THE EFFECTS OF QUADRICEPS-STRENGTHENING EXERCISE ON QUADRICEPS MUSCLE BIOMECHANICS DURING LOCOMOTION IN ADULTS WITH KNEE OSTEOARTHRITIS.

by

Joshua M. Leonardis

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Director of Thesis: Paul DeVita, PhD

Major Department: Kinesiology

Knee Osteoarthritis (OA) is a disease characterized by knee joint deterioration and pain, while also being associated with altered knee joint mechanics and quadriceps strength deficits. Research investigating the effects of quadriceps-strengthening exercise on knee OA has shown improvements in symptoms, function, and strength, but minimal changes to joint mechanics. It is speculated that altered quadriceps muscle biomechanics are the mechanism responsible for this improvement in symptoms, though this concept is untested. The purpose of this study is to examine the effects of quadriceps strengthening exercise on quadriceps muscle biomechanics during level walking, stair ascent, and stair descent in adults with knee osteoarthritis.

Three-dimensional kinematic, ground reaction force, isokinetic strength, and WOMAC data were collected on 10 adults with uni- or bi-lateral knee OA. During the 12-week period between the testing procedures, 6 adults participated in strengthening exercise, while the other 4 adults went untrained. Quadriceps biomechanics were quantified using kinetic data collected during level walking, stair ascent, and stair descent tasks in combination with a mathematical knee model. A 2x2 repeated measures ANOVA ($p<0.05$) was used to analyze each symptomatic, strength, joint kinetic, and muscle biomechanics parameter.

Only the training group experienced significant improvements in pain, function, and strength (All $p<0.02$). At follow-up, this group also climbed and descended stairs at faster velocities (Both $p<0.03$), exhibited greater knee extensor torque and power during level walking

(Both p<0.03), experienced increased quadriceps force and work during level walking and stair ascent (All p<0.05), and exhibited increased knee compressive force during all three conditions (All p<0.03).

The results of this study reinforce the notion that quadriceps-strengthening exercise reduces pain and improves function in adults with knee OA. The data refute the study hypothesis by suggesting that quadriceps muscle biomechanics are, in fact, altered following a strengthening protocol. The study results also refute claims suggesting reduced joint loads are the cause of pain relief, by showing significant increases in knee compressive force alongside significant improvements in pain and physical function.

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MUSCLE BIOMECHANICS DURING LOCOMOTION IN ADULTS WITH KNEE

OSTEOARTHRITIS

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Joshua M. Leonardis

APPROVED BY:

DIRECTOR OF
DISSERTATION/THESIS: _____
                                          Paul DeVita, PhD

COMMITTEE MEMBER: _____
                                          Anthony Kulas, PhD

COMMITTEE MEMBER: _____
                                          John Norbury, MD

COMMITTEE MEMBER: _____
                                          Patrick Rider, MA

CHAIR OF THE DEPARTMENT
OF KINESIOLOGY: _____
                                          Stacey Altman, JD

DEAN OF THE COLLEGE
OF HEALTH AND HUMAN
PERFORMANCE: _____
                                          Glen G. Gilbert, PhD

DEAN OF THE
GRADUATE SCHOOL: _____
                                          Paul J. Gemperline, PhD

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INTRODUCTION

Approximately 51 million people in the United States suffer from some form of physician-diagnosed arthritis (Cheng, Hootman, Murphy, Langmaid, & Helmick, 2010), accounting for $128 billion in costs annually (London, Miller, & Block, 2011). The number of adults with arthritis continues to increase and is expected to reach 67 million by the year 2030 (J. Hootman & Helmick, 2006). Osteoarthritis (OA), one our nation's most common causes for hospitalization, is responsible for 28 of the 51 million total arthritis cases (Lawrence et al., 2008). Up 30% since 1995, the prevalence of OA is on the rise and is currently estimated to affect 1 in 2 people at some point in their lifetime (Lawrence et al., 2008; London, Miller, & Block, 2011).

Osteoarthritis results in the complete deterioration of a joint and all of its components. Many joints are susceptible to OA, though the knee is the most common location, with roughly 250 million people worldwide suffering from knee OA (Vos et al., 2012). The pain associated with knee OA causes loss of knee joint function that is most evident during activities of daily living, such as walking and climbing stairs, and is responsible for a decreased quality of life.

Investigation into the state of osteoarthritic knees has shed light on a significant secondary problem; in the presence of knee OA the quadriceps of the affected leg begin to function inadequately. This dysfunction is exhibited by decreases in strength and altered neuromuscular characteristics (Hortobagyi et al., 2005; C. L. Hubley-Kozey, Deluzio, & Dunbar, 2008; Hubley-Kozey, Deluzio, Landry, McNutt, & Stanish, 2006; Hubley-Kozey, Hill, Rutherford, Dunbar, & Stanish, 2009; Lewek, Rudolph, & Snyder-Mackler, 2004; Rutherford, Hubley-Kozey, Stanish, & Dunbar, 2011; Slemenda et al., 1997). Decreased quadriceps strength has a direct effect on the mechanics of the knee joint during locomotion, typically resulting in

reduced knee extensor torques and a redistribution of torques away from the knee and towards the hip and/or ankle (Kaufman, Hughes, Morrey, Morrey, & An, 2001; Mundermann, Dyrby, & Andriacchi, 2005; J. A. Zeni & Higginson, 2011).

Research into potential treatments for knee OA has led to the examination of the effects of exercise on the condition of the disease. The outcome of most research has provided a positive link between the two. This association is especially strong in terms of the disease's symptoms, as it has been found that with the introduction of exercise comes an improvement in knee joint pain (Foroughi et al., 2011; McQuade & de Oliveira, 2011a; Messier, Thompson, & Ettinger, 1997; T. J. Wang et al., 2011). Additional analyses have discovered that quadriceps-strengthening exercise allows for improved symptoms and physical function (Huang, Lin, Yang, & Lee, 2003; Rogind et al., 1998; T. J. Wang et al., 2011). Meaning, that with an increase in quadriceps strength comes a decrease in knee pain, and indirectly, an improvement in quality of life.

An explanation for the relationship between reduced pain and muscle strengthening has yet to be identified. It is thought that increased quadriceps muscle strength leads to improved quadriceps function during locomotion through an unknown mechanism (Baker et al., 2001; Mikesky, Meyer, & Thompson, 2000). Baker et al. attempts to explain the mechanism by stating, "A stronger muscle may absorb more of the force that otherwise would be transferred across the joint" (2001). However, fundamental flaws exist in the physics described by this statement. Mainly, that energy, not force, is absorbed or attenuated and while total body energy can be reduced, individual joints do not absorb energy. Additionally, no empirical evidence has been found to support this concept. In fact, the positive effects of quadriceps strengthening seem to be limited to the symptoms of knee OA. Many studies have found that with an exercise

induced increase in quadriceps strength and improvement in pain, negligible changes occur to the mechanics of the knee joint during locomotion (Foroughi et al., 2011; Hunt et al., 2010; Lim, Hinman, Wrigley, Sharma, & Bennell, 2008; McQuade & de Oliveira, 2011a; Thorstensson, Henriksson, von Porat, Sjodahl, & Roos, 2007). This suggests that quadriceps function does not change following an increase in its maximal strength capacity. However, no studies have specifically examined quadriceps muscle biomechanics during locomotion through either empirical measurements or biomechanical modeling.

Hypothesis

The connection between increased quadriceps strength and an improvement in the symptoms of knee OA is unclear. Previous research showing no change in knee joint mechanics with an increase in quadriceps strength has led to the formulation of the hypothesis that even with an increase in quadriceps muscle strength and an improvement in the symptoms of knee OA, the biomechanics of the quadriceps muscles will go unchanged. We anticipated no changes to maximum quadriceps force, maximum quadriceps power, or total quadriceps work during these gait tasks despite increases in quadriceps strength caused by 12 weeks of quadriceps strengthening exercise

Purpose

The purpose of this study was to determine the effects of quadriceps strengthening exercise on the biomechanics of the quadriceps muscles during level walking, stair ascent, and stair descent.

Significance

Preventative measures for knee OA are almost nonexistent, while most treatment options, varying from over-the-counter medications to total knee arthroplasty, are limited to alleviating the symptoms of the disease. Determining the effects of strengthening exercise on quadriceps muscle biomechanics will provide important information needed to identify a specific pain relief mechanism. By understanding this mechanism, current treatment options may be maximized and the development of more efficient treatment options is possible.

Delimitations

Delimitations of this study are as follows:

- A physician diagnosed each case of knee OA.

- All subjects were previously untrained.

- All subjects had a BMI of between 19 kg/m^2 and 32 kg/m^2.

- All subjects were between the ages of 40 and 65.

- All trials were performed at self-selected walking speeds.

Limitations

Limitations of this study are as follows:

- Analysis of data was limited by the accuracy of data collection and analysis systems.

- Marker placement was assumed to be correct.

- Information gathered about each subject through interviews and questionnaires was assumed to be accurate.

- Subjects may possess knee OA in both knees

REVIEW OF LITERATURE

The purpose of this thesis was to determine if quadriceps-strengthening exercise will affect quadriceps force, power, and/or work during level walking, stair ascent, and stair descent in adults with knee osteoarthritis. In this review of literature the following topics will be addressed: 1) Effects of Knee Osteoarthritis on Knee Joint Anatomy and Lower Limb Muscle Function, 2) Risk Factors for Knee Osteoarthritis, 3) Effects of Knee Osteoarthritis on Locomotion, 4) Exercise and Knee Osteoarthritis, 5) Summary.

Effects of Knee Osteoarthritis on Knee Joint Anatomy and Lower Limb Muscle Function

Osteoarthritis, the most common degenerative joint disease, is characterized by joint degradation, resulting in the loss of articular cartilage and the exposure of subchondral bone. It is diagnosed by the presence of reduced joint space, unregulated bone growth, and/or increased bone density. The severity of this radiographic evidence possesses a strong relationship with knee pain (Lethbridge-Cejku et al., 1995; Neogi et al., 2009). This knee pain has proven to be the primary reason for a reduced quality of life, because it is at times present before any visual evidence of the disease, and may prevent individuals from participating in activities required to maintain independence (London, Miller, & Block, 2011; Pinto, Robertson, Hansen, & Abbott, 2012). Although pain is the target of most OA interventions, its origin is still unknown. Cartilage, the tissue most affected by OA, is not innervated, ruling it out as a possible location of origin. Bone has also been considered, however pain is present in early- to mid-stage OA, when bone may not yet be affected. Finally, quadriceps muscle strength, a significant secondary problem, has been strongly connected with the origin of pain (Lewek, Rudolph, & Snyder-Mackler, 2004; Segal et al., 2009; Slemenda et al., 1998).

The capacity for a muscle to produce adequate force is fundamental to ones ability to move properly and efficiently. A muscles force-producing potential is partly dependent upon its size and its neuromuscular properties. Therefore, a decrease in muscle size or innervation will result in decreased strength, and an increase in either will improve strength. Reductions in both of these elements of strength have been linked to knee OA, and are at times viewed simultaneously.

Quadriceps muscle size has been investigated by comparing those with unilateral or bilateral knee OA (Fink et al., 2007), with or without pain (Sattler et al., 2012), and with or without radiographic evidence (Beattie, MacIntyre, Ramadan, Inglis, & Maly, 2012). While differences were viewed between the groups in each study, the lack of a true control group make their findings difficult to interpret. Ikeda et al., however, found that when compared to healthy age-matched controls, those with radiographic knee OA possessed 13% smaller quadriceps musculature (2005).

Even in muscles with sufficient cross-sectional area coactivation and deficits in proprioception (neuromuscular alterations commonly associated with knee OA) may explain some of the strength loss witnessed within the quadriceps. Coactivation refers to the simultaneous production of force by opposing muscles or muscle groups. In those suffering from knee OA, coactivation is commonly viewed between the quadriceps and hamstrings as a means to improve compromised knee joint stability (Childs, Sparto, Fitzgerald, Bizzini, & Irrgang, 2004; Hortobagyi et al., 2005; C. L. Hubley-Kozey, Hill, Rutherford, Dunbar, & Stanish, 2009). The presence of hamstring muscle forces in direct opposition to the quadriceps muscle forces may result in a lower perceived quadriceps contribution to locomotion and other activities of daily living.

Proprioception, a term explaining the nervous systems' capacity to recognize the position of a limb in space, is particularly important because of its relationship with the control of movement. Joint proprioception is normally quantified using tests that require the participant to recreate or identify specific joint positions. A loss of proprioception is expected with age, but even when controlling for age significant losses are not atypical in those with knee OA. (Hurley, Scott, Rees, & Newham, 1997; Pai, Rymer, Chang, & Sharma, 1997; Segal et al., 2010).

The origin and onset of quadriceps strength loss is still unknown. What is clear, though, is its strong relationship with pain. It is well documented that those with stronger quadriceps muscles possess fewer symptoms of knee OA and are able to function at a much higher level (Segal et al., 2009; Segal et al., 2010; Slemenda et al., 1997; Wang et al., 2012). Segal et al. has illustrated this by establishing a negative correlation between quadriceps muscle strength and knee OA severity (2010), and a positive relationship between improving symptoms and quadriceps strength (2009).

Interestingly, quadriceps weakness has been shown in the absence of pain (Slemenda et al., 1997), while the acute introduction of experimental knee pain has been shown to decrease quadriceps strength (Henriksen, Rosager, Aaboe, Graven-Nielsen, & Bliddal, 2011). These contradicting findings reinforce the importance of adequate quadriceps strength in the presence of knee OA, while giving an example of the complexity of the relationship.

Risk Factors for Knee Osteoarthritis

Despite its prevalence, there exists no known cause of knee OA, although many risk factors have been identified. Of these potential risk factors, the strongest predictors are age, gender, a body mass index (BMI) of ≥ 25 kg/m^2, and a history of knee injury.

Knee OA does not typically affect individuals until their 30's, with most onsets occurring between the ages of 40 and 50 years and at a greater rate in women (Dillon, Rasch, Gu, & Hirsch, 2006; D. T. Felson et al., 1987; J. Hootman & Helmick, 2006; Jordan et al., 2007). In total, it is estimated that 50% of people will be affected by symptomatic knee OA in their lifetime, with this increasing when adjusted for obesity. This continues to be of concern because individuals forty and older account for roughly 45% of the total U.S. population (U.S. Census, 2010), and about 36% of those in this age group possess a BMI that can be considered overweight or obese (Ogden, Carroll, Kit, & Flegal, 2012).

The excess fat mass associated with an overweight or obese BMI results in increased loads at weight-bearing joints like the knee, potentially accelerating articular cartilage degradation (Cicuttini, Baker, & Spector, 1996; Jarvholm, Lewold, Malchau, & Vingard, 2005). The Framingham cohort found that those in their heaviest category of height-adjusted weights were at a 15% increased rate of incidence then the next category down (1987). The relationship between BMI and knee OA is strengthened by Jarvholm et al. who, after studying over 320,000 subjects, found that a BMI greater than 25 kg/m^2 is associated with an increased incidence rate of the disease (2005). Increases in fat mass have also been linked to the increased prevalence of OA at both weight-bearing and non-weight-bearing joints at a rate of between 9-13% per kg of weight gained (Cicuttini, Baker, & Spector, 1996).

Some suggest a history of too much physical activity, such as high-level athletics or demanding occupations, as a possible predictor. It has been suggested, however, that the connection between physical activity and knee OA may be explained by the increased rate of injury associated with intense physical activity, not performing the activity itself (Gelber et al., 2000; N. Thelin, Holmberg, & Thelin, 2006). Research completed by Thelin et al. helped to provide an answer by showing that physical activity had little association with the incidence of knee OA when controlling for the injuries sustained during the event (2006). The connection between knee injury and OA prevalence was strengthened by the findings of Gelber et al., who investigated the prevalence of knee OA in over 1,300 medical students (2000). After an average follow-up time of 36 years, they found that those that suffered some form of traumatic knee injury exhibited a 7.9% greater incidence rate than those that did not (Gelber et al., 2000).

Effect of Knee Osteoarthritis on Locomotion

The term locomotion refers to the use of the lower limbs to provide propulsion and to ultimately produce total body movement through an environment. This movement is the result of torques produced at the hip, knee, and ankle joints. Joint torques occur in the frontal (abduction and adduction), sagittal (extension and flexion), and transverse planes (internal and external rotation) and are the product of the forces produced by each of the muscles articulating that joint. As one locomotes, their muscles generate these forces in response to the forces produced by the ground against the bottom of their feet. In healthy human locomotion, these ground reaction forces will vary based on individual differences such as body mass and walking velocity, which is the product of stride length (the distance from heel strike to heel strike) and step frequency (the number of steps taken per unit time). For example, a greater body mass or

faster walking speed will result in greater ground reaction forces, which will require greater

muscular forces, culminating in greater joint torques.

Variations in joint torques can be the result of altered muscular contribution, pain, and/or

anatomical changes such as altered bone condition. The joint deterioration and quadriceps

weakness associated with knee OA may result in the inability of the knee to function properly,

typically leading to gait modifications like a slower self-selected walking speed (Kaufman,

Hughes, Morrey, Morrey, & An, 2001; Kiss, 2011; Mundermann, Dyrby, Hurwitz, Sharma, &

Andriacchi, 2004; Mundermann, Dyrby, & Andriacchi, 2005; Weidow, Tranberg, Saari, &

Karrholm, 2006; J. A. Zeni & Higginson, 2011; J. A. Zeni Jr & Higginson, 2009). This

reduction in walking speed is commonly achieved by a shorter step length combined with a

increased step frequency, adaptations believed to be made as an attempt to decrease time spent in

single stance (completely weight-bearing on one leg) (Kiss, 2011; Weidow, Tranberg, Saari, &

Karrholm, 2006). This would result in reduced ground reaction forces, and ultimately, reduced

joint forces, muscle forces, and loads at the specific site of joint degradation (Kiss, 2011;

Richards & Higginson, 2010; J. A. Zeni & Higginson, 2011). While a decrease in self-selected

walking speed is natural with age, its significance as a determinant of overall health has led to its

use as a gauge for the severity of an individual's condition (Mundermann, Dyrby, Hurwitz,

Sharma, & Andriacchi, 2004; Mundermann, Dyrby, & Andriacchi, 2005)

Other gait alterations associated with knee OA can be found in the mechanics of the knee

joint, although the exact onset of these mechanical changes is still unknown. Specific altered

joint torques in the frontal and sagittal planes have been linked to the severity and progression of

knee OA (Kaufman, Hughes, Morrey, Morrey, & An, 2001; Mundermann, Dyrby, Hurwitz,

Sharma, & Andriacchi, 2004; Mundermann, Dyrby, & Andriacchi, 2005; Weidow, Tranberg,

Saari, & Karrholm, 2006; J. A. Zeni Jr & Higginson, 2009). In the sagittal plane, common alterations are viewed as decreased knee extensor torques, a product of decreased quadriceps contribution, although this decrease may be explained by coactivation (Kaufman, Hughes, Morrey, Morrey, & An, 2001). It is though that these reduced knee extensor torques may also reduce knee compressive forces (Henriksen et al., 2006; Kaufman, Hughes, Morrey, Morrey, & An, 2001; J. A. Zeni Jr & Higginson, 2009). In the frontal plane, increased adduction moments are indicative of the unnatural medial and lateral joint loading commonly associated with knee OA, and have been identified as another strong predictor of disease severity (Mundermann, Dyrby, Hurwitz, Sharma, & Andriacchi, 2004; Mundermann, Dyrby, & Andriacchi, 2005; J. A. Zeni Jr & Higginson, 2009).

Exercise and Knee Osteoarthritis

Once a diagnosis is made, the treatment options for this disease range from prescription medications to total knee arthroplasty, depending on severity. Of these treatment options, exercise is considered both beneficial and cost effective (Pinto, Robertson, Hansen, & Abbott, 2012). With the introduction of exercise, the most beneficial change is seen in reduced knee joint pain (Huang, Lin, Yang, & Lee, 2003; M. V. Hurley & Scott, 1998; Lim, Hinman, Wrigley, Sharma, & Bennell, 2008; D. H. Lin, Lin, Lin, & Jan, 2009; McQuade & de Oliveira, 2011b; Messier, Thompson, & Ettinger, 1997; Rogind et al., 1998; T. J. Wang et al., 2011). Additionally, exercise is associated with other physical, psychological, and social benefits outside those linked to knee OA.

Many modes of exercise have been shown to reduce knee pain, though quadriceps-strengthening exercise has displayed promising results due to its ability to also improve physical

function (Huang, Lin, Yang, & Lee, 2003; Jan, Lin, Liau, Lin, & Lin, 2008; D. H. Lin, Lin, Lin, & Jan, 2009; McQuade & de Oliveira, 2011; T. J. Wang et al., 2011). This improvement in pain and strength allows individuals to move with less restriction during activities of daily living, directly improving their quality of life.

The mechanism by which this minimization of pain occurs is still not well understood. Although it seems that by strengthening the quadriceps the knee will function better, ultimately reducing pain, this is not the case. It is becoming clearer that during locomotion, the frontal and sagittal mechanics of a knee with OA are relatively unchanged after increased quadriceps strength (Foroughi et al., 2011; Foroughi, Smith, Lange, Singh, & Vanwanseele, 2011; Lim, Hinman, Wrigley, Sharma, & Bennell, 2008; McQuade & de Oliveira, 2011b; Thorstensson, Henriksson, von Porat, Sjodahl, & Roos, 2007). It has also been shown that with an increase in quadriceps strength and a decrease in pain, self-selected walking speed may also increase (Jan, Lin, Liau, Lin, & Lin, 2008). If this were the case, unchanged knee mechanics and increased self-selected walking speed would lead to greater ground reaction forces, effectively increasing knee joint loads yielding results contrary to what is presumed to happen (Foroughi et al., 2011; Henriksen et al., 2006; Hunt et al., 2010; Hurwitz et al., 2000; Slemenda et al., 1997).

Summary

Pain is the principal reason for a reduced quality of life experienced by individuals with knee osteoarthritis. The origin of this pain is unknown, but its relationship with quadriceps weakness has led to quadriceps strengthening exercise as a treatment option. As quadriceps strength increases with the introduction of exercise, the pain and symptoms of knee OA greatly improve. However, increases in quadriceps strength do not appear to cause knee joint function

to revert back to its pre-disease state. This warrants further inquiry into the role of the

quadriceps muscles during movement in adults with knee osteoarthritis.

METHODOLOGY

An experiment was included in this thesis that tested the hypothesis that quadriceps strengthening exercise will not affect the biomechanics of the quadriceps muscles during level walking, stair ascent, or stair descent in individuals with knee osteoarthritis. This chapter will address the procedures used during this experiment in sections titled: 1) Subject characteristics, 2) Measurements and instrumentation, 3) Testing protocol, 4) Data processing, and 5) Statistical analysis.

Participant Characteristics

This study included a total of ten volunteers between the ages of 40 and 65. These volunteers were recruited via local businesses, email flyers, and newspaper advertisements. In addition to these methods, Dr. John Norbury also aided in the recruitment of subjects via the Brody School of Medicine, East Carolina University, Greenville, NC. Volunteers' eligibility was determined by phone interview prior to any laboratory visits using specific inclusion and exclusion criteria. Once deemed eligible, each subject's physician authorized their participation and confirmed the presence of tibio-femoral knee osteoarthritis. The volunteers were then placed into one of two groups, the first group being an exercise group and the second a non-exercise group.

Inclusion Criteria

- Subjects possessed tibio-femoral knee osteoarthritis, diagnosed by the American College of Rheumatology criteria.

- Subjects did not require assistive walking devices.

- Subjects were willing to meet all study visits and procedures and keep activity levels outside the study constant.

- Subjects were in good health and had a BMI between 19 kg/m^2 and 32 kg/m^2.

Exclusion Criteria

Volunteers meeting any of the following were not eligible for participation.

- Requiring an assistive walking device.

- Pregnant or breastfeeding.

- Diagnosed with patello-femoral OA without evidence of tibio-femoral osteoarthritis.

- Planned surgical procedure during period of study.

- History or diagnosis of:

  o Autoimmune problems

  o Lower extremity musculoskeletal injuries

  o Clinically significant cardiovascular disease

  o Diabetes

  o Neurological disorders

Measurements and Instrumentation

All strength measurements were collected using a HUMAC NORM dynamometer (CSMi, Stoughton, MA). The dynamometer head and seat position were adjusted individually for each subject. Range of motion was set at 5 degrees short of anatomical zero and 90 degrees of knee flexion. Torque measurements were adjusted for gravitational forces due to the mass of the leg being tested.

Each gait trial was recorded at 120 Hz using an eight-camera ProReflex 3D Motion Capture system (Qualisys Motion Capture Systems, Gothenburg, Sweden) mounted at ceiling height above the runway. Ground reaction force data were collected during level walking trials using an AMTI LG6 force platform (Newton, MA) located in the center of the runway. A force platform (AMTI OR6-6, 2000, Newton MA) fitted to the center of the second step of a four-step stairway collected ground reaction forces during stair ascent and stair descent trials. Each force platform measured forces in three dimensions (frontal, sagittal, and transverse) at a frequency of 960 Hz.

During each strength and gait trial, the electrical potential of the vastus lateralis, biceps femoris, tibialis anterior, and lateral gastrocnemius muscles were measured using a Myopac MPRD-101 EMG system (Konigsberg Instruments Inc., Pasadena, CA). Each subject's body composition was determined using dual-energy x-ray absorptiometry (Lunar Prodigy Pro, General Electric Healthcare, Fairfield, CT, USA).

Walking and electromyography data were saved to their respective files using Qualisys Track Manager (Qualisys Motion Capture Systems, Gothenburg, Sweden), and were analyzed using Visual3D (C-Motion Inc., Rockville, MD).

Testing Protocol

Pre-testing was administered over three days while post-testing occurred over two days.

Day One

The initial testing visit was held in building 189, East Carolina University, Greenville, NC. Volunteers completed an informed consent document and a Western Ontario McMaster Universities Arthritis Index (WOMAC) questionnaire prior to the start of testing. The

participant's height, weight, and body composition was then measured. Once these measurements were established, the subject's blood pressure was taken prior to their participation in five minutes of cycling on an ergometer. If blood pressure was determined to be greater than 140/90, the visit was discontinued and rescheduled. Once sufficiently warm, the subject's leg press and knee extension three repetition maximums were determined for each leg.

Day Two

The second testing visit was held in the Biomechanics Laboratory, Ward Sports Medicine Building, East Carolina University, Greenville, NC. Upon their arrival, participants had their blood pressure taken before warming up for approximately five minutes on a cycle ergometer. If blood pressure was determined to be greater than 140/90, the visit was discontinued and rescheduled. Once sufficiently warm, the subjects were timed walking up and down six stairs. The subjects then performed side-step-up movements using their (most) affected leg until he/she fatigued. These two tests were followed by fifteen minutes of rest. After rest, the subjects were fitted with five surface electromyography electrodes. This preparation includes: 1) Palpate and establish location of electrode placement, 2) shave area if necessary, 3) clean and exfoliate area to ensure electrode adhesion, 4) place electrode and secure with tape. Once the EMG system was prepared, the strength of the quadriceps and hamstrings were measured concentrically at 60°, 120°, and 180°/s and isometrically at a constant 60° of knee flexion. Each strength parameter involved up to three practice repetitions to offer the subject a chance to familiarize themselves, followed by three testing repetitions. The greatest of the three testing repetitions was then retained for analysis.

The subjects' final testing visit was held within the Biomechanics Laboratory and began with a measurement of their blood pressure. Once this was completed they warmed up for approximately five minutes on a cycle ergometer. Following this warm-up they changed into black form-fitting shorts if their clothes did not allow for proper marker adhesion. The participants were then prepared for electromyography measurement using the same procedure previously described. The subjects then performed maximum voluntary contractions for the four muscles being measured by electromyography. This was done against manual resistance for 4 seconds. After establishing these values, the subjects had reflective markers placed on them using pre-designated landmarks. Seventeen tracking markers were placed in locations allowing the 3D motion capture system to track lower-extremity joint and limb positions, while ten calibration markers were used to designate joint centers. Once marker and electrode locations were determined to be accurate, a five second static trial was filmed before the ten calibration markers were removed.

The participants were then completed three walking tasks (level ground, stair ascent, and stair descent) while traveling at a comfortable self-selected speed. Each trial was deemed successful if all markers stayed visible while the subjects struck the force plate with their entire foot at a normal speed. Any trials not meeting these criteria were discarded and recollected until five trials at each task were obtained.

Training Protocol

The volunteers randomly selected to the experimental group took part in three training sessions per week for a total of twelve weeks. These sessions lasted approximately 30 minutes

and included three exercises (Figure 1). Each exercise was performed for three sets of ten

repetitions, with the load determined as a percentage of the three repetition maximums

established during pre-testing. These percentages began at 60% and increased linearly to 85%.

Figure 1. Strengthening Exercises

Figure 1 - The three exercises performed from left to right: Leg press, knee extension, and lunge.

Data Analysis

After all data were collected, they were reduced using Qualisys Track Manager software.

Reduction in Qualisys was focused on the positions of the tracking markers for each subject

within the lab's coordinate system. Data from the static trial were used to create an individual

model for each subject. This model was then applied to each trial for each walking task. After

gaps from marker fallout were filled, each trial was exported into Visual3D where it was

analyzed.

Using Visual3D, segment masses, segment moments of inertia, and segment centers were

estimated based on subjects anthropometric data and the position data exported from Qualisys

Track Manager. Ankle and knee joint centers were determined as the midpoint of the medial and

lateral markers placed at each of these joints. The hip joint center was determined to be one-

fourth the distance between the markers placed on the subject's right and left greater trochanters.

A lower extremity link segment model was then created and applied to each gait trial to calculate joint torques and powers through inverse dynamics.

Inverse dynamics is a method of predicting unknown joint forces and joint torques through the application of Newtonian mechanics. This method utilizes a combination of kinematic data obtained from 3D motion capture and force data collected by some form of force measuring device, such as a force platform.

Kinematics refers to the position, velocity, acceleration, and displacement of a segment or joint within an environment and is used to describe the linear and angular pattern of that segments or joints movement. When determining each subject's kinematics, his or her lower extremity segment positions were calculated first. Using each participant's joint centers and segment mass centers, their hip, knee, and ankle joint angular positions were then calculated. Once joint angular positions were determined, each joint's angular displacement was calculated, followed by its angular velocity and finally, acceleration.

Inverse dynamics then utilizes measured ground reaction forces to determine three dimensional joint kinetics. This begins with the calculation of joint reaction forces (JRF_{Distal}) at each lower extremity joint, beginning with the ankle and moving proximally using *equation 1*: where (m) is the segment mass, (a_{cm}) is the acceleration of the segment center of mass, (mg) is the force vector due to gravity, and (f_{grf}) is the ground reaction force vector. Joint torques, which represent the internal torques produced by skeletal muscle and other tissues, were then calculated using *equation 2*: where joint torque (JT_{Distal}) is the product of the moment of inertia (I) and the angular acceleration (α) minus the vector describing the torque as a result of the joint reaction force (d_1 x JRF_{Joint}) and the vector describing the ground reaction force (d_2 x F_{GRF}). Using *equations 3 and 4*, distal joint reaction forces and torques were calculate: where the proximal

joint reaction force (JRF$_{Prox}$) is calculated as the product of the segment mass (m) and the

acceleration of the center of segment mass (a$_{cm}$), minus the gravity vector (mg) and the distal

joint reaction force (JRF$_{Distal}$). And the proximal joint torque is the product of the moment of

inertia (I) and the angular acceleration (α) minus the vector that describes the torque as a result of

the proximal joint reaction force (d$_1$ x F$_{JRF\_Prox}$), the vector describing the distal joint reaction

force (d$_2$ x F$_{JRF\_Distal}$), and the distal joint torque (JT$_{Distal}$).

$$1. \quad JRF_{Distal} = ma_{cm} - mg - f_{grf}$$

$$2. \quad JT_{Distal} = I\alpha - (d_1 \times JRF_{Joint}) - (d_2 \times F_{GRF})$$

$$3. \quad JRF_{Prox} = ma_{cm} - mg - JRF_{Distal}$$

$$4. \quad JT_{Prox} = I\alpha - (d_1 \times F_{JRF\_Prox}) - (d_2 \times F_{JRF\_Distal}) - JT_{Distal}$$

Each joint force and torque calculation was completed within the individual segments

coordinate system and for each frame of data. Positive torques illustrated net extensor, plantar

flexor, internal rotation, and adduction directions. Negative net torques represented flexor,

dorsiflexor, external rotation, and abduction directions. Support torque was calculated as the

sum of the joint torques.

Once joint torques and kinematics were calculated, joint powers were determined using

equation 5: where joint power (P) is the product of joint torque (JT) and the difference in

segmental angular velocities (ω$_{Proximal}$ - ω$_{Distal}$). Joint power was calculated in the sagittal,

frontal, and transverse plane for each lower extremity joint and summed to illustrate total power.

The area under each power curve was used to determine positive, negative, and total work.

$$5. \quad P = JT \times (\omega_{Proximal} - \omega_{Distal})$$

Biomechanical Knee Model

In combination with the kinematics and kinetics calculated through inverse dynamics, a knee model developed by DeVita et al. (Figure 2) was applied to determine quadriceps muscle length, velocity, force, power, and work, as well as knee shear and compressive forces.

Figure 2. Biomechanical Knee Model
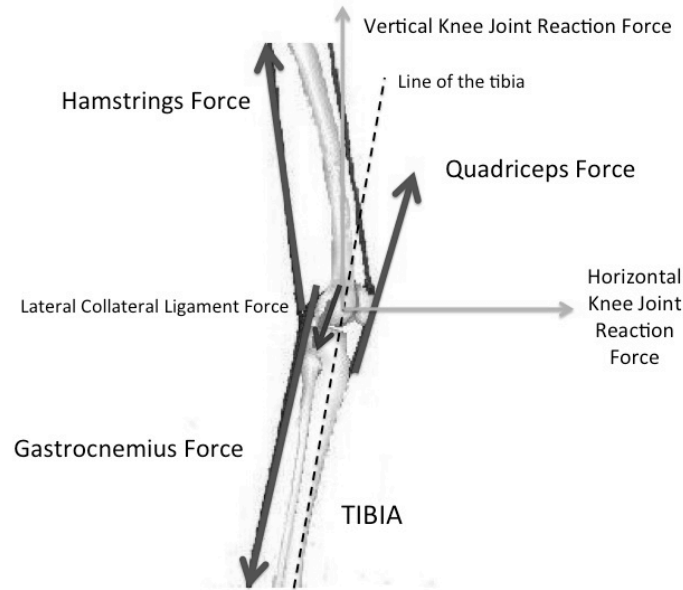
Figure 2 - Biomechanical model used to determine knee joint loads and muscle forces.

The model calculates muscle forces as the dividend of the joint torques calculated through inverse dynamics, and moment arms obtained from the literature (Chow, Darling, & Ehrhardt, 1999). Gastrocnemius force (G) was calculated as the dividend of the ankle plantar flexor torque (At) and its moment arm (ATd) relative to its cross-sectional area (PCA), using *equation 6*. The direction of this calculation was determined using the heel and knee marker positions. Hamstrings contribution to the hip extensor torque (Hp) was then calculated before hamstrings force can be determined. This was done using *equation 7*: where (Ham PCA) is the hamstring cross-sectional area, (GM PCA) represents the gastrocnemius cross-sectional area, and where (Hd) and (GMd) are the hamstring and gluteus maximus moment arms. Hamstrings force

(H) was then calculated using *equation 8*: where the product of the hamstring contribution to the hip extensor torque (Hp) and the hip extensor torque (Het) is divided by the hamstrings moment arm (Hd). Quadriceps force (Q) was then calculated using *equation 9*: where (Kt) is the knee extensor torque and (Qd) is the quadriceps moment arm.

6. $G = At/Atd*PCA$

7. $Hp = [Ham\ PCA/\ (Ham\ PCA + GM\ PCA)]\ (Hd/GMd)$

8. $H = Hp\ (Het)/Hd$

9. $Q = [Kt+H\ (Hd) + G\ (Gd)]\ /Qd$

The predicted hamstring, quadriceps, and gastrocnemius forces and their directions were then combined with the joint reaction forces to determine knee shear forces (Ks) and knee compressive forces (Kc), using *equations 10 and 11*: where Kz and Ky are the vertical and horizontal knee joint reaction forces and Lss is the force produced by the lateral support structures, such as ligaments.

10. $Ks = G\sin \alpha - H\sin \beta + Q\sin \phi - Kz\sin \lambda + Ky\cos \lambda$

11. $Kc = G\cos \alpha + H\cos \beta + Q\cos \phi + Kz\cos \lambda + Ky\sin \lambda + Lss$

Statistical Analysis

Participant characteristics, WOMAC, strength, functional task performance, temporal gait parameters, joint kinetics, and muscle biomechanics were analyzed using a 2x2 mixed model ANOVA with repeated measures on time and between measurements on group. Alpha level was set at <0.05 for all tests of significance.

RESULTS

It was hypothesized that increased quadriceps muscle strength acquired through a 12-week quadriceps-strengthening protocol would result in negligible changes to quadriceps muscle biomechanics in adults with tibiofemoral knee OA. This chapter describes the symptomatic, strength, joint kinetic, and muscle biomechanics outcomes used to test this hypothesis.

Participant Characteristics

The study groups were similar at baseline in age, height, and disease severity (K/L score). No interaction or main effects were observed in mass or body mass index as a result of the treatment (Table 1).

Table 1. Participant Demographics

	Control		Trained	
	Pre	**Post**	**Pre**	**Post**
Number	4		6	
Age	57 ± 4.7		54 ± 5.8	
Height (m)	1.7 ± .10		1.7 ± .04	
K/L Score	3.2 ± 0.5		2.8 ± .04	
Mass (kg)	80 ± 22.2	81 ± 22.8	78 ± 8.9	78 ± 9.0
BMI (kg/m^2)	28 ± 4.0	28 ± 4.2	27 ± 3.2	27 ± 3.2

Table 1 – Group demographics separated by time for mass and body mass index.

Strength Values

A group*time interaction (p=0.014) was observed in isometric quadriceps strength (Figure 3). Follow-up t-tests found a significant (p=0.04) strength increase in the trained group but no between-group differences at pre- or post-test (p=0.04). No significant main or interaction effects were observed in hamstrings muscle strength (Figure 3).

Figure 3. Muscle Strength
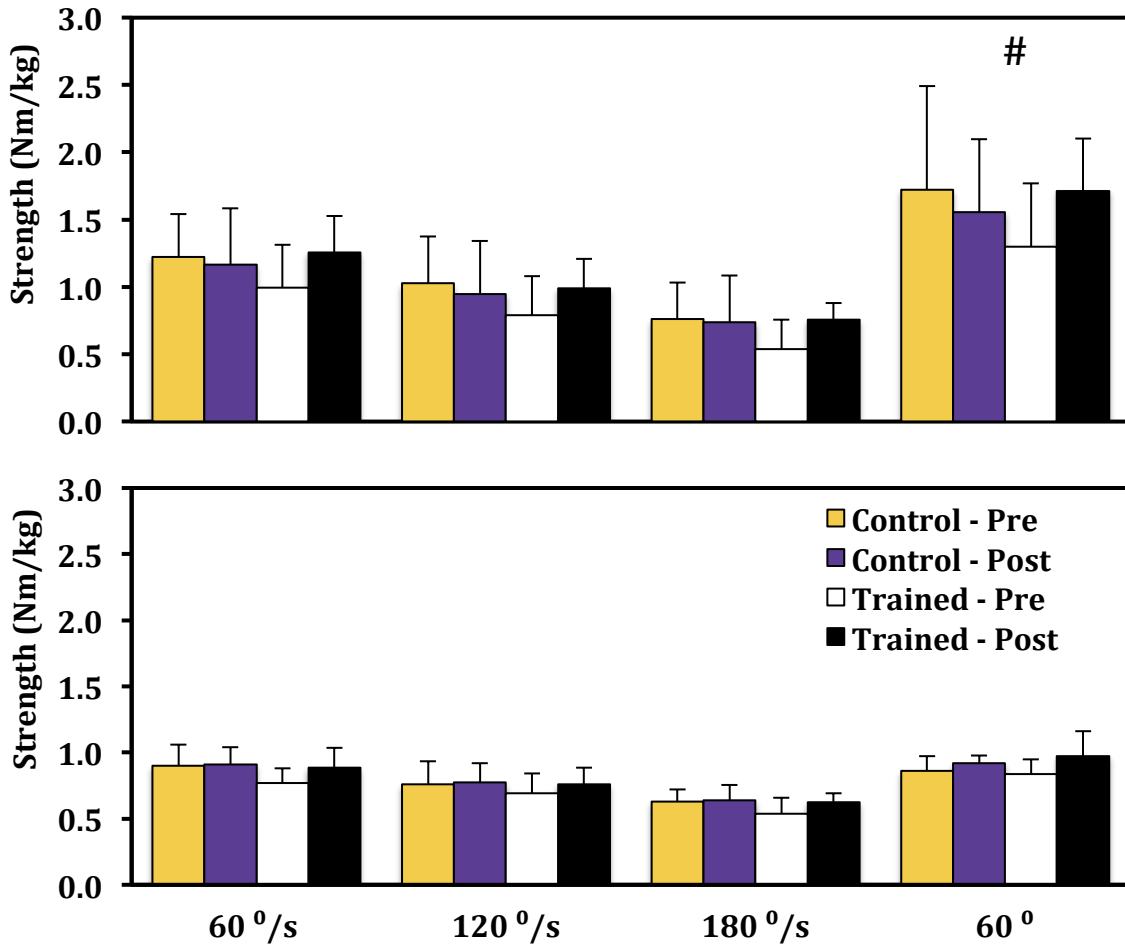
Figure 3 – Mean quadriceps (top) and hamstrings (bottom) strength separated by group, time, and task. [#]Denotes significant group*time interaction effect with p<0.05.

Symptoms and Physical Function

Symptom data collected via WOMAC subjective osteoarthritis questionnaires (Figure 4) showed group*time interactions in pain (p=0.005), physical function (p=0.008), and total (p=0.009) categories, with the trained group improving by 58%, 93%, and 59%, respectively. T-tests revealed the groups did not differ at pre-test, but that the control group reported significantly greater values for all three categories at post-test (all p<0.005) and that only the trained group showed significantly different values from pre- to post-test (all p<0.03).

Figure 4. WOMAC Scores
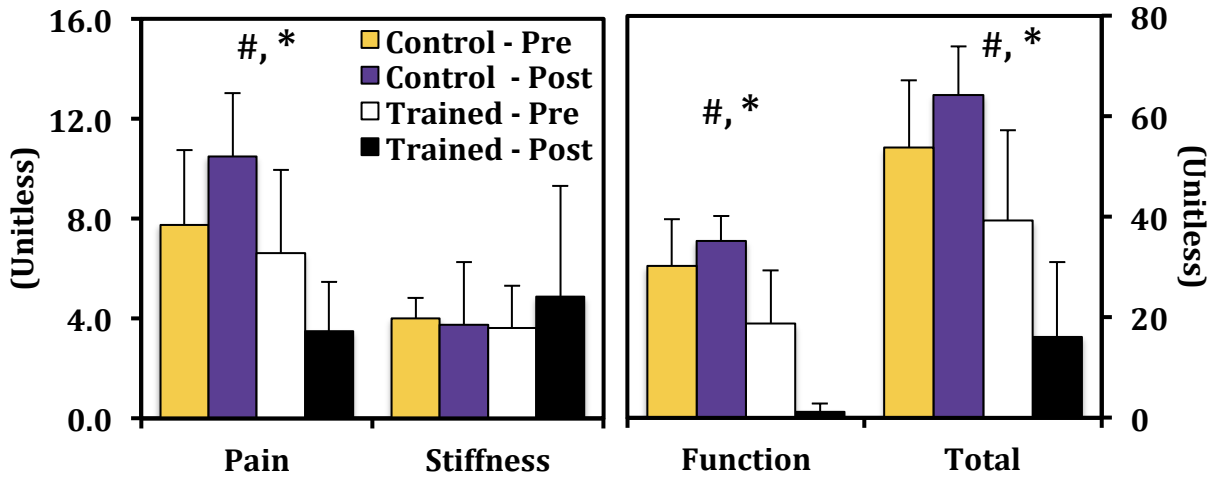
Figure 4 – Symptoms and physical function separated by group, time, and task. #Denotes significant group*time interaction. * Signifies GROUP main effect (Both p<0.05).

No interaction effects were observed in either timed stair gait task (Figure 5). A significant time (p=0.006) main effect was observed in stair ascent, with participants traveling 8% faster at post-test. Control participants ascended stairs 19% faster than trained participants, but this was not significant (p=0.085).

Figure 5. Timed Stair Tasks

Figure 5 – Pooled mean self-selected stair ascent (left) and stair descent (right) times separated by group (untrained-gold, trained-purple) and time (pre-test-white, post-test-black). $^{\alpha}$ Denotes significant TIME main effect (p<0.05).

Joint and Muscle Biomechanics During Level Walking

During level walking no interaction, group main, or time main effects were observed in self-selected velocity, stride length, cadence, or peak knee flexion angle (Table 2). Significant group*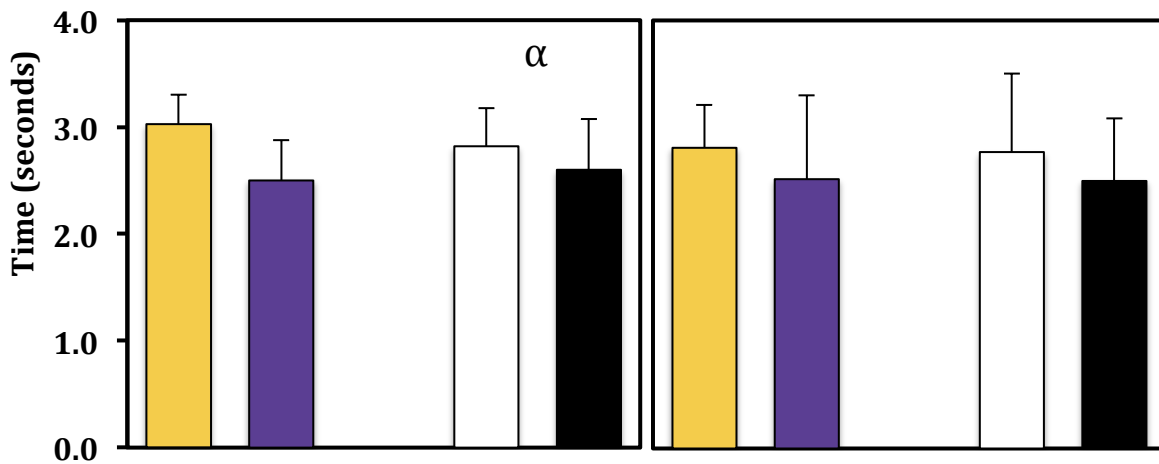time interactions were observed in knee extensor torque ($p=0.005$)(Figure 6) and knee joint power ($p=0.03$)(Figure 6). Independent t-tests found the groups did not differ at baseline or follow-up for either measure, while dependent t-tests showed the control group remained unchanged, but that the trained group experienced significantly increases in both measures (both $p<0.05$). No differences were observed in knee joint work (Figure 7).

Table 2. Mean ± SD Level Walking Temporal Parameters and Joint Kinematics

	Group		Time	
	Untrained	Trained	Pre-Test	Post-Test
Velocity (m/s)	1.42 ± 0.09	1.46 ± 0.12	1.44 ± 0.10	1.45 ± 0.12
Stride Length (m)	1.43 ± 0.07	1.43 ± 0.06	1.43 ± 0.07	1.42 ± 0.06
Cadence (steps/min)	119 ± 8	122 ± 7	120 ± 6	122 ± 9
Knee Flexion Angle (Deg)	9.4 ± 8.3	10.2 ± 6.0	10.5 ± 7.2	9.7 ± 6.9

Table 2 – Pooled group and time means for level walking speed, stride length, cadence, and knee flexion angle.

Figures 6. Level Walking Knee Joint Kinetics
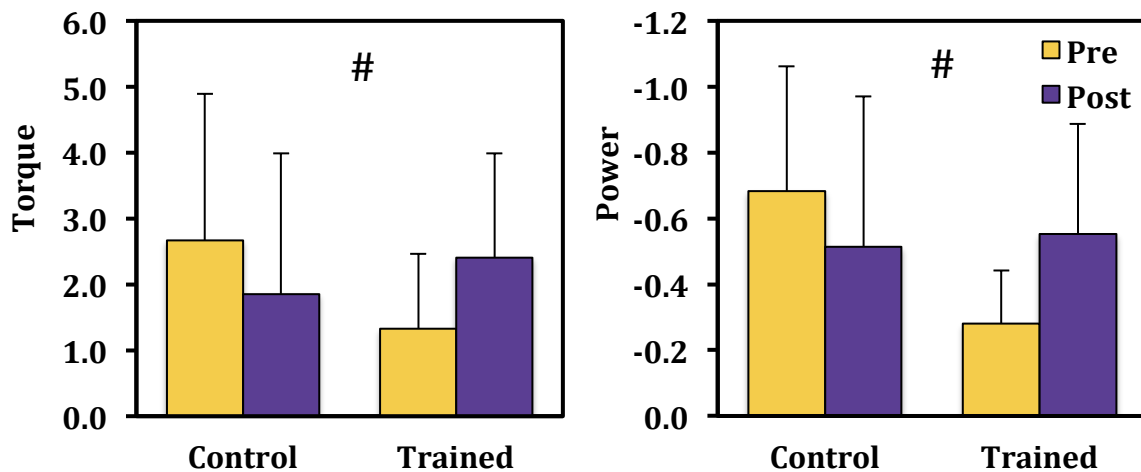
Figure 6 – Mean knee extensor torques (%Bw*ht) and powers (W/kg) separated by group. [#]Denotes significant group*time interaction ($p<0.05$).

Figure 7. Level Walking Knee Joint Work
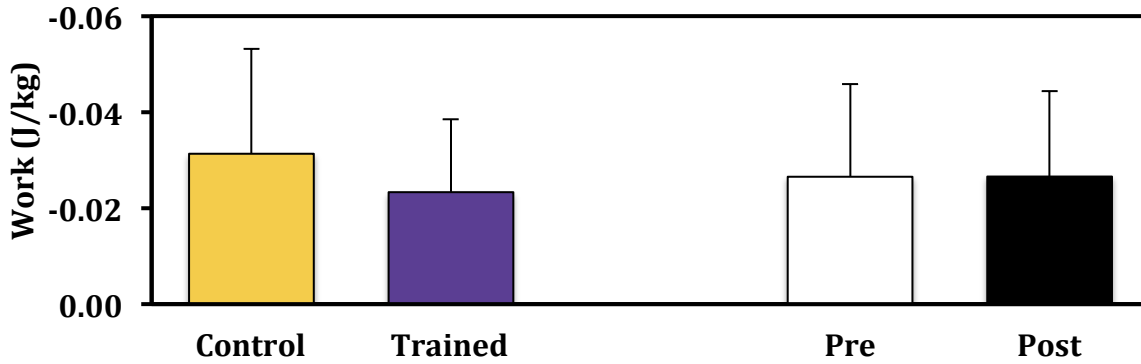
Figure 7 - Knee joint work separated into pooled group and time means.

In quadriceps muscle biomechanics group*time interactions in force (p=0.005)(Figure 8) and negative work (p=0.03)(Figure 9) were observed. T-tests found the groups to be indifferent at both pre- and post-test, and that the 49% increase in quadriceps force experienced by the trained group was the only within-group difference of statistical significance (p=0.03).

A group*time interaction in knee compressive force (p=0.007) was also observed (Figure 11). Groups did not differ from one another at baseline or follow-up, and neither experienced significant within-group differences between tests.

Figure 8. Mean Quadriceps Force Curves During Level Walking
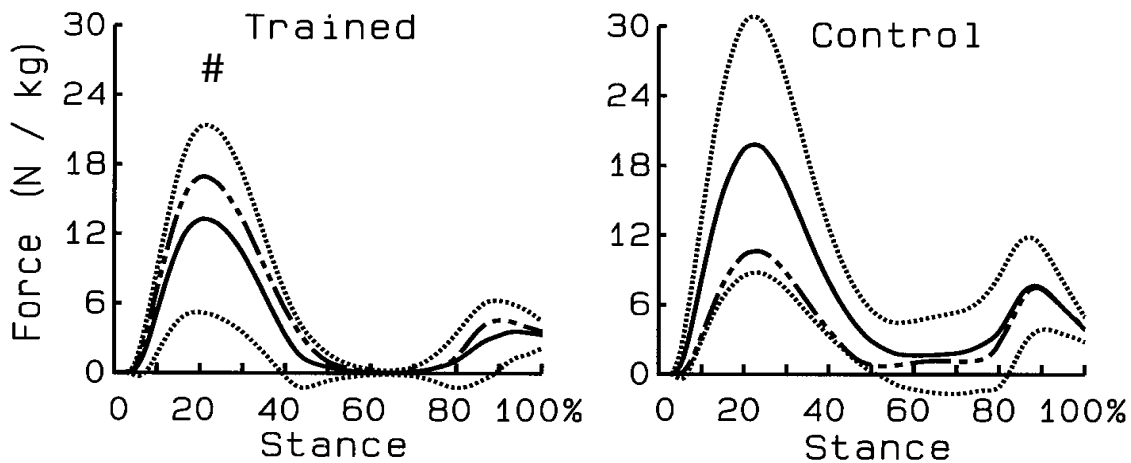
Figure 8 – Solid lines represent pre-test means, dashed lines represent post-test means, and dotted lines represent one pre-test SD. [#]Denotes significant group*time interaction with p<0.05.

Table 3. Mean ± SD Peak Quadriceps Force (N/kg) During Level Walking[#]

Control		Trained	
Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
24.5 ± 5.7	13.1 ± 8.6	12.0 ± 5.7	17.1 ± 7.3

Table 3 - Mean peak quadriceps force values during level walking, separated by group and time. [#]Denotes significant group*time interaction with $p < 0.05$.

Figure 9. Mean Quadriceps Power Curves During Level Walking
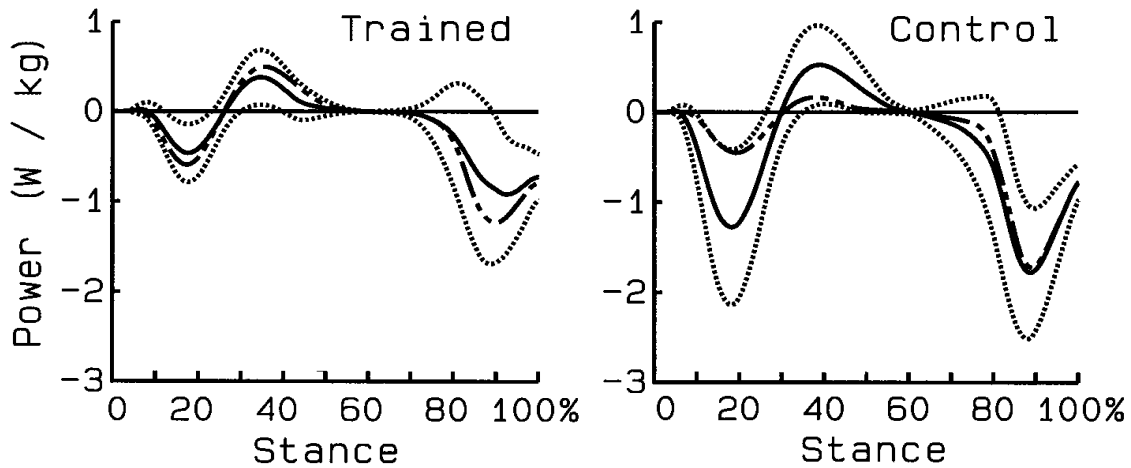
Figure 9 –Solid lines represent pre-test means, dashed lines represent post-test means, and dotted lines represent one pre-test SD.

Table 4. Mean ± SD Peak Quadriceps Power (W/kg) During Level Walking

Group		Time	
Control	**Trained**	**Pre-Test**	**Post-Test**
-1.71 ± 0.68	-1.12 ± 0.58	-1.29 ± 0.77	-1.44 ± 0.59

Table 4 – Pooled group and time mean peak quadriceps powers during level walking.

Figure 10. Quadriceps Muscle Work During Level Walking
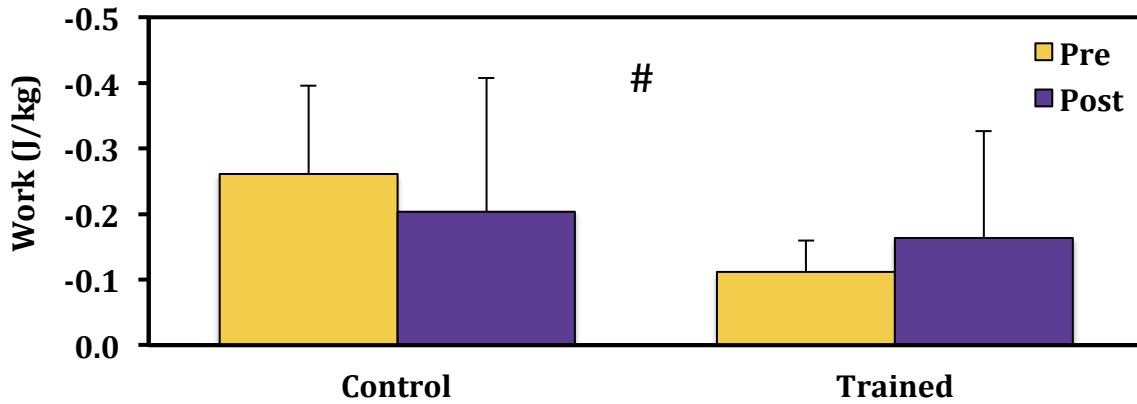
Figures 10 – Quadriceps work separated by group and time. #Denotes group*time interaction effect p<0.05.

Figure 11. Knee Compressive Force During Level Walking
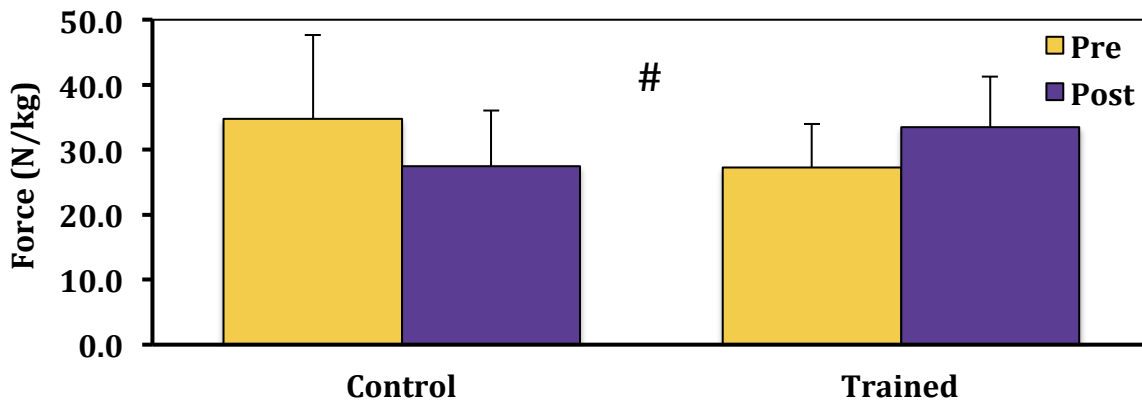
Figures 11 – Knee compressive force separated by group and time. #Denotes group*time interaction effect p<0.05.

Joint and Muscle Biomechanics During Stair Ascent

A group*time interaction (p=0.011) in stair ascent velocity was observed (Table 5). Follow-up independent t-tests showed the groups did not differ from one another at either test and dependent t-tests found pre- and post-test means did not significantly differ within either group. No interaction or main effects were observed in knee extensor torque, joint power, or joint work (Figure 12).

Table 5. Stair Ascent Velocity (m/s)[#]

Untrained		Trained	
Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
.72 ± 0.13	0.59 ± 0.09	0.61 ± 0.11	0.68 ± 0.09

Table 5 –Stair ascent walking velocity means ± SD separated by group and time.
[#]Denotes group*time interaction effect p<0.05

Figure 12. Knee Joint Kinetics During Stair Ascent
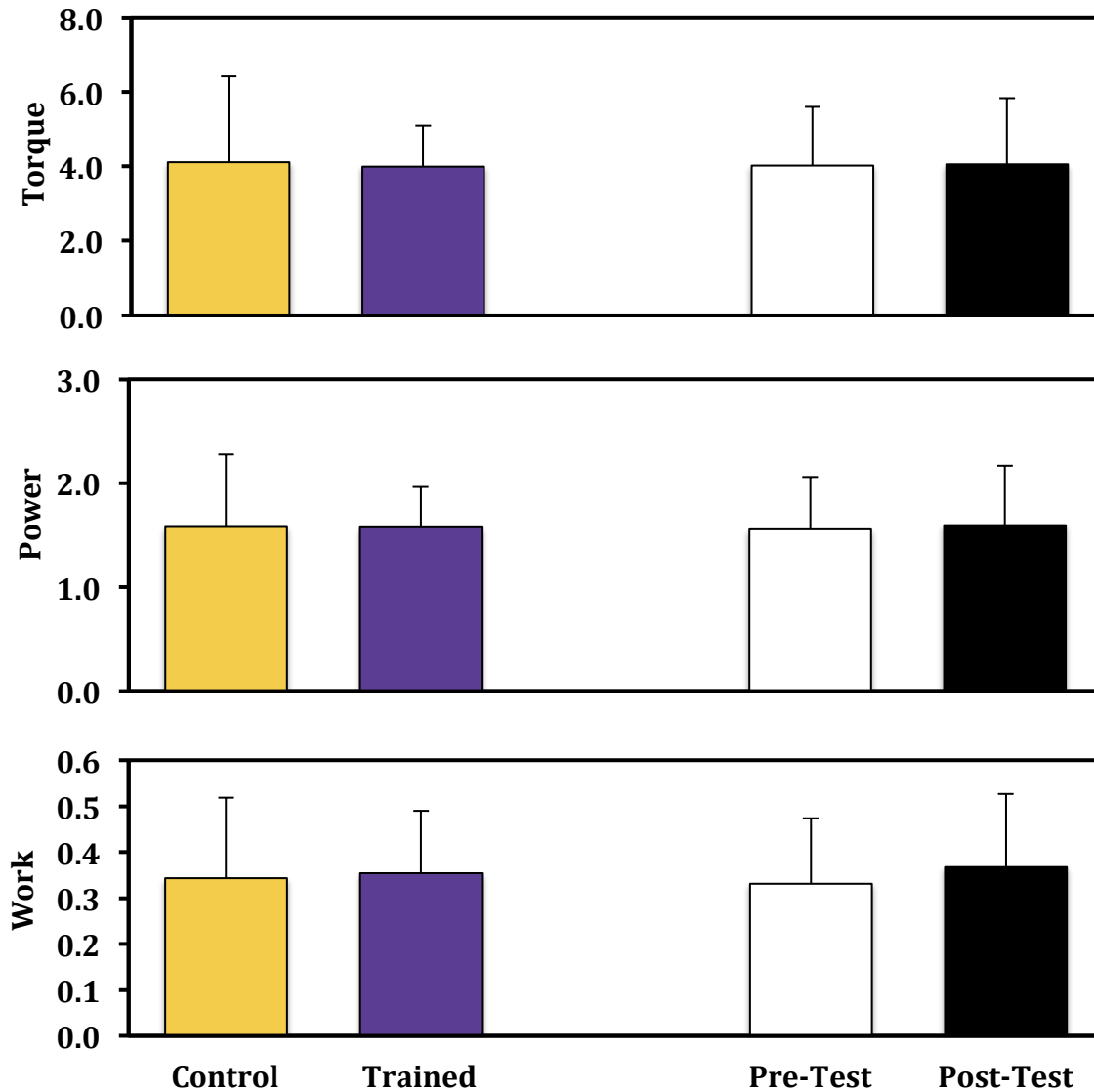
Figure 12 – Pooled group and time means for knee joint torque (%Bw*ht), power (W/kg), and work (J/kg) during stair ascent.

Comparisons of quadriceps biomechanics showed significant group*time interactions in force (p=0.009) (Figure 13) and work (p=0.05) (Figure 15), but no differences in quadriceps muscle power (Figure 14). A group*time interaction was also observed in knee joint compressive force (p=0.004)(Figure 16). The control and trained group did not differ in any of these measures at baseline or follow-up. T-tests showed that only the trained group experienced differences between pre- and post-test values, as the group increased force by 14% (p=0.04), work by 22% (p=0.03), and compressive force by 8% (p=0.03).

Figure 13. Mean Quadriceps Force Curves During Stair Ascent
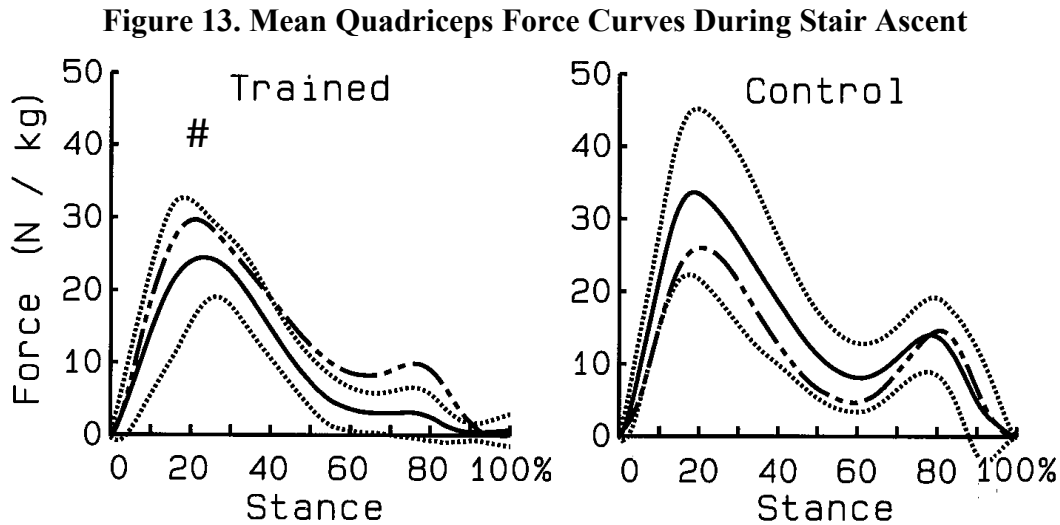
Figure 13 – Solid lines represent pre-test means, dashed lines represent post-test means, and dotted lines represent one pre-test SD. [#]Denotes group*time interaction effect p<0.05.

Table 6. Mean ± SD Peak Quadriceps Force (N/kg) During Stair Ascent[#]

Group		Time	
Control	**Trained**	**Pre-Test**	**Post-Test**
30 ± 12.5	30 ± 4.9	30 ± 8.7	30 ± 8.6

Table 6 - Pooled group and time peak quadriceps force means during stair ascent. [#]Denotes group*time interaction effect p<0.05.

Figure 14. Mean Quadriceps Muscle Power Curves During Stair Ascent

Figure 14 –Solid lines represent pre-test values, dashed lines represent post-test values, and dotted lines represent one pre-test mean standard deviation.

Table 7. Mean ± SD Peak Quadriceps Power (W/kg) During Stair Ascent

Group		Time	
Control	**Trained**	**Pre-Test**	**Post-Test**
2.8 ± 0.6	2.6 ± 0.5	2.7 ± 0.6	2.7 ± 0.6

Table 7 - Pooled group and time peak quadriceps power means during stair ascent.

Figure 15. Quadriceps Muscle Work During Stair Ascent
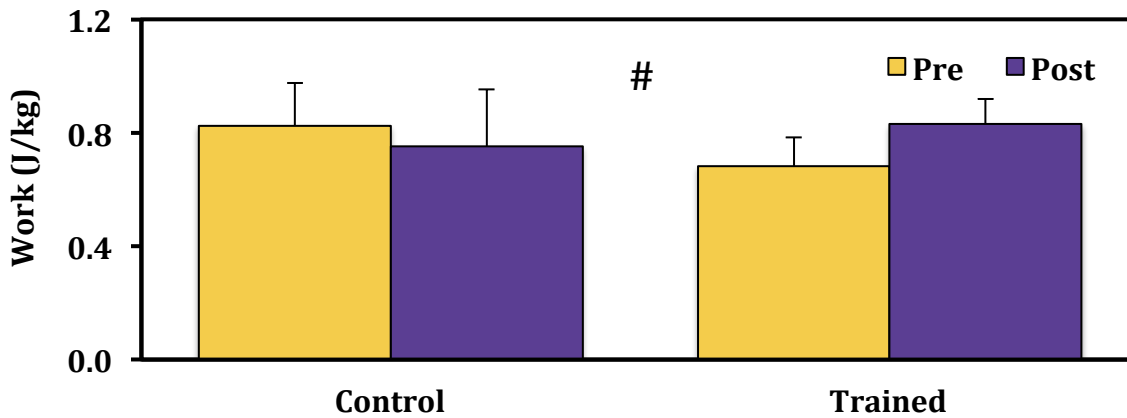
Figure 15 – Quadriceps work means separated by group. [#]Denotes group*time interaction effect p<0.05.

Figure 16. Knee Compressive Force During Stair Ascent
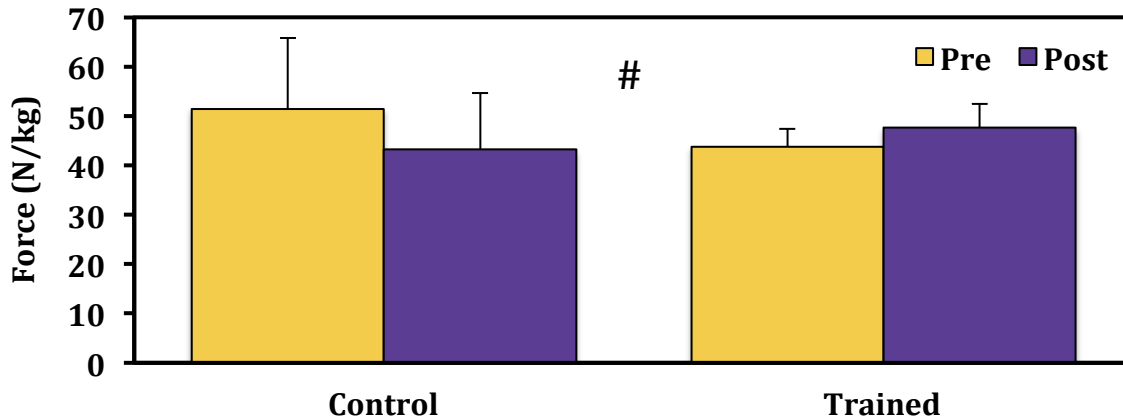
Figures 16– Knee compressive force separated by. [#]Denotes group*time interaction effect p<0.05.

Joint and Muscle Biomechanics During Stair Descent

Similar to the stair ascent task, a group*time effect was observed in stair descent walking velocity (p=0.03) (Table 8). Independent t-tests showed the groups were not different at pre- or post-test, and that only the 13% increase exhibited by the trained group was statistically significant (p=0.04). No interaction, group main, or time main effects were observed in knee extensor torque, knee joint power, or knee joint work (Figure 16).

Table 8. Stair Descent Velocity (m/s)[#]

Control		Trained	
Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
0.60 ± 0.06	0.57 ± 0.12	0.54 ± 0.07	0.62 ± 0.04

Table 8 – Pooled group and time stair descent walking velocity means ± SD.
[#]Denotes group*time interaction effect p<0.05.

Figure 17. Knee Joint Kinetics During Stair Descent
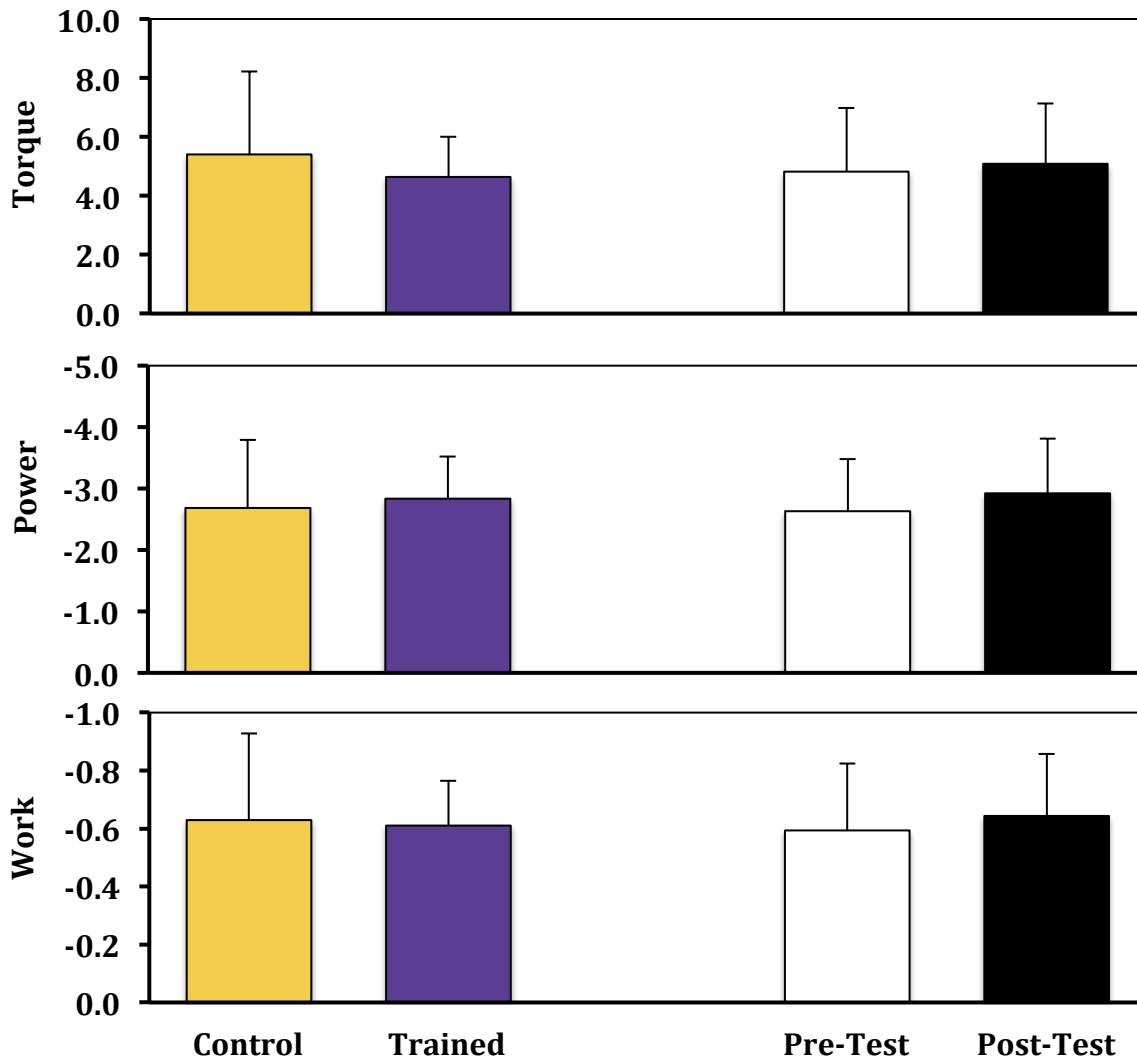
Figure 17 – Pooled group and time means for knee joint torque (%Bw*ht), power (W/kg), and work (J/kg) during stair descent.

Additionally, no significant group main, time main, or group*time interaction effects in quadriceps force (Figure 17), power (Figure 18), or work (Figure 19) were observed. However, a group*time interaction ($p=0.032$) was observed in knee compressive force (Figure 20). Follow-up independent t-tests found no between-group differences at pre- or post-test, and dependent t-tests showed no significant within group differences from test to test.
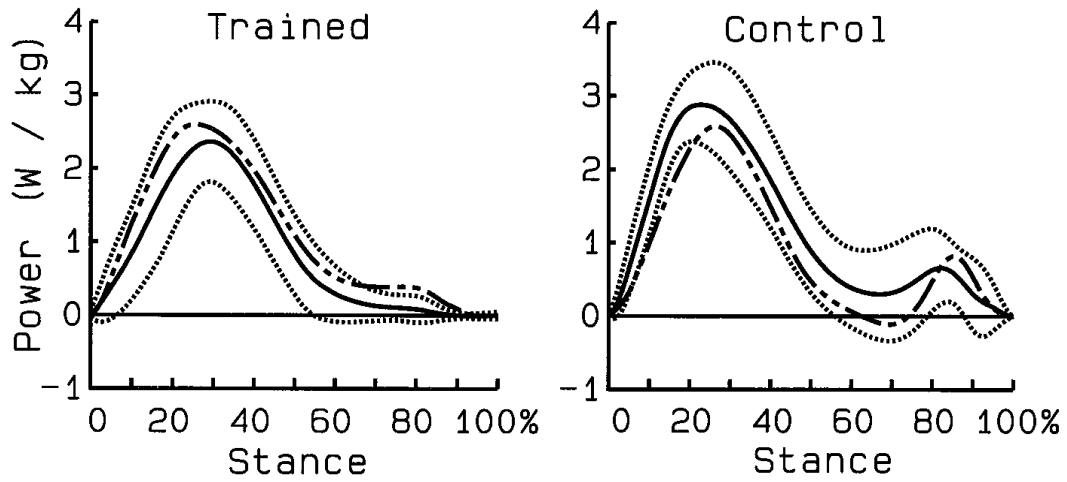
Figure 18. Mean Quadriceps Force Curves During Stair Descent
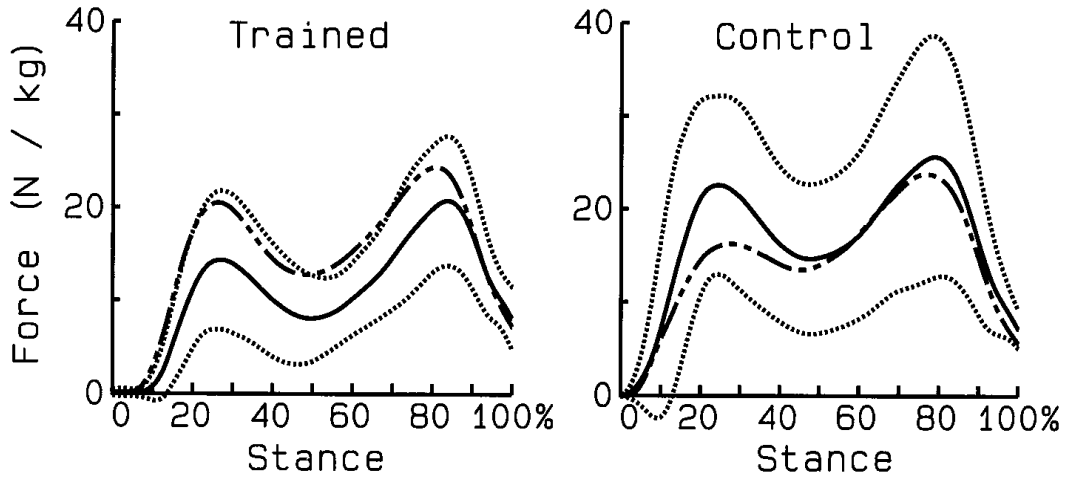
Figure 18 – Solid lines represent pre-test means, dashed lines represent post-test means, and dotted lines represent one pre-test SD.

Table 9. Mean ± SD Peak Quadriceps Force (N/kg) During Stair Descent

Group		Time	
Control	**Trained**	**Pre-Test**	**Post-Test**
29 ± 12.3	25 ± 5.9	27 ± 10.1	26 ± 8.3

Table 9 - Pooled group and time peak quadriceps force means during stair descent.

Figure 19. Mean Quadriceps Power Curves During Stair Descent
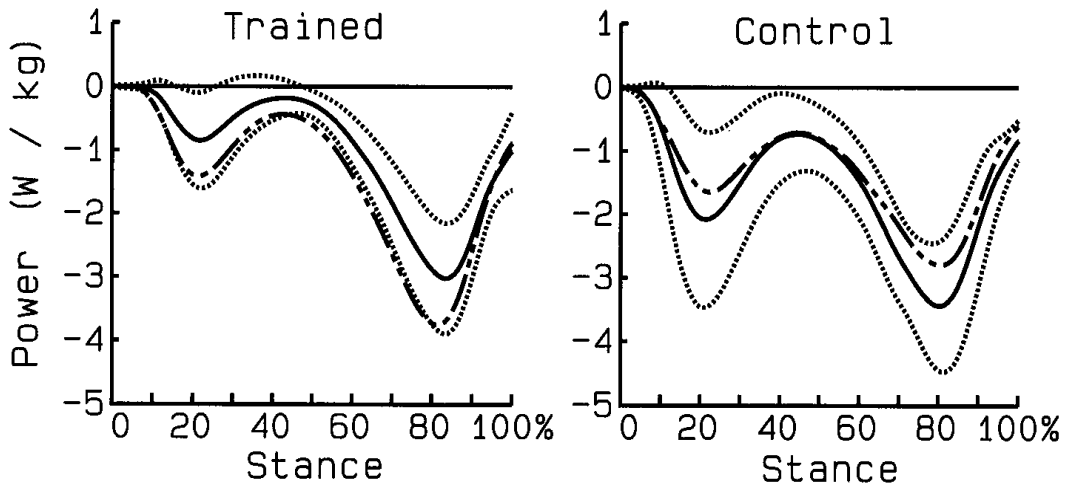
Figure 19 – Solid lines represent pre-test means, dashed lines represent post-test means, and dotted lines represent one pre-test SD.

Table 10. Mean ± SD Peak Quadriceps Power (W/kg) During Stair Descent

Group		Time	
Control	Trained	Pre-Test	Post-Test
-3.3 ± 0.9	-3.6 ± 0.5	-3.4 ± 0.7	-3.5 ± 0.8

Table 10 - Pooled group and time peak quadriceps power means during stair descent.

## Figure 20. Quadriceps Muscle Work During Stair Descent
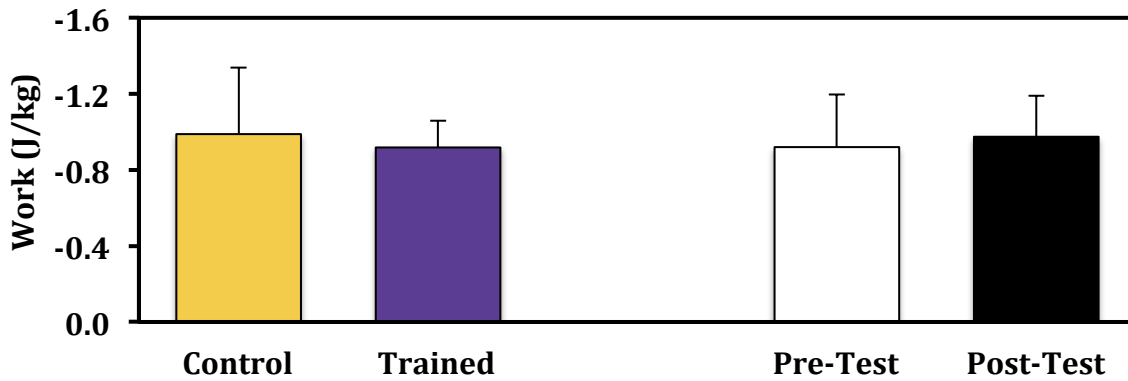
Figure 20 – Quad work separated into pooled group and time means.

Figure 21. Knee Joint Compressive Force During Stair Descent
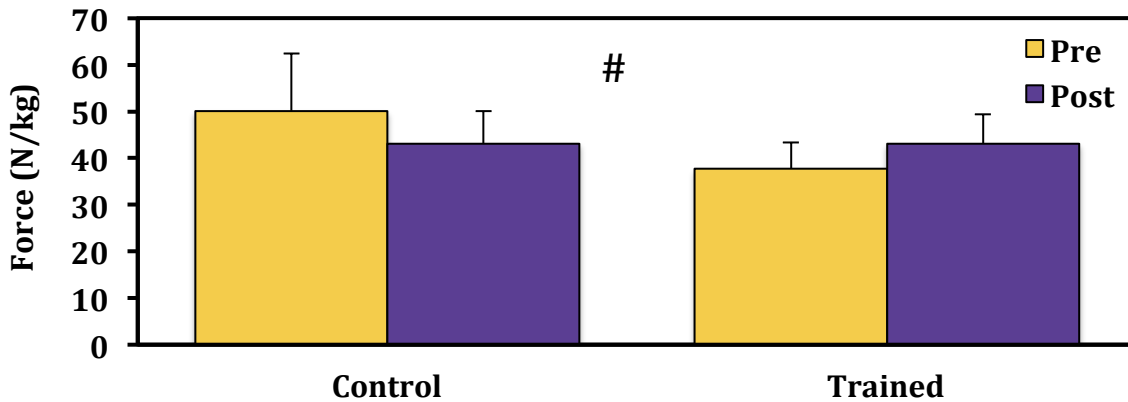
Figure 21 – Knee compressive force means separated by group. [#]Denotes group*time interaction $p<0.05$.

The effects of quadriceps strengthening exercise were evident as the training group experienced significant improvements in disease symptoms, physical function, and muscle strength. Group*time interactions were observed in knee extensor torque, knee joint power,

quadriceps force, quadriceps work, and knee compressive force during level walking, self-selected walking velocity, quadriceps force, quadriceps work, and knee compressive force during stair ascent, as well as self-selected walking velocity and knee compressive force during stair descent. The groups did not differ from one another in any of these parameters at baseline, and only in pain, physical function, and total WOMAC categories did they differ at follow-up. The control group did not experience any changes from baseline to follow-up in any measure, while the trained group experienced significant increases in all measures with the exception of level walking knee compressive force, stair ascent walking velocity, and stair descent knee compressive force.

DISCUSSION

The purpose of this study was to determine the effects of quadriceps-strengthening exercise on quadriceps muscle biomechanics in adults with tibiofemoral knee OA. The positive effects of exercise on the symptoms of knee OA are well documented and it has been suggested that improved or altered quadriceps muscle biomechanics are behind this mechanism, however there is no evidence supporting this theory (Baker et al., 2001; Mikesky, Meyer, & Thompson, 2000). The study hypothesis was that strengthening the quadriceps muscles would lead to improved symptoms and physical function, but that the biomechanics of the quadriceps musculature would be unchanged.

This study was designed to compare symptomatic, thigh strength, knee joint kinetic, and quadriceps muscle biomechanics in adults with tibiofemoral knee OA before and after 12 weeks of strengthening exercise or 12 weeks of unchanged physical activity. This chapter will address the results of this study and how they relate to current literature and our original hypothesis. It is organized into the following sections: 1) Development of the Hypothesis, 2) Strength, Symptoms, and Physical Function, 3) Level Walking Joint and Quadriceps Muscle Biomechanics, 4) Stair Gait Joint and Muscle Biomechanics 5) Summary, and 6) Conclusion.

Development of the Hypothesis

Osteoarthritis is a degenerative joint disease most commonly effecting adults aged 45 or older. In the United States, it is considered a leading cause for disability and hospitalization and has established itself as one of the fastest growing chronic conditions (J. Hootman & Helmick, 2006). Osteoarthritis most commonly affects the knee joint and is characterized by the presence of joint pain, articular cartilage loss, and the exposure of subchondral bone. In the presence of

knee OA, the quadriceps musculature experience substantial strength loss. In combination with joint pain and degradation, this weakness may impair an individual's ability to perform many of the activities that allow them to maintain independence, ultimately decreasing their quality of life.

Most osteoarthritis treatment options are limited to targeting the symptoms of the disease. Many of these options are also associated with side effects and/or costly maintenance procedures. Exercise has become a popular treatment option due to its cost-effectiveness and the positive secondary outcomes it is associated with (Pinto, Robertson, Hansen, & Abbott, 2012). Plentiful literature regarding its positive effects on the symptoms of knee OA is available and it is now widely prescribed by physicians, therapists, and other rehabilitation clinicians (Huang, Lin, Yang, & Lee, 2003; M. V. Hurley & Scott, 1998; Lim, Hinman, Wrigley, Sharma, & Bennell, 2008; McQuade & de Oliveira, 2011b; Messier, Thompson, & Ettinger, 1997; Rogind et al., 1998; T. J. Wang et al., 2011). Of the many modes of exercise studied, quadriceps-strengthening exercise has been shown to both decrease pain and improve the physical function of those with knee OA (Huang, Lin, Yang, & Lee, 2003; Jan, Lin, Liau, Lin, & Lin, 2008; D. H. Lin, Lin, Lin, & Jan, 2009; McQuade & de Oliveira, 2011; T. J. Wang et al., 2011). Still unknown, however, is the role of exercise in the pain relief mechanism.

Studies have suggested a theory that by increasing quadriceps strength, one improves their function during activities of daily living such as walking and climbing stairs (Baker et al., 2001; Mikesky, Meyer, & Thompson, 2000). However, no literature supporting this theory exists. In fact, there are data showing that even after an increase in quadriceps muscle strength no changes occur to knee extensor torque, a measure indicative of unchanged quadriceps function (Foroughi et al., 2011).

Strength, Symptoms, and Physical Function

Consistent with literature, the individuals included in this study exhibited significantly

lower quadriceps strength values (p=0.01) than healthy adults who were obtained from a lab

database and were an average of 16 years older (Figure 19) (Hortobagyi, Garry, Holbert, &

DeVita, 2004; Lewek, Rudolph, & Snyder-Mackler, 2004).

Figure 22. Healthy vs. Knee OA Isometric Quadriceps Strength
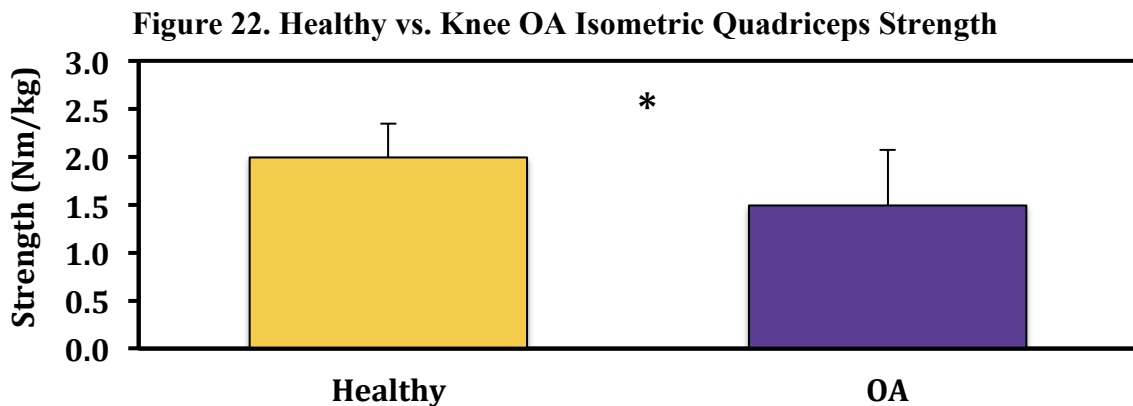
Figure 22 – Baseline Isometric quadriceps strength at 60° of knee flexion between healthy older adults and those included in this study. Older adult data was taken from a laboratory database. * Denotes significant GROUP main effect (p<0.05).

At baseline, the study groups exhibited similar quadriceps and hamstrings strength values

and no differences in timed stair ascent or descent tasks were seen. The groups also reported

comparable pain, stiffness, function, and total WOMAC scores, although each group's scores

were much higher than those expected of healthy adults. Despite suffering from only moderate

OA, the study participants were experiencing substantial functional deficits, pain, and weakness

at baseline.

As expected, analyses showed significant increases in isometric quadriceps strength. The

trained group also experienced increases in quadriceps strength of 26% in the 60°/s concentric

task (p=0.05), 25% in the 120°/s task (p=0.08), and 41% in the 180°/s task (p=0.1), but these

changes were not of statistical significance. However, each of these strength increases was comparable to values from the literature (Table 11).

Table 11. Strength Gains vs. Literature Values

Study	Strength Increase
Rogind et al., 1998	21%
Foroughi et al., 2010	23%
Lim et al., 2008	27%
Present Study	**25 - 41%**
Foroughi et al., 2011	47%

Table 11 – Strength increases for the present study compared to those reported in the literature.

The trained group also reported significantly lower pain, physical function, and total WOMAC scores at follow-up. These reductions were enough to return the trained groups pain and physical function values to asymptomatic levels (Figure 20), even though this group still exhibited 21% lower quadriceps strength than the healthy adults previously described.

Figure 23. Pain and Function Scores vs. Literature Values
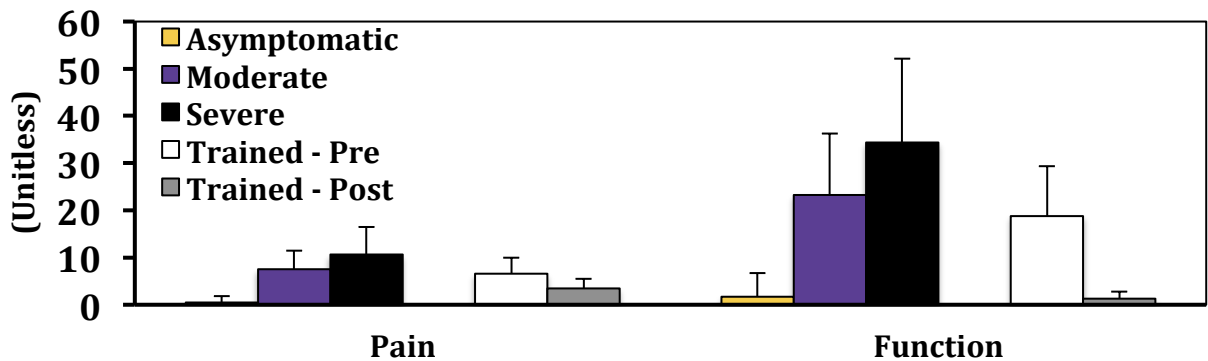
Figure 23 – Pre and post-test pain and function WOMAC scores for the trained group vs. those reported by Astephen et al. for three disease severities (2008).

These findings reinforce the notion that exercise plays an important role in pain relief and improved function. The relationship between strength increases and pain is still unclear, though, as a participant that showed the greatest improvement in total WOMAC score (91%) only

exhibited a 23% increase in strength, when the group averages for these measures were 49% and 37%, respectively. Responses to exercise like the one previously described suggest that large strength increases may not be necessary for pain relief, and that unloaded joint movement or minimal strength gains can cause considerable improvements in symptoms.

Level Walking Joint and Muscle Biomechanics

While walking on level ground, both groups exhibited similar walking speeds, step cadences, and stride lengths at baseline. There were also no baseline differences in knee flexion angle, a measure used to determine quadriceps contributions to locomotion, in knee extensor torque, power, work, or in knee compressive force between the groups. Similarly, no between-group differences in quadriceps force, power, or work existed at baseline.

Increased knee extensor torque and knee joint power experienced by the trained group are contradictory to the findings of Foroughi et al., where sagittal plane joint kinetics were unchanged following a quadriceps strengthening protocol (2011). Significant increases in quadriceps force, negative quadriceps work, and knee compressive force were also unexpected. Increased knee extensor torque explains increased quadriceps force, a parameter derived from knee extensor torque itself, while increased quadriceps force explains increased knee compressive force, which is the product of joint reaction forces and the forces produced by muscles articulating the knee. This increase in compressive force contradicts the theory that suggests an increase in quadriceps function reduces pain by reducing knee joint loads (Baker et al., 2001; Mikesky, Meyer, & Thompson, 2000).

Interestingly, the groups used unchanged temporal parameters to walk at unchanged self-selected velocities, results contrary to what would be expected with increased knee extensor

torques, but consistent with the findings of Astephen et al. (2008). Although, it has been shown that exercise can actually reduce coactivation in adults with knee OA, unchanged coactivation between the knee extensors and flexors is one explanation for this occurrence (M.V. Hurley & Scott, 1998). Our results suggest that this is possible, as the observed 49% increase in quadriceps force (p=0.005) was met by a 10% increase in hamstrings force (p=0.08).

Stair Gait Joint and Muscle Biomechanics

Stair ascent is a task requiring a substantial quadriceps contribution due to the large knee extensor torque needed to raise ones center of mass high enough to clear each step. During the stair ascent task included in this study, the groups did not vary at baseline but the trained group exhibited significantly increased self-selected ascent velocity, quadriceps muscle force and work, and knee compressive force at follow-up.

Due to the decrease in pain experienced by the trained group, an improvement in stair ascent velocity is not unexpected. However, it is interesting velocity increased, but that no changes in knee extensor torque (p=0.23) or knee joint power (p=0.57) were viewed. One explanation is that the redistribution of joint torques away from the knee commonly observed in individuals with knee was not reversed after the strengthening protocol, but that velocity was increased due to increased contribution from the hip or ankle musculature (Huang et al., 2008; J. A. Zeni Jr. & Higginson, 2011). A closer look at the contributions of these joints indicated that while not statistically significant (p=0.056), hip extensor torque was 17% greater at follow-up, an increase that may explain the observed increase in velocity.

It is also interesting that quadriceps force increased but that this did not affect knee extensor torque and power. This could be caused by increases in antagonist (hamstrings) muscle

force negating increases in quadriceps force, ultimately resulting in unchanged extensor torques. This also appears to be possible, as the trained group exhibited 14% greater hamstrings force at follow-up; and while this measure was not significant (p=0.07), it is trending in that direction.

As velocity increases, ground and joint reaction forces also increase. The combination of increased joint reaction forces and increased quadriceps muscle force explain the significant increase in knee compressive force observed. The increased hamstring muscle force experienced by the trained group may have also affected this measure.

Similar to the stair ascent task, group*time interactions in self-selected walking velocity and knee compressive force were observed in the stair descent task. However, these were the only significant changes observed during descent.

Stair descent walking velocity is dependent upon the velocity and control one can lower their center of mass with. This control is achieved by increased contribution from the ankle and/or knee during single support, while stability of these joints is achieved through coactivation. During the stair descent task, the trained group exhibited 28% greater hamstring muscle force at post-test though our analysis found this was not significant (p=0.12). However, this increase in force could help to stabilize the knee joint, allowing for more controlled gait and greater comfort while moving at greater velocities. This increase in velocity would also cause greater joint reaction forces, leading to increased knee compressive force.

Summary

The effects of quadriceps-strengthening exercise were evident as improvements in pain, physical function, and strength. Statistical analyses showed knee joint kinetics were altered during the level-walking task, and quadriceps muscle biomechanics changed during both level

walking and stair ascent. Additionally, knee compressive force significantly increased in the trained group during all three walking tasks.

It appears improvements in pain and muscle strength altered how individuals walked on level ground and while climbing or descending stairs. Increases in stair velocity indicate the participants moved with less restriction following the strengthening protocol, while increases in knee extensor torque, quadriceps force, and quadriceps work show that the quadriceps muscles increase their contribution to movement. Significant increases in knee compressive force in all tasks suggest that these alterations effect the in vivo knee environment.

The results of this study suggest that after a strengthening protocol alterations in quadriceps muscle biomechanics do indeed occur and that contrary to what has been previously suggested, knee joint loads are not decreased as a result of a quadriceps strengthening protocol. The small number of participants emphasizes the importance of further investigation into the effects of quadriceps strengthening exercise on quadriceps muscle biomechanics.

Conclusion

It was hypothesized that quadriceps strengthening exercise would cause negligible changes to quadriceps muscle biomechanics during level walking, stair ascent, and stair descent. It is thought that the improved symptoms commonly experienced after extended exercise by those with knee OA is caused by an improvement in the biomechanics of the quadriceps muscles during activities of daily living. No literature exists supporting this claim or investigating quadriceps muscle biomechanics in individuals with knee OA. It has been shown that strengthening exercise causes very little alterations to sagittal plane knee joint kinetics, suggesting quadriceps contributions to locomotion are unchanged. The study hypothesis was

tested by comparing the strength, symptoms, joint kinetics, and thigh muscle biomechanics of two groups of participants with tibiofemoral knee OA, an experimental group that underwent 12 weeks of quadriceps strengthening exercise and a control that was untrained.

The strengthening protocol served its purpose, as the trained group experienced significant improvements in strength and disease symptoms. Level walking knee extensor torque and power were increased following the intervention, and quadriceps biomechanics were also changed while walking on level ground and climbing stairs. Additionally, knee compressive force significantly increased during all three walking conditions.

In conclusion, our results do not support the study hypothesis by suggesting that quadriceps muscle biomechanics are altered following a quadriceps-strengthening protocol. Our results also refute previous claims that reduced joint loads are behind the pain relief mechanism by showing significant increases in knee compressive force alongside significant improvements in pain and physical function. Due to the small number of participants used, more work should be focused around this topic in the future.

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To: Paul DeVita
CC: Patrick Rider
Date: 1/22/2013
Re: CR00000754
          UMCIRB 11-000932
          Quadriceps function in knee osteoarthritis

The continuing review of your expedited study was approved. Approval of the study and any consent form(s) is for the period of 1/22/2013 to 1/21/2014. This research study is eligible for review under expedited category #4 and 7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The Investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description	Modified	Version
Announce & Daily Reflector Announcements.docx	History	Recruitment Documents/Scripts	10/6/2011 10:30 AM	0.01
General protocol - short description - Sept 2011.docx	History	Study Protocol or Grant Application	10/6/2011 10:25 AM	0.01
Informed Consent Form - Quadriceps Muscle Function Knee OA - Control Group - Fall 2011.docx	History	Consent Forms	11/17/2011 11:32 AM	0.01
Informed Consent Form - Quadriceps Muscle Function Knee OA - Training Group - Fall 2011.docx	History	Consent Forms	11/17/2011 11:32 AM	0.01
Phone Interview - Initial Health Survey.docx	History	Surveys and Questionnaires	9/20/2011 12:41 PM	0.01
WOMAC Survey.pdf	History	Surveys and Questionnaires	9/20/2011 12:40 PM	0.01

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

Informed Consent to Participate in Research Study

Title of Research Study: Quadriceps function in knee osteoarthritis
Principal Investigator: Paul DeVita, Ph.D.
Institution/Department or Division: Department of Kinesiology
Address: 332 Ward Sports Medicine Building
Telephone #: 252.737.4563

INTRODUCTION:

I have been asked to participate in a research study being conducted by Paul DeVita, Ph.D. The purpose of this study is to examine how the thigh muscles work in people with knee osteoarthritis. The decision to take part in this research is entirely up to me.

PLANS AND PROCEDURES
Why am I being invited to take part in this research? I am being invited to participate in this research because I meet the inclusion criteria and have no apparent contraindication to participating in the study. Inclusion criteria are: have knee arthritis in one or both knees but am otherwise healthy and free of other skeletal, nervous, and mental impairments, age 40 to 65 years, not overly heavy, and am willing to participate in the tests and measurements.

I understand I should not volunteer for this study if I am a smoker, not between the ages of 40 and 65 years., suffered a serious injury to my arms or legs, had or have a medical condition (for example stroke, heart attack, cancer, diabetes), a history of falls, surgery on my legs, am unable to walk independently, use walking aids, have uncontrolled high blood pressure, take medications that cause dizziness, am overly heavy, have a heart condition, am pregnant or breastfeeding, or currently lift weights more than once per week.

Where is the research going to take place and how long will it last?
The research procedures will be conducted in the Biomechanics Laboratory, room 332 Ward Sports Medicine Building at ECU and in the exercise room of the Fitt Building at ECU. I will engage in a 12 week exercise program to strengthen my thigh muscles. The study will include three preliminary meetings followed by the training phase, and then final testing.

What will I be asked to do?
During the first visit to the Lab, I will:
1. read and sign this informed consent form and the HIPAA Authorization for this study,
2. provide personal information about my general health and my general movement capabilities,
3. complete a short survey about my knee pain and my walking ability,
4. have my height and weight measured,

5. be escorted to the next building to have my body composition, blood pressure and leg muscle strength measured.

During the second visit to the Lab, I will:
1. have my blood pressure measured,
2. warm up on a stationary bicycle for five minutes,
3. practice walking on the Lab walkway and stairs,
4. be timed as I walk up and down a regular flight of stairs in the building,
5. do repeated side-step-up movements until I tire,
6. rest for 15 minutes,
7. be tested for my maximum thigh muscle strength

During the third visit to the Lab, I will:
1. have my blood pressure taken,
2. warm up on the stationary bicycle,
3. have reflective markers and small muscle sensors placed on one leg,
4. walk across the Lab walkway and up and down the Lab stairs to test my walking style.

I will then be re-tested 12 weeks later, repeating all the tests.

What possible harms or discomforts might I experience if I take part in the research?
As with any strong muscle effort, there is a possibility for muscle strain to occur. A thorough familiarization and warming up will minimize the risks for muscle strain and soreness. There is also a small possibility that I might trip or fall during the level walking and stairway tests. However, since I have no history of falls while walking, falling during the tests is probably a remote possibility. The test areas will be neat, clean, and uncluttered to also minimize the chance of a fall.

What if I get sick or hurt while I am in this research?
If I have a minor muscle strain or if I get minor pain in my arthritic knee, I will stop the test, rest for several minutes and then determine if I can continue exercising. If I cannot continue, the test session will stop. I will determine the next time I can be tested. If I have a more severe injury, even though unlikely, I will stop the test and be assisted to get the appropriate medical attention. I will also determine whether I can continue in the study or if I will end my participation.

If you need emergency care:
Call 911 or 252-737-4563 for help. It is important that you tell the doctors, the hospital or emergency room staff that you are taking part in a research study and the name of the Principal Investigator. If possible, take a copy of this consent form with you when you go.

If you do NOT need emergency care, but have been hurt or get sick:
Contact the Principal Investigator, Paul DeVita, PhD, at 252-737-4563 as soon as you can. As necessary, go to your regular doctor. It is important that you tell your regular doctor

that you are participating in a research study. If possible, take a copy of this consent form with you when you go.

If you believe you have been hurt or if you get sick because of something that is done during the study, you should call Paul DeVita, PhD at 252-737-4563 immediately. There are procedures in place to help attend to your injuries or provide care for you. Costs associated with this care will be billed in the ordinary manner, to you or your insurance company. However, some insurance companies will not pay bills that are related to research costs. You should check with your insurance about this. Medical costs that result from research-related harm may also not qualify for payments through Medicare, or Medicaid. You should talk to the Principal Investigator about this, if you have concerns. You will not be paid for lost wages, disability, discomfort or any other expenses incurred due to this study.

What are the possible benefits I may experience from taking part in this research?
I may not receive substantial benefits personally but I will contribute to medical knowledge related knee osteoarthritis. The information derived from my tests may be used to develop improved rehabilitation programs for people with this disease and so reduce pain and disability in these people. I may also experience some reduction in pain and disability by participating in the four test sessions.

Will I be paid for taking part in this research?
I will be paid a small amount of money depending on the amount of the study I complete. The maximum amount I will receive is $60 after the completion of the entire study. If I leave the study prior to its completion I will receive a proportion of $60 based on the proportion of the study I complete (rounded to the nearest 25%; namely, the amount will be $15, $30, $45, or $60).

What will it cost me to take part in this research?
It will not cost me any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?
To do this research, ECU and the people listed below may know that I took part in this research and may see information about me: Paul DeVita, the main investigator, Patrick Rider, the study coordinator, Dr. John Norbury and other Physical Medicine & Rehabilitation staff present during recruitment, and the graduate students helping me exercise. The UMCIRB staff to provide continuing review of the research project and Institutional officials in connection with duties for monitoring research activity.

How will you keep the information you collect about me secure? How long will you keep it?
Data files will be kept for 6 years after the study is completed in a locked file cabinet in the Biomedical office which can be accessed only by the investigators. The investigators will keep my personal data in strict confidence by having my data coded. Instead of my name, I will be identified in the data records with an identity number. My name and code number

will not be identified in any subsequent report or publication. The study investigators and the research students will be the only persons who know the code associated with my name and this code as well as my data will be kept in strict confidence.

What if I get sick or hurt while I am in this research?
If I have a minor muscle strain or if I get minor pain in my arthritic knee, I will stop exercising, rest for several minutes and then determine if I can continue exercising. If I cannot continue, the exercise session will stop. I will determine the next time I can exercise regardless of the exercise schedule. If I have a more severe injury, even though unlikely, I will stop exercising and be assisted to get the appropriate medical attention. I will also determine whether I can continue in the study or if I will end my participation.

If you need emergency care:
Call 911 or 252-737-4563 for help. It is important that you tell the doctors, the hospital or emergency room staff that you are taking part in a research study and the name of the Principal Investigator. If possible, take a copy of this consent form with you when you go.

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Contact the Principal Investigator, Paul DeVita, PhD, at 252-737-4563 as soon as you can. As necessary, go to your regular doctor. It is important that you tell your regular doctor that you are participating in a research study. If possible, take a copy of this consent form with you when you go.

If you believe you have been hurt or if you get sick because of something that is done during the study, you should call Paul DeVita, PhD at 252-737-4563 immediately. There are procedures in place to help attend to your injuries or provide care for you. Costs associated with this care will be billed in the ordinary manner, to you or your insurance company. However, some insurance companies will not pay bills that are related to research costs. You should check with your insurance about this. Medical costs that result from research-related harm may also not qualify for payments through Medicare, or Medicaid. You should talk to the Principal Investigator about this, if you have concerns. You will not be paid for lost wages, disability, discomfort or any other expenses incurred due to this study.

What if I decide I do not want to continue in this research?
If I decide I no longer want to be in this research after it has already started, I may stop at any time. I will not be penalized or criticized for stopping. I will not lose any benefits that I should normally receive.

Who should I contact if I have questions?
The people conducting this study will be available to answer any questions concerning this research, now or in the future. I may contact the main investigator, Paul DeVita, at 252.737.4563 (work days, between 8 am to 5 pm).

If I have questions about my rights as someone taking part in research, I may call the Office for Human Research Integrity (OHRI) at phone number 252-744-2914 (days, 8:00 am-5:00 pm). If I would like to report a complaint or concern about this research study, I may call the Director of the OHRI, at 252-744-1971.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask me to read the following and if I agree, I should sign this form:
- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

Participant's Name (PRINT)	**Signature**	**Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

Paul DeVita, Ph.D., Study Director
Person Obtaining Consent (PRINT)	**Signature**	**Date**

Family physician / Nurse (PRINT)	**Signature**	**Date**

Informed Consent to Participate in Research Study

Title of Research Study: Quadriceps function in knee osteoarthritis
Principal Investigator: Paul DeVita, Ph.D.
Institution/Department or Division: Department of Kinesiology
Address: 332 Ward Sports Medicine Building
Telephone #: 252.737.4563

INTRODUCTION:
I have been asked to participate in a research study being conducted by Paul DeVita, Ph.D. The purpose of this study is to examine the effects of thigh muscle strength training on my walking behavior. The decision to take part in this research is entirely up to me.

PLANS AND PROCEDURES
Why am I being invited to take part in this research?
I am being invited to participate in this research because I meet the inclusion criteria and have no apparent contraindication to participating in the study. Inclusion criteria are: have knee arthritis in one or both knees but am otherwise healthy and free of other skeletal, nervous, and mental impairments, age 40 to 65 years, not overly heavy, and am willing to participate in the exercise program.

I understand I should not volunteer for this study if I am a smoker, not between the ages of 40 and 65 years., suffered a serious injury to my arms or legs, had or have a medical condition (for example stroke, heart attack, cancer, diabetes), a history of falls, surgery on my legs, am unable to walk independently, use walking aids, have uncontrolled high blood pressure, take medications that cause dizziness, am overly heavy, have a heart condition, am pregnant or breastfeeding, or currently lift weights more than once per week.

Where is the research going to take place and how long will it last?
The research procedures will be conducted in the Biomechanics Laboratory, room 332 Ward Sports Medicine Building at ECU and in the exercise room of the Fitt Building at ECU. I will engage in a 12 week exercise program to strengthen my thigh muscles. The study will include three preliminary meetings followed by the training phase, and then final testing.

What will I be asked to do?
During the first visit to the Lab, I will:
6. read and sign this informed consent form and the HIPAA Authorization for this study
7. provide personal information about my general health and my general movement capabilities,
8. complete a short survey about my knee pain and my walking ability,
9. have my height and weight measured,
10. be escorted to the next building to have my body composition, blood pressure and leg muscle strength measured.

During the second visit to the Lab, I will:
8. have my blood pressure measured,
9. warm up on a stationary bicycle for five minutes,
10. practice walking on the Lab walkway and stairs,
11. be timed as I walk up and down a regular flight of stairs in the building,
12. do repeated side-step-up movements until I tire,
13. rest for 15 minutes,
14. be tested for my maximum thigh muscle strength

During the third visit to the Lab, I will:
5. have my blood pressure taken,
6. warm up on the stationary bicycle,
7. have reflective markers and small muscle sensors placed on one leg,
8. walk across the Lab walkway and up and down the Lab stairs to test my walking style.

I will then exercise my thighs three times a week for 12 weeks under the guidance of the research team at the Fitt Building on ECU campus. I will exercise both thigh muscles with three exercises: leg press, knee extension, and forward lunge which I will be taught. My blood pressure will be taken before each exercise session and if it is over 140 mm Hg, the session will be postponed. Each exercise session will last about 30 minutes.

After 36 exercise sessions I will repeat all the tests listed above. I will then be finished with the exercise program and my portion of the research study.

What possible harms or discomforts might I experience if I take part in the research?
As with any strong effort or working out in a gym, there is a possibility for muscle strain to occur. A thorough familiarization and warming up will minimize the risks for muscle strain and soreness. Except for a few efforts, all other efforts will be done below-maximal intensity, posing minimal risks for any healthy adults who meet the inclusion criteria. I will be supervised during all training and testing sessions by experienced and courteous researchers. There is also a small possibility that I might trip or fall during the level walking and stairway tests. However, since I have no history of falls while walking, falling during the tests is probably a remote possibility. The test areas will be neat, clean, and uncluttered to also minimize the chance of a fall.

What if I get sick or hurt while I am in this research?
If I have a minor muscle strain or if I get minor pain in my arthritic knee, I will stop exercising, rest for several minutes and then determine if I can continue exercising. If I cannot continue, the exercise session will stop. I will determine the next time I can exercise regardless of the exercise schedule. If I have a more severe injury, even though unlikely, I will stop exercising and be assisted to get the appropriate medical attention. I will also determine whether I can continue in the study or if I will end my participation.

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What are the possible benefits I may experience from taking part in this research?
My thigh muscles will probably become stronger and stronger muscles enable people to do more activities and stay more mobile. Preventing or delaying a loss of mobility with age is very important to maintain independence.

Will I be paid for taking part in this research?
I will be paid a small amount of money depending on the amount of the study I complete. The maximum amount I will receive is $60 after the completion of the entire study. If I leave the study prior to its completion I will receive a proportion of $60 based on the proportion of the study I complete (rounded to the nearest 25%; namely, the amount will be $15, $30, $45, or $60).

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How will you keep the information you collect about me secure? How long will you keep it?
Data files will be kept for 6 years after the study is completed. The investigators will keep my personal data in strict confidence by having my data coded. Instead of my name, I will be identified in the data records with an identity number. My name and code number will not be identified in any subsequent report or publication. The study investigators and the research students will be the only persons who know the code associated with my name and this code as well as my data will be kept in strict confidence.

What if I decide I do not want to continue in this research?
If I decide I no longer want to be in this research after it has already started, I may stop at any time. I will not be penalized or criticized for stopping. I will not lose any benefits that I should normally receive.

Who should I contact if I have questions?
The people conducting this study will be available to answer any questions concerning this research, now or in the future. I may contact the main investigator, Paul DeVita, at 252.737.4563 (work days, between 8 am to 5 pm).

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- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

Participant's Name (PRINT)   **Signature**   **Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

Paul DeVita, Ph.D., study director
Person Obtaining Consent (PRINT)   **Signature**   **Date**

Family physician / Nurse (PRINT)   **Signature**   **Date**

Quadriceps Training in Knee Osteoarthritis Patients
Health Survey To Determine Eligibility For Research Participants

Demographic data:

Date   _____

Name   _____ Phone number _____

Address   _____

Birth date   _____ Age _____

Height (ft/in) _____   Height (m)   _____

Weight (lbs) _____   Mass (kg)   _____

BMI (kg/m^2) _____

Do you smoke?   Yes___ No ___
Have you smoked in the past?   Yes___ No ___
      If yes, when did you stop smoking _____

Functional ability in daily activities:

How much difficulty do you have when you

Walk on level surface	None	Some	A lot
Climb stairs	None	Some	A lot
Descend stairs	None	Some	A lot

How much pain do you have in your knee or hip joints when you

Walk on level surface	None	Some	A lot
Walk up and down a ramp	None	Some	A lot
Ascend and descend stairs	None	Some	A lot

Can you do the following activities independently:

Dress	Yes___	No ___
Bath	Yes___	No ___
Continence	Yes___	No ___
Eating	Yes___	No ___

Do you use a walker or cane when walking?   Yes___ No ___

During the past year, did you fall down more than once while walking or climbing stairs?
Yes____ No ___

Medical:

When were you diagnosed with knee osteoarthritis? (exact date or approximate)_____

Do you have any other musculoskeletal problems such as hip arthritis, joint replacement, or other orthopaedic problems?   Yes____ No ____

Do you have any neurological problems such as stroke or Parkinson's disease? Yes__No__

Do you have any problems with your heart such as atrial fibrilliation, pace maker, coronary artery disease, or congestive heart failure?   Yes____ No ____

Do you have any pulmonary diseases such as difficulty in breathing or emphysema?
Yes__No ____

Do you have any peripheral artery disease?   Yes____ No ____

Do you have high blood pressure (>160/90 mm Hg)?   Yes____ No ____

Do you take medication to control your blood pressure? Yes____ No____

List the medications you are currently taking
_____

Do you have any loss of vision?   Yes____ No ____

If yes, do you have eye glasses or contact lenses that correct your vision? Yes____ No ____

Do you have any other medical problems we did not talk about? Yes____ No____
         If, "Yes," what is or are the conditions? _____

List any surgeries you have had.

_____

Please tell us any other health illnesses you have had or currently have.
_____

Please tell us your physician's name, telephone number, and clinic name:

_____

APPENDIX E: WOMAC QUESTIONNIARE

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)

Name:_____ Date:_____

Instructions: Please rate the activities in each category according to the following

scale of difficulty: 0 = None,   1 = Slight,   2 = Moderate,   3 = Very,   4 = Extremely

Circle **one number** for each activity

Pain	1. Walking	0	1	2	3	4
	2. Stair Climbing	0	1	2	3	4
	3. Nocturnal	0	1	2	3	4
	4. Rest	0	1	2	3	4
	5. Weight bearing	0	1	2	3	4
Stiffness	1. Morning stiffness	0	1	2	3	4
	2. Stiffness occurring later in the day	0	1	2	3	4
Physical Function	1. Descending stairs	0	1	2	3	4
	2. Ascending stairs	0	1	2	3	4
	3. Rising from sitting	0	1	2	3	4
	4. Standing	0	1	2	3	4
	5. Bending to floor	0	1	2	3	4
	6. Walking on flat surface	0	1	2	3	4
	7. Getting in / out of car	0	1	2	3	4
	8. Going shopping	0	1	2	3	4
	9. Putting on socks	0	1	2	3	4
	10. Lying in bed	0	1	2	3	4
	11. Taking off socks	0	1	2	3	4
	12. Rising from bed	0	1	2	3	4
	13. Getting in/out of bath	0	1	2	3	4
	14. Sitting	0	1	2	3	4
	15. Getting on/off toilet	0	1	2	3	4
	16. Heavy domestic duties	0	1	2	3	4
	17. Light domestic duties	0	1	2	3	4

Total Score: _____ / 96 = _____%

Comments / Interpretation (to be completed by therapist only):