

**STRATEGIES USED DURING A CHALLENGING WEIGHTED WALKING
TASK IN HEALTHY, OLDER ADULTS AND SUBJECTS WITH KNEE
OSTEOARTHRITIS**

by

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A thesis submitted to the Faculty of the University of Delaware in partial
fulfillment of the requirements for the degree of Master of Science in Biomechanics
and Movement Science

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ABSTRACT

Knee osteoarthritis (OA) is a degenerative joint disease that affects millions of people. While numerous gait differences have been identified between healthy adults and adults with knee OA and some studies have looked at how biomechanics differ during challenging conditions, none have studied healthy, older adults or adults with knee OA during a challenging weighted walking task. Because loading is important to the initiation and progression of knee OA and this type of challenging task will increase the forces that must be absorbed by the body, we investigated the effect of weighted walking on initial contact and loading response (weight acceptance task). We used a split belt instrumented treadmill and motion capture technology to analyze the gait of 40 subjects (20 healthy and 20 knee OA) walking at 1.0 meter per second while unweighted and weighted with 1/6th of their body weight in a front and back loaded weight vest. Subjects were grouped according to their Kellgren and Lawrence (K/L) radiographic score. Healthy subjects had a $K/L \leq 1$, while knee OA subjects had a $K/L \geq 2$. The analysis of initial contact focused on the position of the ankle, knee, and hip in the sagittal plane and step length. The analysis of the loading response included double support percent, peak braking force, peak hip flexion moment, peak knee flexion moment, knee flexion excursion and load rate. We used a two-way,

repeated measures analysis of variance to check for differences within groups, within conditions, and interaction effects. We found significant differences for hip flexion angle at initial contact, double support percent, and load rate. Follow-up t-tests revealed subjects with knee OA had a larger double support percent and hip flexion angle at initial contact and a decreased load rate compared to unweighted, healthy, older adults. Also, both groups increased their double support percent in response to the challenging weighted walking task, but only the healthy, older adults increased their hip flexion angle at initial contact and decreased their load rate. Correlation and regression analysis of the significant findings found that unweighted, knee OA subjects had a significant relationship between the hip flexion angle at initial contact and double support that did not exist in the healthy, older adults and did not remain when they were weighted. The relationship between load rate and double support in the knee OA group got stronger during the weighted condition, but did not persist in the healthy, older subjects. It appears that during the weighted condition the knee OA group places priority on decreasing loads, secondarily increasing weight-bearing stability, while the healthy, older adults make weight-bearing stability a priority, secondarily decreasing load rate.

Chapter 1

INTRODUCTION

Walking is a task that needs to be mastered from an early age if one is to function independently (Cunningham et al., 1993). Each person develops his or her own walking pattern, or gait, and matures according to the structure, function, and coordination of all parts of the neuromusculoskeletal system (Sutherland, 1997). Most people do not have to think in order to keep themselves moving smoothly to wherever they wish to go. Subconsciously, the body is coordinating all its muscles, joints and segments to achieve successful ambulation.

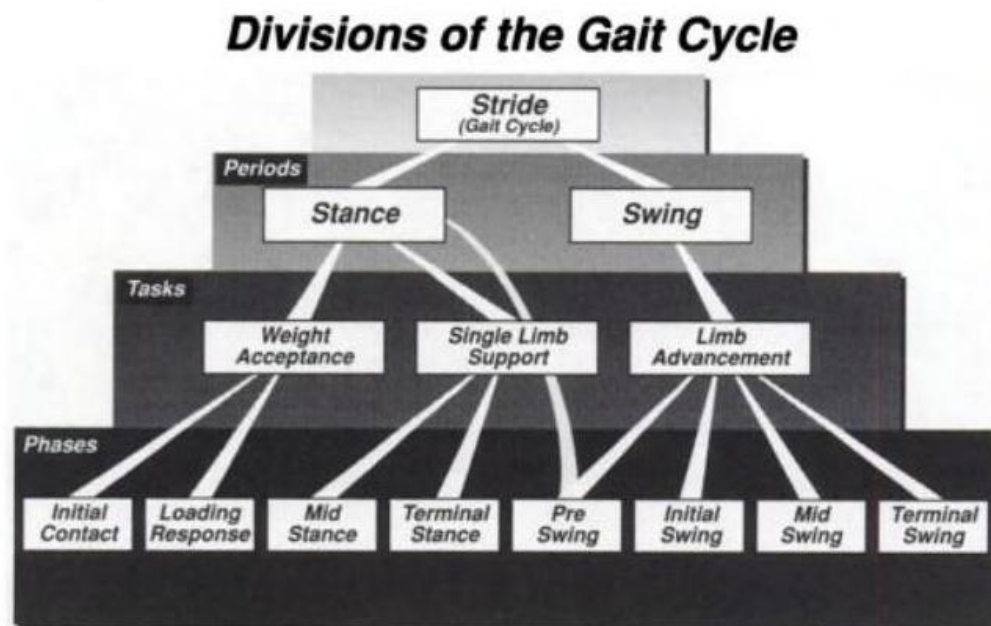


Figure 1.1: Divisions of the gait cycle into periods, tasks and phases (Reprinted with permission from SLACK Incorporated: Perry, 1992).

Eight phases of gait have been observed during normal walking: initial contact, loading response, midstance, terminal stance, pre-swing, initial swing, mid swing, and terminal swing (Figure 1.1). Through these phases, the body is achieving three primary tasks: weight acceptance, single limb support, and forward progression of the limb (Figure 1.1). The first two tasks are accomplished during the “stance” period of gait when the foot of interest is in contact with the ground (Figure 1.2A). The goal of weight acceptance is accomplished in the first two phases of gait: initial contact and loading response. The weight acceptance task begins with initial contact of the leading limb and ends when the trailing limb’s toe comes off the ground. Single limb

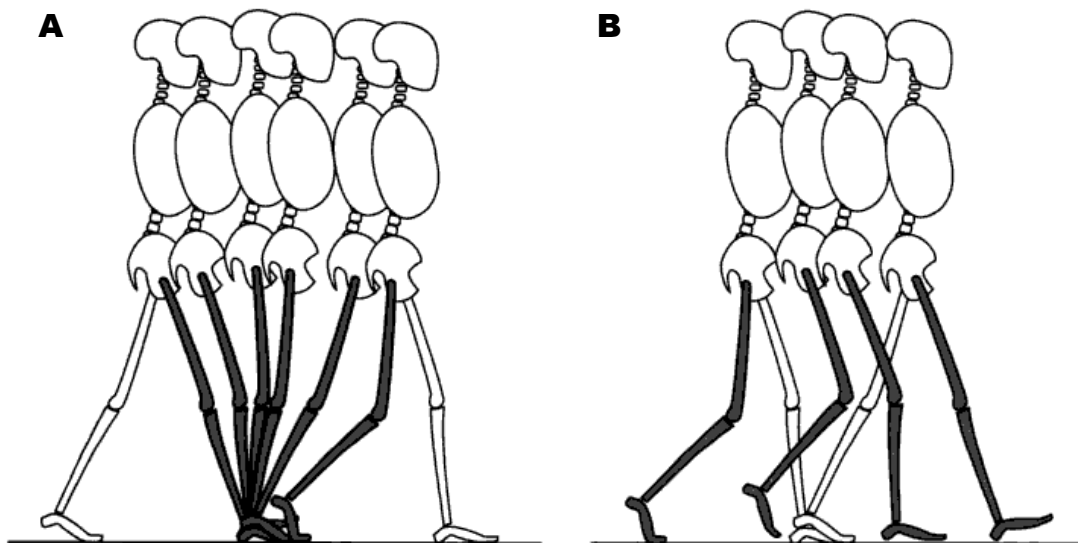


Figure 1.2: (A) Freeze frames of the stance period of gait for the shaded limb (Reprinted with permission from SLACK Incorporated: Perry, 1992). (B) Freeze frames of the swing period of gait for the shaded limb (Reprinted with permission from SLACK Incorporated: Perry, 1992).

support is coordinated from midstance until the beginning of pre-swing. This task begins for the stance limb when the trailing limb’s toe comes off the ground and ends when the trailing limb comes forward to become the leading limb with initial contact.

The final goal of forward limb advancement into the next step is achieved by the “swing” period beginning with initial and ending with terminal swing (Figure 1.2B). Limb advancement is accomplished and distinguished by the limb going from behind the body to the front for the next step without touching the ground. This task ends when the foot hits the ground for the next initial contact. “Healthy” individuals achieve these goals during gait and move within a well-defined range of joint angles. Pathological conditions, which may lead to functional impairment and pathological gait, are products of deformity, muscle weakness, loss of neuromuscular control, or pain (Perry, 1992).

There has been more focus on chronic pain conditions and rheumatic diseases that impact the functional ability of adults in the last decade (Woolf, 2000). Of the diseases that can impact how adults function, arthritis is the leading cause of disability (CDC, 1994). The term “arthritis” encompasses over 100 diseases of the joint and surrounding tissues (CDC, 2001). According to the Arthritis Foundation, around 46 million people in the United States are afflicted by arthritis or a related disease (CDC, 2006). One of the most common forms of arthritis is osteoarthritis. Osteoarthritis (OA) is a disease that is typically associated with “wear and tear” of the components of a synovial joint. Knee OA has the most incidences per 100,000 people in the United States (240), compared to hip (88) and hand (100) OA (Oliveria et al., 1995).

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Figure 1.3: (A) The healthy knee joint with labeled bone, cartilage and meniscus (ReGen Biologics, 2007). (B) An osteoarthritic knee joint showing osteophyte growth, cartilage degeneration and eroding meniscus (Nuffield, 2010).

The knee joint complex is comprised of two joints: tibiofemoral and patellofemoral. The patellofemoral joint is the articulation between the patella and the femur. The tibiofemoral joint is the articulation between the tibia and the femur. The tibiofemoral joint is further separated into the medial and lateral compartments. The medial compartment has a larger prevalence of OA possibly related to the increased joint loads through the medial compartment during gait (Andriacchi and Mündermann, 2006) as well as lower limb mechanical alignment (Cooke et al., 1997). Within the tibiofemoral joint, there is articular cartilage, subchondral bone, synovial fluid, meniscus, synovium, and ligaments which are all surrounded by the knee joint capsule and have been hypothesized to be affected by this disease (Figure 1.3B).

Knee OA affects approximately 27 million adults in the United States and 25% of the population aged 25-74 (Lawrence et al. 2008). The effects of knee OA can impact economic (Gupta et al., 2005), social (Holman and Lorig, 1997), psychological (Creamer et al., 2000), physical (Jinks et al., 2007), and functional (Davis et al., 1991) aspects of life. Biomechanical changes that occur in a person's gait pattern may lead to further progression of the disease (Andriacchi and Mündermann, 2006; Jackson et al., 2004). The knee adduction moment during gait is the major biomechanical factor linked to knee OA, its symptoms and its progression (Thorp et al., 2007; Baliunas et al., 2002; Miyazaki et al., 2002; Sharma et al., 1998). This gait parameter has been the focus of much scrutiny because of its relation specifically to medial joint loading (Zhao et al., 2007; Hurwitz et al., 1998). Increased knee adduction moment has been associated with secondary bone changes (Wada et al., 2001; Hurwitz et al., 1998) and altered joint mechanics in the most severe cases (Astroth et al., 2008).

Other proposed factors that influence the incidence and progression of knee OA are obesity (Felson et al., 1988; Leach et al., 1973), age (Felson et al., 1987), gender (Felson et al., 1995), static standing knee alignment (Hurwitz et al., 2002; Wada et al., 2001) and previous knee injury (Cooper et al., 2000). Other dynamic gait parameters besides the knee adduction moment that influence the progression of primary knee OA are still under investigation. Zeni and colleagues have recently suggested that co-contraction (Zeni et al., 2010) and a stiff knee during walking (Zeni and Higginson, 2009a) decrease the knee's range of motion which may increase the

stress over specific areas within the joint and can cause cartilage breakdown over time (Andriacchi et al., 2004; Burr, 2004). These findings help support the hypothesis that high forces and a change in knee joint mechanics could influence the incidence and progression of this disease (Andriacchi and Mündermann, 2006). Individuals with varying severities of knee OA also exhibit decreased walking speed (Zeni and Higginson, 2009b; Astephen et al., 2008; Mündermann et al., 2004; Chen et al., 2003; Al-Zahrani and Bakheit, 2002; Kaufman et al., 2001), altered pelvis and lower extremity joint kinematics and kinetics (Briem and Snyder-Mackler, 2009; Huang et al., 2008; Bejek et al., 2006; Zeni and Higginson, 2009a; Zeni and Higginson, 2009b; McGibbon and Krebs, 2002) and changes in spatiotemporal parameters (Bejek et al., 2006; Chen et al., 2003; Gök et al., 2002; Al-Zahrani and Bakheit, 2002). If unique strategies that patients with knee OA use to walk can be definitively identified, then it may be possible to target treatment interventions for this group.

Aside from studying how subjects with knee OA walk under normal conditions, using challenging conditions, which impose increased demand on the neuromusculoskeletal system, can be beneficial to understanding movement strategies. Others have tested a knee OA population during challenging conditions such as walking quickly (Zeni and Higginson, 2009b; Landry et al., 2007), walking up and down stairs (Asay et al., 2009; Karamanidis and Arampatzis, 2009; Liikavainio et al., 2007; Guo et al., 2007), and negotiating an obstacle (Chen et al., 2008; Lu et al., 2007). Challenging these individuals to a task that is not part of their normal activities

of daily living can be informative because underlying movement impairments may not be as apparent during a task that a person may face daily. For example, under normal walking conditions, there is no difference in the upper body posture of subjects with severe knee OA compared to healthy subjects, but when these subjects are challenged to walk up stairs, the severe knee OA subjects have significant forward trunk lean which influences their hip and knee flexion moments (Asay et al., 2009). This compensatory mechanism during stair climbing is consistent with the decreased functional status of subjects with severe knee OA and implies that stair ascent could be used as a method of evaluating patient function, quadriceps strength, and knee OA severity (Asay et al., 2009).

Challenging weighted walking conditions have been studied in healthy adults in order to find the effects of the load. When healthy, young adults are subjected to load carrying, they respond with decreased single support, increased double support, and decreased swing with little other effects on sagittal plane motion during stance (Tilbury-Davis and Hooper, 1999; Martin and Nelson, 1986; Kinoshita, 1985; Ghorri and Luckwill, 1985). However, there is increased metabolic demand and increased load rate present as the percent of body weight carried is increased (Puthoff et al., 2006). In other studies, older adults have used a weighted vest for exercise purposes (Klentrout et al. 2007; Frankel et al., 2006; Bean et al., 2004; Salem et al., 2004; Jessup et al., 2003; Bean et al., 2002; Salem et al., 2001; Greendale et al., 2000; Snow et al., 2000; Shaw and Snow, 1998; Greendale et al., 1993). The use of a weighted vest can

decrease body fat percentage (Klentrout et al. 2007) and increase measurements of perceived health, but the risks of injury with exercise in older adults is concerning (Greendale et al. 1993). Though the injury concerns are due to the intensity of the routine, only one study has looked at the kinetic effects wearing a weighted vest has on older adults. Salem and colleagues (2001) found that the kinetic effects of various weight vest loads were joint specific and load dependent. In their study, when the load was increased from 0% body weight to 3% body weight, there was only an increase in the peak external knee flexion moment, but comparing 0% body weight to 5% body weight, there was a significant increase in the peak external ankle dorsiflexion moment and knee flexion moment during the stance phase of gait (Salem et al., 2001).

Biomechanics during a challenging weighted walking condition have not been compared in healthy, older adults and adults with knee OA. The relationship between joint loading and knee OA (Maly, 2008; Wada et al., 2001) and the change in knee kinematics during weight acceptance in normal walking (Zeni and Higginson, 2009a; Zeni and Higginson, 2009b; Briem and Snyder-Mackler, 2009; Childs et al., 2004; Gök et al., 2002) leads us to believe there may be important strategies being used during loading which can influence the disease process. The added load during a weighted condition will increase the forces on the lower extremity, possibly leading to compensatory biomechanical strategies. To determine if there are any differences in walking performance when challenged, two specific aims targeting the weight acceptance task of gait will be addressed.

AIM 1: *Identify the effect of a load during a speed controlled (1.0 m/s), weighted walking challenge on initial contact in the sagittal plane within and between healthy and knee OA populations.*

Subjects with knee OA have different gait patterns during normal walking and when challenged compared to healthy controls. The changes exhibited by knee OA subjects are attributed to the disease while the response to a challenging condition depends on the level of challenge and the task. The position of the limb at initial contact could influence the kinematics and kinetics of the limb during the stance phase, specifically, the load felt at the knee during the loading response phase of gait.

Initial contact is the instantaneous point in time when the foot strikes the ground. Because there are not notable forces being experienced by the lower extremity at this instant, there are no kinetic variables of interest included in the hypotheses. The variables that will be analyzed at initial contact are ankle, knee, and hip angles and step length. These variables are important to quantify how each group prepares for shock absorption. The angle of the limbs in the sagittal plane and their position relative to the center of mass can impact what muscles can absorb the shock of each step. An improper posture of the lower extremity when it is accepting the weight can cause abnormal loading potentially leading to injury and subsequent pathology. Furthermore, a change in lower limb posture could also have a positive impact on the loads the limb faces. A recent study by Riskowski and colleagues (2009) showed that

when young healthy subjects were given feedback about their tibial acceleration through a knee brace they increased their knee flexion angle at initial contact and decreased their load rate.

Previous studies have analyzed the knee angle at initial contact in knee OA subjects and have found conflicting results. Mündermann et al. (2005) found that subjects with knee OA landed at initial contact with a more extended knee position, while others reported that subjects with knee OA landed in less knee extension (Childs et al., 2004; Baliunas et al., 2002). Since each study used different inclusion criteria and different knee OA subsets (bilateral medial, unilateral medial asymptomatic and symptomatic medial after a drug washout period) it cannot be decisively concluded how this population lands at initial contact. Other studies have investigated the ankle, knee and hip angles at initial contact under different conditions and in different populations (Boden et al., 2009; Levinger et al., 2008; McIntosh et al., 2006; Gunther and Blickhan, 2002; Lafortune et al., 1996). Levinger et al. (2008) compared the heel strike transient force and angle at heel strike for the ankle, knee, and hip between limbs in patients 12 months after having a unilateral total knee arthroplasty and found no difference in the angles at initial contact. This study was done in a population that already had a knee replacement and it is uncertain whether or not the symmetrical strategy was already in place before the operation. There has not been any previous work on the kinematics at initial contact of either a knee OA population or a healthy, older adult population during a weighted walking challenge.

Spatiotemporal parameters depend on speed and OA severity (Bejek et al., 2006; Chen et al., 2003; Gök et al., 2002; Al-Zahrani and Bakheit, 2002). Chen et al. (2003) found shorter step length and a longer duration until the first peak in the vertical GRF in women with bilateral knee osteoarthritis (65.5 ± 9.3 yrs) compared to healthy young (21.7 ± 4.5 yrs) and old (63.5 ± 11.3 yrs) women. Bejek et al. (2006) found shorter unnormalized step length in unilateral knee OA subjects compared to healthy age-matched subjects at controlled speeds. Step lengths of older adults and subjects with knee OA have never been reported for walking in a weighted vest.

The changes in the joints of the lower extremity in the sagittal plane at initial contact as well as step length have not been investigated in a healthy, older adult or knee OA population during a challenging weighted walking condition and limited study has been done on initial contact postures of the ankle and hip during unweighted walking. Therefore, the purpose of Aim 1 is: 1) to determine if there is any change in the ankle, knee or hip joint angles in the sagittal plane or step length at initial contact between a knee OA group and healthy, age-matched controls and; 2) to investigate if any changes occur within each group while walking at a controlled speed of 1.0 m/s unweighted and when weighted with $1/6^{\text{th}}$ of their body weight.

AIM 2: *Identify the effect of a load during a speed controlled (1.0 m/s), weighted walking challenge on loading response within and between healthy and knee OA populations.*

Knee OA has been theorized to be initiated by abnormal knee motions and loading during gait which interact with cartilage and bone remodeling in the joint (Brandt et al., 2008; Andriacchi and Mündermann, 2006). These researchers also suggested that the progression is related to loading on the knee using its abnormal kinematics (Andriacchi and Mündermann, 2006). Others have also had this hypothesis (Brandt et al., 2008; Andriacchi et al., 2004; Jackson et al., 2004; Felson et al., 2000) and a current variable obtained during gait analysis that is used to predict the progression of knee OA is the magnitude of the peak external knee adduction moment (Miyazaki et al., 2002).

Loading response is most associated with demanding lower extremity loads due to the weight acceptance that occurs during this part of gait. Loading response occurs after initial contact and is said to continue until the contralateral toe comes off the ground. This phase requires a coordinated action of the lower extremity's degrees of freedom to accept the body's weight while continuing to move forward. The variables of interest in this study are those that will help us understand the loading environment of the lower extremity during this phase: load rate, peak braking force, peak knee flexion moment, peak hip flexion moment, knee flexion excursion, and

double limb support percent only while the more affected limb is forward. Changes in these variables or differences between groups can point to compensatory strategies that could lead to impaired joint function. There has been extensive research done on the changes at the knee with respect to excursion and flexion moment in a knee OA population (Zeni and Higginson, 2009a; Zeni and Higginson, 2009b; Briem and Snyder-Mackler, 2009; Astephen et al., 2008; Landry et al., 2007; Childs et al., 2004; Baliunas et al., 2002; Gök et al., 2002; Kaufman et al., 2001). Results show that a knee OA population has decreased knee excursion during loading response (Zeni and Higginson, 2009a; Zeni and Higginson, 2009b; Briem and Snyder-Mackler, 2009; Childs et al., 2004; Gök et al., 2002) and a decreased external knee flexion moment (Zeni and Higginson, 2009a; Zeni and Higginson, 2009b; Astephen et al., 2008; Landry et al., 2007; Baliunas et al., 2002; Gök et al., 2002; Kaufman et al., 2001). Along with this change in knee flexion moment, a decrease in ankle dorsiflexion moment has been seen at self-selected walking speeds with no significant change in the hip flexion moment for a knee OA population (Zeni and Higginson, 2009b). The load rate has been shown to decrease in a knee OA population (Zeni and Higginson, 2009b; Mündermann et al., 2005) along with the peak braking force during loading response (Zeni and Higginson, 2009b; Messier et al., 1994), while the duration of double support increases (Childs et al., 2004; Chen et al., 2003; Gök et al., 2002). These changes in the gait pattern of subjects with knee OA may be utilized to decrease the loads that are felt across the knee joint. Only one study has presented results on

kinetics during weighted walking in older adults (Salem et al. 2001) and though it is well understood that young adults increase their double support percent in response to added loads (Polcyn et al., 2002; Harman et al., 2000; Lloyd and Cooke, 2000; Martin and Nelson, 1986; Kinoshita 1985), no report of double support time has been presented in an older adult cohort. Also, no report for older adults has been presented related to knee joint excursions during weighted walking. No studies have investigated any of these variables in a knee OA population during a challenging weighted walking condition.

The loading response phase has been studied in a knee OA population and compared to healthy controls, but the kinematic and kinetic changes have not been investigated when the subjects are given a challenging weighted walking condition. Therefore, the purpose of Aim 2 is: 1) to compare the weight acceptance strategy between a knee OA group and a healthy, age-matched group during unweighted and weighted walking conditions; and 2) to compare the strategy within each group during the loading response phase of gait.

In both Aims we only analyzed variables from the sagittal plane. We understand the importance of the frontal plane in knee OA, but are looking for compensations that the individuals made in the plane with the most functional motion.

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Chapter 2

METHODS

SUBJECT RECRUITMENT

Subjects between the ages of 40 and 85 years old were recruited from the general public and university community through flyers, advertisements, and a previous subject database. Initial eligibility was determined by a telephone interview to check that the subjects met inclusion and exclusion criteria (Appendix 1) and were able to participate in the study.

Questions were asked from a modified Physical Activity Readiness Questionnaire (PAR-Q, Appendix 2) as well as approximate body weight and height for body mass index (BMI) estimations, and previous history of orthopaedic conditions which may affect the subject's normal gait pattern. The modified PAR-Q (Appendix 2) includes questions related to a subjects' ability to physically exert themselves (cardiovascular and neurological history) as this study involved carrying a weighted vest with $1/6^{\text{th}}$ of the subject's body weight. Once initial eligibility was verified, the subjects were sent a study information packet (Appendix 3) including a radiograph consent form (Appendix 4). Subjects were then responsible for going to Papastavros' Associates Medical Imaging with the consent form to obtain a bilateral weight-bearing x-ray of the frontal plane of the knee. The radiograph was taken with the patient

standing, toes pointed forward, knees flexed to 30 degrees, and weight equally distributed between the feet. The beam of the x-ray targeted the lower pole of the patella and was kept parallel to the joint surface. The tibiofemoral joint in all radiographs was evaluated using the Kellgren and Lawrence scale (K/L; Kellgren and Lawrence, 1957) by a board certified radiologist. The results of the radiograph were returned to the investigators.

Subjects were grouped into “healthy” or “knee OA” based on their K/L score. The “healthy” group consisted of those subjects who satisfied our inclusion and exclusion criteria (Appendix 1) and had a K/L score of ≤ 1 as determined by the radiologist. The “knee OA” group consisted of those subjects who satisfied the criteria (Appendix 1) but had a K/L score of ≥ 2 as determined by a radiologist. Once all pre-screening and radiographs were completed, the subjects came to the Neuromuscular Biomechanics Lab at the University of Delaware for data collection. The subject received a full explanation of the study including the risks of participation and provided written informed consent. This study was approved by the University of Delaware Human Subjects Review Board (Appendix 5).

STRENGTH TESTS

An isometric strength test was used to estimate knee flexor and extensor strength for each subject. Measurements were taken on a Biodex Systems 3 (Biodex Medical Systems, Shirley, NY, USA) dynamometer using a 60 degree isometric knee

flexion and extension protocol. Sixty degrees of knee flexion has been used by researchers in the past for an isometric strength testing protocol of the thigh musculature (e.g. Hunt et al., 2010; Isakov et al., 1996; Kannus, 1988). Each subject sat with the thigh and hips secured in the Biodex chair, while the knee joint was lined up with the axis of rotation of the Biodex moving arm, and the shank was strapped into the moving arm. The total range of motion was assessed and then a 90 degree reference angle was programmed into the computer. Ninety degrees was selected because it was an angle that all subjects could easily attain. The test involved 3 seconds of isometric knee extension followed by 20 seconds of rest and then 3 seconds of isometric knee flexion and another 20 seconds of rest. During the active muscle contraction, verbal encouragement was provided in order to maximize the force output (McNair et al., 1996). Also, instruction was given so that the subject was not confused during the test. This protocol was repeated 3 times for each leg. The maximum isometric torque production (ft-lbs) was recorded, converted to Newton-meters, and normalized to subject body weight.

SELF-SELECTED WALKING SPEED

Self-selected walking speed was measured over a 10m segment of the hallway. The subjects walked approximately 30m with the middle 10m timed by the researcher. The instructions were given to walk at your “comfortable walking speed”. Two

walking passes were made and timed by a stopwatch. The average time was then used to determine the subject's self-selected walking speed in meters per second.

KNEE INJURY AND OSTEOARTHRITIS OUTCOME SURVEY

The Knee Injury and Osteoarthritis Outcome Survey (KOOS; Appendix 6) is a subjective questionnaire that has 5 subsections asking about Symptoms, Pain, Activities of Daily Living, Sports and Recreation, and Quality of Life (Roos et al., 1998). The directions state to answer the questions based on the past week. Each section has a different number of questions associated with it. There are five answer choices per question. The response to each question is converted into a numerical scale (0=best – 4=worst) and summed for that subsection. This number is multiplied by 100 and divided by the maximum numerical value available for that section. The result of this is subtracted from 100 to get the score for a subsection. All five subsections are added together to get the total KOOS score for each subject. The maximum score for each subsection is 100 and the maximum score overall is 500 signifying no pain or symptoms and high function and quality of life.

GAIT ANALYSIS

The Neuromuscular Biomechanics Lab at the University of Delaware has an 8 camera Motion Analysis system (Santa Rosa, CA) and a dual forceplate imbedded, split-belt treadmill (Bertec Corporation, Worthington, OH). The data were collected

using EVaRT 5.0.4 and Cortex 1.0.0.198 (Motion Analysis Corp., Santa Rosa, CA). Kinematics were tracked using 27 markers (sternal notch, right scapula offset, sacrum, bilateral acromion processes, lateral epicondyles, ulnar styloid processes, anterior superior iliac spines, thighs, medial and lateral femoral condyles, shank, medial and lateral malleoli, first metatarsalphalangeal joint and heel) for a modified Helen Hayes marker set. The kinematic data were collected at 60 Hz and the kinetics at 1080 Hz. Before any walking trials were completed, we collected two static standing trials for 4 seconds each. We then removed the markers bilaterally from the medial knees and ankles and allowed the subjects 6 minutes of accommodation time (Zeni and Higginson, 2010) at their self-selected speed. After accommodation, two satisfactory 30 second walking trials at 1.0 m/s unweighted and while wearing a weighted vest were collected. This controlled speed was selected because it is slower than both groups self-selected speed, but not too slow.

The speeds of the belts were controlled at the computer during the data collection, and there was an emergency stop button within arm's reach of the subject. There was also an emergency stop button located next to the computer. The subjects were permitted to hold the handrails as the treadmill sped up or slowed down, but were not permitted to hold them during the walking trials. Also as a safety precaution, each subject wore a harness, which was connected to a sturdy metal support beam above the treadmill. Throughout the data collection, subjects were asked how they were doing

and given the opportunity to stop whenever they needed to rest and were allowed to withdraw from the study without penalty.

WEIGHTED CONDITION

Subjects were also asked to walk while wearing a weighted vest. For this condition, a front and back loaded weight vest (MiR Vest, Inc., San Jose, CA, USA) was used. The vest was placed over the head of each subject and an elastic strap was used to secure the vest to the subject. One static trial on a single forceplate imbedded into our split-belt treadmill (Bertec Corporation, Worthington, OH) was used to get the most accurate weight of each subject. The vertical force (N) for that forceplate was averaged over the duration of the trial, divided by gravity, multiplied by 2.2 and then finally divided by 6 in order to find $1/6^{\text{th}}$ of the subject's body weight (lbs). The weight was added in 2lbs increments until closest to $1/6^{\text{th}}$ body weight. The maximum capacity of the vest was 50 pounds. In order to verify the amount of weight added to each subject, the static weight was collected again using the same procedure once the weight vest was secured to the subject. Subjects had no acclimatization time in the vest and walked with the weighted vest until two satisfactory 30 second walking trials had been completed.

DATA REDUCTION

Kinematic data was tracked and initially processed within EVaRT 5.0.4 and Cortex 1.0.0.198 (Motion Analysis Corp., Santa Rosa, CA). This included interpolating any gaps in the data and smoothing the curves with a 4th order, phase corrected, Butterworth filter with a cutoff frequency of 6 Hz. This process was done for each subject's static standing trial and their walking trials. One tracked walking file was chosen for each condition to be used for the rest of the analysis based on the minimization of marker dropout, correctness of interpolation, and absence of forceplate crossover. The chosen files were uploaded into Orthotrak 6.3.5 (Motion Analysis Corp., Santa Rosa, CA) to compute inverse dynamics and output kinematic, kinetic and spatiotemporal values into a single spreadsheet. From sequential gait cycles for each subject's 30 second walking trial of approximately 10 strides, the final five full gait cycles were extracted and averaged into one representative gait cycle for each subject normalized to 100% of the gait cycle. For the knee OA group, only data from the more severely affected limb is shown and random legs were chosen for the healthy group.

VARIABLES FOR AIM 1

The variables selected for analysis for Aim 1 were related to the position of the limb at initial contact: step length and ankle, knee, and hip flexion angle at initial contact. Step length was calculated as the distance from the heel marker of the leading

limb to the heel marker of the opposite limb and is reported when the most affected limb was forward. Data were averaged across the last five gait cycles to calculate a step length that would be representative for each subject. Ankle, knee, and hip flexion angles were exported at 0% of the gait cycle.

VARIABLES FOR AIM 2

The variables selected for Aim 2 focused on the loading response phase of gait: double support percent, peak knee flexion moment, peak hip flexion moment, peak braking force, load rate, and knee flexion excursion. Double support percent was defined as the percent of the gait cycle from initial foot contact with the more affected limb forward until the opposite foot left the ground and was averaged over all gait cycles. The peak hip flexion moment, peak knee flexion moment, and peak braking force were also output. Peak hip and knee flexion moments and minimum anteroposterior force were determined during the loading response phase of gait defined as 0% of the gait cycle to the first peak vertical GRF. The load rate was defined as the slope of the vertical GRF from initial contact to the first peak from the representative gait cycle and then unnormalized based on the time from initial contact to initial contact before the representative gait cycle was created. The knee flexion excursion is the difference between the peak knee flexion during the loading response phase of the gait and the knee flexion at 0% of the gait cycle.

STATISTICS

A two-way repeated measures analysis of variance (ANOVA) was performed in SPSS 17.0 (SPSS Inc., Chicago, IL) to determine the effect of knee OA and the weighted condition on walking patterns. The independent variables were the group (Healthy or Knee OA) and the condition (Unweighted or Weighted) while the dependent variables were the variables previously mentioned. We also tested for an interaction effect to analyze the differences between the changes of each group due to the additional weight (Group*Condition). Significance was set at $p < 0.05$. If significance was found with the two-way repeated measures ANOVA, then two-tailed, paired t-tests were done within groups and two-tailed, student's t-tests were done between groups to find exactly where the difference was occurring. Significance for the t-tests was also set at $p < 0.05$. As a final analysis to determine the relationship between any differences found, we performed correlation and regression analyses to see if the changes at initial contact relate to the changes during the loading response.

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Chapter 3

RESULTS

SUBJECTS

The subjects in our study were grouped according to their K/L flexed knee radiograph scored by a board certified radiologist (Table 3.1). The healthy group had a K/L score ≤ 1 and the knee OA group had a K/L score of ≥ 2 . The groups showed distinct differences in other variables that have been associated with the functional decline in knee OA subjects. The knee OA group had a higher weight ($p = 0.001$), increased BMI ($p < 0.001$), decreased isometric knee flexor ($p = 0.003$) and extensor strength ($p = 0.001$), decreased self-selected walking speed ($p = 0.006$), and poorer reported KOOS scores regarding their pain ($p < 0.001$) and symptoms ($p < 0.001$). There was no significant difference between the age ($p = 0.713$) and height ($p = 0.976$) of the two groups. Specific to our study, the percent which each subject was weighted was significantly different ($p = 0.002$), but the overall weight put on each subject was not ($p = 0.087$).

General Subject Characteristics		
	Healthy	Knee OA
Number	20	20
Percent Female (%)	60.0	70.0
Age (years)	63.6 ± 10.0	62.45 ± 8.73
Height (m)	1.69 ± 0.08	1.69 ± 0.10
Weight (kg) *	70.6 ± 12.9	86.8 ± 15.4
BMI (kg/m ²) *	24.7 ± 3.60	30.5 ± 4.31
Quadriceps Strength (Nm/kg) *	1.81 ± 0.42	1.31 ± 0.50
Hamstring Strength (Nm/kg) *	1.02 ± 0.32	0.73 ± 0.24
Self-Selected Walking (m/s) *	1.32 ± 0.17	1.17 ± 0.13
KOOS Pain *	97.5 ± 4.82	65.8 ± 23.0
KOOS Symptoms *	96.8 ± 3.93	63.9 ± 24.9
Percent Weighted (%) *	17.8 ± 2.18	15.9 ± 1.42
Amount Weighted (kg)	12.49 ± 2.09	13.70 ± 2.27
* p ≤ 0.05		

Table 3.1: The table shows a comparison of general subject characteristics. Data is presented as mean ± one standard deviation. An asterisk denotes a significant difference between the groups $p < 0.05$.

AIM 1

Identify the effect of a load during a speed controlled (1.0 m/s), challenging weighted walking task on initial contact (Figure 3.1) in the sagittal plane within and between healthy and knee OA populations.

These results are based on weighted and unweighted walking trials at 1.0 m/s.

There were no significant differences in the ankle angle at initial contact (Figure 3.2A) for main effects of condition ($p = 0.962$) or group ($p = 0.345$) as well as no group*condition interaction effect ($p = 0.621$). For the knee angle at initial contact (Figure 3.2B), there were also no significant differences for condition ($p = 0.189$), group ($p = 0.278$), or group*condition ($p = 0.650$) effects.

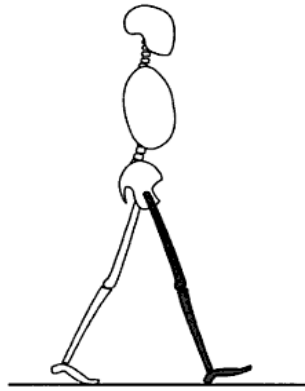


Figure 3.1: Limb posture at initial contact (Reprinted with permission from SLACK Incorporated: Perry, 1992).

The hip flexion angle at initial contact (Figure 3.2C) showed a significant effect for condition ($p = 0.001$), and post-hoc tests revealed that only the healthy group ($p < 0.001$) increased their hip flexion angle at initial contact in response to the load while the knee OA group did not ($p = 0.225$). The effect of group ($p = 0.051$) was approaching significance and post-hoc tests indicated that the knee OA group had an increased hip flexion angle at initial contact compared to the healthy group in the unweighted condition ($p = 0.032$), but differences between the groups in the weighted condition only approached significance ($p = 0.088$). There was not a significant interaction effect for group*condition ($p = 0.138$). To better understand the change in hip flexion angle at initial contact, the pelvic tilt and thigh orientation in the sagittal plane were analyzed post-hoc. Using a two-way, repeated measures ANOVA, we found a significant difference for both group ($p = 0.009$) and condition ($p = 0.014$) effects, but no group*condition interaction ($p = 0.894$) for pelvic tilt at initial contact. Post-hoc t-test analysis revealed that the knee OA group had a larger anterior pelvic tilt

compared to the healthy group in both the unweighted ($p = 0.008$) and weighted ($p = 0.013$) conditions, however, only the healthy group had a change in their pelvic tilt in response to the weighted vest having a larger pelvic tilt during the weighted condition ($p = 0.020$) where the knee OA group did not ($p = 0.166$). The thigh orientation showed similar changes. The two-way, repeated measures ANOVA resulted in significant group ($p = 0.008$) and condition ($p = 0.001$) effects, but no group*condition interaction ($p = 0.315$) for the thigh. The post-hoc analysis of these results indicated that the knee OA group had a more flexed thigh position compared to the healthy group both during the unweighted ($p = 0.004$) and weighted ($p = 0.017$) conditions. In response to the weighted vest, only the healthy group had a significant change in their thigh orientation ($p < 0.001$), increasing it, while the knee OA group did not ($p = 0.139$). The increased hip flexion angle at initial contact in the knee OA subjects during the unweighted condition is due to both an increase in the pelvic tilt and an increase in the thigh flexion. Also, the increase in hip flexion at initial contact in response to the weighted condition in the healthy group was also due to a significant change in both the pelvic tilt and the thigh orientation.

The step length data (Figure 3.2D) showed no significant differences for condition ($p = 0.525$) or for the group*condition effect ($p = 0.530$). There was a significant difference for the group effect ($p = 0.025$). Post-hoc analysis revealed that there was no significant difference between the healthy and knee OA groups in the

unweighted condition ($p = 0.272$), but the knee OA group had a shorter step length compared to healthy in the weighted condition ($p = 0.027$).

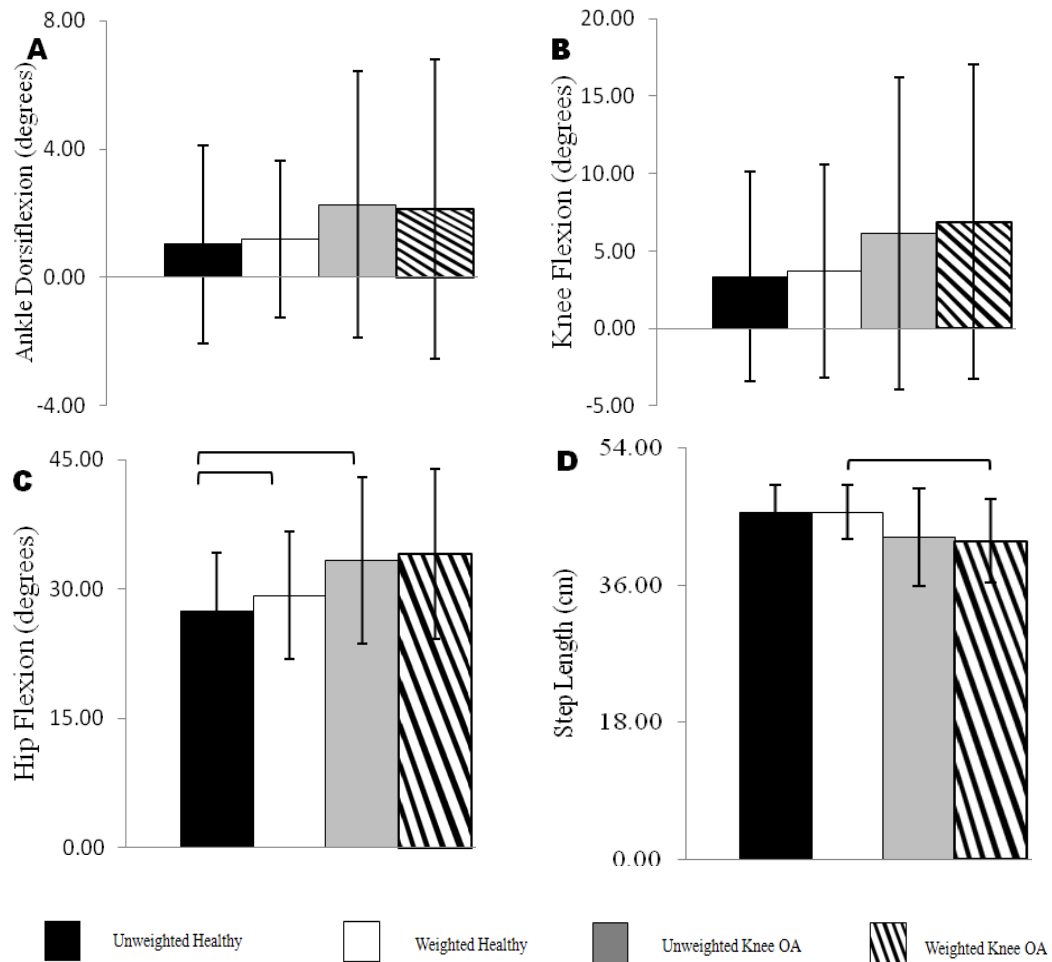


FIGURE 3.2: (A) Ankle dorsiflexion angle at initial contact. The y-axis is the angle in degrees ($^{\circ}$), dorsiflexion is positive and plantarflexion is negative. (B) Knee flexion angle at initial contact. The y-axis is the knee flexion angle in degrees ($^{\circ}$), knee flexion is positive and knee extension is negative. (C) Hip flexion angle at initial contact. The y-axis represents the positive hip flexion angle in degrees ($^{\circ}$). (D) Step length with the more affected limb forward. The y-axis is the length of the step in centimeters (cm). Data are shown with mean $\pm$ one standard deviation. Brackets indicate statistically significant differences where $p < 0.05$. Results are presented for four groups: a) black = unweighted, healthy group; b) white = weighted, healthy group; c) gray = unweighted, knee OA group; and d) stripes = weighted, knee OA group.

AIM 2

Identify the effect of a load during a speed controlled (1.0 m/s), challenging weighted walking task on loading response (Figure 3.3) within and between healthy and knee OA populations.

These results are based on weighted and unweighted walking trials at 1.0 m/s. The ANOVA yielded a main effect of condition ($p < 0.001$) with both the healthy ($p < 0.001$) and knee OA ($p = 0.018$) groups showing a larger percent of gait in double support during the weighted condition compared to themselves during the unweighted condition (Figure 3.4A). There was also a main effect of group ($p = 0.002$), and post-hoc t-tests also showed a significant difference between the groups in both conditions (unweighted $p = 0.002$; weighted $p = 0.027$) with the knee OA group having a significantly longer double support percent in both conditions. No group*condition effect ($p = 0.216$) was observed.

The results for the normalized peak braking force (Figure 3.4B) showed no differences in the ANOVA model for condition ($p = 0.216$), group ($p = 0.512$), or the group*condition effects ($p = 0.320$). The normalized peak knee flexion moment (Figure 3.4C) had no significant differences between conditions ($p = 0.431$), groups ($p = 0.800$) or group*condition interaction effects ($p = 0.124$) in the ANOVA model. For the normalized peak hip flexion moment during loading response (Figure 3.4D), there was no significant difference for condition ($p = 0.092$), group ($p = 0.229$) or

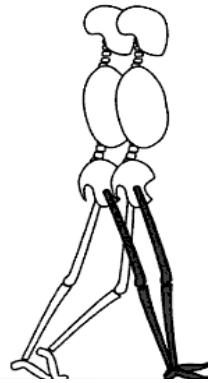


Figure 3.3: Loading response phase of gait with freeze frames of the beginning and end of weight acceptance (Reprinted with permission from SLACK Incorporated: Perry, 1992).

group*condition effects ($p = 0.230$) within the two-way ANOVA. The knee flexion excursion during loading response (Figure 3.4E) showed no significant differences for condition ($p = 0.805$), group ($p = 0.339$) or group*condition ($p = 0.648$) effects in our ANOVA model. Load rate (Figure 3.4F) approached a significant difference in our ANOVA model for a condition effect ($p = 0.057$), but there was a significant difference for the group ($p = 0.038$) and group*condition interaction effects ($p = 0.043$). Post-hoc t-tests revealed a statistically significant difference within the healthy group ($p = 0.020$) who used a lower load rate during the weighted condition compared to unweighted. However, there was no significant difference found within the knee OA group ($p = 0.918$). Between group differences existed during the unweighted condition ($p = 0.009$) with the knee OA group having a lower load rate than their healthy, age-matched counterparts, but there was no statistical difference between groups during the weighted condition ($p = 0.211$).

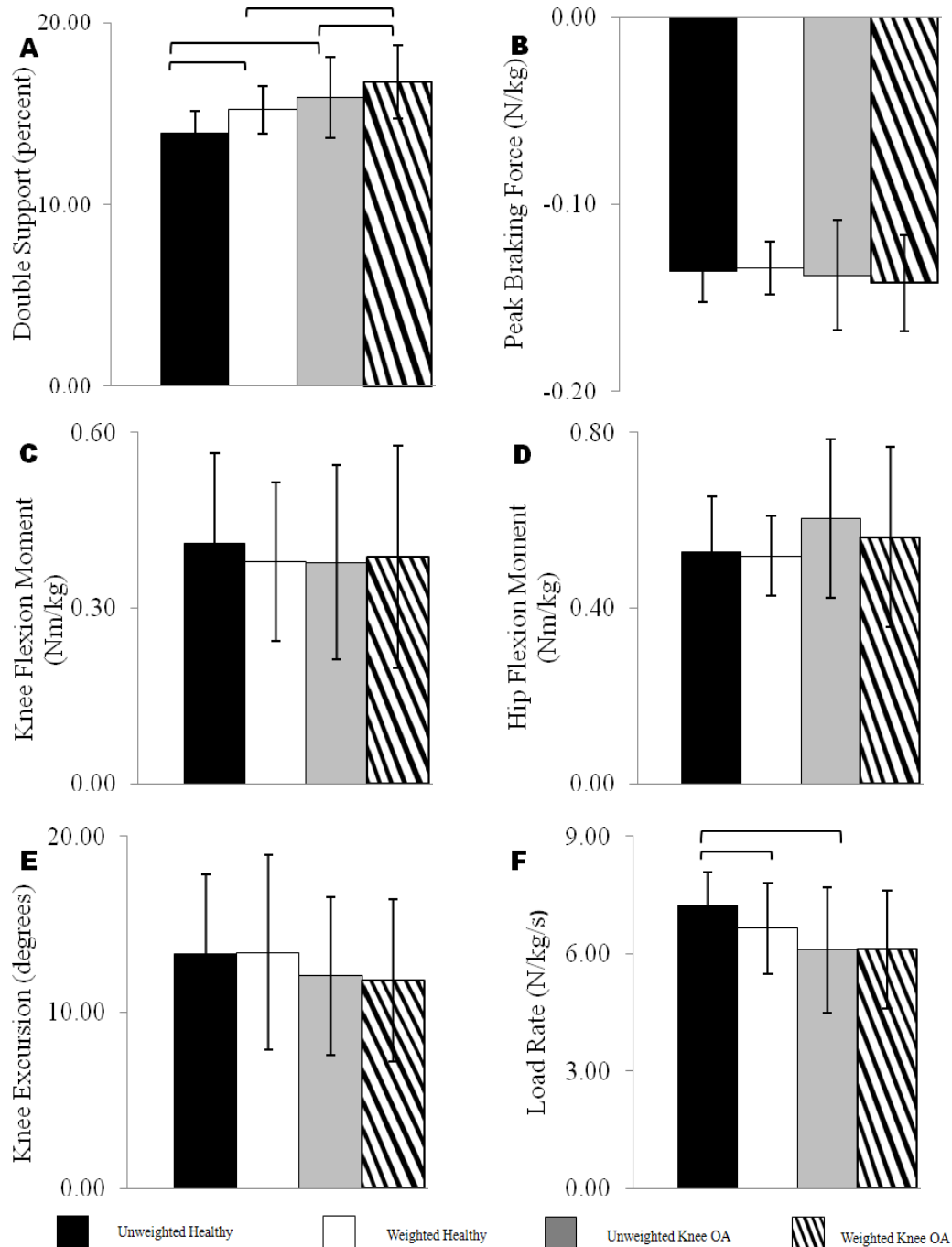


FIGURE 3.4: (A) Double limb support percent with the most affected limb forward. The y-axis is the percent (%) of the gait cycle (out of 100%) that the subject is in double limb support with their most affected limb forward. (B) Peak braking (posterior) force. The y-axis is the magnitude of the force normalized to the weight of the person in kilograms (N/kg). (C) Peak knee flexion moment during the loading response phase of the gait cycle. The y-axis is the moment normalized to the subject's

weight (N-m/kg). (D) Peak hip flexion moment during the loading response phase of the gait cycle. The y-axis is the magnitude of the moment normalized to the subject's weight (N-m/kg). (E) Knee flexion excursion of the knee during the loading response phase of the gait cycle. The y-axis is the amount of knee excursion in degrees (°). (F) Load rate, or the slope of the vertical GRF curve between heel strike and the 1st peak in vertical GRF. The y-axis is the change in force normalized to the subject's weight divided by the change in time (N/kg/s). Data are shown with mean $\pm$ one standard deviation. Brackets indicate statistically significant differences where $p < 0.05$. Results are presented for four groups: a) black = unweighted, healthy group; b) white = weighted, healthy group; c) gray = unweighted, knee OA group; and d) stripes = weighted, knee OA group.

CORRELATION AND REGRESSION ANALYSIS

To determine if the changes at initial contact have any relationship to the changes seen during loading response, we performed correlation and regression analyses. For hip flexion angle at initial contact and the double support percent, during the unweighted condition, the healthy group (Figure 3.5A) showed no significant correlation ($R^2 = 0.013$; $p = 0.635$), while the knee OA group (Figure 3.5B) had a significant correlation ($R^2 = 0.376$; $p = 0.004$). As the hip flexion angle at initial contact increased, the double support percent increased in the unweighted, knee OA group. In the weighted condition, neither the healthy group (Figure 3.5C; $R^2 < 0.001$; $p = 0.936$) nor the knee OA group (Figure 3.5D; $R^2 = 0.151$; $p = 0.091$) had a correlation between hip flexion angle at initial contact and double support percent.

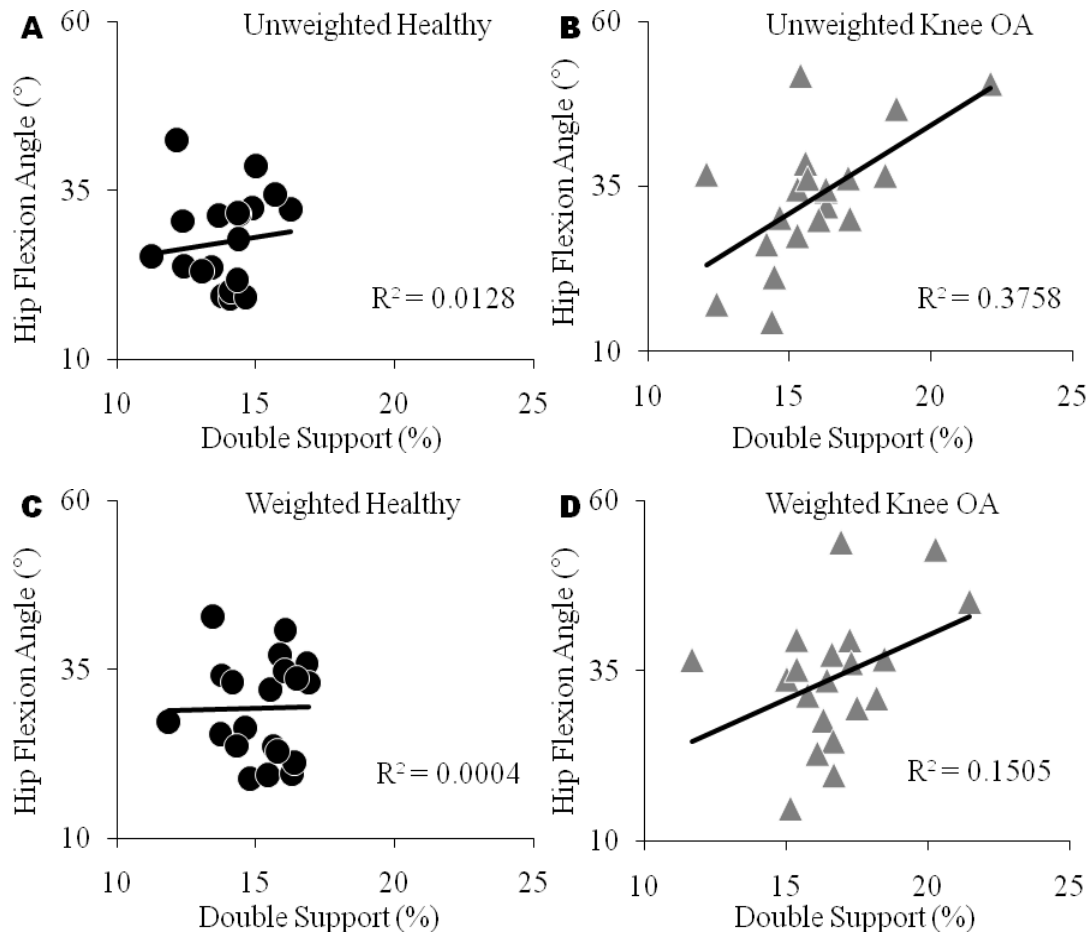


Figure 3.5: Correlation and linear regression analysis between hip flexion angle at initial contact (y-axis) and double support percent (x-axis). Regression lines are imbedded on each graph. (A) Unweighted Healthy, (B) Unweighted Knee OA, (C) Weighted Healthy, (D) Weighted Knee OA.

Between hip flexion angle at initial contact and load rate, in the unweighted condition, neither the healthy group (Figure 3.6A; $R^2 = 0.040$; $p = 0.399$) nor the knee OA group (Figure 3.6B; $R^2 < 0.001$; $p = 0.994$) had a significant correlation. Also, during the weighted condition, neither the healthy (Figure 3.6C; $R^2 = .025$; $p = 0.502$) nor the knee OA (Figure 3.6D; $R^2 = 0.006$; $p = .734$) group had a significant correlation between the two variables.

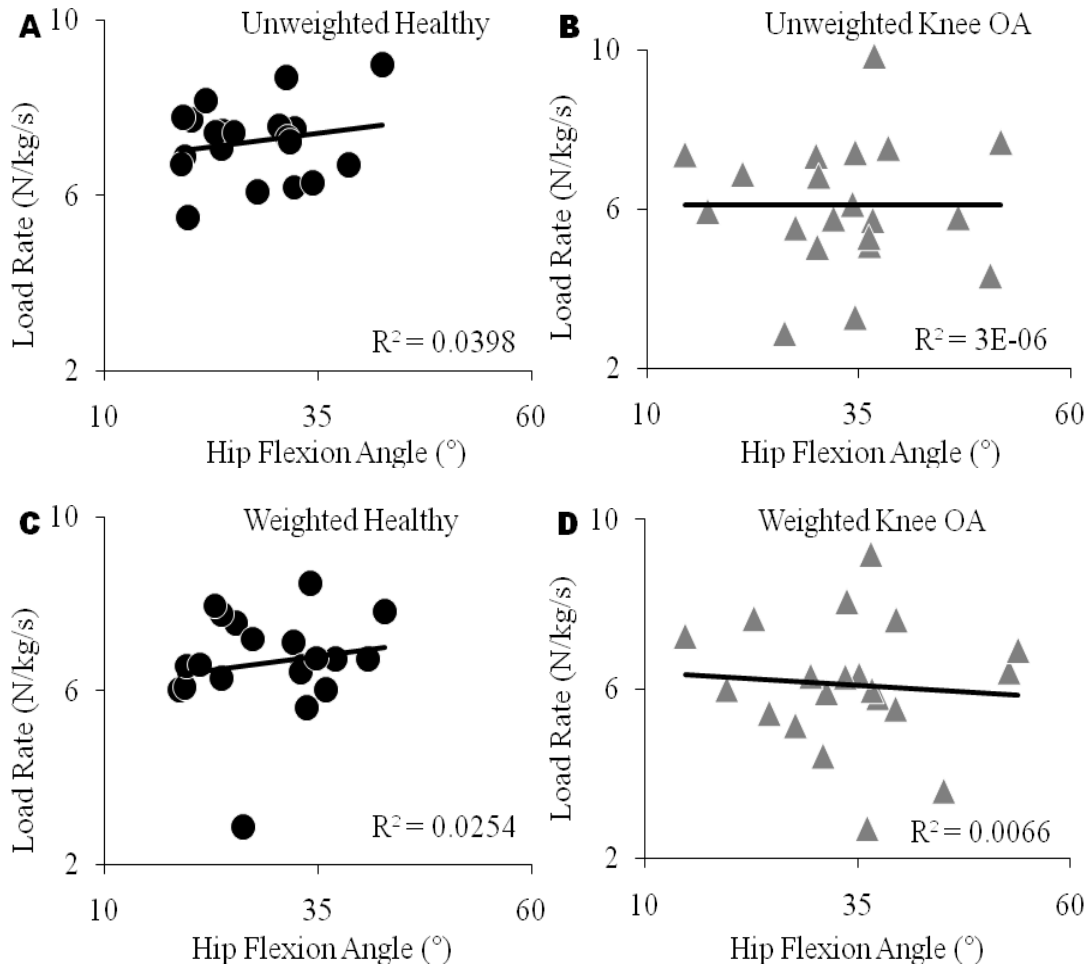


Figure 3.6: Correlation and linear regression analysis between the load rate (y-axis) and the hip flexion angle at initial contact (x-axis). Regression lines are imbedded on each graph. (A) Unweighted Healthy, (B) Unweighted Knee OA, (C) Weighted Healthy, (D) Weighted Knee OA.

During the unweighted condition, the healthy group (Figure 3.7A) had a significant correlation between double support percent and load rate ($R^2 = 0.225$; $p = 0.035$). As the double support percent increased in the unweighted, healthy group, the load rate decreased. For the knee OA (Figure 3.7B) group in the unweighted condition, there was also a significant correlation between the variables ($R^2 = 0.197$; $p = 0.05$). The same relationship existed in the unweighted, knee OA group with the load

rate decreasing while the double support percent increased. For the weighted condition, there was no correlation between the double support percent and the load rate in the healthy group (Figure 3.7C; $R^2 = .078$; $p = 0.233$). However, in the weighted, knee OA group (Figure 3.7D), there was a significant correlation between these two variables ($R^2 = 0.455$; $p = 0.001$).

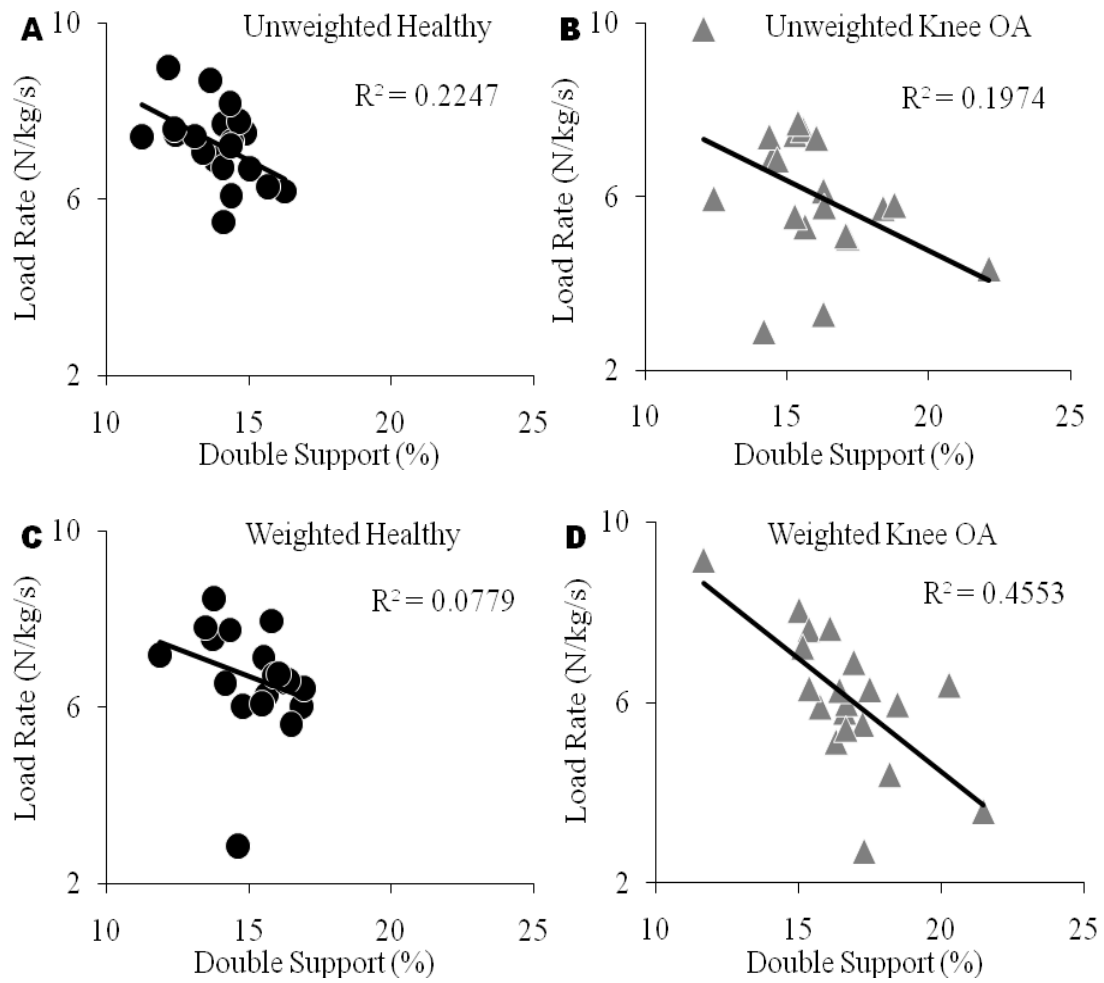


Figure 3.7: Correlation and linear regress analysis between the load rate (y-axis) and the double support percent (x-axis). Regression lines are imbedded on each graph. (A) Unweighted Healthy, (B) Unweighted Knee OA, (C) Weighted Healthy, (D) Weighted Knee OA.

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Chapter 4

DISCUSSION AND CONCLUSION

The goal of this thesis was to see if any compensation existed in a knee OA population during a challenging weighted walking condition compared to age-matched, healthy, older adults during the weight acceptance task in gait. We found changes in the hip flexion angle at initial contact, double support percent, and load rate, but not in the ankle or knee flexion angle at initial contact, step length, knee flexion excursion, peak hip or knee flexion moment, or peak braking force. During the initial contact phase of gait, the knee OA group had more hip flexion during the unweighted condition compared to the unweighted healthy group. When weighted, the knee OA group did not change their hip flexion angle, while the healthy group had an increase. During the loading response, the knee OA group had a higher percent of their gait in double support with the more affected limb forward in the unweighted and the weighted condition compared to the healthy group, and both groups increased their double support percent in response to the load. Also, the unweighted knee OA group had a lower load rate, compared to the healthy group. When weighted, the knee OA group did not change their load rate, while the healthy group's decreased.

UNWEIGHTED HEALTHY VS. KNEE OA

There have been many studies analyzing the changes during gait between healthy subjects and subjects with knee OA (eg. Mündermann et al., 2005; Baliunas et al., 2002; Kaufman et al., 2001; Messier et al., 1992), but few have done so at a controlled speed (Liikavainio et al., 2010; Zeni et al., 2010; Zeni and Higginson, 2009b; Bejek et al., 2006). The decrease in load rate and lack of change in the knee flexion excursion, normalized hip flexion moment, normalized knee flexion moment, and peak normalized braking force were all consistent with the previously reported results of subjects walking at 1.0 m/s during an unweighted condition (Zeni and Higginson, 2009b). This thesis and the previous study by Zeni and Higginson (2009b) analyzed some of the same subjects. However, more subjects were collected in addition to those reported and different subjects were analyzed currently compared to Zeni and Higginson's (2009b) study. Zeni and Higginson (2009b) did not report double support percent and the current study found that the double support percent was increased in a knee OA population, which is consistent with previous research (Chen et al., 2003; Gök et al., 2002). The possible explanations for this increase could be due to an effort to decrease loading (Chen et al., 2003) or reduce pain (Gök et al., 2002). We noticed a correlation between double support percent and load rate, so this hypothesis seems plausible. However, this could also be due to the increased weight of our knee OA subjects, as obesity has been shown to cause an increase in double support percent at controlled speeds in young subjects (Browning and Kram, 2007).

Another possible explanation could be related to the idea that subjects with knee OA have decreased postural stability, balance, and proprioception (Mohammadi et al., 2008; Hinman et al., 2002; Hurley et al., 1997), which could cause them to have a fear of falling which has been associated with an increase in the percent of gait in double support in older adults (Chamberlin et al., 2005; Maki, 2007)

The posture of the limb at initial contact was different at the hip between the knee OA group and the age-matched, healthy, older adults during the unweighted condition but knee postures did not differ. Previous researchers have found conflicting results for the knee flexion angle at initial contact. One group found that knee OA subjects land in more extension (Mündermann et al., 2005), while two groups have shown that knee OA subjects land in more flexion (Childs et al., 2004; Baliunas et al., 2002). However, current results showed no differences in the knee angle at initial contact between groups in an unweighted condition. This could be due to the controlled speed of our experiment being slower than self-selected walking speed for both groups, which was used by all three previous studies that reported a knee angle change at initial contact.

Another typical gait change seen in a knee OA population compared to healthy in an unweighted condition both at controlled and self-selected speeds is decreased step length (Bejek et al., 2006; Chen et al., 2003). Our results show no difference in the step length of subjects with knee OA compared to the healthy group. This is possibly due to the increase in hip flexion angle at initial contact in knee OA subjects

in addition to a slightly increased knee flexion angle. The increase in hip flexion angle at initial contact has not been reported as a gait compensation to knee OA. Instead, hip range of motion has been the focus of previous analyses (Astegh et al., 2008; Messier et al., 1992). The hip range of motion has shown a trend to increase, presumably as a compensation to decreased knee motion (Messier et al., 1992), but it has also been reported that only the subjects with the most severe knee OA decrease their hip flexion range of motion during gait (Astegh et al., 2008). Again, both studies had subjects walking at their self-selected speeds overground. Alton and colleagues (1998) reported different peak hip flexion angles between overground and treadmill walking in a young, healthy population, however, no study exists comparing kinematics and kinetics of overground versus treadmill walking in a knee OA population. A future study of overground versus treadmill walking in a knee OA population could help compare studies of knee OA subjects from the past and present.

The hip flexion angle at initial contact had been hypothesized to be a compensation to decrease loading due to a change in thigh orientation (Attwells et al., 2006), though we found a change in hip flexion angle and thigh orientation, we did not show any correlation to the load rate. It has also been considered as a compensation for weight-bearing stability (Harman et al., 2000) and we did see a correlation between the hip flexion angle at initial contact and double support percent which provides some support at the possibility of this compensation being related to this function. The knee OA subjects in the unweighted condition could be increasing their hip flexion angle

and their double support in response to weight-bearing stability issues associated with the disease (Hurley et al., 1997). Weight-bearing stability is defined as the ability to support the body's weight and stay balanced while walking.

The unweighted knee OA group had a decreased load rate compared to the healthy group. This response agrees with previous reports that knee OA subjects attempt to reduce the loads on their lower extremity to avoid pain (Thorp et al., 2007; Hurwitz et al., 2000; Schnitzer et al., 1993). Our knee OA group was heavier (Table 3.1) which would lead to higher absolute loads on their lower extremity (Browning and Kram, 2007; Messier et al., 1996). They also reported more subjective pain (Table 3.1) which could have been provoked by the higher loads (Amin et al., 2004).

HEALTHY UNWEIGHTED VS. WEIGHTED

No study has analyzed the weight acceptance phase of healthy, older adults when loaded with a weight vest. At initial contact, healthy, young adults showed no change in the ankle angle, increased hip flexion angle and knee flexion angle, and decreased step length (Attwells et al., 2006; Polcyn et al., 2002; Harman et al., 2000; Kinoshita, 1985). Of these compensations, our results showed that only a change in hip flexion angle was present when healthy, older adults underwent a challenging weighted walking condition. A suggested reason for an increase in hip flexion angle in young adults is due to forward trunk lean (Harman et al., 2000). Harman and colleagues (2000) determined hip flexion by the angle between the trunk and the thigh.

In our study, we report the hip angle as the angle between the thigh and the pelvis. The healthy subjects had increased pelvic tilt and an increased thigh orientation during the weighted condition compared to unweighted. These changes could be caused by the carrying of the extra weight in the weight vest, which increased the BMI of the healthy group (29.10 ± 4.03) to an overweight classification and not significantly different from the unweighted knee OA group ($p = 0.310$). However, the weight vest does not accurately distribute the weight of an overweight person, and an obese population decreases their hip flexion angle at initial contact (Spyropoulos et al., 1991), so our weighted condition does not appear to affect kinematics that same way that obesity does. Researchers also cite the need to absorb the heavier load as the reason why the hip flexion angle at initial contact increases (Attwells et al., 2006; Harman et al., 2000), but we found no correlation between the load rate and hip flexion angle at initial contact, even though the load rate showed change also. Another way to decrease the load rate is to remain in double support longer, thereby slowing down the transfer of force from one limb to the other. We found a significant correlation between the double support percent and the load rate in the unweighted healthy group, but not in the weighted healthy group.

The weighted healthy, older adults did increase their double support percent which may promote weight-bearing stability and has been reported for healthy, young adults (Attwells et al., 2006; Harman et al., 2000). Our challenging condition does not mimic obesity, but the subjects still have excess weight. An increase in double

support percent has been seen in obese adults compared to non-obese at self-selected and controlled speeds (Lai et al., 2008; Browning and Kram, 2007). The typical goals during the initial double support period (weight acceptance task) are shock absorption, weight-bearing stability, and continued forward progression (Perry, 1992). During this time, the shock is absorbed minimally by ankle plantarflexion and most by knee flexion excursion and contralateral pelvic drop (Perry, 1992). Because the healthy, older adults did not increase their knee flexion excursion and the correlation between double support and load rate was not significant during the weighted condition, it appears that these subjects are putting the priority during double support on weight-bearing stability. They also are decreasing their load rate, so this could be a secondary benefit to improved weight-bearing stability. The weighted healthy group has similar compensations within the variables we analyzed compared to the unweighted knee OA group. Therefore, the weighted healthy adults could be choosing compensations like those of the knee OA group, based on pain avoidance (Thorp et al., 2007; Hurwitz et al., 2000; Schnitzer et al., 1993) or increased weight. A more thorough analysis of these two groups could show that the gait changes seen in an unweighted knee OA group are related to their excess weight compared to healthy, older adults.

KNEE OA UNWEIGHTED VS. WEIGHTED

No study has analyzed the weight acceptance phase in knee OA subjects when loaded with a weight vest. The knee OA group did not respond to the weighted

condition the same as the healthy, older adults. The knee OA subjects did not show any change of their lower limb posture in the sagittal plane from unweighted to weighted at initial contact. The relationship between the hip flexion angle at initial contact and the double support percent became insignificant but the relationship between the load rate and the double support percent became stronger during the weighted condition for the knee OA group. The knee OA subjects already had a larger hip flexion angle at initial contact during the unweighted condition, so they may not have any more available range of motion in the hip left with which to compensate. If they were to further increase the hip flexion angle at initial contact, they could influence the knee flexion angle and possibly change the loading environment of the knee (Figure 4.1), which could increase pain or overload the already weak quadriceps (Table 3.1), causing them to be unable to walk in the weight vest. Another possible compensation that was not reported in our study but suggested when young adults carry weight is an increased forward trunk lean (Harman et al., 2000). The previous study measured hip flexion between the thigh and trunk (Harman et al., 2000), while we measured it between the pelvis and thigh. The weighted knee OA group did not change their pelvic tilt, peak hip or knee flexion moments in the weighted condition, so a forward posture is not believed to have occurred compared to the unweighted knee OA group. Had this compensation occurred, it would allow the knee OA subjects to accept the weight but decrease the demand on the quadriceps (Asay et al., 2009).

Because they could not increase their hip flexion angle, but did increase their double support percent possibly for weight-bearing stability (Chamberlin et al., 2005), the correlation between the two variables disappeared. Furthermore, in the healthy, older adults, the double support percent was not related to the load rate in the weighted condition, but this relationship persisted in the knee OA subjects. It could be that the knee OA subjects are simultaneously trying to control the load rate and weight-bearing stability, whereas the healthy, older adults are only trying to control weight-bearing stability. Having to coordinate both tasks during the most demanding part of gait could limit the knee OA group's ability to respond to heavier loads. In addition to this, subtle changes in neuromuscular control, originally deemed "microklutziness" by Radin and colleagues (1991), have been shown in knee OA subjects during loading response (Zeni et al., 2010; Rudolph et al., 2007). Overall, the knee OA group appears to give priority to decreasing the load rate by increasing double support which in turn helps with their weight-bearing stability during the task.

Giving priority to the load rate could be due to the larger absolute load that the knee OA subjects were carrying because they weighed more (Table 3.1). Along with the larger absolute load would be a larger external knee adduction moment, which is very influential in medial knee OA (Sharma et al., 1998). Weight has a large impact on the external knee adduction moment as shown by the effect weight loss can have on this parameter (Messier et al., 2005). Our knee OA subjects reported pain before beginning the study (Table 3.1) and subjects with knee OA and symptoms have been

shown to have higher loading (Thorp et al., 2007). Therefore, it could be a possibility that knee OA subjects prefer to compensate to a challenging weighted walking task by giving priority to decreasing load rate because their already heavy body weight plus the weight vest causes them pain and discomfort through increased loads in the knee.

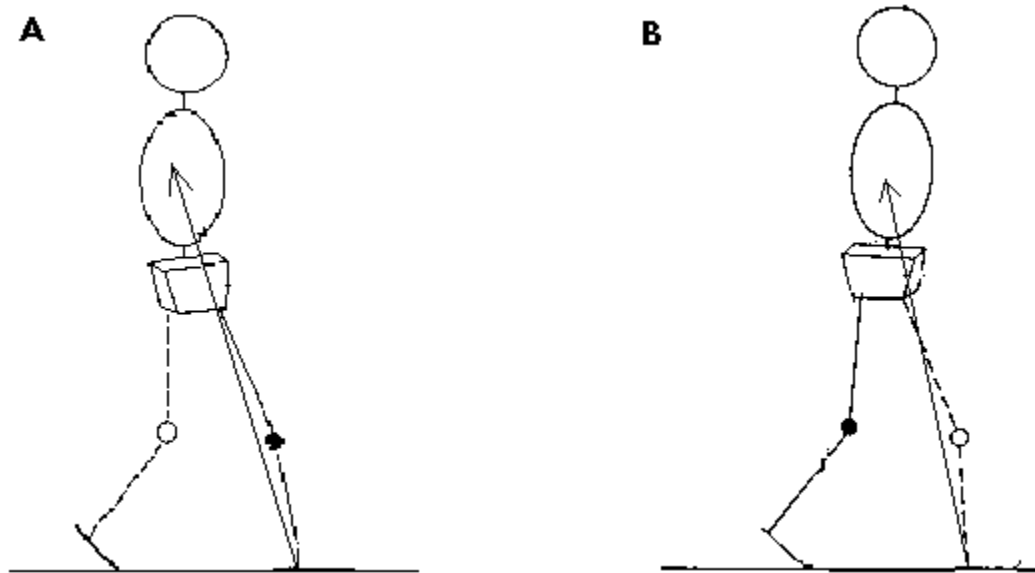


Figure 4.1: (A) Normal sagittal plane lower body posture during loading response. Notice the vertical force vector passing behind the knee and through the hip joint. (B) Increased hip flexion angle. Notice the vector passing slightly farther behind the knee and slightly anterior to the hip joint. This posture would change the loading environment of the lower extremity. (Adapted from Cerny, 1984 with permission of the American Physical Therapy Association)

The lack of response in the knee flexion angle at initial contact, step length and knee flexion excursion in the weighted condition could be because our load (16.7% BW) was lighter than that of the young, healthy subjects (20-68% BW) and our walking speed (1.0 m/s) was slower (1.17 – 1.60 m/s) (Attwells et al., 2006; Polcyn et

al., 2002; Harman et al., 2000; Kinoshita, 1985). The lack of change in the peak braking force and hip and knee flexion moments was most likely due to the normalization of each weighted trial to the weight of the subject plus the weight vest. Salem and colleagues (2001) showed that the peak vertical ground reaction force increased by 2.1% in a 3% body weight condition and 6.3% in a 5% body weight condition in older adults, which helps to support this claim.

FUTURE WORK

Further exploration of the observed compensatory strategy in healthy adults and individuals with knee OA is warranted. Because the only change in sagittal plane kinematics is seen at the hip joint, the possibility of a “hip strategy” in healthy, older adults and adults with knee OA both during unweighted and weighted walking should be analyzed further. Understanding if the hip influences the knee would also be of interest. The idea that the hip is compensating for the knee has already been suggested (Messier et al., 1992). Gait parameters of interest at the hip and knee may include range of motion and excursion to determine whether there is coordinated joint action to compensate for knee OA during a weighted condition. In addition, the lack of compensation to the weighted condition on the more affected limb in knee OA begs the question about the loading environment or biomechanics of the opposite leg. Changes in the loading environment of the contralateral limb has been shown in a knee OA population (Messier et al., 1992) and are a possible cause for the increased

incidence of the development of contralateral knee OA after the more affected limb undergoes a total joint replacement (Shakoor et al., 2002). Finally, further analysis can be done on the upper body posture of the subjects during the weighted condition to verify that trunk flexion did not change as has been suggested in the weighted analysis of younger adults (Harman et al., 2000).

EMG data was also collected for 8 muscles (tibialis anterior, vastus lateralis, rectus femoris, semimembranosus, medial gastrocnemius, soleus, gluteus medius and gluteus maximus) and could be used to analyze muscle control strategies that the subjects undertake during the weighted condition. We also acquired gait data with the subjects walking at self-selected speeds with the weight vest. Analyzing the self-selected walking speed data could provide better insight into the strategies used at normal walking speed.

Follow-up protocols might include recording subject's self-selected walking speed in the vest, if any pain is experienced during the weighted condition on a visual analog scale, balance and disability measures, a range of weighted conditions, and various speeds in addition to what has already been collected. An experiment like this could statistically determine if the subject chooses a slower speed during a weighted condition and how the biomechanics are different than during an unweighted self-selected condition; if an individual's balance and overall disability score influence their response to a weighted condition; if pain has any influence on the gait mechanics of knee OA subjects when they undergo a challenging weighted walking condition;

what amount of weight is too much weight for older adults to carrying in a weight vest; and what are the changes in biomechanics as a result of a change in speed. Also, we expect that compensatory strategies will vary with different severities of knee OA. A comprehensive study to determine the effects of a challenge on individuals with knee OA could discriminate the effects of disability and function, pain, weight added, and speed during a weighted walking condition in older adults and adults with varying severities of knee OA. Also, a study to understand how exposure to the challenging condition (acclimatization) impacts the changes seen may help to understand if the compensations disappear over time.

LIMITATIONS

Some limitations of the current work should be addressed. First, we reported a difference in weighted condition between the groups (Table 3.1). This difference existed in preliminary analysis, where subject's self-reported weight was used to determine the amount of weight to add, and a change was made to the research methods in order to have an equally challenging weighted task between groups. Even though the difference between weighted conditions of the subjects collected later was less, a majority of the subjects had already been collected before the change. Therefore, the difference seen preliminarily existed throughout the study. Future studies should be more careful to have an equal weighted condition between groups. It was only a small difference and could be negligible because the healthy group was

weighted more but had increased strength and decreased pain which may have actually made the condition not as challenging for them compared to knee OA subjects.

The grouping of the subjects could be called into question. Some studies consider radiographic and symptomatic evidence of knee OA for grouping (eg. Briem and Snyder-Mackler, 2009; Childs et al., 2004; Chen et al., 2003; Goh et al., 1993). Other studies distinguished between various knee OA severities (eg. Zeni and Higginson, 2009a; Zeni and Higginson, 2009b; Astephen et al., 2008; Huang et al., 2008; Sharma et al., 1998). We grouped subjects only on the basis of tibiofemoral K/L score (Kellgren and Lawrence, 1957) and matched the subjects for age due to gait changes with aging (Messier, 1994; Murray et al., 1969). As can be seen in Table 3.1, the knee OA group was heavier, with a larger BMI, had decreased isometric quadriceps and hamstrings strength, decreased self-selected walking speed, and more pain and symptoms on the subscales of the KOOS. The resultant groups, based on the K/L scores alone, appeared representative of a healthy, older adult population and a knee OA population. The majority of the knee OA group (80%) had K/L scores of 2 - 3, so future studies may prefer to evaluate the subjects more thoroughly (include patellofemoral radiograph and functional evaluations) or group the subjects differently.

Some useful information was left out of the protocol completely. No pain scores were taken during the weighted condition and no functional measures were taken to establish the functional level of the subjects. Many studies have been done showing the influence pain has on gait biomechanics (Lu et al., 2010; Thorp et al.,

2007; Henriksen et al., 2006; Tang et al., 2004; Hurwitz et al., 2000; Schnitzer et al., 1993; Blin et al., 1990) and the weighted condition could have elicited a pain response from subjects which could have changed their gait. Also, if we want to extrapolate the response of healthy, older adults and subjects with knee OA to a decline in function or performance of activities of daily living, then we should have taken some functional measurements.

CONCLUSION

Healthy, older adults did not respond to the weighted challenge the same way as healthy, young adults according to previous reports. This study did have a slower speed and decreased load compared to those studies, which may explain the differences. The knee OA group did not respond the same way as the healthy, older adults to the weighted condition. The knee OA group already made compensations during unweighted walking that the healthy, older adults only made after they were weighted. It appears that during the weighted condition the knee OA group places priority on decreasing loads, secondarily increasing weight-bearing stability, while the healthy, older adults make weight-bearing stability a priority, secondarily decreasing load rate.

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APPENDIX 1: Inclusion and exclusion criteria

<u>Inclusion</u> • Age: 40-85 • BMI: < 40 • Ambulatory (including those who use a cane or a walker) • Able to walk for 5 minutes at self-selected speed • Able to walk up to 2 x 30 second bursts at fastest tolerable speed on treadmill without assistance.
<u>Exclusion</u> • Congestive heart failure • Any other heart problems or heart murmur • Peripheral artery disease with claudication • Cancer • Pulmonary or renal failure • Unstable angina • Uncontrolled hypertension (> 190/110 mmHg) • Dizziness &/or neurological disorder (stroke, Parkinson's, etc.) • Pregnancy • Joint replacement or pacemaker with metallic parts • OA due to significant bony deformity • ACL deficient knees • Diagnosed arthritis of other lower extremity joints • Any reason why they should not exert themselves physically • Other orthopaedic condition affecting ambulation • If answers YES to 2 of these: ○ Smokes ○ Diabetes ○ Family history of heart disease prior to age 55 ○ Unmedicated high cholesterol • Joint injections within 6 months (good if they had them before and are past 6 months) • Lower extremity surgical procedure that would affect ambulation

Appendix 1: The inclusion and exclusion criteria for the subjects who are to be involved in the study

APPENDIX 2: Physical Activities Readiness Questionnaire

Physical Activities Readiness Questionnaire (PAR-Q)

University of Delaware
PI: Jill Higginson, PhD

	YES	NO
1. Has your doctor ever said that you have heart problems or a heart murmur?	☐	☐
2. Do you ever suffer pains in your chest?	☐	☐
3. Do you ever pass out, have spells of severe dizziness, or experience a persistent, rapid or irregular heartbeat?	☐	☐
4. Has your doctor told you that you currently have high blood pressure for which you are not taking medication (systolic pressure greater than or equal to 160 mmHg. or diastolic pressure greater than or equal to 90 mmHg.)?	☐	☐
5. Do you smoke cigarettes?	☐	☐
6. Do you have diabetes?	☐	☐
7. Do you have a family history of heart disease in parents or siblings prior to the age of 55?	☐	☐
8. Has your doctor told you that you currently have high cholesterol for which you are not taking medication?	☐	☐
9. Is there any physical reason not mentioned here why you should not perform physical exertion?	☐	☐

Name: _____

Age: _____

Participant signature: _____

Date: _____

Appendix 2: Our modified PAR-Q used to screen each subject for physical readiness to participate in this study. The subject is excluded if they answer “yes” to any of questions 1-4 and 9 or if they answer “yes” to two of questions 5-8.

APPENDIX 3: Study information form

Risk Factors for Progression of Osteoarthritis of the Knee
Investigators: Jill Higginson, PhD, Andrew Kubinski, Chris Henderson

General description of the study

For this study, we are interested in the relationship between the bones and muscles that comprise the knee joint in individuals between the ages of 30 and 85 years of age with and without knee osteoarthritis. The knowledge gained from this study will provide a better understanding of knee osteoarthritis and its risks and causes for progression.

There are three parts to this study.

The first part of the study will require you to get an x-ray at Papastavros Medical Imaging on Polly Drummond Hill Road in Newark. The purpose of the x-ray is to establish the severity of your osteoarthritis. The imaging center is a walk-in clinic and you may go at your convenience. The x-ray will be taken at no cost to you or your insurance. This portion should take no more than 30 minutes and is completed at your convenience.

The second part of the study involves coming to the Neuromuscular Biomechanics Lab at the University of Delaware. There you will have your leg strength tested and walking pattern analyzed. The strength testing component involves sitting in a chair and kicking and pulling as hard as you can. The purpose of this is to evaluate the changes in strength that may occur as a result of osteoarthritis. We will also study how the changes in strength can in turn influence how your muscles act. Once the strength testing portion is completed, small adhesive pads will be placed on your muscles of both legs by a trained technician to record your muscle activity during walking. Small round balls will also be attached to your body and read by special cameras while you walk on a treadmill. You will be asked to walk at three different treadmill speeds: a slow speed, your self-selected speed, and a fast speed. You will also be asked to walk at the same slow and self-selected speed with a weighted vest. In total, this portion takes approximately 2 ½ hours and you will be compensated \$40 for your time and travel expenses.

The final part of the study is conducted at Diagnostic Imaging Associates: Brandywine Imaging Center in Wilmington. It is a series of 8 MRIs in a standing open MRI machine. For each of the MRIs, you will be asked to bend your knee at a slightly different angle in each MRI. The purpose of this is to look at how osteoarthritis affects the cartilage of your knee depending on how much your knee is bent. The MRI will be taken at no cost to you or your insurance. This portion takes approximately 2 hours and you will be compensated \$40 for your time and travel expenses.

After completing the three portions of the study, you will be contacted again in 18 to 24 months and asked to complete the three portions again in order to look for changes in your knee joint, strength, and walking pattern. You will be similarly compensated for your time during the follow-up.

Appendix 3: This document was mailed to each subject prior to participation in the study. It gives a description of what to expect while involved.

APPENDIX 4: Radiograph consent form

INFORMED CONSENT FORM - SUPPLEMENT

Project: The progression of osteoarthritis and altered muscle coordination
PI: Jill Higginson, Ph.D. - University of Delaware

RADIOGRAPH CONSENT

Study Description

This consent form supplements the form signed for participation in a study conducted by Dr. Jill Higginson to investigate the progression of knee osteoarthritis (OA). Since you do not have a recent (within six months) flexed-knee radiograph (x-ray), you will be asked to obtain one to determine the status of your knee OA. A flexed-knee radiograph of both knees will be taken at Papastavros' Associates (Polly Drummond office, 40 Polly Drummond Hill Road, Newark, DE, phone: 302-737-5990), and will be paid for by the study investigators. You will be responsible for scheduling the appointment and transportation to/from the Papastavros' Associates Medical Imaging clinic. One of the staff radiologists at Papastavros' Associates will read the radiograph to classify the type and severity of knee osteoarthritis. Dr. Higginson will notify you of the results in a few weeks following the testing session.

Conditions for Participation

You should not participate in this project if you are currently pregnant. A Papastavros' Associate Medical Imaging Radiologist will provide an interpretation of the radiograph films, and the report will be sent to the investigators' research laboratory. Once the results have been recorded, the report will be returned to you by U.S. mail. The results of the research study may be published but your name or identity will not be revealed and your data will remain confidential and in the possession of the investigators indefinitely. You may withdraw consent and discontinue your participation in this study at any time without penalty.

Risks and Benefits

The radiograph will expose you to the same risk as a routine diagnostic x-ray. In the event of physical injury, you will receive emergency first aid at that time. If you require additional medical treatment, you will be responsible for the cost.

Participant's initials: _____
Page 1 of 2

INFORMED CONSENT FORM - SUPPLEMENT
Project: The progression of osteoarthritis and altered muscle coordination
PI: Jill Higginson, Ph.D. - University of Delaware

Financial Considerations

The study investigators will pay for the flexed-knee radiograph. You will not receive any financial compensation for participation in this study.

Contacts

Further information regarding this study may be obtained from the project director, Dr. Jill Higginson, at telephone number (302) 831-6622. Other questions about your rights as a research subject can be directed to the Chair of the University of Delaware Human Subjects Review Board at (302) 831-2136.

Subject Consent

I agree to participate in the research study described above. I understand that I may withdraw from this study or the principal investigator may terminate the study at any time without penalty.

Name: _____ (please print)

Signature: _____ Date: _____

Participant's initials: _____
Page 2 of 2

Appendix 4: The radiograph consent form that each subject received in order to have their knee x-rayed.

APPENDIX 5: Informed consent

INFORMED CONSENT FORM

Project: Risk factors for progression of osteoarthritis of the knee
PI: Jill Higginson, Ph.D. – University of Delaware

Risk factors for progression of osteoarthritis of the knee

Summary

You are invited to participate in a research study conducted by Dr. Jill Higginson to investigate the progression of knee osteoarthritis (OA). **This is a two-part longitudinal study involving (1) strength and walking trials and (2) MRI scans. You will be asked to repeat both parts in approximately 18 months.** In this study, we will compare muscle and joint forces with cartilage properties in 30 adults with diagnosed knee OA and 30 healthy adults.

Study Description

Participants: Healthy adults with no history of orthopedic injury and adults with diagnosed osteoarthritis of the knee will be eligible for this study. You must be between 30 and 85 years of age to participate. If you decide to participate, Dr. Higginson or her research associates will ask you to complete two questionnaires. One will assess your overall health status and your ability to safely complete the experiment. The second questionnaire will assess your knee pain, symptoms and physical function. You will be also be asked about conditions for which MRI poses risks, such as implanted metal or electronic devices.

Part 1

This part of the study will occur in the biomechanics lab in Spencer Laboratory and you will be asked to wear shorts, t-shirt and comfortable walking shoes. We will measure your weight and height and ask about your current level of knee pain, if any. For the strength test, we will ask you to sit on the strength testing chair and push/pull as hard as you can against a non-movable arm three times on each leg. Each push will last about 3 seconds. We will assess your comfortable walking speed in the hallway. We will place surface electrodes on your legs with tape in order to measure the electrical output of your muscles. The attachment sites will be cleaned and shaved if necessary. While you are seated, we will attach reflective markers to your legs and upper body with tape. You may

Participant's initials: _____
Page 1 of 5

INFORMED CONSENT FORM
Project: Risk factors for progression of osteoarthritis of the knee
PI: Jill Higginson, Ph.D. – University of Delaware

be asked to walk on a treadmill in five conditions (slow, comfortable speed, as fast as you can, slow speed with moderate load equal to 1/6 body weight, and comfortable speed with load) for less than two minutes at each speed. You may be asked to complete three additional walking trials at the follow-up visit. The movement of your legs and upper body will be recorded using special cameras which detect reflective objects attached to your body segments. The electrical activity of your leg muscles will be recorded during the walking trials using surface electrodes applied previously. We may also collect video for comparison with the motion data. You will have at least two minutes to rest between trials.

Total time: Setup will take approximately 1 hour, strength testing will take approximately 15 minutes, and the walking trials should take less than 30 minutes. The total time for your participation in this session will be no longer than 3 hours per visit.

Part 2

This test session will occur at Diagnostic Imaging Associates of Wilmington (Brandywine Office). We will contact you to schedule the appointment. You will be responsible for transportation to the Imaging center. You will be asked to wear shorts, t-shirt and comfortable walking shoes. We will use a magnetic resonance imaging (MRI) scanner to acquire images of both knees. Unlike most MRI scanners in which the patient lies down, the open MRI scanner we will use has a bed that can be inclined to any angle between vertical and horizontal positions. We will image your knees while you are standing in a near upright position (5° from vertical). We will also image your knees with the table tilted at a position of 45° from the horizontal (head up) which puts less load on your legs. In the reclined position, three scans will be performed with the knees flexed to 0, 15 and 30°, respectively. You will be required to maintain this position during scanning. A total of 8 scans of varying durations will be acquired, which should each last up to seven minutes.

Total time: A total of 8 scans of varying durations will be acquired and the total duration of the testing session will not exceed two hours.

Participant's initials: _____
Page 2 of 5

INFORMED CONSENT FORM
Project: Risk factors for progression of osteoarthritis of the knee
PI: Jill Higginson, Ph.D. – University of Delaware

Conditions for Participation

You may have been referred to us by your physician or physical therapist as having some degree of OA of the knee, or you may have responded to advertisements posted in the University community or by word-of-mouth. You will be asked several questions by phone to assess your ability to perform physical activities and will be excluded if your answers suggest you should not physically exert yourself.

You should not participate in this project if you are currently pregnant or have a muscle, bone or nervous system disorder (other than osteoarthritis). In addition, we will calculate your body mass index which is a measure of body fat and must be less than 40 for you to participate. Your personal information will remain confidential and will not be released (including any publication) without your written consent. Data obtained from this study will be recorded on a computer and archived indefinitely. If you agree, video acquired during this study may be used as part of educational presentations and we will block out your face so that your identity will not be revealed. **We will contact you for the second evaluation approximately 18 months following your first visit.**

Financial Considerations

You will receive \$40 each for completing parts (1) and (2) of this study at the initial visit and follow-up visit 18 months later (total of \$160). You will not be compensated additionally for any travel expenses you incur.

Risks and Benefits

The type of MRI imaging procedure being used in the study is performed routinely. MRI does not involve exposure to radiation. Claustrophobia, experienced by some during MRI, is not a factor for this study since the scanner being used has an open design. There is a possibility of a small amount of discomfort due to fatigue from maintaining a stationary position during scanning and there is a risk of fainting or nausea.

Participant's initials: _____
Page 3 of 5

INFORMED CONSENT FORM
Project: Risk factors for progression of osteoarthritis of the knee
PI: Jill Higginson, Ph.D. – University of Delaware

Risks and Benefits (continued)

Strength testing may result in mild soreness that is associated with exertion of muscles during strengthening exercises. Recording the electrical activity of your muscles using surface electrodes poses very little risk. There may be some minor irritation of the skin around the site of the electrode following the experiment. As with any physical activity, risks during walking include dizziness, discomfort in breathing and heart problems. While walking on the treadmill, you will wear a protective harness and a handrail will be within reach.

You will receive first aid in the event of injury during this project. If you require additional medical treatment, you will be responsible for the cost. Although there may be no direct benefit to you, it is hoped that your participation in this project will improve our understanding of the progression of knee OA.

Contacts

Further information regarding this study may be obtained from the project director, Dr. Jill Higginson, at telephone number (302) 831-6622. Other questions about your rights as a research subject can be directed to the Chair of the University of Delaware Human Subjects Review Board at (302) 831-2136.

Subject Consent

I agree to participate in the research study described above. I understand that I may withdraw from this study or the principal investigator may terminate the study at any time without penalty.

Name: _____ (please print)

Signature: _____ Date: _____

Participant's initials: _____
Page 4 of 5

INFORMED CONSENT FORM
Project: Risk factors for progression of osteoarthritis of the knee
PI: Jill Higginson, Ph.D. – University of Delaware

Video Consent

I will allow video to be taken during data collection. YES / NO Initial: _____

I will allow video to be used as part of educational
presentations, provided that my identity is not revealed. YES / NO Initial: _____

Participant's initials: _____
Page 5 of 5

Appendix 5: The informed consent form used during our study.

APPENDIX 6: Knee Injury and Osteoarthritis Outcome Survey

Knee and Osteoarthritis Outcome Score (KOOS), English version LK1.0

1

KOOS KNEE SURVEY

Today's date: ____/____/____ Date of birth: ____/____/____

Name: _____

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to do your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms

These questions should be answered thinking of your knee symptoms during the last week.

S1. Do you have swelling in your knee?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always ☐

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always ☐

S3. Does your knee catch or hang up when moving?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always ☐

S4. Can you straighten your knee fully?

Always ☐ Often ☐ Sometimes ☐ Rarely ☐ Never ☐

S5. Can you bend your knee fully?

Always ☐ Often ☐ Sometimes ☐ Rarely ☐ Never ☐

Stiffness

The following questions concern the amount of joint stiffness you have experienced during the last week in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

S7. How severe is your knee stiffness after sitting, lying or resting later in the day?

None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

Pain

P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4. Standing

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5. Bending to floor/pick up an object

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A14. Sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A17. Light domestic duties (cooking, dusting, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2. Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Quality of Life

Q1. How often are you aware of your knee problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3. How much are you troubled with lack of confidence in your knee?

Not at all	Mildly	Moderately	Severely	Extremely
☐	☐	☐	☐	☐

Q4. In general, how much difficulty do you have with your knee?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire.

Appendix 6: Questionnaire administered to the subjects regarding their symptoms, pain, activities of daily living, sport and recreational activities, and quality of life.

APPENDIX 7: SLACK Incorporated permission letter



August 17, 2010

Andrew Kubinski
University of Delaware
130 Academy St
Newark, DE 19716

Reference #: B026111923

Material Requested: Table 2-1; Figures 2-1, 2-2, 3-4, and 3-5

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APTA Request Reference: **PTJ 93/10**

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