by Hsu et al.(2007) and there are several factors which may account for this.

Firstly Hsu et al.(2007) measured knee flexion using an electrogoniometer whereas the current study used three dimensional motion analysis. Piriyaprasarth, Morris, Winter and Bialocerkowski (2008) found that despite electrogoniometers having ICC's for intertester reliability between 0.57- 0.8, the lower of these two scores occurred when the participant was in a standing position with the knee in a more extended position (angles of less than 90°) and in that position the limits of agreement were -12.3 to +7.22. Three dimensional motion analysis systems more accurately locates the centre of knee rotation and has none of the potential sources of error such as slippage of the device during movement or poor initial positioning of the device that may occur with electrogoniometers.

Secondly in the study by Hsu et al. (2007) the older participants were 72 years (SD 4.5) and the younger participants were 21.2 years (SD 0.5) whereas in the current study our older participants were 65.3 years (SD 4.9) and our younger 22.8years (SD 2.5). A study by Frontera (2008) helps explain why the additional 7 years in older subjects may increase age related changes and reduce the amount of knee flexion. The study by Frontera found that beyond the age of 50 there is a loss of muscle strength between 1.4 and 2.5% per year, with larger declines being seen in the lower limbs compared to the upper limbs. However, this explanation does not account for the changes seen in the younger group of participants in the current study. The difference in knee range between the current study and the study by Hsu et al. is obviously not related to age because the mean age of both groups was very similar. It is possible that there were other demographic or anthropometric factors that differed between groups but that were not reported.

Finally, once the participants in the current study had negotiated one step they proceeded to walk along a walkway, a task involving minimal risk to an older person. In the study by Hsu et al.(2007) there was a series of step descents to negotiate which is a more complex and inherently risky task. Chambers and Cham (2007) demonstrated that co-contraction increased around both the ankle and knee joints not only where there was actual risk during an activity but also where there was a perceived increased risk of falls. The consequence of Hsu et al's (2007) trial involving a more demanding motor task may therefore have produced more co-contraction and therefore less knee range of motion.

6.3 Null Hypothesis 2

> *There will be no difference between older and younger participants in maximum hip angles in the frontal plane between initial contact and loading response.*

The range of motion at the hip joint in the frontal plane during step descent has been investigated in only one previous study by Mian et al. (2007). The authors found that older participants had significantly larger range of motion than the younger participants, older 9.4° (SD 4.3), and younger 4.7° (SD 2.2) of adduction. They identified the occurrence of peak range during the step descent only as “in late stance” (p. 15), this is difficult to quantify but seems to correspond less to initial impact and energy absorption and more to the weight transfer that occurs in preparation for the contralateral leg to leave the step. In the current study, although there was no significant difference found between older and younger participants in the hip range of motion, the mean for older adults was slightly *lower* than for younger when measured at initial contact.

It seems clear that the current study and the study by Mian et al.(2007) are measuring two different temporal phases of the step descent cycle. The current study investigated initial contact and Mian et al. seems to have measured weight transference during double leg support phase. This suggests that the results are not directly comparable. When the two studies are viewed together, it could be assumed that an increase in frontal plane hip range of motion, when preparing for the contralateral leg to leave the step, occurs as a direct consequence of weakness in the hip abductors. However Rutherford and Hubley-Kozey (2009) discovered that in level walking the range of hip adduction, and consequently the external adductor moment that needed to be counteracted by the internal hip abductor moment, was not directly related to hip abductor strength. It is possible that the increase in range of adduction is due more to a failure to generate sufficient force quickly enough than a lack of sufficient strength. The reason that an increased range of motion is not observed at IC may be due to a prolonged period of pre-activity of the muscles prior to IC and co-contraction of the muscles at IC. These two mechanisms have been found to decrease flexion at IC in the knee, but to date there has been no investigation into this strategy in the hip muscles.

6.4 *Null Hypothesis 3*

> *There will be no difference in magnitude of maximum vertical GRF between younger and older participants.*

Contrary to the study by Robbins et al.(2001) no increase in vertical GRF was found in the older participants, compared with the younger in this study. The current study however does differ from that by Robbins et al. in the type of task undertaken. The current study aimed for a realistic functional task, whereas Robbins et al. instructed participants to step down onto the force plate and remain balanced on one leg for a few seconds. The act of decelerating quickly and halting the forward momentum may have contributed to the observed differences in results between the two studies. The other important difference between the study by Robbins et al. and all the other studies in the area of step descent is that the authors used a step height of only 4.5cm. Other studies use step heights of 21cm (Andriacchi et al., 1980), 18cm (Christina & Cavanagh, 2002; Yu et al., 1997; Zachazewski et al., 1993) or a range from 13.8-23cm (Riener et al., 2002). These step heights all fit within the range of step heights found in everyday life, steps and stairs under 10cm are identified as a tripping hazard and are not recommended for domestic or commercial use (Roys, 2001). When the step height and task parameters of the study by Robbins et al. (2001) are considered in combination, it is difficult to see how the findings can have very much generalisability to forces encountered in everyday life, it also makes comparison with other studies cursory at best. However despite the differences between this and the majority of other step descent studies it is counterintuitive that such a shallow step would generate an increase in vertical GRF in older adults when much higher steps have failed to do so. One possible explanation is that the task presented so little challenge, that any caution in choice of strategy that may otherwise have reduced impact may have been abandoned. The majority of other studies (Hsu et al., 2007; Larsen et al., 2008; Reeves et al., 2008; Stacoff et al., 2005) agree with the current study in finding no increase in vertical GRF during a stepping activity when comparing older and younger adults.

6.5 *Null Hypothesis 4*

There will be no difference in time taken to reach maximum vertical GRF from IC between older and younger participants.

The finding in the current study of no significant difference in time taken to reach maximum vertical GRF between younger and older participants was a surprising finding for two reasons. Firstly because a number of the previous studies have found an increase in loading rate when comparing older and younger adults (Christina & Cavanagh, 2002; Hamel et al., 2005; Hsu et al., 2007). Also the current study did identify a decrease in knee flexion angle and an increase in vastus lateralis activation levels at initial contact in older adults. The combination of these two variables which have the potential to increase the stiffness of the lower limb, would seem to predispose to decreased time to reach maximum vertical GRF.

One factor which may have obscured any difference was the variability of time to reach maximum vertical GRF loading rates among individual participants. The group means were similar but there was a larger range of values in the older age group, although the lowest values (corresponding to the fastest time to maximum vertical GRF) were seen in the older participants. There is a possibility that the study was underpowered to see a change in time to reach maximum vertical GRF. However of the other studies that found a difference in rate of loading, only Hsu et al.(2007) had larger groups than the current study with 16 younger and 16 older adults. The other studies had similar sample populations 12 in each group (Christina & Cavanagh, 2002) and 12 young and 10 older (Hamel et al., 2005).

When looking in detail at the experimental protocol undertaken in the three studies that did find an increase in loading rate, small differences are noted that may account for the findings in comparison with the current study. Hsu et al.(2007) did not allow any arm swing, which may have affected the way that the step task was executed. A study by Ortega Fehlman and Farley (2008) found that arm swing in normal walking improved stability and it seems probable that this finding would apply to a step descent task. Christina and Cavanagh (2002) supported the participants in their study in a full body safety harness and although not explicitly described, it can be assumed that Hamel et al. (2005) also used a harness as, citing Christina and Cavanagh they stated that, “The staircase used in this study has been described in depth previously”(p. 1049). The co-contraction of muscles supporting a joint increases with the perceived risk of a fall (Chambers & Cham, 2007), so it is likely that a harness would significantly reduce fear of falling, as no injury could occur if balance was compromised. If fear of falling was reduced it may in turn reduce co-contraction of muscles attenuating impact. As Lark et al. (2003) have established, reduced stiffness is associated with reduced loading rates. In the present study, no instructions were given regarding arm movement and there was no external safety device in place, this may account for the differences seen in the loading rates.

6.6 *Null Hypothesis 5*

The relative amount of muscle activity used at initial contact to attenuate impact will be the same for both young and older participants.

The current study was exploratory and measured variables that have had little investigation in previous literature. Muscle activity used in attenuation of impact was explored in this study. The end of energy absorption actually occurs at the minimum (Fz3) between the two peaks on the vertical GRF trace. However the period from IC to peak vertical GRF (Fz2) represents a significant part of energy absorption and are points on the vertical GRF trace that are easily identifiable on the trace for each step, which improves the reliability of the measurement.

Overall the common finding for all but vastus lateralis EMG recordings was that there was more variability within and between individuals than between the two age groups.
This is often considered to be error and is seen as a problem to eradicate but Davids et al. (2003, p. 245) contend a very different interpretation.

> "…it is argued that trial-to-trial movement variations within individuals and performance differences observed between individuals may be best interpreted as attempts to exploit the variability that is inherent within and between biological systems."

Despite the fact that the task and environment were kept as constant as possible there will have been subtle variations over the course of the task that will have affected the participant's performance, including boredom, learning effect and minor unavoidable distractions.

The activation of each of the tested muscles will be considered separately in light of the findings from step descent literature.

6.6.1 Gluteus Medius

The role of gluteus medius in attenuation of impact at initial contact during stair descent has been almost ignored. Even when hip range of motion and moments are measured there is no recording of the main muscle providing the internal moment to counteract the measured external moment. Prior to the present study only McFadyen and Winter (1988) had monitored EMG of gluteus medius during the entire step descent. The EMG trace is published and timing of activity is reported as beginning just prior to initial contact and continuing to increase in magnitude until the maximum activity towards the end of double support. The quantification of muscle activity (μV) given by McFadyen and Winter was an ensemble mean for the entire task, ascent or descent and gives some measure of relative muscle activity for the task. It gives no ability to separate a single phase of a task but what is of interest is that gluteus medius was equally active in ascent and descent, whereas most of the other muscles monitored (vastus lateralis, semitendinosis, gluteus maximus, medial gastrocnemius, soleus and tibialis anterior) were considerably less active in descent than ascent. This implies that the role gluteus medius plays may be different during the two tasks and is perhaps both a stabilising muscle and one involved in energy absorption. However if energy absorption was an important role a larger magnitude of activity would be expected during descent compared with ascent. As further confirmation that gluteus medius has a smaller role in energy absorption than other more distal muscles, in a figure in the paper published by McFadyen and Winter, showing muscle powers of the ankle, knee and hip during descent, the relative magnitude of energy absorption at the hip is minute compared to the ankle and the knee but there was no report of exact numerical values. In the current study there was no significant difference between older and younger adults in percentage of activity of gluteus medius. Joint angle is one of the important factors contributing to the external moment about the hip in the upright posture. It may be that the range of motion at the hip is so small that the external moment that has to be counteracted is also small and that relative to the knee and ankle musculature, the hip muscles are not as important for energy absorption at the IC phase of step descent.

6.6.2 Vastus Lateralis

The finding of a significant difference in activation of vastus lateralis between older and younger participants was congruent with previous research of stair descent. However other research has investigated *timing* of onset of quadriceps femoris prior to initial contact (Hinman et al., 2005; Liikavainio et al., 2007), and pre-activation of vastus lateralis and co-activation of biceps femoris during the gait cycle (Hortobagyi & DeVita, 2000; Hsu et al., 2007; Larsen et al., 2008). The only study that sought to *quantify* the activity of vastus lateralis after IC was Reeves et al. (2008), however the results for normalised EMG recordings from vastus lateralis show that there was no difference in the pattern of EMG activity between older and younger adults but that when considering joint moments, the older participants were working at a higher relative capacity than the younger. As far as I am aware ours is the first study to report relative magnitude of vastus lateralis activity in the early energy absorbing phase of step descent.

The finding of increased activity in vastus lateralis in the older adults does concord with previous research (Hortobagyi & DeVita, 2000; Hsu et al., 2007) and may explain why some authors have also recorded an increase in impulsive loading. The underlying reason for the increase in activity during early loading is not fully understood. The loss of muscle strength secondary to sarcopenia and reduction of accurate grading of submaximal force due to the denervation-reinervation of motor units with aging helps to explain the finding, but other factors that were not measured in this study may also have a significant role, such as fear of falling. In a study by Adkin, Frank, Carpenter and Peysar (2002) anticipatory postural adjustments and voluntary movements in response to differing levels of fear of falling were investigated. It was found that anticipatory movements in situations of most threat were smaller in amplitude, but the voluntary movement required to complete the task lasted for a longer duration with increased level of muscle activity. It is possible that the increased level of risk offered by steps increases muscle activity in a similar way.

6.6.3 Gastrocnemius

Most energy at initial contact is absorbed by the plantar flexors (McFadyen & Winter, 1988) as the most common strategy for stepping on to a lower step is to contact it in full plantar flexion. In this study we did not see any variation from this strategy of IC with the forefoot, but as noted in the results we did record 3 participants, one younger and two older who had less than 5% gastrocnemius activation at IC. This is an unexpected finding in light of the literature, which states that gastrocnemius is active at initial contact. The absence of activity in gastrocnemius during the energy absorption phase was recorded in 30-40% of the step descents by the three participants and as such does not appear to be an occasional aberration. It appears to be part of the variability that has been reported for many of the lower limb muscles during step descent.

6.6.4 Tibialis anterior

Tibialis anterior has been identified in some literature as having a variable role in step descent, as opposed to the more regular one during step ascent, where it is the main muscle used to ensure the toe is lifted clear of the edge of the step above. The muscles that are most active in step descent are those involved in energy absorption. However co-contraction of muscles around a joint is a strategy that is employed to increase stability, particularly with increasing age, so it was considered possible in the current study, based on step descent literature, that we would see an increase in tibialis anterior muscle activity in the older participants. Hortobagyi and DeVita (2000) investigated muscle activity around the ankle during a step descent activity. They reported that in a 100 ms time period after IC older participants had significantly higher activity and co-contraction in tibialis anterior than the younger participants. Muscle activity in tibialis anterior in older participants was 71 µv (SD 271) and in younger 162 µv (SD 31). Co-contraction of tibialis anterior and gastrocnemius was measured as a relative quotient of the peak root mean square amplitude of the two muscles. In older participants it was 0.66 (SD 0.39) and in younger 0.33(SD 0.14) indicating that the older participants had twice as much activity of tibialis anterior compared to gastrocnemius, as the younger participants. The current study did not measure co-contraction but did measure activity in the muscle in a short time period after IC, but rather than directly comparing the activity of muscles between subjects, we compared the amount of muscle activity with the maximum for task for each individual. This is because an EMG signal is dependent on a large number of variables, including; skin impedance, location of the electrode in relation to the motor end plate, fixation of electrode to the skin and proportion of body fat (Hermens et al., 2000). It has been found that comparisons of absolute activity (measured in mμ) between individuals and between different muscles are unreliable (Winter, 2005). Nevertheless the differences found in amount of muscle activation by Hortobagyi and DeVita are of a large magnitude and suggest a significant difference between participants which we did not find.

This may be accounted for by the step height used which in our study was 20cm and in the study by Hortobagyi and DeVita (2000) is 20% of the patient's height. This corresponds to about 30cm, which is a higher step and would represent a more challenging task and probably result in an increase in muscle activation in older adults. In addition the current study recorded muscle activity during the period from IC to maximum vertical GRF compared with 100ms in the study by Hortobagyi and DeVita, which means that muscle activity was recorded for more of the time period of energy absorption in our study. The study by Hortobagyi and DeVita would have measured muscle activity for different proportions of energy absorption as individuals reach maximum vertical GRF at different time periods after IC.

6.7 *Null Hypothesis 6*

> *The relationship between upper body and the stepping leg at IC in an antero-posterior direction at IC will remain the same within and between each group of participants.*

The measurement of the relationship between the upper body and the stepping leg generated a result that showed very little variability either within participant or between older and younger participants.

It was thought that older adults might adopt one of two possible strategies that could affect the relationship between the upper body and the stepping leg. The older adults who were less confident about their ability to attenuate the impact of landing from a step could maintain their body weight over the lowering leg to move their body in a controlled way to the level below. This would have resulted in an increased antero-posterior distance between the mid PSIS and lateral malleolus of the stepping leg at IC. The prerequisite for this strategy would be sufficient strength and eccentric control in both quadriceps and gastrocnemius of the stance leg. The other strategy would be one brought about by the lack of ability to maintain such control and would fit into the category of the *controlled fall* discussed by Townsend et al. (1978) Winter (1995) and Zachazewski et al. (1993). This would maintain the relationship found in younger adults between the upper body and the stepping leg but would result in an increase of either vertical GRF or rate of loading, neither of which were found. However there was no difference in the measured distance between the mid PSIS and the lateral malleolus of the stepping leg within trials for each participant, or between participants. This was an unexpected finding when considering the huge variability measured within individuals for variables such as knee range of motion and muscle activation. *The uncontrolled manifold theory* proposed by Latash, Scholz and Schöner (2007) may help explain this surprising finding. The authors suggest that humans have many possible permutations of muscle activity and joint degrees of freedom to achieve a stable primary motor outcome. In this case the maintenance of a safe relationship of the upper body over the stepping leg was the primary requirement and a variety of permutations of muscle activation and joint range of motion could achieve the same result. To achieve stability of performance during a motor task, the central nervous system can generate many permutations of the components that make up the task.

In support of the findings of the current study, two other studies were found that looked specifically at the antero-posterior movement of the body during a step descent. The study by Mian et al. (2007) measured the relationship between the centre of mass and the centre of pressure of the stepping leg. These authors also found that the relationship between the upper body and stepping leg was maintained when comparing younger and older men. The older participants in this study, as in our study were all healthy community dwelling adults but were considerably older (73-84 years) than our study. However despite this, no significant differences between the groups was found. The other study was undertaken by Reeves et al. (2008) investigating a similar population of older adults,(74.8 years(SD 2.8)) they also found no significant difference between the older and younger participants between the relationship of upper body and stepping leg during a step descent.

6.8 Limitations of the Study

Several of the studies encountered in the literature had aspects to their investigation that made the results difficult to generalise to the population. The current study also has limitations despite efforts to address this problem. Laboratory studies are required in order to gather reliable data but are by their nature, not able to replicate real life situations completely. This may have produced movement constraints of which we were unaware as the task and the environment were not ones normally encountered. The number of step descents was more than you might typically encounter at one time but rest time was given to help offset any effects attributable to fatigue.

Recruitment was by advertisement and so attracted those people who were motivated and interested and who were able to travel to the university independently. Older adults for whom the changes in muscle strength and activation were causing any physical limitation may have not volunteered, especially as the session lasted between 1.5 and 2 hours and necessitated stepping, which has already been identified as an activity that sedentary older adults find challenging. This may have influenced the sample of adults who volunteered, accounting for observed characteristics of our older group of participants. The older participants in the study were all active and mostly at the younger limit of the age cut off with a mean age of 65.3 years. Several of our older participants still engaged in exercise at the gym or sport, possibly making them fitter than average for their age group. Measurable deterioration in this younger and fitter group may be of a much smaller magnitude than we had expected based on the literature and therefore would have necessitated a larger sample size to observe a difference based on age.

During the modelling of the kinematics the joint range of motion at the knee and hip were calculated based on a rigid link model, which assumes that both joints were hinge joints rotating about fixed axes. This is not the case and the axis of rotation does move during both knee flexion (van den Bogert, Reinschmidt, & Lundberg, 2008) and hip adduction (Schwartz & Rozumalski, 2005). This is a limitation of the model used but the technical difficulties of accounting for a moving axis was beyond the scope of available technology.

The method used to normalise the EMG to the percentage of 'maximum for task' has some limitations associated with it. The method is used to ascertain the amount of muscle activity for a component of a task, as a proportion of that used during the most difficult aspect of the task. It is a proxy measurement for the degree of difficulty the component presents to an individual. In a series of a repeated task such as in the current study, there will be variations in the maximum EMG recorded from one task to another. Compared with the 'maximum voluntary contraction' method, the maximum recorded value, using the 'maximum for task' method, will be dependent on more variables, including the exact way the task is carried out. However, we felt that for this research the benefits of gaining a task specific measurement of EMG outweighed the potential limitations of the method. In choosing a method for normalisation, consideration was given to the fact that there is no consensus on the 'gold standard' for normalising EMG (Burden & Bartlett, 1999).

6.9 Conclusion

There has been recent research into the theory that muscle weakness and dysfunction, directly attributable to age related sarcopenia, predisposes older adults to cumulative joint damage. There has been some research undertaken investigating muscle pre-contraction and co-contraction during a step descent and how this may affect the energy absorption at IC. There has been very little investigation into muscle activity during the impact phase and conflicting evidence about the magnitude and rate of loading of vertical GRF during step descent.

This was an exploratory study quantifying differences in strategies used by older and younger adults during step descent. We compared the kinematic and muscle activation patterns in older and younger adults and the influence these differences may make to the magnitude and time taken to reach maximum vertical GRF. This research into the role that muscle activity and subsequent joint range of motion has on impulsive loading, might add to literature investigating progressive joint deterioration in older adults. The focus of the study was on the role of the joints and muscles of the stepping leg in the attenuation of impact in the critical energy absorption phase from IC to maximum vertical GRF. The results of our study showed that the main difference between older and younger adults occurs at the knee joint. The older adults were found to use significantly less range of movement and a higher percentage of muscle activation at the energy absorption phase of step descent. Despite these findings that may have been expected to stiffen the limb, we did not find an increase in magnitude or time to reach vertical GRF. This unexpected finding was discussed previously and in the following section possible areas for further research to explore these findings in more detail are suggested.

6.10 Further Research

In light of the findings of the current study and review of the literature, the final section will highlight possible areas of interest for future research. Much of the research into stair descent involves patients with specific pathologies, which are implicated in altering movement strategies or the firing patterns of muscles secondary to pain or derangement of the joint (Brindle et al., 2003; Sheehy et al., 1998; Wu et al., 2005). There is a small but slowly growing body of research investigating the kinematic and kinetic variables of the stair descent task in normal adults. Some of this research investigates the differences between younger and older adults to investigate whether the normal aging process causes changes that may predispose to joint damage. The life expectancy of adults in New Zealand is now 78 years for males and 82 years for females and the number of New Zealanders over the age of 60 currently almost 800,000 or approximately 20% of the population (Statistics

New Zealand, 2009). Any changes in movement patterns that have the potential for significant deleterious effects on joint health for so many people require investigation.

There is some conflicting evidence about whether changes that occur with aging have an effect on either the rate or the magnitude of the vertical GRF. There have been authors who have noted a significant increase in vertical GRF with aging, and some, including the current study, who have found none. Studies with larger sample sizes would be able to identify smaller changes and may ascertain whether vertical GRF magnitude or rate of loading do alter with increasing age. Future studies may benefit from further sub division of groups into age categories for example 60-69, 70-79 and may further examine the activity level of participants to differentiate between the active and sedentary older adults. These studies may be able to identify the population at risk of damage from cumulative impact stress. It seems reasonable to suggest from the current and previous studies, along with knowledge of muscle physiology changes that occur with aging that older more sedentary adults may be less able to attenuate impact than fit adults in their early to mid 60's.

The current study found both a decrease in knee range of motion to absorb energy at IC and an increase in vastus lateralis activity that may have helped account for that reduction. Despite not finding a concomitant increase in vertical GRF the reduction in ability to absorb energy has potential long term consequences. Future research may investigate the reasons for the increased muscle activity and reduction in range of movement. The research so far strongly supports the theory that these two observations are in response to reduced stability and a need to co-contract lower limb muscles prior to impact. In that case is this a strategy that can be returned closer to the normal strategy observed in younger adults with targeted intervention? Exercise interventions for older adults are often focussed on increasing maximum strength but there is some evidence that task specific training with an emphasis on timing and accurate scaling of sub maximal force, can lead to significant improvements in returning muscle activity to patterns normally found in younger adults (McGibbon et al., 2003). In support of this suggestion Hsu et al. (2007) also recommend that a lower limb strengthening programme for older adults should include focus on the timing of the contraction of muscles.

The findings for gastrocnemius suggest that there may be some variation in muscle activity between right and left legs. It may be that further study of muscle activity in attenuation of impact should endeavour to recruit equal numbers of right and left handed participants to ascertain if, with larger numbers, a difference in muscle activity involved in energy absorption can be found. The possibility is that there is a difference between right and left legs or the difference may be due to leg dominance. It is also possible that other muscles might show a similar effect to gastrocnemius with larger numbers.

6.11 Clinical implications

Strengthening exercises are important for older adults as a preventative strategy as well as to ameliorate the secondary weakness that occurs with advancing age and disability. However there are changes in muscle structure and function with increasing age and physiotherapist need to be aware of the consequences of these changes in order to prescribe exercise appropriately. Early changes to muscle innervation increase the number of motor units innervated by a single nerve and as a consequence change the ability of muscle to grade force and co-ordinate movement accurately (Patten, 2000). Changes in co-ordination often significantly precede a noticeable reduction in strength. It is important that any exercise prescription includes an element of movement control and co-ordination at sub-maximal strength to address the specific deficit. Task related exercises that include movements requiring changes in speed and timing have been shown to improve motor performance and return movement patterns to those expected in the younger population.

This has possible implications with assisting older adults with task planning, if one leg affords better protective strategies than the other it may be better to lead with that leg for potentially higher impact activities, such as higher steps. It may also help therapists to consider more unilateral exercises to ensure that both lower limbs have adequate loading for strength and co-ordination of muscle activity. Bilateral strengthening may mask limitations in one limb and limit the improvement of the weaker or less co-ordinated limb.

In light of the findings of subtle changes found in adults without pathology and with no noticeable functional decrement, the question must be asked where physiotherapists are likely to be able to influence this population. Most of these adults will be working or engaging in everyday activities and are unlikely to seek advice about exercise from a health professional until problems present. If advice is sought it may be a gym where the focus is mainly on strength training. The challenge is to disseminate information about incorporating co-ordination exercises in to a strength programme. Physiotherapists are gradually moving away from a mainly *treatment* model to a more *preventative* approach as evidenced by an increase in physiotherapists running exercise programmes in the community. The role of physiotherapy at a time when there is a growing percentage of older adults in the population, must be to advise and educate on the most effective exercises and activity regimes. In order for that to take place there needs to be an increasing emphasis on growing our evidence base, so our advice can be built more on empirical evidence and rely less heavily on anecdotal evidence of success.

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7 Appendices

Appendix A: Advertisement

Appendix B: Participant Information sheet

Appendix C: Ethics approval

Appendix D: Consent form

7.1 *Appendix A: Advertisement*

A comparison between older and younger healthy adults of muscle activity during a stepping task
We are looking for volunteers for this study

WHO?
If you are interested and are:

- Between the ages of 20-30 years OR
- Between the ages of 60-80 years

AND

- Healthy and physically active
- Have no severe arthritis, severe cardiovascular problems and no neurological disability such as stroke, that impacts on your activity levels
- No allergy to sticking plaster or adhesive tape

WHY?
We are interested in whether muscles around the hip and knee, act differently in older and younger age groups during a stepping task. This information will be used to add to current knowledge of the development of lower limb osteoarthritis.

WHERE?
At the Health & Rehabilitation Research Centre,
AUT, Akoranga Campus

For more information contact
Nicola Saywell
nsaywell@aut.ac.nz
(09 921 9999) Ext 7084
Please leave a message with your phone number and I will get back to you.

Many thanks for considering volunteering for this project.

7.2 Appendix B: Participant Information Sheet

Date Information Sheet Produced: 7th January 2008

Project Title: Age dependent differences in recruitment and phasing of lower limb muscles at loading response and the corrolation with impact forces

Researchers are: Nicola Saywell and Dr Denise Taylor

Address: AUT, Private Bag 92006, Auckland

Phone number: 921 9999 ext 7084

Invitation

You are invited to take part in a research study that will explore the muscle activity around your hip and knee during walking and the forces produced by the impact of your step. This supervised study is the work of a qualified physiotherapist as part of their Masters degree. You may be eligible for this study if you meet the entry criteria of being between 20 and 30 years OR 60 and 80 years; you can walk without a walking aid; you have no neurological, cardiovascular or musculoskeletal disorders, and no known allergy to taping materials.

What is the purpose of the study?

The aim of the study is to examine whether muscle activity around the hip and knee changes with increased age. There is some information in current research that as we age our muscles get less efficient at absorbing the forces that occur when we step and the purpose of this study is to investigate this further. It is hoped that this will add to the current literature on the development of lower limb arthritis.

How do I join the study?

If you wish to join the study please contact:

Nicola Saywell **(09) 921 9999 ext 7084**

How are people chosen to be asked to be part of the study?

If you meet the entry criteria of being between the ages of 20 and 30 years OR 60 and 80 years; you have no neurological, cardiovascular or musculoskeletal disorders and no known allergy to taping materials and can spare two and a half hours of your time then we welcome your assistance.

What happens in the study?

You're given about a week to consider if you would like to take part. If you decide to participate an appointment will be made for you to attend the research laboratory. When you arrive for your appointment, the details on this sheet will be discussed with you to check that you understand the details and are happy to participate. You will be asked to sign a consent form and will be given a copy to keep.

You will be asked to change into a pair of shorts***** so that small electrodes can be placed on different muscles on your legs. The electrodes detect muscle activity, are about four centimetres in size and have self adhesive pads. A little extra tape may be needed to assist with adhesion. It will be necessary to shave off hair where the electrodes will stick as this will help with adhesion, and will make removal of the electrodes more comfortable. The patch of skin where the electrode will stick will be cleaned to remove any skin oils or creams. There will be eight electrodes put on each leg including ones on the hip and thigh. The information from the electrodes will be sent to a belt that you will wear around your waist and will be recorded by the computer. Small polystyrene markers will also be attached to your skin to allow your movement to be tracked by 9 cameras.
You will be asked to step down from a step (height 4.5cm) onto the floor. The information from the cameras, the electrodes and a force plate will all be collected by computer and stored. You will be asked to do this for up to 20 trials with rests as needed.

***Note if you own shorts we will ask you to bring your own, otherwise the researcher will provide shorts of varying sizes for use during the trial.**

What are the discomforts and risks?

There is a small chance that you are allergic to the adhesive pads on the electrodes. Occasionally mild skin irritation occurs on the shaved area of skin, this usually lasts less than a day.

How will these discomforts and risks be alleviated?

Low allergy taping products will be used to minimise any risk of allergy. You will be closely monitored during the trials to ensure that you are comfortable, and given opportunities to rest. You are also free to indicate when you need to rest or stop.

What are the benefits?

There are no direct benefits to you; however your participation would be most helpful in furthering knowledge in this area. This research will add to current literature on the factors effecting the development of lower limb osteoarthritis.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and ACC regulations. If you have any questions about ACC please feel free to ask Nicola for more information before you agree to take part in this study.

How will my privacy be protected?

Your confidentiality will be maintained in the following ways. No material which could personally identify you will be used in any reports on the study. Your identity will remain confidential to the researchers. Data collected in this study will be kept secure in a locked filing cabinet and office.

What are the costs of participating in the project?

There is no monetary cost to you. It will involve about two and a half hours of your time. Petrol vouchers will be offered as partial recompense for travel costs.

Opportunity to consider invitation

You will have approximately a week to consider whether to take part after you receive this sheet. The researcher will then make contact by phone to arrange a time to undertake the walking activity, if you are happy to participate.

Will I receive feedback on results of this research?

If you wish, at the end of the study you will be sent a summary of the results of the study. It is usual for there to be a substantial delay between the time of your participation and the time of receiving these results. The results may be published in a journal and presented at a physiotherapy conference. The results may be used for publicity purposes.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor. Denise Taylor dtaylor@aut.ac.nz on 921 9680
You are welcome to discuss this information further with Nicola who will attempt to answer any questions you may have. If you have any queries or concerns about your rights as a participant in this study you may wish to contact Health Advocates Trust on 0800 555 055. Please feel free to contact Denise Taylor on 921 9680 if you have any other questions about this study.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz , 921 9999 ext 8044.

Researcher Contact Details: Nicola Saywell. Masters Degree student. Phone 9219999 ext 7084 or

Project Supervisor Contact Details: Dr Denise Taylor, Phone 09 921 9680

Approved by the Auckland University of Technology Ethics Committee on AUTEC Reference number

7.3 Appendix C: Ethics approval

M E M O R A N D U M

Auckland University of Technology Ethics Committee (AUTEC)

To:	Denise Taylor
From:	**Madeline Banda** Executive Secretary, AUTEC
Date:	12 February 2008
Subject:	Ethics Application Number 08/06 **Age dependent differences in recruitment and phasing of lower limb muscles at loading response and the correlation with impact forces.**

Dear Denise

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 21 January 2008 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 10 March 2008.

Your ethics application is approved for a period of three years until 12 February 2011.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through *http://www.aut.ac.nz/about/ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 12 February 2011;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/about/ethics*. This report is to be submitted either when the approval expires on 12 February 2011 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Nicola Saywell, Mark Boocock

7.4 Appendix D: Consent form

Consent to Participation in Research

Age dependent differences in recruitment and phasing of lower limb muscles at loading response and the corrolation with impact forces.

Researchers : Nicola Saywell & Dr Denise Taylor

- I have read and understood the information provided about this research project (Information Sheet dated: 7th January 2008).
- I do not have a known allergy to adhesive tape or sticking plaster, a history of neurological problems (such as a stroke), severe arthritis, or severe cardiovascular problems.
- I meet the age criteria; 20-30 years or 60-80 years.
- I understand that taking part in this study is voluntary, my choice.
- I have had an opportunity to ask questions and am satisfied with the answers that have been given.
- I understand that I may withdraw at any time prior to and during the collection of data, without it disadvantaging me in any way.
- If I withdraw, I understand that all relevant data will be destroyed.

- I have read and understood the provision for ACC compensation in the 'Participant Information Sheet'.
- I agree to take part in this research.
- I wish to receive a summary the results of the research: tick one: Yes O No O

Participant signature: ....……………………..

Participant name: ………………………………………………………….

Participant Contact Details:

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Date:

Approved by the Auckland University of Technology Ethics Committee on Reference number. nb give a copy to participant to retain.