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Joint Moments and Powers in Healthy Young Adults During Stair Negotiation

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JOINT MOMENTS AND POWERS IN HEALTHY YOUNG ADULTS DURING STAIR NEGOTIATION

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The primary objective of this study was to determine lower limb joint moments and powers of stair negotiation in healthy young individuals. These results will provide baseline information for future studies with elderly and clinical populations designed to prevent falls that occur during stair negotiation. In previous stair negotiation studies, researchers investigated joint moments and powers initiating stair ascent in front of the stairway. Starting farther away from the stairway allows individuals to stabilize gait velocity and thus, exclude the influence of velocity on joint moments and powers generated during stair ascent. Ten young, healthy individuals underwent gait analysis during stair negotiation. Two way repeated measures ANOVA was used to determine the differences between two different conditions, starting farther away from the stairway (C1) and starting in front of the stairway (C2), for two consecutive steps (s1 and s2) on the stairway performed by the same leg. A motion analysis system was used to collect the three-dimensional spatial trajectories of the markers (joint angle data). Ground reaction forces were collected using two AMTI force platforms embedded in the first and the third stair treads. Our results demonstrated that ankle power absorption (PA1) was significantly higher during the s1 and s2 in C1 than during the s1 in C2. PA1 was significantly greater during s2 than during s1 in condition 2. Ankle power generation (PA2) was significantly higher during s2 than s1 in C1. The hip power absorption (PH2) was significantly higher during s1 in C1 than during s2 in C1, and s1 and s2 in C2. PH2 was significantly higher during s1 in C2 than s2 in both C1 and C2. These findings

showed that the way individuals approach stairs will have a different affect on ankle and the hip joints which has to be considered in future studies in stair negotiation.

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

Chapter I. Introduction

Statement of Hypothesis and Specific Aims

Previous studies have shown that most falls occur during locomotion (Overstall et al., 1977; Prudham and Evans, 1981). These falls lead to injury and mortality as well as major health-care co sts (Startzell et al., 2000). Hemenway et al. (1994) reported that stair related injuries among older persons are more likely to result in hospitalization and are more likely to result in multiple injuries than accidents in the young. Approximately 10% of fall-related deaths were reported to occur on stairs (National Safety Council, 1994). Practically, stair negotiation which is performed with ease by healthy individuals is much more difficult to perform by individuals who suffer decrements in motor function, balance problems or reduced lower-limb function (Reid et al., 2007). It has been reported that stair negotiation is among the top five tasks that elderly individuals list as being difficult to perform (Williamson and Fried, 1996).

The high incidence of falls on stairs seen in elderly is likely due to deterioration in physical capacities that occur with aging, coupled with the demands of the task itself (Hemenway et al., 1994; Pauls, 1991). Significant physiological decrements in the musculoskeletal system such as bone density loss and sarcopenia or loss of the muscle mass, can lead to immobility and activity restriction (Tiedemann et al., 2007). In addition, changes in the sensory system can also affect the ability to safely negotiate stairs. For example, vision plays an important role in successful stair negotiation (Startzell et al., 2000). Archea et al. (1979) found that looking at the first step was highly related to successful stair negotiation. These changes in musculoskeletal and sensory systems are reflected in the biomechanical measurement of lower limb joint muscular responses (joint moments) and their contributions (joint powers). Such measures can be used to examine the lower extremity adaptations that occur in order to negotiate stairs. However, before such an evaluation can be conducted with pathological populations, it is important to establish baseline measures with healthy young adults, especially when significant knowledge gaps currently exist in the biomechanics of stair negotiation literature.

A knowledge gap in previous research on stair negotiation is that subjects initiated movement directly in front of the stairway (Mian et al., 2007; Costigan et al., 2002; Reid et al., 2007; Riener et al., 2002; Nadeau et al., 2003). Initiating stair ascent farther away from the staircase could allow subjects to achieve a more natural gait velocity before the transition phase from level walking to stepping on the stairway (Sutherland et al., 1980). This is important because gait velocity can affect joint moments and powers (Brechter et al., 2002). In normal everyday activities and for most of the time, people approach stairs after walking thus initiating stair ascent farther back and with a stabilized walking velocity. However, there are everyday life situations where stair ascent is also initiated in front of the stairs such as: stepping onto stairs when entering a bus, or climbing stairs in public places that have short corridors and multiple stair sections where the distance between one set of stairs and the other is short. Therefore, in this study we investigated stair ascent starting both directly in front of the stairway and farther away so that a natural gait velocity is achieved before the transition to the stairs. The following specific aim was investigated.

Specific Aim #1: Determine joint moments and powers in healthy young individuals during stair ascent starting in front or father away from the stairs.

In order to understand the role of the lower extremity dysfunctions in clinical populations, baseline or ‘normal’ values must be calculated for comparison. Current literature has attempted to determine these 'normal' values but with limited resources and equipment. No comprehensive analysis is available in the literature that discusses biomechanics of stair ascent starting farther from the stairway before stair ascent initiation. The strength of this protocol was in determining the joint moments and powers over consecutive footfalls on the stairway and making subjects start farther away from the stairway thus enabling them to stabilize their gait velocity. In the present study, we investigated the biomechanical characteristics of young and healthy population's gait during stair ascent in order to lay the groundwork for future comparisons with elderly and pathological populations. Two hypotheses have been tested:

H1: Gait mechanics, as reflected in joint moments and powers, are different when starting directly in front of the stairway and when starting farther away from the stairway, for stair ascent.

H2: These differences in the gait mechanics may not only be present during the first step on the stairs but also on the second consecutive step being performed by the same leg.

Chapter II. Review of Literature

Problem Statement

Going up and down stairs is an everyday activity that imposes great demands on the musculoskeletal system of the lower limbs. The ability to successfully ascend and descend stairs seems to require greater strength in the lower limbs than is needed for any other activities of daily life (Startzell and Cavanagh, 2000). It has been shown that an individual may have adequate strength for level walking but not sufficient strength to negotiate stairs (Norkin and Levangie, 1992). This particular functional task can be very demanding for individuals with joint disease, musculoskeletal impairments, joint replacements and those recovering from injury (Startzell et al., 2000). Older adults are another target group who experience higher incidence of injurious and fatal falls on stairs that increase as they age further (Hemenway et al., 1994). It has been shown that age-related declines in musculoskeletal, somatosensory and visual systems do affect successful stair negotiation (Startzell et al., 2000). Determining the baseline measurements of biomechanical gait parameters in young healthy individuals would provide information that is important to be used as a reference point for further comparisons of the same biomechanical parameters obtained from elderly and clinical population groups. Moreover, no comprehensive analysis is available in the literature that discusses biomechanics of stair ascent starting farther from the stairway, thus allowing a person to stabilize the walking velocity and make a smooth transition onto the stairway. In addition, there is no evidence in the previous research with respect to joint moments and powers from multiple footfalls on the stairs that can allow a more detailed evaluation of the gait patterns through a greater period of time.

In order to better understand the topic of the current study, the literature review of stair negotiation is divided into two sections addressing the past and current research performed on stair negotiation: 1) Joint moments, and 2) Joint Powers.

Stair negotiation

Kinetic measurements, combined with musculoskeletal models, have been used to predict changes in joint contact forces and joint contact loads (Andriacchi et al., 2000). Numerous research studies performed measurements of ground reaction forces (GRF) in different populations. It has been shown that patients develop adaptive changes in gait patterns that can be analyzed in terms of the changes in kinetic measures (Prodromos et al., 1985; Schipplein and Andriacchi, 1991; Berchuck et al., 1990). Use of a force platform to measure GRF is an especially vital part to understanding mechanical changes. Variables measured by a force platform are simply impossible to measure with the naked eye and casual observation (Winter, 2004). Along with GRF, stair negotiation studies have also examined joint moment and power changes in patients with osteoarthritis, total joint replacement, patellofemoral pain, and anterior cruciate ligament deficiency (Thambyah et al., 2004; Salsich et al., 2001; Kowalk et al., 1997; Bergmann et al., 1995; Larsen et al., 2008).

Compared to level walking, stair negotiation is characterized by large joint moments and powers, especially in the sagittal plane of motion (McFadyen and Winter, 1988). Stair ascent is characterized by concentric muscle contraction and energy generation which refers to positive muscle work, whereas stair descent is characterized by eccentric muscle contraction and energy dissipation which refers to negative muscle work (Winter, 2004; McFadyen and Winter, 1988).

Joint Moments

Joint moments together with joint powers give valuable insight into all agonist and antagonist muscle activity during stair locomotion and represent an integration of the neural control acting at each joint (Rose et al., 2006). Joint moments and powers can provide important information that cannot be derived from other gait measures (Brechter et al., 2002). Looking from a mechanical viewpoint, stair ascent is quite different from level walking in terms of changes in both joint kinematics and kinetics (Protopapadaki et al., 2007; Yu et al., 1997; Kirkwood et al., 1999; Spanjaard et al., 2008; Reeves et al., 2007; Costigan et al., 2002; Reid et al., 2007; Andriacchi et al., 1980; McFadyen and Winter, 1988; Lin et al., 2005; Riener et al., 2002). In the previous stair negotiation studies, investigations of sagittal plane joint moments and powers were done when subjects started directly in front of the stairway (Protopapadaki et al., 2007; Spanjaard et al., 2008; Reeves et al., 2007; Reeves et al., 2008). In the sagittal plane of motion, considerably higher moments at the knee and ankle joints are required during stair ascent than level walking (Costigan et al., 2002). They reported that during the first phase of stance both the knee extensors and hip extensors were increasingly active which agrees with the electromyography findings from several authors (Vaughan et al. 1992; Joseph and Watson, 1967).

Andriacchi et al. (1980) found that the highest knee joint moments occur during stair descent in healthy subjects. According to their study, knee flexion moments during stair descent were 2.7 times greater than during stair ascent, and reported the values of 146Nm during stair descent and 54.2Nm during stair ascent. The differences in the results obtained among the research studies are probably due to differences in the way joint moments were calculated as well as the methodology used to record the motion of the body.

During stair descent young and elderly adults distribute differently knee and ankle joint moments (Reeves et al., 2008). Reeves et al. (2008) showed that elderly used the gastrocnemius to reduce the angular velocity at the knee joint and transfer energy down to the ankle to enhance the plantarflexion moment. The concept of joint moments being distributed differently between young and elderly adults has been reported by DeVita and Hortobagyi (2001). During level walking they found that the elderly reduced the joint moment at the ankle and knee but increased the joint moment at the hip compared to young adults. These strategies are employed by the elderly to successfully accomplish the locomotor task. By thoroughly examining the stair negotiation gait pattern we might be able to find an optimal solution for safe and functional performance of the stair negotiation task.

Riener et al. conducted a study in 2002 and investigated stair ascent at different inclinations in the sagittal plane of motion. They found out that there was significant dependency on stairway inclination when comparing the joint moments during the stance phase. The maximum moment values increased with increasing stair inclination especially at the knee and hip joints. A study of Nadeau et al. (2003) examined hip, knee and ankle joint moments in the sagittal plane of motion during stair ascent. They were mostly interested in examining the differences between joint moments in stair ascent and level walking. Significant differences between stair ascent and level walking were found in the sagittal plane for all three joints and in the frontal plane for the knee joint ($p<0.017$). Observing the sagittal plane of motion, the ankle plantar flexion moment was significantly lower during stair ascent when compared to level walking (1.17Nm/kg and 1.39Nm/kg, $p<0.017$) arguing that level ground walking might be more demanding at the ankle joint. Furthermore, during stair ascent, the hip flexion moment was significantly lower than in level walking

(0.28Nm/kg compared to 0.71Nm/kg, $p<0.017$). The only joint that was shown to be significantly more involved in stair ascent than in level walking was the knee joint. It was found that the knee extension moment was significantly higher in stair ascent than in level walking (0.98Nm/kg compared to 0.46Nm/kg, $p<0.017$). This can be very important information about the role of the knee joint musculature in postural stability during stair negotiation.

Joint Powers

Only a few studies have provided data on lower limb joint powers in the sagittal plane of motion. Human locomotion is a complex process that includes generation and dissipation of mechanical energy (i.e. positive and negative work) throughout the stride cycle. At level ground walking, locomotion utilizes equivalent and counterbalancing phases of positive and negative work to maintain the average energy level (DeVita el al., 2007). Main generators and dissipators of the energy are skeletal muscles through either shortening (concentric) or lengthening (eccentric) contractions (Cavagna and Kaneko, 1977; McFadyen and Winter, 1988).

Stair negotiation is categorized as a non-level gait where most of the energy generated is during stair ascent and most of the energy dissipated is during stair descent (DeVita et al., 2007). From the current literature it is clear that ascending versus descending gaits have longer stance durations and higher average joint powers which dictate that muscle work derived from joint powers would be greater in ascent than in descent (Lay et al., 2007; McFadyen and Winter, 1988; Riener et al., 2002). Previous studies have shown that larger powers are produced in the sagittal plane of motion during stair ascent (McFadyen and Winter, 1988; Nedeau et al., 2003). Energy generated by the skeletal muscles is required to support and propel the body against gravity and to generate movements that advance the body forward (Eng and Winter, 1995; Nadeau et al., 2003). This progression is enabled by the knee extensor muscles assisted by the ankle plantar flexors and the hip extensors (McFadyen and Winter, 1988; Moffet et al., 1993; Nadeau et al. 2003).

In a study by Nadeau et al. (2003), the authors investigated stair ascent and highlighted the differences between stair ascent and level walking regarding the time-distance parameters and joint powers. The knee joint flexors and extensors were significantly engaged in the energy generation ($p=0.000$), as opposed to level walking where those muscles mainly absorbed energy to decelerate the lower limb segments. Interestingly, in stair ascent the power absorption by the hip joint flexors was significantly reduced ($p=0.000$) and the burst of energy generation occurred later in the swing phase. They argued that this delay allowed the knee flexors to generate sufficient energy to clear the intermediate step. In the frontal plane of motion they found that considerable power generation was produced by the hip abductor muscles at 21% of the gait cycle. However this power generation by the hip joint musculature was not significantly increased when compared to level walking. Initiating stair ascent in front of the stairway would probably require more energy generation than starting farther away. This might influence the joint moment magnitudes and consequentially joint power magnitudes.

DeVita et al. (2007) aimed to compare positive and negative muscle work in level walking and work in ascending and descending walking on a ramp and on a stairway. Joint powers were used to calculate the work done by the hip, knee and ankle joints during these tasks in the sagittal plane of motion only. They hypothesized that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to the mechanical energy they dissipate in gait tasks to lower the center of mass. Ascent work was 23% ($p<0.010$) and 43% ($p<0.000$) greater than descent work in ramp and stair gaits, respectively. According to their results, muscles crossing the knee and ankle joints were the primary contributors to negative and positive power and work both in stair ascent and stair descent. The energy produced by the muscles of these joints was significantly more negative power sharing the dissipation of mechanical energy in stair descent. They proposed that the principle cause of this outcome was the relatively high magnitude of the accelerations occurring in the descending gaits particularly in the initial portion of the stance phase. However, this needs to be investigated further more by recording the velocity while subjects perform stair descent.

The ankle joint is of great importance in stair descent, especially in elderly people (Spanjaard et al., 2008; Reeves et al., 2007; Reeves et al., 2008; Andriacchi et al., 1980; McFadyen and Winter, 1988; Riener et al., 2002). This fact is supported by the large negative ankle joint powers during stair descent (Spanjaard et al., 2008; McFadyen and Winter, 1988) and power absorption just after foot contact (Riener et al., 2002). Riener et al. (2002) assumed that the ankle, knee and hip joints of both sides are activated in a sequence aimed at sharing energy absorption among them. They found that during ascent, all the joints produced energy during most of the stride. The knee and hip joint powers reached their maximum at the beginning of the stance phase at approximately 14-20% of the gait cycle. At the hip joint, a second lower peak was detected during the swing phase. On the other side, the ankle joint exhibited maximum power production at the end of the stance phase at approximately 53-59 of the gait cycle. More than joint moments, joint powers tend to increase as the stair inclination increase. The greatest increase was observed at the hip joint during stair ascent (51.7% increase of maximum joint power from minimum to maximum stairway inclination) and in the ankle joint during stair descent (67.3%) and ascent

(45.4%). Hip joint power profiles were affected by the variation in the joint moments as shown in the study of McFadyen and Winter (1988). They recruited three healthy subjects and had them perform eight trials for stair ascent and eight trials for stair descent. The major deviation between the subjects was seen for the hip joint moments, especially during stair ascent which was further manifested in the power profiles. Results showed that the hip joint musculature was dominant in balance control during the single support phase. While moving up and forward, the hip joint flexion was reflected in the positive power burst in early swing. Furthermore, final placement of the foot on the step was controlled by the hip extensors. Stair descent phase was dominated by the absorption of the energy at both the ankle and the knee. However, for the last part of the controlled lowering phase from 85% to the end of the descent stride, there was a positive power burst at the hip for all subjects. This power generation by the hip joint musculature existed to pull the leg through to the next position, as well as pull it off the present step which is also seen in the level walking (the hip abductor muscles control the lateral pelvic obliquity to allow the contralateral leg to swing properly and help the swinging leg to avoid the intermediate step) (Nadeau et al., 2003). These results indicate the importance of the hip musculature in stair negotiation which is usually much weakened in physically inactive and elderly population.

Conclusions

The understanding of the mechanics of stair negotiation is an important step toward greater knowledge of the function of the lower extremities especially for gait pathologies. Sagittal plane of motion is the dominant plane of motion to examine the joint moments and powers within. A significant amount of the lower limb muscular strength and energy is required in the sagittal plane of motion in order to propel the body forward. Similarly, the frontal plane movements are as significant as the sagittal plane movements, because they play the key role in maintaining the balance while ascending and descending stairs thus preventing the occurrence of sudden falls. In the Table 1 below, I have summarized the research performed thus far on stair negotiation. In this Table I have indicated the numbers of steps evaluated on the staircase, the location that the subjects started their ascent, and the most important results. It is evident from this Table that the questions answered in the present study are going to fulfill a very important knowledge gap.

Table 1. Summary of Stair Negotiation Review of Literature

Study	Author	Purpose	#of Force Platforms and location	# of Footfalls	Starting Position	Results
A study of lower-limb mechanics during stair-climbing	Andriacchi et al., 1980	Analyze the mechanics of the lower limbs during stair ascent and stair descent	One, In the 1st step	One, Both legs	In front	Flexion-extension moments greater during stair climbing than level walking.
Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals.	Protopapadaki et al., 2007	Identify normal functional parameters in the hip, knee and ankle joints during stair climbing in healthy individuals	One, In the 2nd step	One, Right leg	N/A	The maximum angles and moment occurred while ascending stairs.
Knee and hip kinetics during normal stair climbing	Costigan et al., 2002	Investigate the knee dynamics during stair climbing and estimate the net knee forces and moments	One, In the 1st step	One, Dominant leg	In front	The hip and knee AP shear forces and the knee flexion moment were higher during stair climbing than level walking.
Frontal and sagittal plane analysis of the stair climbing task in healthy adults aged over 40 years: what are the challenges compared to level walking?	Nadeau et al., 2003	Compare stair climbing and level walking in healthy adults aged over 40 years	Three, In the floor, 1st step and 2nd step	One, Right leg	In front	Dominant role of the knee extensors during stair climbing and knee-hip energy generation patter that allows the avoidance of the intermediate step
Stair ascent and descent at different inclinations	Riener et al., 2002	Investigate the biomechanics and motor coordination in humans	Three, In the 1st, 2nd and 3rd step	One, Right leg	In front	Maximum joint powers in the hip and ankle changes with inclination up

		during stair climbing at different inclinations				to ~67%
Lower-limb biomechanics during stair descent: Influence of step-height and body mass	Spanjaard et al., 2008	Examine the biomechanics of the lower limb during stair descent and the effects of increasing step height and body mass	Four, In the floor, 1st, 2nd and 3rd step	Two, Left leg	On top	Ankle and knee joint moments increased with increasing step height.
An integrated biomechanical analysis of normal stair ascent and descent	McFadyen and Winter, 1988	Provide integrated analysis concentrating on net joint moments and powers for stair negotiation	One, In the 2nd step	One, Right leg	N/A	The greatest variability at the hip. Stereotypic kinetic patterns emerged at the ankle and knee
Knee biomechanics of alternate stair ambulation patterns	Reid et al., 2007	Compare the kinematics and kinetics of the knee joint during step-over-step to step-by-step lead leg and step-by-step trail leg	One In the 2nd step	One, Test leg not specified	In front	Step-by-step lead leg during stair ascent and step-by-step trail leg during stair descent had the highest loads
Muscles do more positive than negative work in human locomotion	DeVita et al., 2007	Compare positive and negative muscle work in level walking and net positive and negative muscle work in ascending and descending walking on a ramp and on a stairway	One, In the 2nd step	One, Right leg	N/A	Skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass
Comparisons of joint kinetics in the lower extremity between stair	Lin et al., 2005	Perform a complete 3D analysis on the kinetics of the joints of the lowers	Two., In the 2nd step next to each other	One, Both legs	Examiner adjusted the starting position	Peak joint moments and angular impulses were larger during stair

ascent and descent		limb during stair ascent and descent, and compare the mechanical interactions of the joints between these two activities and level walking			so that the tested foot could place naturally on the force platform	ascent than during descent
Abduction-adduction moments at the knee during stair ascent and descent	Kowalk et al., 1996	Recommend an anatomically consistent set of axes for determining joint moments and to examine the relative magnitude of the knee abduction-adduction moments in stair climbing	Two, In the 1st and 2nd step	One, Both legs	In front	Knee joint moments were similar in shape and magnitude for the first and second steps during both stair ascent and descent. The abduction knee moments were statistically smaller than the extension moments for stir ascent and descent
Knee joint moments during stair climbing of patients with anterior cruciate ligament deficiency	Thambyah et al., 2004	Establish the gait adaptations of patients with anterior cruciate ligament (ACL) deficiency during stair ascent	One, In the 2nd step	One, Both legs	N/A	Patients with ACL displayed a significant reduction up to 50% in peak knee flexion moments in the involved leg
Lower extremity kinetics during stair ambulation in patients with and without patellofemoral pain	Salsich et al., 2001	Compare lower extremity kinetics during stair ascent and descent in subjects with and without patellofemoral pain	One, In the 1st step	One, Involved leg (Patellofemoral pain individuals) and right leg (controls)	In front	Subjects with patellofemoral pain had decreased peak knee extensor moments during stair ascent and descent.

CHAPTER III. Methodology

Summary of Research Methods

Subjects

The sample included 10 healthy young subjects (males and females). Subjects were recruited via informational flyers posted in areas at the University of Nebraska at Omaha campus, where any such subjects could see them, and through UNO e-Notes (the daily electronic news source for UNO faculty and staff). The subjects were between 19 and 35 years old and able to provide informed consent. Informed consent was obtained from all subjects prior to data collection according to the guidelines of the University's Institutional Review Board. Subjects were asked to fill out the medical history questionnaire (Appendix A) in order to see if they had previous injuries or changes that influence the way they walk. Subjects were not allowed to participate in the study if they had or still have any known sensory, neuromuscular, skeletal or cardiovascular disorders that may affect a person's gait pattern, or are not able to negotiate the stairway used in the study without use of the handrail**.** All subjects were free of any pathological condition that directly affects the musculoskeletal system such as rheumatoid arthritis, arterial disease, neuropathy or myopathy, vertigo, scoliosis, joint replacement, diabetes, stroke, pulmonary diseases, asthma, recent surgery, acute illness, or a history of pulmonary, cardiac, or locomotor disorders.

<u>Research Measures</u>

Experimental Equipment

Data were collected in the Nebraska Biomechanics Core Facility in the Health, Physical Education and Recreation building at the campus of the University of Nebraska at Omaha (Figure 1). Eight high speed digital cameras (Figure 2) (Motion Analysis System, Santa Rosa CA) were used to capture the motion of 27 retro-reflective markers placed on the anatomical landmarks on the pelvis and lower extremities. The motion capture system sampling at 60Hz was used to collect the three-dimensional spatial trajectories of the markers (kinematic or joint angle data).

Figure 1. Biomechanics laboratory

Kinetic data (ground reaction forces) were collected using two AMTI (Advanced Mechanical Technology Inc.) force platforms embedded in the first and the third stair treads, sampled at 600Hz.

Figure 2. Camera

Experimental Measures

Kinematics

Joint kinematics, hip, knee, and ankle relative angles were calculated in order to obtain the ankle, knee and hip joint powers. The Motion Analysis system (8 camera Eagle system, Motion Analysis Corp., Santa Rosa, CA) allows for definition of each marker during the collection so marker position was recorded in real time. The motion capture system sampled at a speed of 60 Hz. The marker position data were analyzed using custom MatLab code (MathWorks, Inc., Natic, MA) available in the Laboratory which outputs the specified discrete points for a gait cycle. A standing calibration was used to obtain a rotation matrix for each limb segment to align the local (anatomical) reference frames of the thigh, shank, and foot to the global (laboratory) reference frame. Relative joint angles were calculated by the methods described by Vaughan et al. (1992) and Nigg et al. (1993).

Kinetics

The kinetic force data were collected based on the eight force channels collected by the force platform (Fx_{12}, Fx_{34}, Fy_{12}, Fy_{34}, Fz_1, Fz_2, Fz_3, Fz_4) sampled at 600 Hz. The medial lateral force is based on the summation of the output of two channels Fx_{13}, Fx_{24} or $Fx = Fx_{13} + Fx_{24}$, the anterior posterior force is based on the summation of the output of two channels Fy_{13}, Fy_{24} or $Fy = Fy_{13} + Fy_{24}$, and the vertical force is based on the summation of the output of four channels Fz_1, Fz_2, Fz_3, Fz_4 or $Fz = Fz_1 + Fz_2 + Fz_3 + Fz_4$. The ground reaction force data were also analyzed using custom made MatLab software to output the specified ground reaction force parameters.

Joint moments were calculated from the joint angles of the lower limb segments and the kinematic and kinetic variables used to calculate joint moments and powers listed in Tables 2 and 3 (these tables are from Winter, 2004). Joint moments are first calculated on the ground reaction forces applied to the foot and the distance between the application of force and the center of mass of the segment. Joint powers are then calculated based on the resultant joint moment multiplied by the angular velocity of the limb segment. The application of inverse dynamics to calculate the unknown variables is performed on each segment separately (this Figure 3 is from Winter, 2004), moving from the most distal limb segment to the most proximal. Calculation of joint moments and powers was accomplished using a custom MatLab program available within the laboratory.

Joint Moment Calculation Variables	
Known	Variable Definition
a_x, a_y	Acceleration of segment COM
Θ	Angle of segment in plane of movement
Α	Angular acceleration of segment in plane of movement
Rxd, Ryd	Reaction forces acting at distal end of segment, usually determined from prior analysis of proximal forces acting on distal segment (use of GRF)
M_d	Net muscle moment acting at distal joint, usually determined from an analysis of the proximal muscle acting on distal segment
M	Mass
I_0	Inertia of the segment calculated based on anthropometric measurements
Unknown	
R_{xp}, R_{yp}	Reaction forces acting at proximal joint
M_p	Net muscle moment acting on segment at proximal joint
Equations	
[1] $\Sigma F_x = m*a_x$	Summation of all forces acting in x-direction
[2] $R_{xp} - R_{xd} = m*a_x$	Equating the measured forces from the proximal and distal ends to the summation of forces
[3] $\Sigma F_y = m*a_y$	Summation of all forces acting in y-direction
[4] $R_{xp} - R_{xd} = m*a_y$	Equating the measured forces from the proximal and distal ends to the summation of forces
[5] $\Sigma M = I_0*\alpha$	Sum of the joint moment calculated

Table 2. Joint Moment Calculation variables and necessary equations

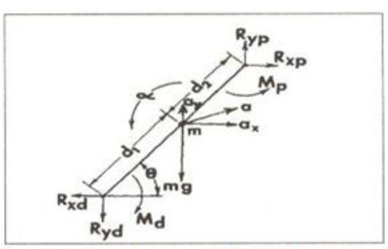


Figure 3. Complete free-body diagram of a single segment, showing reaction forces and gravitational forces, net moments of force, and angular and linear accelerations

Joint Power Calculation Variables	
Known	
M_j	Net Moment (Nm)
Ω_j	Joint angular velocity (rad/sec)
Unknown	
P_m	Muscle Power (watts)
Equations	
[6] $P_m = M_j * \Omega_j$	Calculation of joint power is based on the joint angular velocity and net moment

Table 3. Joint Power Calculation variables and necessary equations

Experimental Protocol

Upon the subject's arrival at the laboratory, the informed consent was administered, and subjects were asked to fill out a medical history questionnaire (Appendix A). Then, subjects were asked to change into the tightly fitting suit (e.g. wrestling suit; Figure 4), a t-shirt if they would like, and athletic shoes (either provided by the subject or from the shoes available in the lab). The tight fitting suit allows correct positioning of reflective markers (about the size of a marble; Figure 4) onto specific anatomical landmarks.

Figure 4. Lower limb marker set and a camera

Retro-reflective markers were placed on the following anatomical body landmarks both on the right and left side: anterior superior iliac spine, posterior superior iliac spine, greater trochanter, mid thigh, lower front thigh, lateral knee, medial knee, mid shank, lower shank, lateral ankle, medial ankle, top of the foot, heel, lateral metatarsal phalange, medial metatarsal phalange, sacrum, and back of the heel (Figure 4). In addition, several anthropometric measures were taken for each lower-limb segment, as well as measures of weight and height. All subjects were

Figure 5. Instrumented stairway

allowed to ascend stairs several times until they were comfortable. In order to reduce the risk of falling while ascending the stairs, subjects could use the handrail to catch himself or herself (Figure 5). There were no trials in which the subject lost balance or grabbed the handrail. When subjects reach the top of the stairs, they were protected by a reachable safety bar which connects the left side and right side handrails. To test the hypotheses, the following conditions were performed. Subjects were asked to perform two stair ascent conditions at the pace which was within ± 10% of their self-selected pace, starting with the right limb for each condition: 1) stair ascent starting farther away from the stairway (condition 1) (Figure 6a), and 2) stair ascent starting in front of the stairway (condition 2) (Figure 6b).

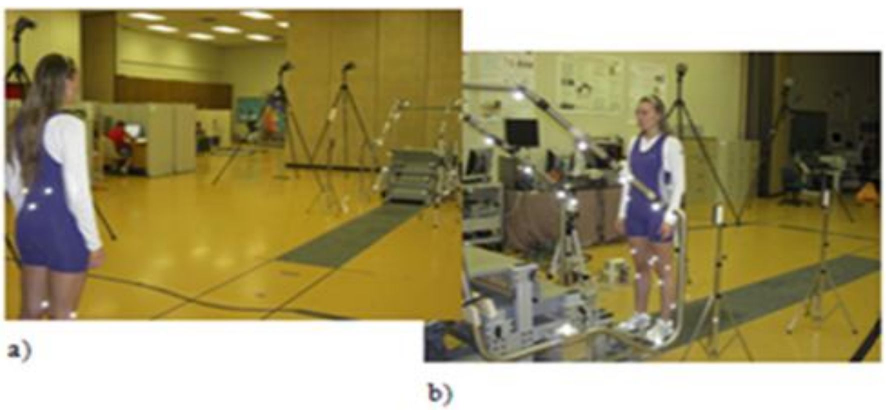


Figure 6. a) Starting farther away from the stairway, and b) Starting in front of the stairway

The order of the conditions was randomized. The random numbers were generated at the graphpad software website http://www.graphpad.com/quickcalcs/index.cfm).

Figure 7. Motion sensor with photo cell

Photo cells were used to determine the self-selected speed for the approach of stair ascent (Figure 7). The photo cells record the time used to calculate gait velocity. They were positioned right in front of the stairway. Subjects were allowed to ascend stairs several times until they were comfortable.

An acceptable stair ascending for the condition when starting farther away from the stairway was when a subject ascended the stairway within $\pm$ 10% of the determined self selected speed. At least ten acceptable trials for each condition were recorded. In addition, subjects were given a break between conditions and between trials if they felt they needed it.

Data Analysis

Key variables included for analysis were the ankle, knee and hip joint moment and power discrete points (Tables 4 and 5) during both conditions for the right limb. Data were expressed as mean and standard deviation. For each condition five trials were averaged for each subject individually and the mean maximum and minimum joint moment and power at discrete points in the sagittal plane were calculated. Discrete points of all subjects were then averaged to provide the group mean maximum and minimum values and standard deviation for joint moments and powers for discrete points.

Statistical Analysis

The statistical analysis was performed using the SPSS software (SPSS Inc., Chicago, IL). The dependent variables of the study were gait kinetics (mean and standard deviation of discrete points from joint moments and powers). The α-value was set at 0.05. A two by two ANOVA with repeated measures was used. The two main effects were a) two consecutive footfalls on the stairway with the same lag and b) the two stair ascent conditions (starting farther away from the stairway and starting in front of the stairway). A Tukey's HSD post hoc test was used to identify significant differences between conditions when an interaction was found to be significant.

Table 4. Joint moment discrete points in the sagittal plane of motion.

	Variable	Definition	Explanation
AM0	Ankle Dorsiflexor Peak Moment	Peak ankle dorsiflexion torque during stance	**During stair ascent** there is a maximum plantarflexor moment at the ankle immediately following foot contact and during weight acceptance (loading response). Next, a dorsiflexion moment occurs through midstance to control the transfer of weight over the ankle as the body moves over the foot. Right before toe off the second max plantarflexion moment occurs and is higher than the fist max plantarflexion moment.
AM1 and AM2	Ankle Plantarflexor Peak Moment	Peak ankle plantarflexion torque during stance	
MK1	Knee Extensor Peak Moment	Peak knee extension torque during stance	**During stair ascent** the loading response at the knee involves an extensor moment of the knee which transfers to a flexor moment before toe off.
MK2	Knee Flexor Peak Moment	Peak knee flexion torque during stance	
MH1	Hip Extensor Peak Moment	Peak hip extension torque during stance	**During stair ascent** the hip joint produces a max extension moment right after foot contact and continues producing an extension moment during most of the stance phase.
MH2	Hip Flexor Peak Moment	Peak hip flexion torque during stance	

Table 5**.** Joint power discrete points in the sagittal plane of motion.

Variable	Definition	Explanation
PA1	Peak power absorption and eccentric contraction at the ankle during stance	**During stair ascent** the ankle joint plantarflexors exhibit max power production at the end of the stance phase (~53-59% cycle time).
PA2	Peak power generation and concentric contraction at the ankle during late stance	
PK1	Peak Power generation and concentric contraction at the knee after foot strike	**During stair ascent** there is power generation of the knee extensors that reaches maximum at the beginning of the stance phase (~14-20% cycle time) to pull up the body to the next step.
PK2	Peak Power generation and concentric contraction at the knee during mid/late stance	
PH1	Power generation and concentric contraction at the hip after foot strike	**During stair ascent** at foot contact, there is power generation of the hip extensors. In late stance (40-60% cycle time) there is new power generation by the hip extensors to pull up the body to the next step.
PH2	Peak power absorption and eccentric contraction at the hip during midstance	
PH3	Peak Power generation and concentric contraction at the hip during late stance	

Chapter IV. Results

Subject's demographics are summarized in Table 6 by age, height, weight, and gender. For further information on individual subjects please refer to Appendix B.

Table 6. Subjects characteristics and self-selected speed for stair ascent reported in means and standard deviations.

					Self-selected speed (m/s)	
Age Group	Age (years)	Gender (F/M)	Height (cm)	Weight (kg)	Lower	Upper
Young	25.1 ± 3.3	5/5	173.3 ± 10.7	80.6 ± 17.3	0.77 ± 0.15	0.78 ± 0.19

Lower: 10% below the self-selected speed; Upper: 10% above their self-selected speed

The two hypotheses that have been tested are:

H1: Gait mechanics, as reflected in joint moments and powers, are different when starting directly in front of the stairway and when starting farther away from the stairway, for stair ascent.

H2: These differences in the gait mechanics may not only be present during the first step on the stairs but also on the second consecutive step being performed by the same leg.

Joint Moments

Mean sagittal plane moments of the ankle, knee and hip joint during stair ascent starting farther away from the stairway and starting in front of the stairway are illustrated in Figure 8. Table 7 shows the means of the selected discrete points identified from the moments of the ankle, knee and hip joint during stair ascent starting farther away from the stairway (condition 1) and starting in front of the stairway (condition 2).

Ankle

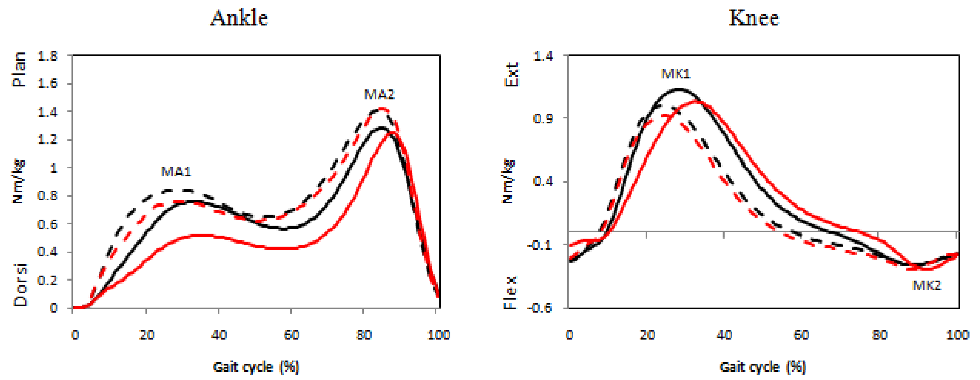
The ANOVA results revealed a significant main effect of condition for the initial peak of the ankle plantarflexion moment (MA1) ($p=0.022$) as well as a significant main effect of step for the same variable (p=0.001). MA1 significantly increased when ascent started father away as compared to when starting in front of the stairway. MA1 also significantly increased from the first step to the second step in both conditions. There was a significant main effect of step for the second peak of the ankle plantarflexion moment (MA2) (p=0.001) but not a condition effect. Similarly with MA1, MA2 also significantly increased from the first step to the second step in both conditions. No significant interactions were found for the ankle joint moment variables.

Knee

The ANOVA results revealed a significant main effect of condition for the knee extension moment (MK1) (p=0.012) as well as a significant main effect of step for the same variable (p=0.001). MK1 significantly increased when ascent started father away as compared to when started in front of the stairway. MK1 also significantly decreased from the first step to the second step in both conditions. No significant differences were found for MK2. No significant interactions were found for the knee joint moment variables.

Hip

The ANOVA results revealed a significant main effect of step for the hip extension moment (MH1) (p= 0.002) but not a condition or interaction effect. MH1 significantly increased from the first step to the second step in both conditions. A significant main effect of step was also found for the hip flexion moment (MH2) that occurred later in the stance phase (p= 0.001) but not a condition or an interaction effect. MH2 significantly decreased from the first step to the second step in both conditions.



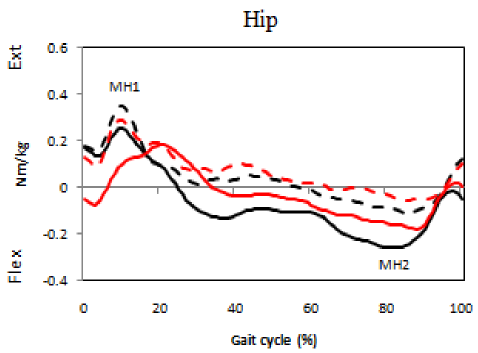


Figure 8. Sagittal plane joint moments during stair ascent starting farther away (condition 1) and starting in front of the stairway (condition 2). The cycle starts with foot contact. The solid black line represents the group mean for step 1 condition 1, the solid red line represents the group mean for step 1 condition 2, the dashed black line represents the group mean for step 2 condition 1, and the dashed red line represents the group mean for step 2 condition 2.

Table 7. Ankle, knee and hip joint moments during stair ascent starting farther away from the stairway (condition 1) and starting in front of the stairway (condition 2). Step 1 is the first step on the stairway and step 2 is the second step on the stairway with the right leg.

	Condition 1				Condition 2						
	Step 1		Step 2		Step 1		Step 2				
Moments	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-condition	p-step	p-interaction
MA1	0.748	0.303	0.865	0.251	0.551	0.200	0.784	0.178	0.022*	0.001*	0.091
MA2	1.306	0.224	1.431	0.222	1.277	0.132	1.446	0.219	0.838	0.001*	0.164
MK1	1.180	0.211	1.046	0.216	1.088	0.221	0.956	0.230	0.012*	0.001*	0.968
MK2	-0.383	0.127	-0.326	0.130	-0.338	0.129	-0.346	0.179	0.614	0.263	0.103
MH1	0.268	0.245	0.391	0.193	0.187	0.171	0.288	0.185	0.092	0.002*	0.844
MH2	-0.296	0.277	-0.174	0.138	-0.212	0.127	-0.075	0.150	0.122	0.001*	0.863

*p-condition is the significant main effect of condition; *p-step is the significant main effect of step; *p-interaction is the significant interaction of condition by step

Joint Powers

Mean sagittal plane powers of the ankle, knee and hip joint during stair ascent starting farther away from the stairway and starting in front of the stairway are illustrated in Figure 12. Table 8 shows the means of the selected discrete points identified from the powers of the ankle, knee and hip joint during stair ascent starting farther away from the stairway (condition 1) and starting in front of the stairway (condition 2).

Ankle

The ANOVA results revealed a significant main effect of step for the ankle power absorption (PA1) ($p= 0.050$) but not a condition effect. There was also a significant interaction found for the ankle power absorption ($p=0.007$). This interaction was the result of an increase of eccentric ankle power from step 1 to step 2 when starting the ascent in front of the stairway while the opposite occurred in a much smaller degree when started farther away from the stairway (Figure 9). The Tukey's post hoc analysis showed that during step 1 when starting the ascent away from the stairs the ankle joint absorbed significantly more energy (eccentric contraction) than during step 1 when starting in front of the stairs (Table 9; Figure 9). Furthermore, the ankle joint absorbed significantly more energy during step 2 when starting away from the stairs than during step 1 starting in front of the stairs (Table 9; Figure 9). A significant difference in the ankle power absorption was also found between step 1 and step 2 when the ascent was started in front of the stairway. The amount of energy absorbed by the ankle joint was significantly greater during step 2 as compared with step 1 when the ascent was started in front of the stairway.

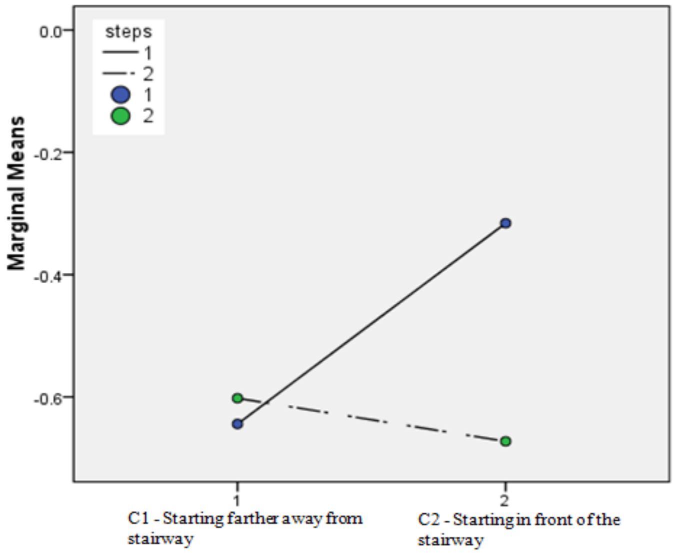


Figure 9. The graphic representation of interaction found for the ankle power absorption (PA1). It is obvious that this interaction was the result of an increase of eccentric ankle power from step 1 to step 2 when starting the ascent in front of the stairway while the opposite occurred in a much smaller degree when started farther away from the stairway.

No significant condition or step main effects were observed for PA2. However, a significant interaction was found for the peak ankle power generation (p= 0.026) (Figure 10). This interaction was the result of an increase of concentric ankle power from step 1 to step 2 when starting farther away from the stairway while the opposite occurred in a smaller degree when starting in front of the stairway. A Tukey post hoc analysis revealed that the ankle joint generated more power (concentric contraction) during step 2 than during step 1 when stair ascent started farther away from the stairway (Table 9).

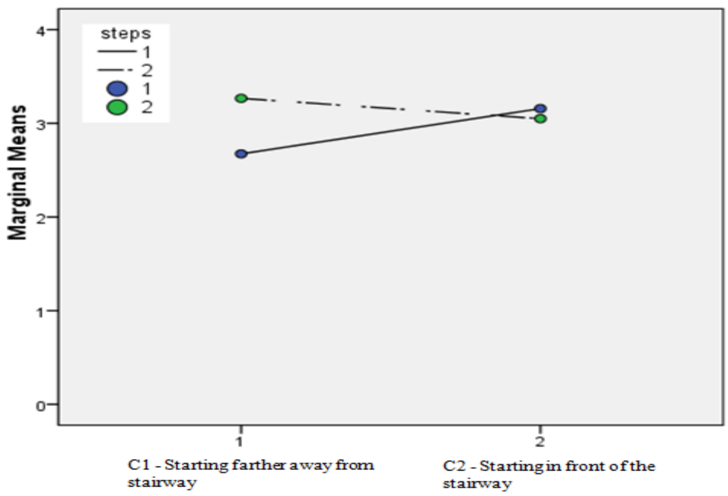


Figure 10. The graphic representation of interaction found for the ankle power generation (PA2). It is obvious that this interaction was the result of an increase of concentric ankle power from step 1 to step 2 when started farther away from the stairway while the opposite occurred in a smaller degree when started in front of the stairway.

Knee

No significant differences were found for the knee peak power (PK1) between the steps or the conditions (Table 8).

Hip

The ANOVA results revealed a significant main effect of step for the hip joint power generation (PH1) (p= 0.017) but not a condition main effect or interaction. PH1 significantly increased from the first step to the second step in both conditions. There was a significant main effect of both step (p= 0.006) and condition (p= 0.008) for the hip joint power absorption (PH2). Furthermore, a significant interaction was found between step and condition for the hip joint power absorption (0.007) (Figure 11). Practically, when the ascent was started farther away from the stairway larger eccentric contraction was required at the hip late at stance in both steps. Furthermore, the difference between the two ascent conditions was much larger for the first step than the second. A Tukey's post hoc analysis verified these observations and showed that the hip joint absorbed more energy during step 1 than during step 2 when stair ascent started farther away from the stairway (Table 9). Significantly higher energy absorption by the hip joint occurred during step 1 when stair ascent started farther away from the stairway than during step 1 when stair ascent started in front of the stairway (Table 9). Moreover, the energy absorbed by the hip joint during step when stair ascent started farther away from the stairway was significantly greater than the energy absorbed during step 2 when stair ascent started in front of the stairway (Table 9). The hip joint absorbed significantly more energy during step 1 when stair ascent started in front of the stairway than during step 2 when stair ascent started farther away from the stairway (Table 9). A significant difference in energy absorption by the hip joint was found between step 1 and step 2 when stair ascent started in front of the stairway. A significantly greater energy absorption by the hip joint occurred during step 1 than during step 2 when stair ascent started in front of the stairway (Table 9).

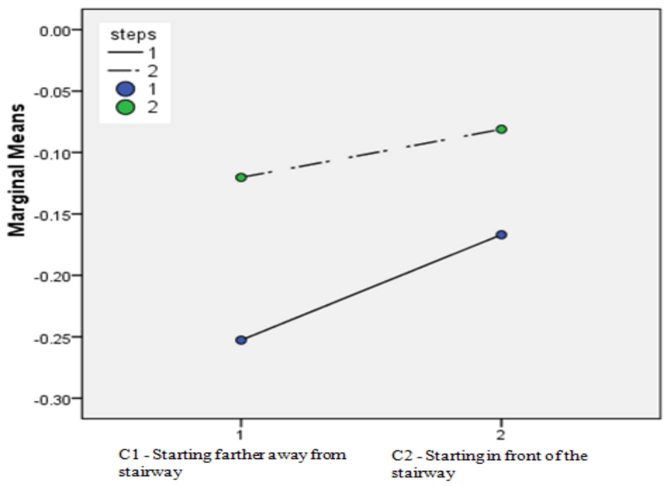
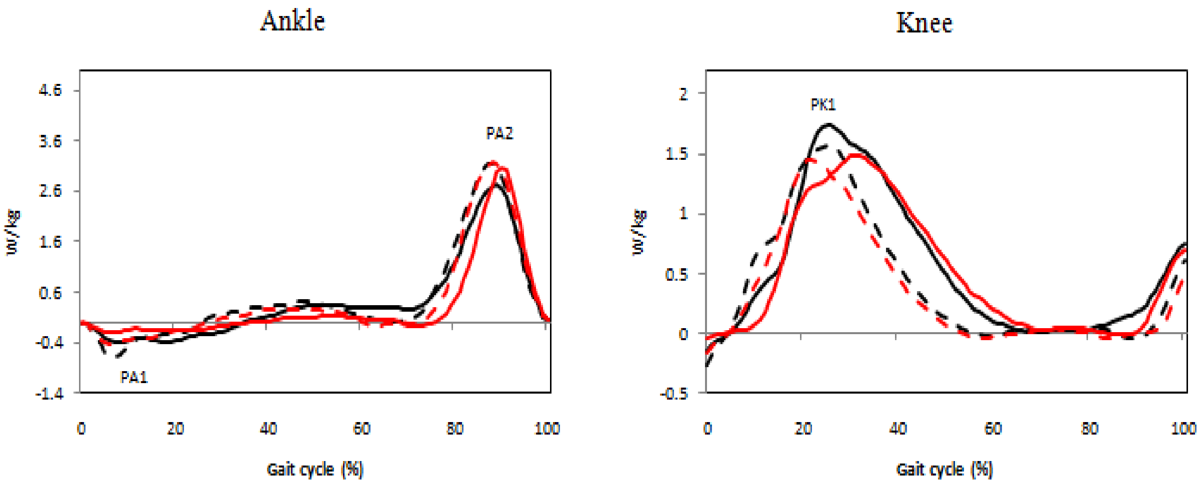


Figure 11. The graphic representation of interaction found for the hip power absorption (PH2). When the ascent was started farther away from the stairway larger eccentric contraction was required at the hip late at stance in both steps. Furthermore, the difference between the two ascent conditions was much larger for the first step than the second.



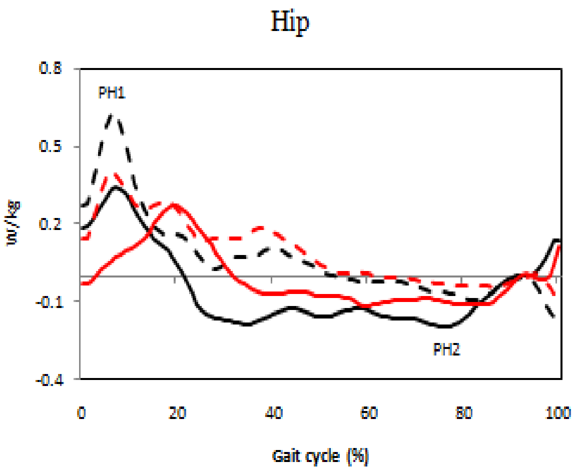


Figure 12. Sagittal plane joint powers during stair ascent starting farther away (condition 1) and starting in front of the stairway (condition 2). The cycle starts with foot contact. The solid black line represents the group mean for step 1 condition 1, the solid red line represents the group mean for step 1 condition 2, the dashed black line represents the group mean for step 2 condition 1, and the dashed red line represents the group mean for step 2 condition 2.

Table 8. Ankle, knee and hip joint powers during stair ascent starting farther away from the stairway (condition 1) and starting in front of the stairway (condition 2). Step 1 is the first step on the stairway and step 2 is the second step on the stairway with the right leg.

	Condition 1				Condition 2						
	Step 1		Step 2		Step 1		Step 2				
Powers	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-condition	p-step	p-interaction
PA1	-0.644	0.387	-0.602	0.423	-0.316	0.159	-0.673	0.385	0.077	0.05*	0.007*
PA2	2.674	0.425	3.266	0.841	3.157	0.513	3.049	1.056	0.239	0.201	0.026*
PK1	1.801	0.587	1.625	0.502	1.699	0.434	1.497	0.651	0.21	0.16	0.895
PH1	0.466	0.340	0.733	0.415	0.285	0.395	0.487	0.336	0.099	0.017*	0.710
PH2	-0.253	0.219	-0.120	0.149	-0.167	0.196	-0.081	0.122	0.006*	0.008*	0.007*

p-condition is the significant main effect of condition; p-step is the significant main effect of step; p-interaction is the significant interaction of condition*step

Table 9. Tukey's HSD post-hoc analysis. Group means and standard deviations of ankle power absorption (PA1), ankle power generation (PA2), and hip power absorption (PH2). Critical value at 0.05 was 4.42.

PA1	Mean Difference	Q Ratio	p-value
s1_c1 x s2_c1	0.042	0.7	NS
s1_c1 x s1_c2	0.328	5.47	< 0.05
s1_c1 x s2_c2	0.029	0.48	NS
s2_c1 x s1_c2	0.286	4.77	< 0.05
s2_c1 x s2_c2	0.071	1.18	NS
s1_c2 x s2_c2	0.357	5.95	< 0.05
PA2	Mean Difference	Q Ratio	p-value
s1_c1 x s2_c1	0.592	4.55	< 0.05
s1_c1 x s1_c2	0.483	3.71	NS
s1_c1 x s2_c2	0.375	2.88	NS
s2_c1 x s1_c2	0.109	0.84	NS
s2_c1 x s2_c2	0.217	1.66	NS
s1_c2 x s2_c2	0.108	0.83	NS
PH2	Mean Difference	Q Ratio	p-value
s1_c1 x s2_c1	0.133	13.3	< 0.05
s1_c1 x s1_c2	0.086	8.6	< 0.05
s1_c1 x s2_c2	0.172	17.2	< 0.05
s2_c1 x s1_c2	0.047	4.7	< 0.05
s2_c1 x s2_c2	0.039	3.9	NS
s1_c2 x s2_c2	0.086	8.6	< 0.05

s1 represents step 1; s2 represents step 2; c1 represents condition 1 (starting farther away from the stairway); c2 represents condition 2 (starting in front of the stairway).

Chapter V. Discussion

In the present study, we investigated the biomechanical characteristics of stair ascent in order to lay the groundwork for future comparisons with elderly and pathological populations. We explored two hypotheses. The first hypothesis was that gait mechanics, as reflected in joint moments and powers, are different when starting directly in front of the stairway and when starting farther away from the stairway, for stair ascent. The second hypothesis was that these differences in the gait mechanics may not only be present during the first step on the stairs but also on the second consecutive step being performed by the same leg.

In the sagittal plane of motion the moment and power profiles and values for discrete points were almost identical to those previously reported during stair negotiation (Riener et al., 2002; Reeves et al., 2007; Nadeau at al., 2003). Riener et al (2002) reported a value of ~ 0.5 Nm/kg for the hip joint extension moment, 1.1 Nm/kg for the knee extension moment, 0.6 Nm/kg for the initial peak of the ankle plantarflexion moment, and 1.2 Nm/kg for the second peak of the ankle plantarflexion moment. In comparison our values for these parameters were 0.27 Nm/kg for the hip extension moment, 1.18 N/kg for the knee extension moment, 0.75 Nm/kg for the initial peak of the ankle plantarflexion moment, and 1.31 Nm/kg for the second peak of the ankle plantarflexion moment. Nadeau et al. (2003) reported peak ankle power generation at 2.53 W/kg, the peak ankle power absorption at –0.40 W/kg, and the hip joint power generation at 0.58 W/kg. In comparison our values for these parameters were 2.67 W/kg for the peak ankle power generation, -0.64 W/kg for the peak ankle power absorption, and 0.47 W/kg for the hip power generation.

Our results have partially supported the first hypothesis - joint moments and powers are different when starting stair ascent directly in front of the stairway and when starting farther away from the stairway, suggesting that different strategies have been used. Out of six moment variables, only two produced a significant condition effect. These were the initial peak of the ankle plantarflexion moment (MA1) and the knee extension moment (MK1). As far as powers are concerned, only one variable produced a significant condition effect; the hip joint power absorption variable (PH2). All three variables, MA1, MK1, and PH2 significantly increased when stair ascent started farther away from the stairway as compared to when started in front of the stairway. A possible reason for this is walking velocity which can have a larger effect when starting stair ascent from farther away. Previous gait studies have found that kinetic parameters are influenced by walking speed (Grieve and Gear, 1966; Cavanagh and Gregor, 1975; Andriacchi et al., 1976). Practically this velocity allows an individual to climb these stairs easier allowing generating higher moments more efficiently.

With respect to the second hypothesis, the results showed a large number of differences between the two steps evaluated. Step differences were seen in the following joint moment and power variables: the initial ankle plantarflexion moment (MA1), the second ankle plantarflexion moment (MA2), the knee extension moment (MK1), the hip extension moment (MH1), the hip flexion moment (MH2), the ankle power absorption (PA1), the hip power generation (PH1), and the hip power absorption (PH2). Joint moment variables (MA1, MA2, MH1, and MH2), and the PA1 and PH1 power variables significantly increased from the first step to the second step in both conditions, whereas MK1 significantly decreased from the first step to the second step in both conditions. According to our results, in the first 50% of the gait cycle, the ankle plantarflexion moment and the hip extension moment increased from the first step to the second step and the knee extension moment decreased from the first step to the second step. The reason for the decrease in the knee extension moment might be that subjects are now trying to save some of the considerable moment generated by the extensors for stair negotiation by using the other joints. Since the hip extension moment increased at the same time when the knee extension moment decreased, from the first step to the second step, we might say that the hip joint was practically "helping" the knee joint in the first 50% of the gait cycle. This finding may be of a great importance for the elderly. It was shown that the elderly redistribute the joint moments and powers differently than young adults (DeVita and Hortobagyi, 2000). Old adults used more hip moment and less knee and ankle moment to walk at the same speed as young adults (DeVita, 2000). Therefore, this natural redistribution which was observed during stair negotiation may actually work detrimentally for the elderly negating their adaptations due to aging thus resulting in more falls. This hypothesis needs to be explored with further study.

Because of the differences in velocity between the two conditions (starting in front of the stairs means practically no additional momentum) more differences were observed in the power variables. Since the power is calculated by multiplying the moment and angular velocity, the increase in joint powers in the condition when subjects started stair ascent farther away from the stairway was present. Since no significant main effect of condition was found for the knee power generation (PK1), we may say that the influence of angular velocity was not present in the knee power no matter where our subjects started the stair ascent. Therefore, this methodological difference can not affect the knee related results in the great number of studies that have been performed with respect to osteoarthritis during stair negotiation. The ankle joint absorbed more energy (PA1) at the first step than at the second step in both starting farther away from the stairway and starting in front of the stairway. This increase in ankle power absorption and the associated increase in the hip power generation at the same time may indicate greater energy contribution from the hip joint in order to lift the body up onto the next step (Riener et al., 2002). We assume that when starting farther away from the stairway, subjects leaned their body forward thus flexed their trunk more which resulted in greater hip extension moment and hip joint power generation at the beginning of the gait cycle. Following the phase of energy generation at the hip joint, a phase of energy absorption occurred (PH2). PH2 significantly decreased form the first step to the second step on the stairs. This energy absorption was necessary in order to surmount the second stair and transition onto the next step (Riener et al., 2002).

Significant interactions between condition and step were found for three power variables: the ankle power absorption (PA1), the ankle power generation (PA2), and the hip power absorption (PH2). These significant interactions indicate the different strategies used to negotiate steps when stairs were approached differently verifying the importance of the present study. As mentioned before, the significant differences among the steps within and between the conditions with respect to joint powers were the result of the additional momentum present in the condition when subjects started farther away from the stairway as compared to when they started in front of the stairway. It is important to state that there is no past research work, to the author’s knowledge, on stair ascent strategies when starting farther away from the stairway. Therefore, the results presented here are a great contribution to the existing research in stair negotiation. The significant interaction found for the ankle power absorption (PA1) was the result of an increase of eccentric ankle power from the first step to the second step when stair ascent started in front of the stairway while the opposite occurred in a smaller degree when stair ascent started farther away from the stairway. This means that the ankle platarflexors were eccentrically contracting, which can be seen in the generation of the initial peak of the ankle plantarflexion moment and its increase from the first step to the second step. The predominant activity of the ankle plantarflexors in stair ascent is due to the foot placement onto the step of the stairway. As opposite to level walking where the initial contact with the ground is made with the heel and the foot being in dorsiflexion, in stair ascent the initial foot contact with the step of the stairway was made with the forefoot and the foot being in plantarflexion. Therefore, the activity of plantarflexors was mainly involved in lifting and some translation of the body in order to place it over the contralateral limb on the next step (McFadyen and Winter, 1988). At the same time, there was a burst of energy generated by the hip joint. This positive power burst at the hip joint was necessary to bring the leg up and over to the next step and also to keep the foot clear of the intermediate step (McFadyen and Winter, 1988). In the later phase of the gait cycle the major contributions to stair ascent from the first step to the second step came from the ankle and the hip joints. Riener and colleagues (2002) also showed that the ankle and the hip joints were the major joints involved in stair ascent with an increase in the power at the ankle during late stance and at the hip during early stance. In the later phase of the gait cycle the significant interaction found for the ankle power generation (PA2). This interaction was the result of an increase of concentric ankle power from the first step to the second step when stair ascent started farther away from the stairway while the opposite occurred in a smaller degree when stair ascent started in front of the stairway. It seems that when you are on the stairs, from the first step to the second step, the ankle plantarflexors can more effectively provide propulsion when you start stair ascent farther away. This make perfect sense considering that any time we want to jump further or climb higher we take additional steps away to build momentum and accomplish the task easier. This is exactly what happened in this situation.

Another significant interaction was found for the hip joint power absorption (PH2). When stair ascent started farther away from the stairway larger concentric contraction was required at the hip joint late at stance in both steps. Furthermore, the difference between the two stair ascent conditions was much larger for the first step than the second step. The hip joint absorbed more energy at the first step than at the second step; while this was reversed for the ankle joint – it absorbed more energy at the second step than at the first step. What is actually happening here is that earlier in the gait cycle the ankle joint produced smaller plantarflexion moment which was seen in the smaller amount of power absorbed at the same time. At the hip joint, the extension moment early in the gait cycle indicated energy production by the hip joint and facilitated lifting the body up. Later in the gait cycle the ankle joint generated energy that minimized the contribution from the hip joint which at this moment absorbed the energy. The power generation by the ankle joint was reflected in the second peak ankle plantarflexion moment, whereas for the hip joint, the hip energy absorption was reflected in the hip flexion moment later in the stance.

Conclusions

This is the first study that investigated stair ascent starting farther away from the stairway. Previous stair negotiation research studies were more concentrated on investigating joint moments and powers when subjects initiated stair ascent directly in front of the stairway. The importance of starting farther away from the stairway is to allow subjects to stabilize their walking/approaching velocity and make a smooth transition onto the first and later steps of the stairs. It was already documented that walking velocity affects joint moments and powers and that their magnitudes will depend on how fast one walks. Our results showed how walking velocity affected joint moments and powers in two conditions of the stair ascent (starting farther away from the stairway and starting in front of the stairway) and what strategies subjects used to negotiate two steps on the stairway in these two different stair ascent conditions. Reported results indicated that starting farther away from the stairway mostly generated large joint moments and powers at the first step of the stairway. Lifting the body up and propelling it from one step to the next was facilitated by the energy generated at the hip and ankle joints. It was found that the knee joint power variable was not influenced by the angular velocity and that no matter where the stair ascent is initiated the knee joint did not contribute more to locomotion on stairs. Overall, our findings showed that the influence of velocity was significant as it resulted in increase or decrease in joint moment and power variables between the conditions and the steps on the stairs. Our findings suggest different strategies applied by the subjects to negotiate the steps on the stairs in two stair ascent conditions – starting farther away from the stairway and starting in front of the stairway. Further studies on both stair ascent and stair descent are necessary to address how elderly adults and other pathological populations negotiate stairs under the same conditions used in the present study. Our results may also be helpful as a database of comparison for locomotion on stairs.

References

American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. Eight Edition

Allard P, Lachance R, Aissaoui R, Duhaime M. Simultaneous bilateral 3-D able bodied gait. *Hum Mov Sci*. 1996 15: 327-346.

Andriacchi TP, Andersson GB, Fermier RW, Stern D, Galante JO. A study of lower-limb mechanics during stair-climbing. *J Bone Joint Surg Am.* 1980 62: 749-757.

Andriacchi TP, Andersson GBJ, Fermier RW, Stern D, Glante JO. The influence of total knee-replacement design on walking and stair climbing. *J Bone Joint Surg Am.* 1982 64:1328-1335.

Andriacchi TP, Birac D. Functional testing in the anterior cruciate ligament-deficient knee. *Clin Orthop Relat Res.* 1993 288:40-47.

Andriacchi TP, Galante JO. Retention of the posterior cruciate ligament in total knee arthroplasty. *J Arthroplasty*. 1988 S13-S19.

Andriacchi TP, Ogle JA, Galante JO. Walking speed as a basis for normal and abnormal gait measurements. *J of Biomech.* 1976 10:260-8.

Andriacchi TP, Eugene JA. Studies of human locomotion: Past, Present and Future. *J of Biomech.* 2000 33:1217-1224.

Archea J, Collings B, Stahl F. Guidelines for stair safety. Vol. Series 120. Washington, DC: U.S. Government Printing Office, 1979.

Aune AK, Ekeland A, Nordsletten L, Effect of quadriceps or hamstring contraction on the anterior shear force to anterior cruciate ligament failure. An in vivo study in the rat. *Acta Orthop Scand.* 1999 66:261-265.

Beaulieu FGD, Pelland L, Gordon D, Robertson E. Kinetic analysis of forwards and backwards stair descent. *Gait & Posture*. 2008 27: 564-571.

Berchuck M, Andriacchi TP, Bach BR, Reider B. Gait adaptations by patients who have a deficient anterior cruciate ligament. *J Bone Joint Surg Am.* 1990 72(6):871-877.

Brechter JH, Powers CM. Patellofemoral joint stress during stair ascent and descent in persons with and without patellofemoral pain. *Gait & Posture.* 2002 16:31-37.

Cavagna GA, Kaneko M. Mechanical work and efficiency in level walking and running. *J Physiol.* 1977 268:467-481.

Cavagna GA, Tesio L, Fuchimoto T, Heglund NC. Ergometric evaluation of pathological gait. *J Appl Physiol Resp Env Exerc Physiol*. 1983 55(2):607-13.

Cavanagh PR, Gregor RJ. Knee joint torque during the swing phase of normal treadmill walking. *J of Biomech.* 1975 8:337-44.

Cesari Paola. An invariant guiding stair descent by young and old adults. *Exp Aging Research* 2005 31:441-455.

Chen IH, Kuo KN, Andriacchi TP. The influence of walking speed on mechanical joint power during gait. *Gait & Posture*. 1997 6:171-176.

Chhibber SR, Singh I. Asymmetry in muscle weight and one-sided dominance in the human lower limbs. *J Anat.* 1970 106(3):.553-556.

Chodera JD, Levell RW. Foot patterns during walking. Kenedi RM editor. Perspectives in Biomedical Engineering, Baltimore; University Park Press. 1973, 81-90.

Chodera JD. Analysis of gait from footprints. *Physiother*. 1974 60: 179-81.

Christina KA, Cavanagh PR. Ground reaction forces and frictional demands during stair descent: Effects of age and illumination. *Gait & Posture.* 2002 15;153-158.

Costigan PA, Deluzio KJ, Wyss UP. Knee and hip kinetics during normal stair climbing. *Gait & Posture*. 2002 16: 31-37.

Costigan PA, Wyss UP, Deluzio KJ, Li J, Cooke TVD, Olney SJ. Forces and moments at the knee during stair climbing. *Proc XVIth Congr Int Soc of Biomech, Paris, France.* 1993 288-289.

DeVita P, Helseth J, Hortobagyi T. Muscles do more positive than negative work in human locomotion. *The J of Exp Biol*. 2007 210: 3361-3373.

DeVita P, Hong D, Hamill J. Effects of asymmetric load carrying on the biomechanics of walking. *J Biomech*. 1991 24(12): 1119-1129.

Di Fabio RP, Zampieri C, Tuite P. Gaze control and foot kinematics during stair climbing: Characteristics leading to fall risk in progressive supranuclear palsy. *Phys Ther.* 2008.

Duncan JA, Kowalk DL, Vaughan CL. Six degree of freedom joint power in stair climbing. *Gait & Posture*. 1997 3: 204-210.

Eng J, Winter AD. Kinetic analysis of the lower limbs during walking: what information can be gained from a three-dimensional model?. *J Biomech.* 1995 28:753-758.

Grenholm A, Stensdotter AK,Hager-Ross C. Kinematic analysis during stair descent in young women with patellofemoral pain. *Clin Biomech.* 2009 24:88-94.

Grieve DW, Gear RJ. The relationship between the length of stride, step frequency, time of swing and speed of walking for children and adults. *Ergonomics.* 1966 5:379-99.

Hamel KA, Cavanagh PR. Stair performance in people aged 75 and older. *J of the Am Ger Soc.* 2004 52(4):563-567.

Hemenway D, Solnick SJ, Koeck C, Kytir J. The incidence of stairway injuries in Austria. *Accid Anal Prev.* 1994 26:675-679.

Hortobagyi T, Mizelle C, Beam S, DeVita P. Old adults perform activities of daily living near their maximal capabilities. *J Gerontol A Biol Sci Med Sci.* 2003 58:M453-460.

ICC/ANSI A117.1-2003 Standard and Commentary ICC 2003; pp.145.

Irvine Ch, Snook SH, Sparshatt JH. Stairway risers and treads: acceptable and preffered dimensions. *Appl Erg.* 1990 21:215-225.

James B, parker AW. Electromyography of stair locomotion in elderly men and women. *Electromyogr Clin Neurophysiol.* 1989 29:161-168.

Jevsevar DS, Riley PO, Hodge WA, Krebs DE. Knee kinematics and kinetics during locomotor activities of daily living in subjects with knee arthroplasty and in healthy control subjects. *Phys Ther*. 1993 73:229-39.

Joseph J, Watson RD. Telemetering electromyography of muscles used in walking up and down stairs. *J Bone Joint Surg.* 1967 49:774-780.

Kartus J, Magnusson L, Stener S, et al. Complications following arthroscopc anterior cruciate ligament reconstruction. A 2-5 year follow up of 604 patients with special emphasis on anterior knee pain. *Knee Surg Sports Traumatol Arthrosc.* 1999 7:2-8.

Kirkwood RN, Culham EG, Costigan, P. Hip moments during level walking, stair climbing, and exercise in individuals aged 55 years or older. *Phys Ther*. 1999 79(4): 360-370.

Kovacs CR. Age-related changes in gait and obstacle avoidance capabilities in older adults: A review. *J of Appl Geront*. 2005 24(1):21-34..

Kowalk DL, Duncan JA, Vaughan Cl. Abduction-adduction moments at the knee during stair ascent and descent. *J. Biomech*. 1996 29(3): 383-388.

Kowalk DL, Duncan JA, McCue FC, Vaughan CL. Anterior cruciate ligament reconstruction and joint dynamics during stair climbing. *Med and Sc in Spor and Exerc.* 1997.

Lee HJ, Chou LS. Balance control during stair negotiation in older adults. *J of Biomech*. 2007 40:2530-2536.

Lin HC, Lu TW, Hsu HC. Comparisons of joint kinetics in the lower extremity between stair ascent and descent. *J of Mechan*. 2005 21: 41-50.

Lin HC, Lu TW, Hsu HC. Three-dimensional analysis of kinematic and kinetic coordination of the lower limb joints during stair ascent and descent. *Biomed Eng-Appl, Basis & Commun.* 2004 59-66.

Livingston LA, Stevenson JM, Olney SJ. Stair climbing kinematics on stairs of differing dimensions. *Arch Phys Med Rehabil.* 1991 72: 398-402.

Loy DJ, Voloshin AS. Biomechanics of stair walking and jumping. *Journal of Sports Sciences*. 1991 *9*(2): 137-149.

Luepongsak N, Amin S, Krebs DE, McGibbon CA, Felson D. The contribution of type of daily activity to loading across the hip and knee joints in elderly. *Osteoarthr Cartil* 2002 10:353-359.

Marottoli R, BerkmanL, Cooney L. Decline in physical function following hip fracture. *J Am Geriatr Soc* 1992 40:861-866.

McFadyen BJ, Winter DA. An integrated biomechanical analysis of normal stair ascent and descent. *J of Biomech*. 1988 21: 733-744.

McGinnis PM. Biomechanics of sport and exercise. 2005, Second edition.

Mena D, Mansour JM, Simos SR. Analysis and synthesis of human swing leg motion during gait and its clinical applications. *J Biomech.* 1981 14:823-832.

Mian OS, Naricia MV, Minetti AE, Baltzopoulos V. Centre of mass motion during stair negotiation in young and older men. *Gait & Posture*. 2007 26: 463-469.

Mille ML, Johnson ME, Martinez KM, Rogers MW. Age-dependent differences in lateral balance recovery through protective stepping. *Clin Biomech*. 2005 20: 607-616.

Moffet H, Richards CL, Malouin F, Bravo G. Load-carrying during stair ascent: a demanding functional test. *Gait & Posture.* 1993 1:35-44.

Morrison JB. Function of the knee joint in various activities. *Biomed Eng*. 1969 4: 573-580.

Nadeau S, McFadyen BJ, Malouin F. Frontal and sagittal plane analysis of the stair climbing task in healthy adults aged over 40 years: what are the challenges compared to level walking? *Clin Biomech*. 2003 18: 950-959.

Nagurney J, Borczuk P, Thomas S. Elderly patients with closed head trauma after a fall: Mechanism and outcomes. *J Emerg Med.* 1998 16:709-713.

National Safety Council. Accident facts. Itasca, IL, National Safety Council. 1994.

Nigg B, Cole G, Nachbauer W. Effects of arch height of the foot on angular motion of the lower extremities in running. *J Biomech.* 1993 26(8):909-16.

Norkin C, Levangie P. Stair and running gaits. In Norking C, Levangie P, Eds. Joint Structure and Function. Philadelphia: Davis Company 1992 481-484.

Olney SJ., Costigan PA., Hedden DM. Mechanical energy patterns in gait of cerebral palsied children with hemiplegia. *Phys Ther.* 1987 67:1348-54.

Overstall PW, Exton-Smith AN, Imms FJ, Johnson AL. Falls in the elderly related to postural imbalance. *British Med J.* 1977 1:261-264.

Ploutz-Snyder LL, Manini T, Ploutz-Snyder RJ, Wolf DA. Functionally relevant thresholds of quadriceps femoris strength. *J Gerontol Biol Sci.* 2002 57A:B144-B152.

Prodromos CC, Andriacchi TP, Galante JO. A relationship between gait and clinical changes following hight tibial osteotomy. *J of Bone and Joint Surg.* 1985 67A(8): 1188-1194.

Protopapadaki A, Drechsler W,,Cramp MC, Coutts FJ, Scott OM. Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. *Clin Biomech*. 2007 22:203-210.

Prudham D, Evans JG. Factors associated with falls in the elderly: a community study. *Age Ageing.* 1981 10:141-146.

Reeves ND, Spanjaard M, Mohagheghi AA, Baltzopoulos V, Maganaris CN.The demands of stair descent relative to maximum capacities in elderly and young adults. *J of Electromyograph and Kinesiol*. 2008 18: 218-227.

Reeves ND, Spanjaard M, Mohagheghi AA,, Baltzopoulos V, Maganaris CN. Older adults employ alternative strategies to operate within their maximum capabilities when ascending stairs. *J of Electromyograph and Kinesiol*. 2007 19:e57-e68.

Reid SM, Lynn SK, Musselman RP, Costigan PA. Knee biomechanics of alternate stair ambulation patterns. *Med & Sc in Sports & Exerc.* 2007.

Riener R, Rabuffetti M, Frigo C. Stair ascent and descent at different inclinations. *Gait & Posture*. 2002 15:32-44.

Rose J, Gamble JG. Human Walking. Third Edition. Lippincott Williams and Wilkins. 2006.

Salsich GB, Brechter JH, Powers CM. Lower extremity kinetics during stair ambulation in patients with and without patellofemoral pain. *Clin Biomech*. 2001 16: 906-912.

Schipplein OD, Andriacchi TP. Interaction between active and passive knee stabilizers during level walking. *J of Orthoped Res.* 1991 9: 113-119.

Simoneau GG, Cavanagh PR, Ulbrecht JS, Leibowitz HW, Tyrrell RA. The influence of visual factors on fall related kinematic variabls during stair descent by older woman. *J of Gerontol.* 1991 46:188-195.

Spanjaard M, Reeves ND, Van Dieën JH, Baltzopoulos V, Maganaris CN. Lower-limb biomechanics during stair descent: Influence of step-height and body mass. *The J of Exp Biol*. 2008 211:1368-1375.

Startzel JK, Cavanagh P. The mechanics of stair negotiation. *J Appl Biomech.* 2000.

Startzell JK, Owens DA, Mulfinger LM, Cavanagh PR. Stair negotiation in older people: A review. *J of the Am Geriatr Soc*. 2000 48:567-580.

Sutherland DH, Olshen R, Cooper L, Danier D. The development of mature gait. *Am J Bone J Surg*. 1980 62:336-353.

Suzuki M, Okamura T, Shimazy Y. A study of falls experienced by institutionalized elderly. *Nipon Koshu Eisei Zasshi*. 1992 39:927-940.

Svanstrom L. Falls on stairs. An epidemiological accident study. *Scand J Soc Med.* 1974 2:113-120.

Templer J. The staircase studies of hazards, falls and safer design. Cambridge, MA: The MIT Press 1992.

Thambyah A, Thiagarajan P, Cho Hong JG. Knee joint moments during stair climbing of patients with anterior cruciate ligament deficiency. *Clin Biomech*. 2004 19:489-496.

Tiedemann AC, Sherrington C, Lord SR. Physical and psychological factors associated with stair negotiation performance in older people. *J of Gerontol, Med Sc.* 2007 62A: 1259-1265.

Tinetti M, Speechley M, Ginter S. Risk factors for falls among elderly persons living in the community. *N Engl J Med.* 1988 319:1701-1707.

Vaughan C, Davis B, O'Connor J. *Dynamics of human gait*: 2nd ed. Cape Town, South Africa: Kiboho Publishers 1992.

Whatling GM, Evans SL, Holt CA. Introducing a new staircase design to quantify healthy knee function during stair ascent and descent. *Comp Meth in Biomech and Biomedic Eng.* 2009 1-8.

Williamson J, Fried L. Characterization of older adults who attribute functional decrements to “old” age. *J Am Geriatr Soc* 1996 44:1429-1434.

Winter AD. Biomechanics and motor control of human movement. 2004.

Winter AD. Sagittal plane balance and posture in human walking. *Engng Med Biol.* 1987 6: 8-11.

Yu B, Kienbacher T, Growney ES, Johnson ME,,Kai-Nan An. (1997). Reproducibility of the kinematics and kinetics of the lower extremity during normal stair-climbing. *J of Orthop Res*. 1997 15: 348-352.

Zachazewski JE, Riley PO, Krebs DE. Biomechanical analysis of body mass transfer during stair ascent and descent of healthy subjects. *J of Rehabil Res and Develop* 1993 30:412-422.

Appendix A: Medical History Questionnaire

IRB#360-09-EP

MEDICAL HISTORY

Date ________________

Name ______________________________________ Age ______________

Address ____________________________________ Height ____________

Phone (home)________________________________ Weight ____________

Check any of the following which has occurred in your medical history:

________	Sensory disorders	________	Scoliosis
________	Neuromuscular disorders	________	Joint replacement
________	Skeletal disorders	________	Diabetes
________	Cardiovascular disorders	________	Pulmonary diseases
________	Stroke	________	Asthma
________	Rheumatoid arthritis	________	Recent surgery
________	Arterial disease	________	Acute illness
________	Neuropathy/Myopathy	________	Pulmonary disorders
________	Vertigo	________	Cardiac disorders
		________	Locomotor disorders

Appendix B: Demographics for Young Subjects and self-selected speed for stair ascent

					Self-selected speed (m/sec)	
Subject	Age (years)	Gender (F/M)	Height (cm)	Weight (kg)	Lower	Upper
1	22	F	170.2	86	0.74	0.91
2	25	F	155	49	0.7	0.86
3	24	F	163	75	0.97	1.18
4	21	M	180	86	0.58	0.71
5	26	M	185	96	0.68	0.83
6	31	F	174.5	81	0.66	0.54
7	23	F	168	63	1.055	0.86
8	22	M	182	109	0.85	0.7
9	28	M	189	92	0.66	0.54
10	29	M	167	69	0.84	0.69
Mean	25.1 $\pm$ 3.3	5/5	173.3 $\pm$ 10.7	80.6 $\pm$ 17.3	0.77 $\pm$ 0.15	0.78 $\pm$ 0.19

Appendix C: Mean ankle, knee and hip joint moment and power discrete points

MA1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	0.821	0.634	0.705	1.342	1.032	0.488	0.491	0.875	0.814	0.281	0.748	0.303
Step2_C1	1.102	0.771	0.839	1.347	1.128	0.579	0.596	0.848	0.755	0.680	0.865	0.251
Step1_C2	0.400	0.419	0.753	0.934	0.656	0.339	0.367	0.690	0.400	0.557	0.551	0.200
Step2_C2	0.909	0.829	0.848	1.131	0.799	0.601	0.466	0.751	0.804	0.707	0.784	0.178

MA2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	1.024	1.163	1.029	1.669	1.522	1.227	1.315	1.264	1.601	1.249	1.306	0.224
Step2_C1	1.178	1.432	1.057	1.744	1.519	1.490	1.378	1.286	1.757	1.468	1.431	0.222
Step1_C2	1.163	1.299	1.107	1.514	1.426	1.220	1.296	1.109	1.342	1.297	1.277	0.132
Step2_C2	1.280	1.612	1.041	1.768	1.574	1.469	1.366	1.232	1.640	1.484	1.446	0.219

MK1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	1.231	1.277	1.314	1.170	1.343	1.502	1.139	1.075	1.014	0.733	1.180	0.211
Step2_C1	1.241	1.098	1.190	1.112	1.092	1.293	0.979	0.909	1.020	0.528	1.046	0.216
Step1_C2	1.422	1.202	1.127	0.961	1.041	1.398	1.094	0.953	1.013	0.668	1.088	0.221
Step2_C2	1.207	1.057	1.128	0.966	0.884	1.319	0.890	0.810	0.761	0.539	0.956	0.230

MK2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	-0.535	-0.290	-0.174	-0.597	-0.336	-0.330	-0.275	-0.417	-0.454	-0.420	-0.383	0.127
Step2_C1	-0.209	-0.243	-0.120	-0.525	-0.316	-0.316	-0.243	-0.353	-0.428	-0.506	-0.326	0.130
Step1_C2	-0.205	-0.381	-0.141	-0.543	-0.298	-0.250	-0.246	-0.425	-0.446	-0.451	-0.338	0.129
Step2_C2	-0.201	-0.305	-0.102	-0.655	-0.245	-0.244	-0.213	-0.443	-0.501	-0.546	-0.346	0.179

MH1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	0.399	0.351	0.164	-0.388	0.374	0.441	0.287	0.263	0.421	0.367	0.268	0.245
Step2_C1	0.303	0.625	0.172	0.074	0.417	0.493	0.296	0.378	0.711	0.440	0.391	0.193
Step1_C2	0.039	0.469	0.051	0.210	0.099	-0.066	0.098	0.391	0.269	0.305	0.187	0.171
Step2_C2	0.259	0.455	0.125	-0.082	0.297	0.402	0.138	0.318	0.452	0.518	0.288	0.185

MH2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	-0.576	-0.412	-0.393	0.400	-0.257	-0.594	-0.267	-0.190	-0.348	-0.328	-0.296	0.277
Step2_C1	-0.265	-0.111	-0.242	0.008	-0.080	-0.479	-0.142	-0.066	-0.235	-0.128	-0.174	0.138
Step1_C2	-0.194	-0.067	-0.310	-0.288	-0.148	-0.490	-0.138	-0.081	-0.153	-0.254	-0.212	0.127
Step2_C2	-0.007	0.036	-0.165	0.053	-0.023	-0.466	-0.055	-0.005	-0.051	-0.071	-0.075	0.150

PA1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	-1.266	-0.954	-0.429	-1.184	-0.727	-0.283	-0.351	-0.709	-0.371	-0.169	-0.644	0.387
Step2_C1	-0.952	-0.659	-0.076	-1.586	-0.669	-0.296	-0.343	-0.347	-0.595	-0.500	-0.602	0.423
Step1_C2	-0.361	-0.528	-0.157	-0.492	-0.405	-0.205	-0.111	-0.447	-0.107	-0.345	-0.316	0.159
Step2_C2	-1.135	-1.209	-0.344	-1.254	-0.589	-0.367	-0.235	-0.436	-0.478	-0.680	-0.673	0.385

PA2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	2.196	3.033	2.156	2.813	2.864	3.411	2.849	2.011	2.933	2.472	2.674	0.425
Step2_C1	3.235	4.061	2.054	2.522	3.242	5.114	3.290	2.496	3.767	2.880	3.266	0.841
Step1_C2	3.205	3.934	2.827	2.788	3.105	3.862	3.636	2.214	3.236	2.759	3.157	0.513
Step2_C2	1.987	4.769	1.383	3.124	3.683	4.653	3.310	1.998	2.765	2.822	3.049	1.056

PK1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	2.175	2.345	1.722	1.270	2.384	2.376	1.322	2.299	1.302	0.813	1.801	0.587
Step2_C1	1.094	1.832	1.372	1.484	1.801	2.739	1.567	1.664	1.811	0.883	1.625	0.502
Step1_C2	2.014	1.968	1.619	1.350	1.367	2.670	1.656	1.583	1.626	1.134	1.699	0.434
Step2_C2	0.896	2.002	1.258	1.380	1.634	3.086	1.126	1.537	1.046	1.006	1.497	0.651

PH1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	0.935	0.806	0.239	-0.233	0.552	0.769	0.480	0.217	0.422	0.469	0.466	0.340
Step2_C1	1.279	1.297	0.406	-0.060	0.733	0.930	0.781	0.528	0.961	0.477	0.733	0.415
Step1_C2	-0.153	1.031	0.133	0.568	0.063	-0.318	0.107	0.494	0.476	0.449	0.285	0.395
Step2_C2	0.910	1.080	0.224	0.058	0.360	0.718	0.182	0.261	0.449	0.628	0.487	0.336

PH2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean	SD
Step1_C1	-0.789	-0.268	-0.292	0.094	-0.111	-0.395	-0.189	-0.133	-0.285	-0.160	-0.253	0.219
Step2_C1	-0.456	-0.052	-0.165	0.008	-0.014	-0.335	-0.070	0.004	-0.103	-0.019	-0.120	0.149
Step1_C2	-0.674	-0.167	-0.278	0.068	-0.035	-0.267	-0.069	-0.054	-0.084	-0.108	-0.167	0.196
Step2_C2	-0.344	-0.006	-0.200	0.029	-0.012	-0.232	-0.019	0.015	0.000	-0.044	-0.081	0.122

Appendix D: Results of the statistical analysis for the ankle, knee and hip joint moment and power discrete points

	Condition 1				Condition 2						
	Step 1		Step 2		Step 1		Step 2				
Moments	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-condition	p-step	p-interaction
MA1	0.748	0.303	0.865	0.251	0.551	0.2	0.784	0.178	0.022*	0.001*	0.091
MA2	1.306	0.224	1.431	0.222	1.277	0.132	1.446	0.219	0.838	0.001*	0.164
MK1	1.18	0.211	1.046	0.216	1.088	0.221	0.956	0.23	0.012*	0.001*	0.968
MK2	-0.383	0.127	-0.326	0.13	-0.338	0.129	-0.346	0.179	0.614	0.263	0.103
MH1	0.268	0.245	0.391	0.193	0.187	0.171	0.288	0.185	0.092	0.002*	0.844
MH2	-0.296	0.277	-0.174	0.138	-0.212	0.127	-0.075	0.15	0.122	0.001*	0.863

	Condition 1				Condition 2						
	Step 1		Step 2		Step 1		Step 2				
Powers	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-condition	p-step	p-interaction
PA1	-0.644	0.387	-0.602	0.423	-0.316	0.159	-0.673	0.385	0.077	0.05*	0.007*
PA2	2.674	0.425	3.266	0.841	3.157	0.513	3.049	1.056	0.239	0.201	0.026*
PK1	1.801	0.587	1.625	0.502	1.699	0.434	1.497	0.651	0.21	0.16	0.895
PH1	0.466	0.34	0.733	0.415	0.285	0.395	0.487	0.336	0.099	0.017*	0.71
PH2	-0.253	0.219	-0.12	0.149	-0.167	0.196	-0.081	0.122	0.006*	0.008*	0.007*

PA1	Mean Difference	Q Ratio	p-value
s1_c1 x s2_c1	0.042	0.7	NS
s1_c1 x s1_c2	0.328	5.47	< 0.05
s1_c1 x s2_c2	0.029	0.48	NS
s2_c1 x s1_c2	0.286	4.77	< 0.05
s2_c1 x s2_c2	0.071	1.18	NS
s1_c2 x s2_c2	0.357	5.95	< 0.05
PA2	Mean Difference	Q Ratio	p-value
s1_c1 x s2_c1	0.592	4.55	< 0.05
s1_c1 x s1_c2	0.483	3.71	NS
s1_c1 x s2_c2	0.375	2.88	NS
s2_c1 x s1_c2	0.109	0.84	NS
s2_c1 x s2_c2	0.217	1.66	NS
s1_c2 x s2_c2	0.108	0.83	NS
PH2	Mean Difference	Q Ratio	p-value
s1_c1 x s2_c1	0.133	13.3	< 0.05
s1_c1 x s1_c2	0.086	8.6	< 0.05
s1_c1 x s2_c2	0.172	17.2	< 0.05
s2_c1 x s1_c2	0.047	4.7	< 0.05
s2_c1 x s2_c2	0.039	3.9	NS
s1_c2 x s2_c2	0.086	8.6	< 0.05

Appendix E: Informed Consent

SCHOOL OF HEALTH, PHYSICAL EDUCATION AND RECREATION
Nebraska Biomechanics Core Facility

IRB #360-09-EP

ADULT INFORMED CONSENT FORM

Title of this Research Study

JOINT MOMENTS AND POWERS IN HEALTHY YOUNG ADULTS DURING STAIR NEGOTIATION

Invitation

You are invited to take part in this research study. Participation is completely voluntary, therefore, the information in this form is meant to help you decide whether or not to take part. If you have any questions, please ask.

Why are you being asked to be in this research study?
You are being asked to participate in this study because you are 19 to 35 years old and have no history of injury to the lower limbs, any type of lower extremity surgery, systematic disease, neuromuscular disease or balance problems that may affect the way you walk. If you are pregnant you may not participate in this study.

What is the reason for doing this research study?
Stair climbing is a common activity of daily life, but can be very challenging and maybe a dangerous task for some individuals. Compared to walking on level ground, stair climbing imposes greater demands to the muscles and more work from the legs. The purpose of this study will be to determine the normal muscular and energy requirements.

What will be done during this research study?
Testing will be done at the Nebraska Biomechanics Core Facility on the University of Nebraska at Omaha campus. You will be asked to wear comfortable walking shoes and a form fitting suit (like a wrestling unitard). You will then have your height and body weight measurements recorded. Next, small reflective markers (Styrofoam balls about the size of a marble) will be placed on your hips, legs, and feet. The position of these markers will be recorded while you walk. The cameras cannot see any image of you; it can only see the reflective markers.

You will be asked to perform walking trials. This includes walking about 10 meters (about 32 feet) at your normal pace. In order to determine your normal pace you will be allowed to perform several walking trials until you are comfortable with the chosen walking pace. You will be asked to walk the 10 meter walkway starting with either right or left leg a minimum of 5 times and up to a maximum of 10 times. After performing the walking trials you will be provided

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(402) 554-2670 / FAX (402) 554-3693 / http://biomech.unomaha.edu

Subject's Initials ___________

a rest period of three minutes at least or more if you feel you need it.
You will then be asked to walk up and down a four step stairway at your self-selected pace. You will be allowed to perform several trials until you are comfortable with the stairway and the chosen ascending and descending speed. You will perform at least 20 trials. Between each condition (stair ascent and stair descent) you will be provided a rest period of three minutes at least or more if you feel you need it. This visit should take about one and a half hour of your time.

What are the possible risks of being in this research study?
There is a slight chance you may experience a mild leg discomfort/fatigue while climbing the stairway without using the rails. However, if at any time you need to rest you may do so. In order to reduce the risk of falling while ascending or descending the stairs you will be allowed to use the handrail to catch yourself. There is a handrail attached to the right and left side of the stairway for this purpose. There may also be a small risk of loss of confidentiality.

What are the possible benefits to you?
You are not expected to get any direct benefit from being in this research study.

What are the possible benefits to other people?
Society could benefit from this study because it may help form a basic knowledge of muscular and energy requirements of stair negotiation as well as a baseline for future studies with elderly and clinical population.

What are the alternatives to being in this research study?
Instead of being in this research study you can choose not to participate.

What will being in this research study cost you?
There is no cost to you to be in this research study.

Will you be paid for being in this research study?
You will not be paid to be in this research study.

Who is paying for this research?
This research is being paid by the Nebraska Biomechanics Core Facility at the University of Nebraska at Omaha.

What should you do if you are injured or have a medical problem during this research study?
If you are injured or have a medical problem as a result of being in this study, you should immediately contact one of the people listed at the end of this consent form.

How will information about you be protected?
You have rights regarding the privacy of your medical information collected before and during this research. This medical information, called "protected health information" (PHI), typically may include, depending upon the nature of this research, demographic information (like your address and birth date), the results of physical exams, blood tests, x-rays and other diagnostic and medical procedures, as well as your medical history.

By signing this consent form, you are allowing the research team to have access to your PHI. The research team includes the investigators listed on this consent form and other personnel involved in this specific study at UNMC and the Nebraska Medical Center.

Your PHI will be used only for the purpose(s) described in the section "What is the reason for doing this research study?"

Your PHI will be shared, as necessary, with the Institutional Review Board (IRB) and with any person or agency required by law.

You are authorizing us to use and disclose your PHI for as long as the research study is being conducted.

You may cancel your authorization for further collection of PHI for use in this research at any time by contacting the principal investigator in writing. However, the PHI which is included in the research data obtained to date may still be used. If you cancel this authorization, you will no longer be able to participate in this research.

The information from this study may be published in scientific journals or presented at scientific meetings, but your identity will be kept strictly confidential.

What are your rights as a research subject?
You have rights as a research subject. These rights have been explained in this consent form and in The Rights of Research Subjects that you have been given. If you have any questions concerning your rights or complaints about the research, talk to the investigator or contact the Institutional Review Board (IRB) by:

Telephone: (402) 559-6463
Email: IRBORA@unmc.edu
Mail: UNMC Institutional Review Board, 987830 Nebraska Medical Center, Omaha, NE 68198-7830

What will happen if you decide not to be in this research study?
You can decide not to be in this research study. Deciding not to be in this research study will not affect your relationship with the investigator or the University of Nebraska at Omaha. You will not lose any benefits to which you are entitled.

What will happen if you decide to stop participating once you start?
You can stop being in this research study ("withdraw") at any time before, during, or after the research study begins. Deciding to withdraw will otherwise not affect your care or your relationship with the investigator, the University of Nebraska at Omaha. You will not lose any benefits to which you are entitled.

You may be taken off the study if you don't follow instructions of the investigator or the research team. If the research team gets any new information during this research study that may affect whether you would want to continue being in the study you will be informed promptly.

Documentation of informed consent
You are freely making a decision whether to be in this research study. Signing this form means that (1) you have read and understood this consent form, (2) you have had the consent form explained to you, (3) you have had your questions answered and (4) you have decided to be in the research study.

If you have any questions during the study, you should talk to one of the investigators listed below. You will be given a copy of this consent form to keep.

____

Signature of Subject Date Time

My signature certifies that all the elements of informed consent described on this consent form have been explained fully to the subject. In my judgment, the participant possesses the legal capacity to give informed consent to participate in this research and is voluntarily and knowingly giving informed consent to participate.

____

Signature of Person obtaining consent Date

Authorized Study Personnel

Mira M Momcilovic, BS, Principal Investigator	Phone: 402-554-3228
Nick Stergiou, PhD, Secondary Investigator	Phone: 402-554-3075
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