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I am submitting herewith a dissertation written by Michael George Wortley entitled "Effects of Taiji and Strength Training Interventions on Knee Osteoarthritis of Older Adults." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Exercise and Sport Science

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Effects of Taiji and Strength Training Interventions on Knee Osteoarthritis of Older Adults

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ABSTRACT

Objective. The objective of this study was to evaluate a 10-week Taiji intervention to a 10-week strength training intervention in terms of their ability to relieve osteoarthritis (OA) symptoms, alter gait, and improve mobility in seniors with knee OA.

Methods. Men and women between the ages of 60 and 85 years who met the American College of Rheumatology criteria for knee OA were recruited to participate in either a simplified Taiji program (n=12), an open-chain strength training program (n=13), or a control group (n=6). All participants completed the Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC), three physical performance tests, and a 3-D gait analysis at baseline and again after the 10-week intervention.

Results. The strength training group significantly improved on the time up-and-go test ($p = 0.001$), the WOMAC pain sub-score ($p=0.006$), WOMAC stiffness sub-score ($p<0.001$), and WOMAC physical function sub-score ($p=0.011$). The Taiji group significantly improved on the timed up-and-go ($p<0.001$), but there was no change in their WOMAC scores. Neither group showed any significant changes in either kinematic or kinetic gait variables.

Conclusion. Strength training was effective for improving mobility and improving the symptoms of knee OA. Taiji was also effective for improving mobility, but did not improve the participants' knee OA symptoms. Neither intervention had an effect the participants walking gait.

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CHAPTER I

INTRODUCTION

Arthritis is the leading cause of disability in the United States, and osteoarthritis (OA) is by far the most common type of arthritis (1). Lawrence et al. (1) estimated that in 2005 approximately 27 million American adults had clinical osteoarthritis, with an estimated prevalence of symptomatic knee OA of 12.1% in people over 60 years-old. Knee OA causes pain and stiffness, which can lead to a decline in knee strength and slowing of gait speed beyond what is normally expected due to advancing age (2), as well as other changes in gait biomechanics (3-5). These changes often result in significant limitation of daily activities for people with knee OA.

Osteoarthritis is a dynamic disease involving a disruption in the balance between cartilage synthesis and degeneration (6). The recommended treatment is a combination of pharmacological and non-pharmacological methods which aims to manage pain, improve physical function, and maintain the patient's quality of life (7, 8). Joint bracing and exercise have been highly recommended by consensus drawn at a National Institute of Health (NIH) OA conference (9) and by the Osteoarthritis Research Society International (OARSI) (8). Many forms of exercise, including walking, resistance training, hydrotherapy, flexibility training, and balance training, have been tested as OA treatments, and most were shown to be effective for managing OA symptoms to differing degrees (7, 10). However, while both *in vitro* and *in vivo* studies have demonstrated that healthy cartilage will thicken in response to loading (6, 11-13), arthritic cartilage has been shown to break down in response to increasing loads (14-17). The in vivo pathomechanics of OA are still largely unknown (6), but it does appear that careful balance must be struck between maintaining mobility and loading arthritic joints.

Strength training is one type of exercise which is strongly recommended for knee OA patients (8). Several studies have shown that knee OA patients can improve strength and physical function without increasing knee pain (18, 19), while other studies have reported that strength training actually reduced the reported pain (20-22). Strength training is also exceptionally adaptable. Frequency, duration, intensity, and modality can be modified to meet individual needs, but there are always trade-offs to be considered. For example, closed kinetic chain exercises have been shown to be more effective at improving physical performance, but open kinetic chain exercises expose the joints to smaller compressive loads (23).

Taiji is another form of exercise which has been gaining popularity as a means of managing OA symptoms in recent years. Taiji, a four centuries-old Chinese martial art featuring slow, flowing movements (24), is practiced around the world as a form of exercise and meditation. Several studies have examined Taiji's potential health benefits, including cardiovascular health (25) and improving physical function in old age (26). A handful of studies have found that Taiji can relieve pain and stiffness, and improve the quality of life for OA sufferers (27, 28), but there is still some contention about the effectiveness of Taiji as treatment for OA (29, 30).

The effectiveness of most arthritis interventions is measured using the Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC), a questionnaire which was developed to evaluate clinically important changes in OA status (31). The WOMAC measures OA symptoms on three sub-scales: pain, stiffness, and physical function, of which the pain and physical function sub-scales have well established validity, reliability, and responsiveness (32). However, it would be desirable to have physical evidence of improvement, in the form of favorable changes in gait, to corroborate the WOMAC.

The presence of knee OA leads to several known changes in gait biomechanics. The knee flexion excursion during the loading response has been shown to decrease from about 15° in healthy participants to approximately 10° in participants with knee OA (3, 33). People with knee OA are also known to walk with a reduced knee extension moment (5, 34, 35). Perhaps the most commonly reported finding in OA gait research is that people with knee OA walk with a greater external knee adduction moment, during both the loading response and terminal stance (5, 14, 16, 34-39). Several studies that have employed whole-curve analysis techniques have indicated that the ratio between the adduction moment during initial stance and terminal stance may be changed as a result of OA, although the nature of that change is in question (5, 35).

Tibiofemoral contact forces are of interest because of their relationship to cartilage degeneration. Although inverse dynamic methods are not capable of calculating the forces acting on articular cartilage, forward dynamic modeling has produced an estimate of the tibiofemoral contact force during healthy gait (40). Those results indicate that tibiofemoral forces are primarily due to the ground reaction force (GRF) and the quadriceps muscle during initial stance, and the GRF and gastrocnemius muscle force during terminal stance. While it is not possible to calculate the tibiofemoral contact force from the GRF and sagittal plane ankle and knee moments, considering all three of these together should provide clues about the relative changes in tibiofemoral loading.

STATEMENT OF THE PROBLEM

The objective of this study was to evaluate a 10-week Taiji intervention and a 10-week strength training intervention in terms of their ability to relieve OA symptoms, alter gait, and improve mobility in seniors with knee OA. Specifically, the participants' gait was examined for a change in the knee flexion excursion during the loading phase of walking, and for changes in four kinetic variables related to tibiofemoral loading during initial stance and terminal stance. Mobility was assessed through the 6-minute walk test, timed stair climb and descent, and the timed up-and-go test. The WOMAC was used to evaluate changes in the participants' pain, stiffness, and perception of physical function.

Hypotheses

Following the 10-week intervention, it is hypothesized that the following changes will be observed:

1. The Taiji and strength training groups will both increase their knee flexion excursion during gait relative to the control group.
2. The Taiji and strength training groups will accept a greater load on their arthritic knees during gait relative to the control group. This change will be indicated by an increase in the ground reaction force and knee extension moment during initial stance and by increases in ground reaction force and ankle plantarflexion moment during terminal stance.

3. The Taiji and strength training groups will decrease their internal knee abduction moment during both initial and terminal stance relative to the control group.
4. The Taiji and strength training groups will improve their maximum isometric knee flexion and extension strength relative to the control group. The strength training group will improve more than the Taiji group.
5. The Taiji and strength training groups will improve their mobility relative to the control group, as measured by the 6-minute walk test, the timed up-and-go test, and the timed stair climb and descent.
6. The Taiji and strength training groups will improve their OA symptoms relative to the control group, as measured by the WOMAC pain, stiffness, and physical function sub-scales.

Delimitations

The participants in this study were all elderly (>60 years old) and met the Classification Criteria for knee OA of the American College of Rheumatology (41). Participants also had to have minimal OA in other joints and be free of other systematic inflammatory diseases such as rheumatoid arthritis and gout. Other exclusion criteria included:

- neurologic disease (e.g. Parkinson's Disease, stroke)
- previous participation in Taiji or strength training in past 6 months
- current participation in structured fitness activities such as aerobics, water aerobics, or fitness walking more than twice per week

- inability to walk without a walking aid
- arthroscopic surgery or intra-articular injection within the past 3 months
- lower back pain referred to the lower limbs
- unable to see, hear, or follow instructions

Limitations

The participants in this study were all recruited from a population of senior citizens in connection with the Knox County Office of Aging, and subject to many specific inclusion and exclusion criteria. This could limit the generalizablity of the results.

The gait testing protocol contains several trade-offs that may influence the results. Gait speed is known to influence most kinetic gait variables (3), which is why we decided to control the participants gait speed. The use of two force platforms to collect ground reaction force data from consecutive steps constrains the participants' foot placement. The combination of constrained speed and foot placement may prevent the participants from changing their gait, even if there was a marked improvement in gait quality. This configuration may also force some participants, particularly those that are extremely short or extremely tall, into an atypical gait pattern.

The Taiji and strength training interventions were administered to two cohorts, which met at different locations and had different instructors. Since the cohorts were relatively small, they were combined for statistical analysis. All of the instructors followed the same program, and all training for instructors was done in a single group to minimize the differences between cohorts.

ABBREVIATIONS AND DEFINITIONS

OA – Abbreviation for Osteoarthritis.

K/L Grade – Kellgren/Lawrence Grade. The most commonly used system for grading the severity of OA based on x-ray images. The scale runs from 0-4, with 4 being the most severe. Grade 0 = no osteophytes. Grade 1 = possible osteophytes. Grade 2 = definite osteophytes and possible joint space narrowing. Grade 3 = multiple osteophytes, definite joint space narrowing, some sclerosis, and possible bone contour deformity. Grade 4 = large osteophytes, marked joint space narrowing, severe sclerosis, and definite bone contour deformity (42).

ST – Abbreviation for the strength training group

TJ – Abbreviation for the Taiji group

CON – Abbreviation for the control group

WOMAC – The Western Ontario and MacMaster Universities Osteoarthritis Index, a questionnaire which was developed to evaluate clinically important changes in OA status (31).

6MWT – Abbreviation for the six-minute walk test.

TUG – Abbreviation for the timed up-and-go test.

SCD – Abbreviation for the timed stair climb and descent test.

KEXC – Abbreviation for the knee flexion excursion, which is the difference between the knee angle at heel strike and the peak knee flexion during the loading response.

Initial Stance Peak – The estimated time of peak tibiofemoral contact force during the initial stance phase of gait, corresponding approximately to the opposite toe-off. In this study, the initial stance peak was chosen to correspond to the peak internal knee extension moment.

GRF_i – Abbreviation for the ground reaction force during the initial stance peak.

AMX_i – Abbreviation for the internal sagittal plane ankle moment during the initial stance peak.

KMX_i – Abbreviation for the internal sagittal plane knee moment during the initial stance peak.

KMY_i – Abbreviation for the internal frontal plane knee moment during the initial stance peak.

Terminal Stance Peak – The estimated time of peak tibiofemoral contact force during terminal stance, corresponding approximately to opposite heel-strike. In this study, the terminal stance peak was chosen to correspond to the peak internal ankle plantarflexion moment.

GRF_t – Abbreviation for the ground reaction force during the terminal stance peak.

AMX_t – Abbreviation for the sagittal plane ankle moment during the terminal stance peak.

KMX_t – Abbreviation for the sagittal plane knee moment during the terminal stance peak.

KMY_t – Abbreviation for the frontal plane knee moment during the terminal stance peak.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this study was to evaluate the effectiveness of Taiji and strength training interventions for improving the symptoms of knee osteoarthritis (OA) and the gait of elderly people with knee OA. The following review first presents information about the causes, progression, and treatments of OA. Next there is a review of both normal gait biomechanics and common gait features of people with knee OA. Finally, there are reviews on the benefits of Taiji and strength training for people with knee OA.

OSTEOARTHRITIS

Osteoarthritis (OA) is a degenerative joint disease that most often afflicts the knees, hips, lower back, and finger. Often described as “wear and tear” arthritis because it is the literal wearing away of the articular cartilage that projects the joint surfaces, recent studies have begun describing OA as a dynamic disease involving a disruption in the balance between cartilage synthesis and degeneration (6). Both *in vitro* and *in vivo* studies have demonstrated that healthy cartilage will thicken in response to loading (6, 11-13), while arthritic cartilage tends to break down further in response to increasing loads (14-17). Although an exact mechanism has not been identified, the metabolic health of cartilage appears to at least partially depend on the tissue’s mechanical environment.

Risk Factors and Progression

Many studies have identified risk factors for the incidence of OA, and the three most commonly cited risk factors are age, gender, and obesity (43, 44). Of these risk factors, obesity seems to be the strongest. Using data from more than 3,000 participants in the longitudinal Johnson County Osteoarthritis Project, Murphy and colleagues (45) estimated that the lifetime risk of developing OA in at least one knee was approximately 1-in-3 in people with a body mass index (BMI) of less than 25 kg/m^2, 1-in-2 in people with a BMI between 25 and 30 kg/m^2, and 2-in-3 in people with a BMI of 30 kg/m^2 or greater. An analysis performed on data from the Melbourne Collaborative Cohort Study (46) estimated the risk of receiving a total knee replacement based on several different measures of adiposity. They found that the hazard ratio (the rate of knee replacement for one group relative to a baseline group) increased by a factor of 1.88 (95% CI: 1.76 – 2.00) for every 5 kg/m^2 increase in BMI or 10 kg increase in fat mass, or by a factor of 2.84 (95% CI: 2.47 – 3.26) for every 10% increase in percent body fat. Similarly, Niu et al. (47) found that the relative risk of OA incident relative to normal BMI was 1.8 (95% CI: 1.0 – 3.2) for overweight subjects, 2.4 (95% CI: 1.3 – 4.3) for obese subjects, and 3.2 (95% CI: 1.7 – 5.9) for very obese subjects with a BMI greater than 35 kg/m^2. Interestingly, Niu and colleagues (47) also found that increasing BMI did not increase the relative risk of their participants' knee OA progression (95% CI of relative risk: 0.8 – 1.2). The authors compared their results to three previous studies that had similar findings, and pointed out that these results do not mean that the overweight and obese participants' OA did not progress, just that the progression could not be predicted from their BMI alone.

While being female is widely recognized as a risk factor for OA, this increased risk does not appear to apply equally to all joints. A meta-analysis performed by Srikanth et al. (44) estimated the risk ratio (defined as the incidence rate for males divided by the incidence rate for females) for knee OA to be 0.65 (95% CI: 0.55 – 0.77) in populations over 55-years-old (number of studies = 10) and 0.82 (95% CI: 0.65 – 1.03) in populations under 55-years-old (number of studies = 5). However, women did not appear to be a greater risk for hip OA. Theories to explain these results include anthropometric difference, differences in muscle strength, and hormonal changes during menopause (48), but no definitive answer has yet been found.

When re-evaluated in light of a metabolic definition of OA, it seems likely that age, gender, and obesity all correlate to factors which affect the rates of cartilage catabolism and anabolism (6). Increasing age is associated with a decrease in muscular strength and ligament stiffness, both of which affect the mechanical environment of the joints. Both obesity and the female gender are associated with hormonal changes and changes in the biomarkers of cartilage metabolism. There is a framework in place for the further study of this theory of OA causation, but there is still much research needed before it can be accepted as fact.

Treatments

There is currently no cure for OA. It is suggested that once a person develops OA it may deteriorate at an accelerating rate (6, 15). Managing OA of any joint is primarily a matter controlling the pain, improving physical function, and maintaining the patient's quality of life (7). It is recommended that a combination of pharmacological and non-pharmacological methods be used in managing OA (8). Lateral-wedge shoe inserts (38, 49-51), valgus knee braces (50, 52-54), and contra-lateral walking canes (55) are all common non-pharmacological interventions. Among the non- pharmacological treatments for knee and hip OA, alternative therapies such as neutriceuticals and acupuncture and biomechanical intervention such as exercise and joint bracing are highly recommended by the consensus drawn at an NIH OA conference (9) and the OARSI (8). Exercise and physical activity, including walking, resistance training, hydrotherapy, flexibility, and balance training, have proven to be effective for managing OA symptoms and improving functionality (7, 10). When a patient is no longer obtaining adequate pain relief or is unable to maintain physical function through conservative management techniques, joint replacement surgery is recommended (8). Joint replacements have been shown to be very effective at reducing pain (56) and improving function during activities of daily living (56, 57).

Many popular therapies which are commonly used to treat OA but are not part of mainstream medicine are referred to as "complementary or alternative medicine" (CAM) (58). Evidence has been found that some of these treatments, such as acupuncture (59), may add benefit to conventional pharmacological treatments. Other CAM treatments, such as homoeopathy (60), have consistently been shown to have no more effect than placebo. Despite this, the prevalence of CAM in the United States remains high, possibly due to dissatisfaction with orthodox medicine (58). Due to the constant pain and absence of a cure, patients with end-stage knee OA are particularly vulnerable to dishonest practitioners and unsound treatments, and for this reason it is important that CAM treatments are thoroughly studied and held to the same standards as conventional medicine.

GAIT

Because gait is the most common repetitive loading activity in daily life, many studies have been done on gait as it pertains to knee OA. Many studies have identified a consistent set of gait adaptations associated with both knee and hip OA, but an overview of what is normal gait biomechanics is helpful to appreciate these differences. It is also important to keep in mind that what constitutes a "normal" gait varies with age and gender (61). Since terminology can vary from study to study, the rest of this dissertation will use the terminology published by Whittle (61), which is summarized below.

Normal Gait

The gait cycle during walking is divided into a stance phase (when the foot is on the ground) and a swing phase (when the foot is in the air). Seven events are used to further dived the gait cycle in smaller phases. The *loading response* begins at *initial contact* of the foot, and ends at *opposite toe off*. *Mid-stance* occurs between opposite toe off and *heel rise* of the ipsilateral foot. *Terminal stance* is between heel rise and *opposite initial contact*. Stance phase ends with *pre-swing*, which occurs between opposite initial contact and ipsilateal *toe off*. *Initial swing* begins at toe off and ends at *feet adjacent*, *mid-swing* occurs between feet adjacent and *tibia vertical*, and *terminal swing* occurs between tibia vertical and *initial contact*. Other important features of the walking gait are the *walking base, toe out angle*, *stride length*, and *cadence*, or stride rate. The walking base is the side-to-side distance between the paths of the two feet. Toe out angle is the angle between the long axis of the foot and direction of travel. The stride length is the distance between two successive initial contacts of the same foot, which can also be thought of as the sum of the *right step length* (distance from left initial contact to right initial contact) and the *left step length*. The stride length and the cadence together determine the speed of the walking gait.

Probably due to the differences in size and shape, men and women have different preferred values of cadence and stride length (61). Between the ages of 18 and 49 years, both genders have a similar preferred cadence of (118 ± 10 steps/min for women, 113 ± 11 steps/min for men), but women have shorter stride length (1.32 ± 0.13 m versus 1.55 ± 0.15 m for men) and thus a slower preferred walking speed (1.30 ± 0.18 m/s versus 1.46 ± 0.18 m/s for men). Both genders decrease their preferred walking speed as they age, but the nature of this change is different. Women age 50-64 years slow down very little (1.27 ± 0.18 m/s), but women age 65-80 years shorten their average stride length to 1.2 ± 0.13 m, resulting in a preferred speed of 1.16 ± 0.18 m/s. Cadence appears to remain fairly constant through old age in women. Men, on the other hand, seem to slow down in two phases. Men age 50-64 years slow their preferred cadence to 104 ± 11 steps/min, resulting in an preferred speed of 1.32 ± 0.18 m/s. Then, the stride length shortens to 1.41 ± 0.15 m for the 65-80 years age group, resulting in a reduction in preferred walking speed to 1.16 ± 0.20 m/s.

Estimating Knee Joint Loading during Gait

Most biomechanics studies employ inverse dynamics to compute the joint moments and joint reaction forces. In the case of knee, these joint reaction forces represent the net forces applied to the proximal end of the shank, including contributions from three major muscle groups, ligaments, and the contact force between the tibia and femur. This tibiofemoral contact force is what we want to quantify in knee OA studies, but it is fundamentally indeterminable by traditional biomechanics methods. There are too many unknown quantities and not enough equations of motion. The best we can do is to estimate the tibiofemoral contact force, and there are currently several methods available in the literature.

The simplest method for finding a solution to these indeterminate problems is called heuristic reduction, which is a rule-based approach to dividing the joint moments between groups of muscles based on EMG data and functional anatomy (62). These estimated muscle forces can then be used to estimate the tibiofemoral contact force. This approach is often used when researches use “equivalent” muscles to represent the actuators of specific movements (i.e. using the “hamstring” as the sole knee flexor.) This method is not computationally demanding, and is especially useful for making a first inquiry into a new movement. Pollo et al. (54) provided a simple example of heuristic reduction which attributed flexion moments entirely to the hamstring muscle group, extension moments entirely to the quadriceps muscle group. The frontal plane moment was balanced by medial and lateral knee compartment forces, and any transverse plane moment was neglected. Fuller and Winters (62) used a much more anatomically detailed model with rules for dividing all three components of the internal knee moment between

6 muscle groups, including two multi-joint muscles, and a lateral knee ligament. They also collected EMG data, which was found to be qualitatively similar to the estimated muscle forces during walking.

An alternative to calculating muscle forces and joint reaction forces through heuristic reduction is a process known as dynamic optimization. In this process, a forward dynamics approach is used to recreate the motion while optimizing a performance criterion over the entire task (62). This requires that the behavior and geometry of ligaments, tendons, and muscles be modeled in detail, as well as the excitation dynamics of muscle. A research group at Stanford University has had significant success with this approach (40, 50, 63, 64), but this method is very computationally demanding (65) and is ultimately still an estimate made from incomplete information. In fact, in 2001 Anderson and Pandy (66) compared their dynamic optimization solution for normal walking to two other solutions calculated by much simpler heuristic reduction techniques, and found that the three solutions were nearly identical.

Most research conducted on knee OA has used the external knee adduction moment as a representation of dynamic knee loading, especially when studying OA of the medial knee compartment. Medial knee OA is the most common form of knee OA, and its occurrence has been linked to excessive external adduction moments in numerous studies (3, 5, 12, 14, 16, 17). However, there appears to be some confusion in the literature about what an "external" joint moment is and how it should be calculated. The minority opinion is that the moments caused by external forces, i.e. gravitational forces and ground reaction forces, should be summed about the knee joint center (40, 67). Since the moments due to gravity acting on the shank and foot are small compared to the ground reaction force, these moments are often not included in the calculation. The majority opinion is that the external moment should be equal and opposite to the internal moment (4, 5, 12, 14, 16, 19, 39, 68-76). In this paradigm the inertial forces are considered external forces, and the inertial moments are external moments (77). While this seems like an important distinction, in practice the magnitude of the difference at the knee joint is actually relatively small.

Shelburne, Torry, and Pandy (40) modeled the relationship between tibiofemoral forces, the external adduction moment and internal abduction moment, and muscle and ligament forces during walking using a forward dynamic simulation. Their results indicated that nearly all of the tibiofemoral contact force during walking is centered in the medial compartment and that the external adduction moment curve and the medial compartment loading curve have nearly identical shapes, with peaks occurring at opposite toe off and opposite initial contact. The ground reaction force contributed approximately twice as much to the medial compartment force as the combined muscle forces, except at opposite initial contact when the muscle force and ground reaction force contributed nearly equally. Ligaments only played a role at times when the muscles were relatively inactive, and even then they never contributed more than 50% of the internal abduction moment. The internal abduction moment was generated by a combination of the posteriolateral knee ligaments (PLC) and the hamstrings at initial contact, the quadriceps at opposite toe off, the PLC and quadriceps during late midstance, and the gastrocnemius at opposite initial contact. These results suggest that frontal plane knee moments can provide a clear picture of dynamic knee loading. The internal knee extension moment, which can be primarily attributed to the quadriceps, may provide additional information about knee loading during the first peak at opposite toe-off. The internal ankle plantarflexion moment, which can be primarily attributed to the gastrocnemius, may provide additional information about knee loading during the second peak at opposite heel strike.

There is no standard axis about which the frontal plane knee moment is calculated in the literature. Newell et al. (37) investigated how the choice of axis affects the shape and magnitude of the external knee adduction moment curve in 44 healthy subjects and 44 persons with OA. The external knee joint moments were calculated using inverse dynamics and the result was expressed about three axes: a 2-D axis that was perpendicular to the long axis of the shank and parallel to the plane of the subject's direction of travel, a floating 3-D axis that was perpendicular to both the medial-lateral axis of the thigh and the long axis of the shank, and the 3-D axis that was fixed to the shank. While there were similarities between the adduction moment curves, there were also several significant differences, particularly between the 3-D tibia-fixed axis and the other two axes. The tibia-fixed axis was also the most effective for discriminating between the healthy and arthritic subjects.

Osteoarthritic Gait

Knee OA has been widely reported to negatively impact gait speed, cadence, and stride length, but there is not much of a consensus on the magnitude of these effects. In fact, there is considerable amount of evidence that the laboratory environment may distort the participants walking gait, particularly when two force platforms constrain the participant's foot placement. In one such study, a group of 9 men and 11 women age 30 ± 8 years who were used as healthy controls had a mean self-selected walking speed of 1.17 ± 0.14 m/s, much slower than would be expected in healthy young participants (78). Another two-force platform study by Gok, Ergin, and Yavuzer (2) reported that a group of 13 healthy women 58 ± 11 years old self-selected walking speed of 1.0 ± 0.1 m/s. In both studies, the mean walking speed of the OA group was slower than the control group, but the speed reported may not be indicative of the actual preferred walking speed of people with knee OA. A study by Mundermann et al. (79) which only used one force platform reported that a control group of 24 women and 20 men age 63.3 ± 10.7 years walked at an average speed of 1.24 ± 0.19 m/s, and the OA group walked with the same speed despite the majority of participants having a Kellgren/Lawrence (K/L) grade of 2, 3, or 4. Thorp et al. (39) reported that group of 38 women and 14 men age 56.2 ± 10.4 years all having symptomatic K/L grade 2 knee OA used a self selected speed of 1.20 ± 0.21 m/s when walking over a single force platform, compared to 1.32 ± 0.25 m/s reported for asymptomatic controls. These values seem to be more in-line with the age-adjusted normal values reported by Whittle (61), and are likely closer to the actual preferred walking speed of adults with moderate knee OA.

The speed at which the participants walk could be an important confounding variable in laboratory gait studies. In a recent study by Zeni and Higginson (3), 56 participants were divided into three groups: a control group (n=22, age 59 ± 11 years), a moderate OA group with a K/L grade of 2 or 3 (n=21, age 63 ± 9.3 years), and a severe OA group with a K/L grade of 4 (n=13, age 59 ± 9.8 years). All participants had their preferred walking speed determined by a timed 10 m walk outside of the laboratory, and then completed 3 trials each of walking at 1.0 m/s, preferred speed, and fastest possible speed on an instrumented treadmill. The preferred walking speeds showed the expected trend, with speeds of 1.22 ± 0.14 m/s, 1.13 ± 0.12 m/s, and 1.03 ± 0.26 m/s for the control, moderate, and severe OA groups, respectively. The same trend was evident at the fast walking speeds, which were 1.75 ± 0.23 m/s, 1.50 ± 0.21 m/s, and 1.37 ± 0.28 m/s. When the peak sagittal plane ankle, knee, and hip moments, frontal plane knee moments, and peak vertical and anterior/posterior ground reaction forces (GRF) were analyzed at 1.0 m/s, only one variable (loading rate of the vertical GRF) was significantly different between groups. Many variables were significantly different between groups at the preferred walking speeds, and all of the variables were significantly different at the fast speeds. However, when walking speed was used the covariate in a MANCOVA procedure, once again only one variable (knee excursion during the loading response) was found to be significantly different between groups. While using walking speed as a covariate may be inappropriate since it is correlated with OA severity (80), Zeni and Higginson's work does demonstrate that many of the biomechanical changes identified in the literature could be attributed to gait speed just easily as it can be to OA severity.

Many studies have examined the knee angle at several instances during the gait cycle, but some care must be taken in synthesizing these results due to the variety of ages, speeds, and methodologies used. Mundermann et al. (36) found that knee angle at initial contact was significantly more flexed in both patients with moderate OA (4.6°) and severe OA (5.3°) than their healthy controls (1.8°), and Manetta et al. (33) reported a similar trend that was not statistically significant, possibly due to their small sample size.

One study reported that the peak knee flexion during loading response was greater for healthy subjects (2), while two others reported that there was no difference between patients and controls (14, 33). Two case control studies both found that healthy participants had a greater knee flexion excursion during the loading response than participants with OA at self-selected speeds (3, 33). Some studies have also looked at the peak knee flexion angle during swing phase (2, 14, 81) and the total knee range of motion during the entire gait cycle (14, 78, 81), typically reporting that knee OA patients exhibit less of both variables, but the magnitude of the difference has varied from study to study.

Kinetic knee variables are also a common topic of research, but much like the kinematics there is little consensus. During the loading response, one study found that the OA group had a greater internal extension moment than controls (2), one study found the opposite (78), and third study found no difference (33). Zeni et al. (3) found that OA patients had a significantly small external flexion moment than controls when walking at their self-selected speed. However, the kinetic variable that gets the most attention by far is the external adduction moment. People with knee OA have routinely been shown to have a higher than normal peak external adduction moment (14, 16, 36-39), although some studies have found no difference between OA patients and controls (70, 71). Several studies employing principle component analysis have also found that the shape of external knee adduction moment curve significantly systematically varies with knee OA severity, with the peaks becoming greater and the characteristic M-shape diminishing as OA becomes more severe (5, 34, 35, 82, 83).

TAIJI

Taiji, also spelled Tai Chi, is a martial art that has its origins in 16^{th} century China. Taiji is widely considered a CAM therapy (7, 58). It is a common misconception that the word ‘chi’ in Tai Chi is the same word as ‘qi’, the internal energy flows in the human body according to traditional Chinese medicine, although this is not the case (84). In many ways, it seems more appropriate to consider Taiji as a form of moderate exercise (10, 25, 85). Although Taiji has evolved from martial arts, today it is practiced more for health and meditation than for self-defense.

The movements in Taiji have been described in qualitative studies as slow, smooth, and dance-like with a semi-squatting posture (24). However, the lower extremity dynamics of Taiji exercises have not been thoroughly studied. Mao, Hong, and Li (86) described the foot movements in a 42-form Taiji exercise and reported that a group of 16 Taiji masters spent 64% of the time in double support (33% in full double support, and 31% with one leg primarily weighted while the other foot made ground contact with the toe or the heel), and 18% of time in single support on each leg. They also reported that 30% of the time the feet were fixed, 20% of the time stepping forward, 18% of the time turning, 14% of the time stepping sideways, 13% of the time stepping up or down, and 5% of the time stepping backwards (86). Wu and Hitt (87) examined the ground reaction force characteristics of “Tai Chi gait”, a style of gait that is common to several Taiji styles. The speed of Tai Chi gait was 0.09 ± 0.05 m/s, which is a full order of magnitude slower than a typical walking gait. The peak vertical GRF was 109 ± 2%

body weight (BW) during single limb support and the vertical GRF ranged from 10% to 70% BW during double support. A follow up study found that the Tai Chi gait had significantly smaller peak net knee joint compressive force but larger knee extension moment than normal gait (88). The peak compressive and shear forces in Tai Chi gait occurred at the transition from double support to single support.

General Health Benefits of Taiji

Many studies have examined the health and fitness benefits of Taiji. Lan et al. (89) found that participants in a 12 month Taiji program made significant improvements in VO_2 max, thoracolumbar flexibility, and both knee flexor and extensor strength compared to controls, although he assignment to groups was not randomized. Li, Xu, and Hong (26) found a significant improvement in knee flexor strength compared to controls after a 16-week Taiji intervention, but the changes in knee extensor strength were not significant. Takeshima et al. (10) found that healthy elderly participants in 12 week 2 day/week Tai Chi program had improvements in arm-curl strength, chair stand, and up-and-go test that were similar to a resistance training program of the same frequency and duration. Chen et al (90) recruited elderly men who lived in a long-term care facility to participate in 6-month simplified Taiji exercise program, finding a significant drop in systolic and diastolic blood pressure, as well as improvements in hand grip strength and lower body flexibility. Hui, Woo, and Kwok (25) randomly assign subjects by neighborhood to one of three groups: 5 day/week walking or Taiji program, or a non-exercising control group. After 316 volunteers completed the 12-week study, authors found that walking and Taiji had similar health benefits in terms of body composition, aerobic fitness, fasting blood glucose, and perceived health.

One highly touted benefit of regular Taiji practice is that it is said to improve balance, although is not as strongly supported in the literature as many are led to believe. Mao, Hong, and Li (86) theorized that Taiji could improve balance because the forms involve reaching and stepping movements of the legs in all directions, similar to a reach balance test. However, Takeshima et al. (10) found that a group practicing Taiji for 12 weeks did no better than controls in a functional reach test, and actually did worse that participants in the walking and resistance training groups. On the other hand, a published review of 10 randomized controlled trials examining Taiji for improvements in balance and risk of falling found that 8 of the studies reported improvement in a variety of outcome measures, including risk of falling, time to first fall, fear of falling, physical function questionnaires, and postural sway tests (91).

Osteoarthritis-Specific Health Benefits of Taiji

Taiji has received much attention as a treatment for OA symptoms, particularly pain, physical function, and quality of life. Pain is typically measured by having by having the participant indicate the level of pain he or she experiences on visual analog scale (VAS), or by filling out a questionnaire such as the Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC) (31), which has subscales for pain, stiffness, and physical function. Physical function is often measured through the use of surveys such as the WOMAC, but there are also a number of simple tests that can be used to determine how well participants are able to meet the physical demands of daily living (57). Quality of life is reported through surveys such as the Arthritis Impact Measurement Scale (AIMS) or several versions of the Medical Outcomes Study Short Form.

Pain is the most common outcome measure reported by studies of Taiji and OA. Eleven out of twelve studies in a recently published systematic review used pain as a primary outcome, seven of which reported that pain scores were improved after a Taiji intervention (30). Shen et al. (92) had 40 elderly men complete a 6-week and two sessions per week Taiji program, and found that the group improved their WOMAC pain score (Likert scale) from 16.3 ± 4.3 to 13.2 ± 4.5 ($p < 0.001$), and they improved VAS of their maximum pain from 5.2 ±2.3 to 4.1 ± 2.8 ($p = 0.002$). Lee et al. (93) conducted a randomized control trial of an 8 week Taiji intervention, and found that the Taiji group improved WOMAC pain scores (Likert scale) from 6.8 ± 4.2 to 4.6 ± 4.0, which was significantly more improvement than the waitlist control group ($p = 0.030$). An earlier randomized control trial also found that the mean improvement in WOMAC pain score (Likert scale) was 2.45 ± 3.96, and was significantly better than the control group ($p=0.030$) (94). Brismee et al. (27) conducted a randomized control trial in which the participants were assigned to either a Taiji intervention or an attention controlled group. The intervention consisted of 6 weeks of 3 classes per week, followed by 6 weeks of home-based practice, and finally a 6 week detraining period. Overall knee pain was recorded on a 10 cm VAS every three weeks throughout the study. Overall knee pain improved relative the baseline value starting from week 3 for the Taiji group, but was not significantly different from the control group until weeks 9 and 12. At week 15 (after 3 weeks of detraining) the two groups were not significantly different from one another, and at week 18 the groups were not significantly different from baseline. Another study compared 12 weeks of Taiji to 12 weeks of hydrotherapy and controls, and found that the hydrotherapy group improved their WOMAC pain scores significantly more than the controls (29). The Taiji group, however, was not significantly different from the other two groups.

WOMAC physical function scores typically show improvements from a Taiji intervention. The subjects in Shen et al. (92) improved WOMAC physical function scores from 40.6 ± 14.1 to 33.0 ± 13.2 ($p < 0.001$), while the participants in the study by Brismee et al. (27) showed an improvement from 42.74 ± 12.07 at baseline to 32.2 ± 13.3 after 9 weeks of practice. After 6 weeks of detraining, the WOMAC physical function scores of the participants worsened to 38.61 ± 15.62, which was not significantly different from baseline (27). Fransen et al. (29) quantified physical function through both the WOMAC scale and three physical performance tests, the timed up-and-go, 50-foot walk time, and timed stair climb. Both the hydrotherapy group and the Taiji group improved their WOMAC physical function score more than the control group (mean changes of 11.4, 10.6, and 0.9, respectively). However, the hydrotherapy group also significantly improved their performance on the three physical performance tests, while the Taiji group was not significantly different from the controls. Lee et al. (93) had a somewhat opposite result, with the Taiji group not improving significantly more than the controls on the WOMAC physical performance scale, but they did improve their 6 m walk time by 1.6 ± 1.7 seconds, significantly more than the control group ($p < 0.001$).

Only one study, to the knowledge of the author, has examined the effects of Taiji on gait characteristics in people with knee OA. Shen et al. (92) examined the stride length, cadence, and gait velocity, as well as the ankle, knee, and hip ROMs before and after a 6 week Taiji intervention. They found no changes in any of the ROM variables, but the participants did increase stride length from 1.17 ± 0.17 m to 1.20 ± 0.14 m ($p = 0.023$), and cadence from 109.2 ± 9.6 steps/min to 111.6 ± 9.6 steps/min ($p = 0.014$). This resulted in a significant increase in gait speed from 1.06 ± 0.19 m/s to 1.12 ± 0.15 m/s ($p < 0.025$), but since there was no control group in the study it is not conclusive that the Taiji was responsible for these increases.

STRENGTH TRAINING

Strength training, or resistance training, is highly recommended for knee and hip OA patients (Zhang, 2008 #296), and is an important form of exercise for maintaining mobility and functional independence in the elderly (95). For people with knee OA, strength training is mainly used to maintain functionality, quadriceps strength, and gait speed, and occasionally to relieve pain and stiffness (96). The modality, frequency, intensity, progression (tendency make exercise more challenging as the participant gains strength), duration, and equipment can be modified to suit the means and need of the users. While this adaptability is useful in practice, it can make the research literature difficult to interpret.

A primary concern in most strength training studies is the increase in strength. Large gains in strength are readily attainable in frail populations. For example, a study conducted with 8 nonagenarians performing 3 sets of 8 repetitions at 80% of their one-repetition maximum (1RM) reported that the average increase in strength after 8 weeks was 172 ± 31 %. At the other end of the intensity spectrum, Tracy and Enoka (97) had elderly participants perform 10 repetitions of knee extensions at 30% 1RM for 16 weeks, and found that the participants 1RM at the end of the intervention did not differ from the control group. However, the exercise group in this study was able to lift 4.6 times of their baseline 1RM at week 16, as opposed to 2.4 times for the control group, demonstrating that there may be some strength-gain benefit even to low-intensity resistance training, which is often recommended for patients with knee OA. In one such study, participants improved their right quadriceps strength by 4.7% and left quadriceps strength by 4.0% after performing 5 home-based exercises for 6 months (98).

While knee extensor weakness is widely considered a risk factor for knee OA, a recent longitudinal study found no association between quadriceps strength and tibiofemoral cartilage loss (as assessed through MRI) at 15 and 30 month follow-ups (99). They did report that greater quadriceps strength had a protective effect on the lateral patellofemoral joint, and that participants with greater quadriceps strength reported less pain at the follow-ups. Similarly, Mikesky et al. (100) conducted randomized control trial of knee strengthening exercises with elderly participants for 30 months, and found that the incidence of joint space narrowing was not related to changes in quadriceps strength or knee pain.

As with other interventions, pain is often measured using the WOMAC or VAS in strength training interventions. Gur et al. (21) reported changes in pain in their study using at 10-point numeric rating scale for 7 different activities of daily living, and a summed total score. The 8-week study had a group doing concentric knee flexion and extension exercises on a Cybex 6000 machine, a group doing the same exercises in a typical concentric-eccentric fashion, and a non-exercising control group. Both exercising groups reported significant reductions in total pain (53 ± 18 % reduction for concentric-eccentric group, and a 69 ± 12 % reduction for concentric only group) compared to the control group ($p < 0.01$). The concentric only group had lower pain scores after inactivity and after ascending and descending stairs, although there were no statistics provided to test if these were statistically significant. In most training modalities, however, it is not an option to only perform the concentric part of the movement, but other modalities do show significant reductions in pain. Ettinger et al. (20) had participants complete a 3-month facility-based free weight program 3 times per week, followed by a 15-month home-based program where the intensity was increased when the participant was able to perform 2 sets of 12 for 3 consecutive sessions. After 18 months, the resistance training group had a significantly lower pain score than the control group ($p=0.02$). Topp et al. (22) reported that a group of participants performing dynamic Theraband exercises 3 times per week for 16 weeks reduced their WOMAC pain score from 12.40 to 10.71, while another group performing isometric Theraband exercises reduced their WOMAC pain scores from 11.75 to 10.38. The control group in this study did not change their WOMAC score, although they did begin the study with a lower score than the exercising groups. A study by O'Reilly, Muir, and Doherty (98) had participants do 5 low-intensity knee exercises every day for 6 months, and reported a reduction in WOMAC pain scores of 1.45 (95% CI: 0.86 to 2.04), which was also significantly better than a non-exercising control group ($p = 0.02$).

Gait speed is considered an indicator of health in the elderly, and is often used as an outcome measure in studies. In one study, a group of participants with a mean age of 81.6 years participated in a 12 week exercise program aimed at improving flexibility, strength, and balance. After the intervention, they improved their knee extension 1RM from 55 ± 4 Nm to 72 ± 5 Nm ($p < 0.001$), increased their usual gait speed from 1.04 ± 0.07 m/s to 1.12 ± 0.06 m/s ($p=0.006$), and increased their maximum gait speed from 1.43 ± 0.1 m/s to 1.49 ± 0.1 m/s (not significant, $p=0.054$) (101). A 6-minute walk (6MW) distance is also often used for this purpose. Mian et al. (102) had their participants underwent a 12-month conditioning program, which included aerobics and resistance training 3 times per week, and improved their 6MW distance from 587 ± 90 m to 624 ± 88 m (significantly greater improvement than controls, $p < 0.01$). Populations with OA typically walk slower than healthy older adults. One group of 105 persons with knee or hip OA had a median 6MW distance of 336.0 m, and an interquartile range of 296.0 m, though participants in the exercise groups (hydrotherapy or resistance training) were able to increase this distance by approximately 50 m in 6 weeks (103).

Physical function tests are often considered along with gait speed in many studies of elderly populations, particularly for tasks such as standing from a chair or ascending and descending stairs. Stair descending can be particularly challenging for older adults. Mian et al. (104) compared the kinematics of descending 3 steps in young people (mean age 26.6 ± 3.1 years) and old people (mean age 73.4 ± 3.7 years), and found that the older group had a significantly smaller total knee range of motion and significantly larger frontal and transverse plane motions of the pelvis and hip. The older group was then randomly split into a control group and a group which underwent 12-months of resistance training. No significant differences between these groups were found at the end of the intervention. However, another study on adults with OA found that they decreased the time it took to climb 22 stairs by an average of 2.52 % after 16-weeks of a dynamic home exercises with resistance bands, and they also decreased the time it took to descend the stairs by 3.33 % (22). Gur et al. (21) found that participants with knee OA who completed 8 weeks of strength training reduced the time it took to rise from a chair with no arm rests 10 times 22 ± 8 %. The same group also deceased the time it took to climb 12 stairs from 6.38 ± 1.73 s to 4.88 ± 0.74 s ($p < 0.01$) and also decreased their stair descent time from 6.75 ± 2.22 s to 4.58 ± 0.74 s ($p < 0.001$).

SUMMARY

OA is a degenerative disease of the joints that causes pain, stiffness, and disability which most commonly afflicts people in old age. The current treatments focus on relieving the symptoms of OA through a combination of pharmacological and non-pharmacological means. Because of the need to maintain health and physical function as people age, exercise is a common non-pharmacological method for controlling OA symptoms. Strength training is among the most highly recommended types of exercise for older adults because of its adaptability and effectiveness at improving strength and mobility. There is also some evidence to suggest that strength training can improve OA symptoms. Taiji has become a popular exercise for persons with OA in recent years. Although Taiji is a gentle form of exercise with many known health benefits, there is still conflicting information on its effectiveness for reducing OA symptoms.

CHAPTER III

PARTICIPANTS AND METHODS

For this study, people 60-85 years-old with knee osteoarthritis (OA) were recruited to take part in either a strength training or Taiji intervention, or to serve as a control subject (Figure 1). After reading and signing an informed consent document approved by the institutional review board of the University of Tennessee, all qualified participants partook in a testing session in which they filled out surveys on their knee OA status and physical activity, completed three physical performance tests, underwent a three-dimensional gait analysis, and had their knee strength measured. After the 10-week intervention, the participants completed the testing session for a second time, and the changes from pre-test to post-test of several key variables were analyzed to identify meaningful differences between groups. This chapter describes the methods of this study in detail, and a graphical overview of the study is shown in Figure 1.

PARTICIPANTS

Two cohorts of participants were recruited from Knox county area to participate in the study. The first cohort was recruited through flyers placed in area senior centers, an announcement printed in the Elder News and Views, a local newsletter for seniors published by the Knox Country Office of Aging, and an announcement printed in the Knoxville News Sentinel. The second cohort was recruited through an announcement in

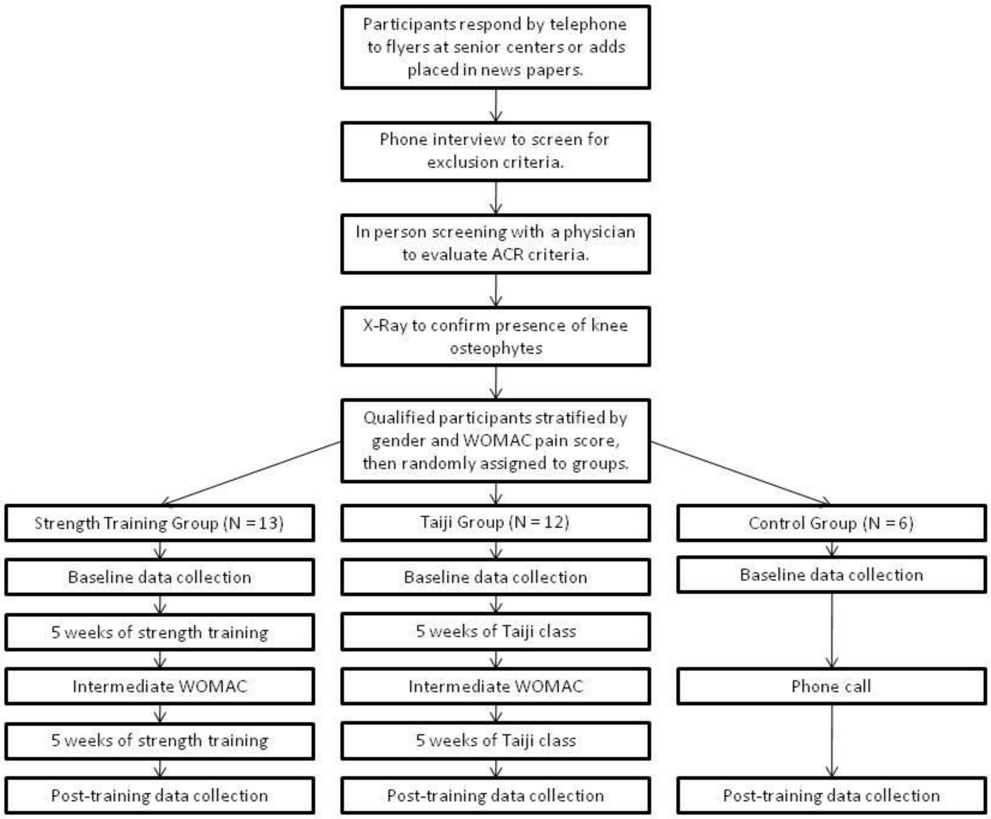


Figure 1. Flow chart of subject participation.

the Knoxville News Sentinel. Potential participants were interviewed over the phone to see if they met the exclusion criteria (see Chapter 1).

Participants who were not excluded by the phone interviewed were invited to a screening session at the John O'Connor Senior Center or the UT Medical Center with Dr. Gary Klipple, a rheumatologist at the UT Medical Center. Dr. Klipple determined whether a participant met the Classification Criteria for Knee OA of the American College of Rheumatology (41), which has been reported to have 86% specificity and 91% sensitivity for knee OA diagnosis. The specific criteria included:

- knee pain for at least 6 months occurring on a majority of the days in the month
- the presence of osteophytes on knee x-rays
- one or more of the following:
    - age greater than 60 years
    - morning stiffness for longer than 30 minutes
    - crepitus on active motion of the knee
    - a grade 2 or 3 out of a maximum of 4 on a modified Kellgren/Lawrence (K/L) grade on the knee radiograph within the past six months

Participants who were qualified to participate in the study had bilateral x-rays taken of their knees, which were later graded on the K/L scale by Dr. Klipple (42).

All participants were given a copy of the informed consent document, which was approved by the institutional review board of the University of Tennessee, at the screening session for them to take home and review. Participants who elected to continue with the study were given a second copy of the informed consent document to sign and return.

TESTING PROTOCOL

All qualified and willing participants were scheduled to participate in a pre-testing session in the Biomechanics/Sports Medicine Lab at the University of Tennessee. All of the pre-test sessions were conducted within a two-week period prior to the commencement of the intervention program.

Each testing session began with the participant filling out the Physical Activity Scale for the Elderly (PASE) survey (105) and the Western Ontario and McMasters University Osteoarthritis Index (WOMAC) (31). Each participant completed two copies of the WOMAC survey, one for each knee. The WOMAC surveys used had the participants indicate the level of pain, stiffness, and physical function in their knee on a 10 cm visual analog scale (VAS). In addition to the surveys, the participants were asked to rate the pain experienced in each knee on a 10 cm VAS after each activity during the testing session. All VAS ratings were measured and recorded to the nearest half of a millimeter.

Next the participants performed three physical function tests: the 6-minute walk test (6MWT), timed up-and-go (TUG) test, and the timed stair climb and descent (SCD). For the 6MWT, a 49 m x 1 m rectangle was marked with painters tape on the floor of a large hallway. The participants were instructed to walk around the rectangle in order to cover as much ground as possible in 6 minutes (106). Participants were permitted to stop and rest as needed during the test, but were encouraged to begin walking again as soon as possible. Standardized encouragement (e.g., "Good job" or "Keep up the good work") was given to the participant once each minute while the laps were counted. The participant's final position was marked with a piece of tape, and then the total distance for the 6MWT was measured to the nearest tenth of a meter. For the TUG, the participant was timed while she/he rose from an arm chair, walks 3 meters, turned, walked back, and sat down again (57). This was repeated three times, and average time was used for data analysis. During the SCD the participants were timed as they climbed a single flight of 11 stairs, turn around, and descended the same flight of stairs at a quick but safe speed. They were instructed that they could use the hand rails for support, but not for pushing or pulling their way up the stairs (57). Since participants often found this activity painful, it was only performed once.

The range of motion (ROM) of both knees was measured for each participant while they lied supine on an examination table. Lines were drawn on the participants' thighs and shanks, and the angles between these lines were measured with a goniometer. A straight leg measurement was taken while the participant's heel rested on shoe box. Then the participant's hip and knee were passively flexed by the researcher to the tolerance of the participant. The flexed measurement was repeated three times and average value was used to estimate the participant's ROM.

For the gait analysis each participants wore a pair of standard lab shoes and disposable orthopedic shorts. Two cones were placed approximately 10 meters apart on either side of two force platforms (Advanced Medical Technologies, Inc, Waterford, MA) arranged in staggered formation (Figure 2). The participants were instructed to walk from one cone to the other at a speed of 1.1 m/s (± 5%), as monitored by two photo cells placed 3 m apart around the force platforms. Participants were given an opportunity to practice until they could consistently walk at the correct speed, and then the position of the starting cone was adjusted so that their feet would make correct contact with the force platforms.

Reflective markers were applied to the participant bilaterally on the 1st and 5th metatarsal heads, medial and lateral malleolus, medial and lateral femoral epicondyles, greater trochanter, and iliac crest. Tracking markers were applied to the heel counter of the shoes and to the shank, thigh, and pelvis via thermoplastic shells. The participants stood on one of the force platforms with their feet parallel and shoulder width apart while 1-second static calibration trial was captured using a seven camera 3-D motion capture system (Vicon, Oxford, U.K.) with a video frame rate of 240 Hz and an analog sampling rate of 1200 Hz. Then the anatomical markers were removed and five successful walking trials were recorded. For a trial to be considered successful, the participant had to make full contact with each force platform without targeting while walking at the correct speed, as practiced previously.

The final activity of the testing session was a test of maximum isometric knee strength. The participants sat in a custom-built muscle testing chair with the seat depth adjusted to the participant’s leg length, and the height set so that the feet could not rest on the ground. The participant was secured in the chair by three straps: one across the waist,

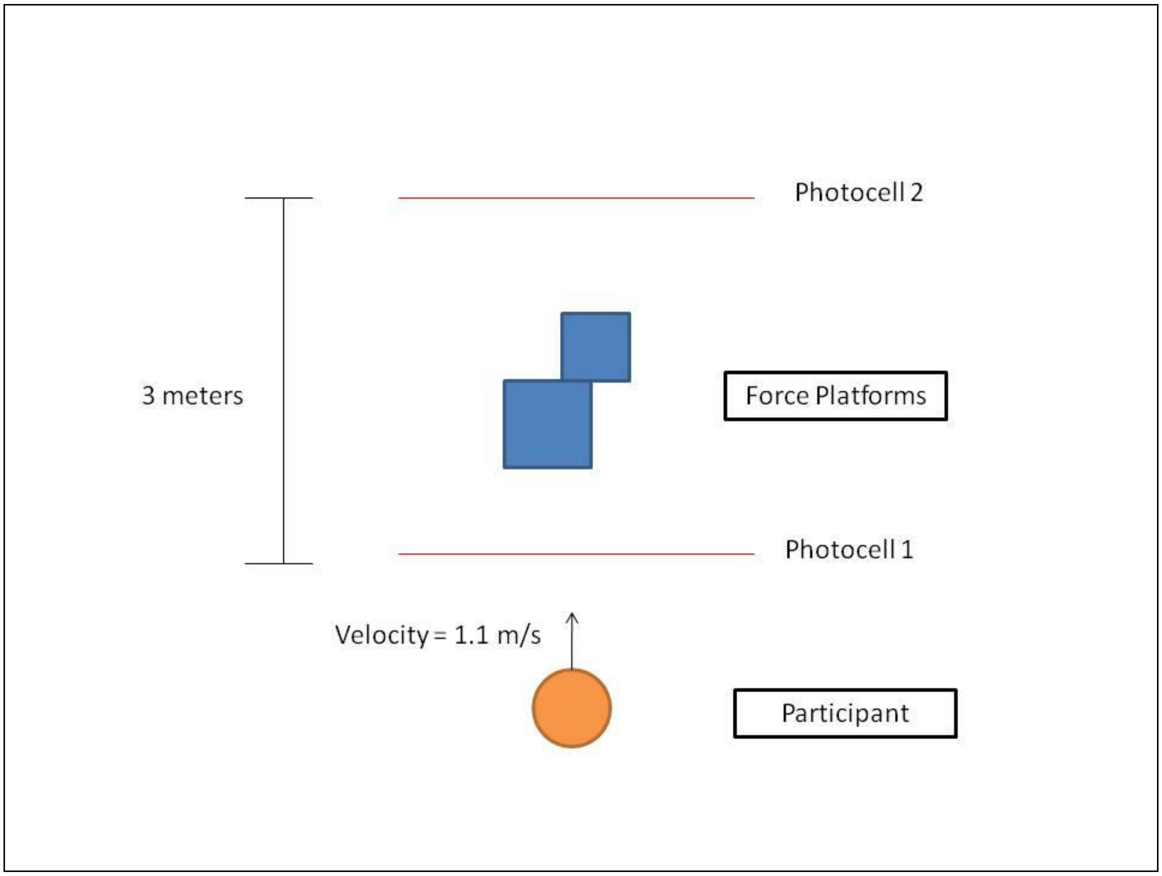


Figure 2. Laboratory set-up for gait analysis.

one across the shoulder, and one over the lap. A chain with an embedded strain gauge (MPL-300, Transducer Techniques) was anchored to the wall at one end, and to the participant's ankle via a Velcro ankle strap at the other end. The chair could be moved to test either flexion or extension or either knee, and the order in which these were tested was randomized. Before the chain was attached to the ankle for each testing condition the participants knee was flexed to 90°, and then the on the distance (moment arm) between the participant's knee joint center and the ankle strap was measured, as well as the angle between the chain and the participant's shank. On command, the participant attempted to flex or extend the knee as forcefully as possible against the chain for 3 seconds while the stress in the chain was sampled at 1200 Hz using the Vicon system. Each testing condition was repeated three times. The peak force value from the three trials was used, along with the moment arm and the angle between the chain and shank, to calculate the maximum isometric joint moment for each condition.

Within two weeks of completing this testing session the participants were assigned groups and began their respective 10-week interventions. Within a two-week period following the intervention each subject returned to the Biomechanics/Sports Medicine lab to repeat the protocol.

Since the first cohort began with only 16 participants, they were randomly assigned to the Taiji and strength training programs using the criteria given below. The second cohort of 23 participants was randomly assigned to Taiji, strength training, and control groups. For both cohorts, the process of assigning groups began by separating the participants by gender, and then dividing both genders into subgroups based on whether they were above or below the median pain sub-score on the WOMAC survey. The participants were then randomly assigned to a group from their subgroup in order to ensure that the groups began with a similar distribution of genders and similar mean pain scores. Using this method, the first cohort began with 7 participants in the Taiji group and 9 participants in the strength training group. The second cohort began with 8 participants in the Taiji group, 6 participants in the strength training group, and 9 participants in the control group. The control was intentionally larger than the training groups since there was no control group in the first cohort.

TRAINING INTERVENTIONS

The Taiji and strength training groups each attended two 60-minute training sessions each week for 10 weeks. The first cohort met at the John O'Connor Senior Center in east Knoxville, while the second cohort met at the Frank R. Strang Senior Center in west Knoxville. Participants were asked not to practice Tai Chi or strength training outside of the two weekly sessions. All participants were asked not to participate in any other new physical activity during the 10-week period, and were asked to inform us if the doses and type of medications changed during the study.

The Taiji program (Appendix A) had 12 basic movements adapted from the Yang style, and was designed by Taiji Master Larry Brown, MS, CTRS, CAS, Senior Coordinator, Recreation and Leisure Studies, The University of Tennessee, who had 35 years of Taiji training and teaching experience. The movements in the program were selected to suit knee OA patients with a high standing posture and slow, low impact movement. The sessions were led by two members of the research team who received instruction and a Tai Chi certification from Mr. Brown on how to teach the Tai Chi exercises. The instructors had practiced the Taiji program for two months before commencing the intervention.

The strength training program (Appendix B) was designed specifically for the knee OA patients following the position stand of American College of Sports Medicine (2009) and the guidelines of the American Geriatric Society (2001). The strength training program was designed by John Krusenklaus, an experienced physical therapist who had extensive experience treating lower extremity injuries and diseases. The strength training sessions were led by two members of the research team, one of which had previous experience with resistance training with an elderly population.

The control group was asked not to alter their usual physical activity during the 10 weeks of the intervention. Like the two other groups, the controls were asked not to participate in any new physical activity during the 10-week period, and were asked to inform us if the doses and type of medications changed during the study. They were contacted by phone once five weeks into the intervention.

DATA PROCESSING AND ANALYSIS

Following data collection, data processing was done using Visual 3D software (C-Motion, Inc., Germantown, MD). Gaps in the marker trajectories were interpolated using a cubic spline, and all trajectories were filtered using a fourth-order lowpass filter at a cutoff frequency of 6 Hz. The ground reaction force data was lowpass filtered at a cutoff frequency of 50 Hz. Three-dimensional kinematics and inverse dynamics were computed using Visual 3D software. The maximum isometric knee moments were also calculated in Visual 3D using unfiltered force data from the strain gauge.

To test the hypotheses of this study, the several variable of interest were calculated in Visual 3-D. The knee flexion excursion (KEXC) about the medial-lateral axis of the thigh was calculated as the difference between the knee angle at heel strike and the peak knee flexion angle during midstance. Knee joint loading was examined at two events (instants of time): the initial stance peak, as determined by the peak in the knee extension moment after heel strike, and the terminal stance peak, determined by the peak ankle plantarflexion moment before toe off. These two events were chosen because a modeling study has indicated these are the moments of peak knee loading during walking (40). At each of these two events, four variables were examined: the ground reaction force (GRF) component directed along the long axis of the tibia, the ankle plantarflexion moment (AMX) expressed about the medial-lateral axis of the shank, the knee flexion/extension moment (KMX) expressed about the medial-lateral axis of the thigh, and the internal knee abduction moment (KMY) expressed about the anterior-posterior axis of the shank. The maximum isometric knee flexion and extension moments were also calculate in Visual 3-D.

After data processing one leg was selected for the statistical analysis using the following rules. In most cases (57.9 % of participants), the leg with the higher K/L grade was chosen. If both legs had an equal K/L grade, the leg with higher baseline WOMAC pain sub-score was chosen (31.6 % of participants). In cases where the K/L grades of each leg were equal and the baseline WOMAC pain sub-score were with 25 mm of one another, the overall baseline WOMAC score was used to select a leg (2.6 % of participants). If the K/L grades were equal, baseline WOMAC pain sub-scores were within 25 mm, and the overall baseline WOMAC scores were within 120 mm, then a leg was chosen randomly (7.9 % of participants).

For all of the variables, three statistical tests were performed. A one-way analysis of variance (ANOVA) was used to determine if there were differences among groups in the pre-training values of any variable. Paired sample t-tests were used within each group to determine if there was a significant difference between the pre- and post-training values of a variable. Finally, the difference between (baseline) and post-training values of each variable was used in a one-way ANOVA to detect the difference of training effect among the groups. Post hoc comparisons using the Tukey method were used to detect group differences. The alpha level for all statistical tests was set at 0.05 a priori. All statistical tests were performed using PASW 18.0 (SPSS, Chicago, IL).

Effect sizes were calculated for each group using the difference between the baseline and post-training values of each variable. In all cases, the effect size is the training group mean minus the control group mean divided by the pooled standard deviation (96). Effect sizes between 0.5 and 0.8 were considered moderate, while effect sizes larger than 0.8 were considered large.

CHAPTER IV

EFFECTS OF STRENGTH TRAINING AND TAIJI ON THE MOBILITY, SYMPTOMS, AND GAIT OF SENIOR CITIZENS WITH KNEE OSTEOARTHRITIS

Arthritis is the leading cause of disability in the United States, and osteoarthritis (OA) is by far the most common type of arthritis (1). Lawrence et al. (1) estimated that in 2005 18.6 million US citizens over 60 years-old had mild, moderate, or severe radiographic knee OA, of which about 6 million were clinically symptomatic. Knee OA causes pain and stiffness, which can lead to a decline in knee strength and slowing of gait speed beyond what is normally expected due to advancing age (2), as well as changes in gait biomechanics (3-5). These changes often result in significant limitation of daily activities for people with knee OA.

Many forms of exercise, including walking, strength training, hydrotherapy, flexibility training and balance training, have been investigated as methods of managing OA symptoms and improving mobility (7, 10). Strength training has been shown to improve strength and mobility in elderly populations (95, 101, 107), and to improve strength and physical function of knee OA patients without increasing knee pain (18, 19). Some studies have reported that strength training also helped reduced the participants' OA pain (20-22). However, reports of the effectiveness of strength training to reduce OA symptoms vary widely, and the use of different training modalities and intensities make the literature difficult to interpret.

Taiji, a four centuries-old Chinese martial art characterized by slow, flowing movements (24), has gained increasing popularity as an OA treatment. A growing number of randomized and controlled clinical trials in the past 20 years have found that participation in Taiji can improve quality of life and physical function (85). Some studies have found an improvement in pain (27, 28), while others have found this change was not significantly different from control subjects (29). Only a handful of randomized clinical trials evaluating Taiji for OA have been conducted (30), and the evidence for effectiveness of Taiji is mixed.

The differences between a healthy walking gait and an OA gait have been well established in the literature. Knee flexion excursion during the loading response, as well as the corresponding internal knee extension moment, is known to decrease (3, 33-35). The external knee adduction moment is known to be higher in people with knee OA, both during the loading response and the terminal stance (5, 14, 16, 34-39). There may also be a change in the ratio between the peak external knee adduction moments during initial stance and terminal stance, although the nature of that change is in question (5, 35). To the knowledge of the authors, there are no studies in the literature that have investigated whether a strength training or Taiji intervention could have an effect on the gait biomechanics of OA sufferers. Furthermore, no studies have compared effectiveness of these two intervention programs on knee OA patients.

Most OA intervention studies do not investigate potential changes to the tibiofemoral loading environment during walking, probably because the inverse dynamics method is not capable of isolating the forces acting on articular cartilage. However, a forward dynamics approach has been used to estimate of the tibiofemoral contact force during healthy gait (40). Those results indicated that tibiofemoral contact forces are primarily due to the ground reaction force (GRF) and the quadriceps muscle during initial stance, and the GRF and the gastrocnemius during terminal stance. Considering the ground reaction force along with the sagittal plane moments at both the knee and ankle could provide clues about the relative changes in tibiofemoral loading environment during gait.

The objective of this study was to evaluate and compare the effectiveness of a 10-week Taiji intervention and a 10-week strength training intervention in senior citizens with knee OA. Each intervention was evaluated in terms of its ability to improve strength and mobility, reduce pain and other symptoms of knee OA, and improve the gait biomechanics of the participants. It was hypothesized that both interventions would improve the participants' mobility and OA symptoms compared to a control group, while also increasing the knee flexion excursion and knee loading while reducing the internal knee abduction moment during gait.

PARTICIPANTS AND METHODS

Participants were recruited from Knox county area through flyers placed in area senior centers and announcements printed in the local news paper and a local newsletter for seniors. Interested persons were asked to contact the researchers by telephone, and all callers were given a brief telephone interview to see if they passed the exclusion criteria. To be eligible, potential participants had to be between the ages of 60 and 85 years with knee OA and free of neurological disorders. They could not have had arthroscopic surgery or an intra-articular injection within the past three months, and they could not have participated in a strength training or Taiji in the past six months. Participants not excluded by the phone interview were invited to a screening session at the John O'Connor Senior Center or the University of Tennessee (UT) Medical Center with Dr. Gary Klipple, a rheumatologist at the UT Medical Center. Dr. Klipple determined whether a participant met the Classification Criteria for Knee OA of the American College of Rheumatology (41). Finally, bilateral knee x-rays were taken and evaluated for osteophytes and joint space narrowing.

All qualified and willing participants were scheduled to participate in a baseline data collection session in the Biomechanics/Sports Medicine Lab at the University of Tennessee. During their data collection session, each participant completed a Physical Activity Scale for the Elderly (PASE) survey (105) in order to monitor their overall level of activity, followed by tests to evaluate the participant's mobility, strength, OA symptoms, and gait. All of the baseline data collection was conducted within a two-week period prior to the commencement of the 10 week intervention program. All participants who completed the training intervention also completed a post-training data collection that was identical to the baseline session. Prior to participating in data collection, all participants read and signed an informed consent document approved by the Institutional Review Boards of the University of Tennessee and the UT Medical Center.

Training Interventions

Within two weeks of completing the baseline testing session the participants were randomly assigned to either a strength training program (ST), a Taiji program (TJ), or a control group (CON) in a manner that balanced gender and Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC) pain scores across the groups. All three groups were asked not to alter their regular physical activity or pain medications during the 10-week intervention programs.

Two cohorts of ST groups participated in a program designed specifically for knee OA patients that followed the position stand of American College of Sports Medicine (2009) and the guidelines of the American Geriatric Society (2001). The program consisted of 7 knee and hip exercise performed with ankle cuff weights, and met twice per week for hour each session. Participants gradually progressed from 2 sets of 8 repetitions to 3 sets of 12 repetitions.

Two cohorts of TJ groups participated twice per week in an hour long class in which they learned and practiced a program of 12 basic movements adapted from the Yang style Taiji. The program was designed by a Taiji master with 35 years of experience.

The CON group was asked not to alter their usual physical activity during the 10 weeks of the intervention, and was contacted once by telephone during the intervention. At the end of 10 weeks, all participants returned to the lab to repeat the same tests that were done during the baseline data collection session.

Analysis of Strength and Mobility

To evaluate mobility, participants performed three physical function tests. The 6-minute walk test (6MWT) was conducted on a 49 meter (m) x 1 m rectangle that was marked with painters tape on the floor of a large hallway. The participants were instructed to walk around the rectangle in order to cover as much ground as possible in 6 minutes (106), and the distance walked was measured to the nearest tenth of a meter. In the timed up-and-go test (TUG), participants were timed as they rose from an arm chair, walked 3 m, and then walked back to the chair and sat down (57). This was repeated three times, and the average time was used for data analysis. During the timed stair climb and descent (SCD), the participants were timed as they climbed a single flight of 11 stairs, turned around, and descended the same flight of stairs at a quick but safe speed. They were instructed that they could use the hand rails for support, but not for pushing or pulling their way up the stairs (57). Since participants often found this activity painful, it was only performed once.

Each participant's knee strength was evaluated using their maximum isometric knee flexion and extension moment. The participants sat in a custom-built muscle testing chair with the seat depth adjusted to the participant's leg length, and the height set so that their feet could not rest on the ground. The participant was secured in the chair by three straps: one across the waist, one across the shoulder, and one over the lap. A chain with an embedded strain gauge (MPL-300, Transducer Techniques) was anchored to the wall at one end, and to the participant's ankle via a Velcro ankle strap at the other end. The chair could be moved to test either flexion or extension of either knee, and the order in which these were tested was randomized. The chain was attached to the ankle for each testing condition such that the participant's knee was flexed to 90°. Then the distance (moment arm) between the participant's knee joint center and the ankle strap was measured, as well as the angle between the chain and the participant's shank. Sub-maximal practice trials were performed prior to each testing condition. For each recorded trial the participant attempted to flex or extend their knee as forcefully as possible against the chain for 3 seconds while the force measured by the strain gauge was sampled at 1200 Hz using the Vicon system. Three trials were recorded for each testing condition with at least 45 seconds of rest in between trials. The peak force value from the three trials was used, along with the moment arm and the angle between the chain and shank, to calculate the maximum isometric joint moment in Newton meter (Nm) for each condition.

Analysis of OA Symptoms

OA symptoms were evaluated using the Western Ontario and MacMaster University Osteoarthritis Index (WOMAC) (31). The WOMAC survey has 24 questions with questions related to pain, stiffness, and difficulty performing physical. All questions were answered by making a mark on a 10 cm visual analog scale, and all answers were recorded to the nearest half millimeter.

Analysis of Gait

For the gait analysis each participants wore a pair of standard lab shoes and disposable orthopedic shorts. Two cones were placed approximately 10 meters apart on either side of two force platforms (1200 Hz, Advanced Medical Technologies, Inc, Waterford, MA) arranged in staggered formation. The participants were instructed to walk from one cone to the other at a speed of 1.1 m/s (± 5%), as monitored by two photo cells placed 3 m apart around the force platforms. Participants were allowed to practice until they could consistently walk at the correct speed. Anatomical reflective markers were applied to the participant bilaterally on the 1st and 5th metatarsal heads, medial and lateral malleolus, medial and lateral femoral epicondyles, greater trochanter, and iliac crest. Tracking markers were applied to the heel counter of the shoes and to the shank, thigh, and pelvis via thermoplastic shells. The participants stood on one of the force platforms with their feet parallel and shoulder width apart while 1-second static calibration trial was captured using a seven camera 3-D motion capture system (240 Hz, Vicon, Oxford, U.K.). Then the anatomical markers were removed and the participant performed walking trials until five successful trials were recorded. For a trial to be considered successful, the participant had to make full contact with each force platform without targeting while walking at the desired speed.

Following data collection, the gait data was processed using Visual 3D software (4.75, C-Motion, Inc., Germantown, MD). Gaps in the marker trajectories were interpolated using a cubic spline, and all trajectories were filtered using a fourth-order lowpass filter at a cutoff frequency of 6 Hz. The ground reaction force data was filtered using a fourth-order lowpass at a cutoff frequency of 50 Hz. Three-dimensional kinematics and inverse dynamics were computed using Visual 3D software.

Several variables of interest were calculated in Visual 3D. The knee flexion excursion (KEXC, in degrees) was calculated as the difference between the knee angle at heel strike and the peak knee flexion angle during midstance. The kinetic variables that affect compressive knee joint loading were examined at two moments in time. The initial stance peak was assumed to correspond to the peak knee extension moment during loading response. The terminal stance peak was assumed to correspond to the peak ankle plantarflexion moment during terminal stance. These two events were chosen based on a modeling study which indicated that these were the moments of peak knee loading during walking in healthy participants (40). The four variables used to describe the knee load were the component of ground reaction force (GRF) directed along the long axis of the tibia in Newtons (N), the sagittal ankle moment (AMX, in Nm) expressed about the medial-lateral axis of the shank, the sagittal knee moment (KMX, in Nm) expressed about the medial-lateral axis of the thigh, and the frontal knee moment (KMY, in Nm) expressed about the anterior-posterior axis of the shank. All moments were computed as internal moments. Positive values indicate dorsiflexion at the ankle, and extension or adduction at the knee. The subscript following the variable abbreviation indicates whether it is from the initial stance peak (i) or the terminal stance peak (t).

Statistical Analysis

For all of the dependent variables, three statistical tests were performed. A one-way analysis of variance (ANOVA) was used to determine if there were differences between groups in the baseline values of any variable. To determine if the training interventions had an effect, paired sample t-tests were performed within each group comparing the baseline and post-training values of each variable. Difference scores were computed for each variable by subtracting each baseline value from its post-training value. A one-way ANOVA of the difference scores was used to detect the difference of training effect between the groups. Post hoc comparisons using a Tukey procedure were performed to detect differences among the groups. The alpha level for all statistical tests was set at 0.05 a priori. All statistical tests were performed using PASW 18.0 (SPSS, Chicago, IL).

The effect size (ES) was calculated for each intervention using the difference scores of each variable. In all cases, EFFECT SIZE was calculated by subtracting the mean difference score of the control group from the mean difference score of a training group, and then dividing by the pooled standard deviation (96). Effect sizes between 0.5 and 0.8 were considered moderate, while effect sizes larger than 0.8 were considered large.

RESULTS

Participants

Thirty-nine participants began the study, and 31 participants completed the study. Of the participants who did not complete the study, three were unable to finish due to their OA (two in the TJ group, one in the CON group), two suffered lower extremity injuries unrelated to the study (both in the CON group), and three had work or family commitments that did not allow them to complete the intervention (two in the ST group, one in the TJ group). The participants who did not complete the intervention did not differ from the other participants in age, height, or mass. The overall attrition rate was 20.5%, and ranged from 13.3% among ST participants to 33.3% in the CON group. The participants who completed the study had a mean age of 69.13 ± 5.79 years, mean height of 1.66 ± 0.10 m, and mean mass of 89.31 ± 20.36 kg (Table 1). One-way ANOVAs found no significant differences between groups at baseline for any variable. The attendance rates were 87.7% and 81.7% for the ST and TJ groups, respectively (Table 1).

All participants were asked not to alter their physical activity outside of the study before and during the intervention programs. The paired t-tests indicated that there were no differences between the baseline and follow-up PASE scores for the CON group. The post-training PASE scores were significantly greater than baseline for both the ST ($t=-4.664$, $p<0.001$) and the TJ ($t=-2.446$, $p=0.032$) groups (Table 1).

Although the groups were balanced on their baseline WOMAC pain scores, the groups did have different distributions of K/L grades (Table 2). A one-way ANOVA of the K/L grades, however, found no significant difference between the three groups.

Strength and Mobility

Table 3 contains the baseline and post-training values of the 6MWT, TUG, SCD, and the maximum isometric knee strength. There were no significant differences between the baseline values of any variable. The paired t-tests showed that the TUG times were significantly faster post-training for both ST ($t=4.243$, $p<0.001$) and TJ groups ($t=5.245$, $p<0.001$). However, the difference scores were not significantly different between the groups for any of the other mobility tests.

Table 1. Participant and training group information.

	Strength Training		Taiji		Control	
N (female/male)	13 (9/4)		12 (9/3)		6 (4/2)	
Age (years)	69.48 ± 6.71		68.06 ± 5.31		70.52 ± 5.04	
Height (m)	1.67 ± 0.10		1.65 ± 0.12		1.67 ± 0.10	
	Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training
Mass (kg)	85.30 ± 18.03	84.80 ± 18.69	96.10 ± 21.94	95.95 ± 21.35	84.41 ± 21.57	84.34 ± 21.64
PASE Score	104.88 ± 42.33	*177.24 ± 62.12**	92.60 ± 79.28	*120.89 ± 90.74**	139.27 ± 94.14	142.03 ± 74.59
Attendance (%)	87.69 ± 9.04		81.67 ± 9.85		n/a	

PASE = Physical Activity Scale for the Elderly
* - Significantly different from baseline.

Table 2. Distribution of knee osteoarthritis severities in the three groups.

	Strength Training	Taiji	Control
K/L Grade 1	2	2	0
K/L Grade 2	6	1	4
K/L Grade 3	5	5	2
K/L Grade 4	0	4	0
Mean	2.2 ± 0.7	2.9 ± 1.1	2.3 ± 0.5

K/L Grade = Kellgren/Lawrence Grade

The t-test revealed that the CON group performed significantly worse in isometric extension strength during the post-training session (t=4.285, p=0.008). The ST and TJ groups did not change either isometric flexion of extension strength. A one-way ANOVA of the difference scores for extension strength found a significant difference between groups (F(2, 28)=4.827, p=0.016). Post hoc comparisons indicated that the ST group and CON group were different from one another (p=0.012). No other comparisons for isometric strength were significant.

Knee OA Symptoms

The t-tests on the WOMAC sub-scales showed that the ST group significantly improved on the pain sub-scale (t=3.313, p=0.006), the stiffness sub-scale (t=5.190, p<0.001), and the physical function sub-scale (t=2.990, p=0.011) (Table 4). Neither the TJ nor CON groups significantly improved on any of the WOMAC sub-scales. A one-way ANOVA of the difference scores for the stiffness sub-scale scores was significant (F(2, 28) = 4.482, p = 0.020). Post hoc comparisons revealed that the ST group had a significantly greater improvement than the TJ group (p=0.026). Neither the ST nor TJ groups had a significantly different improvement from the CON group.

Gait Analysis

Table 5 presents the baseline and post-training values of the gait analysis variables. There were no significant differences in KEXC between baseline and post-training for any group. There were also no significant differences between baseline and

Table 3. Strength and mobility test results at baseline and post-training.

	Strength Training		Taiji		Control	
	Baseline	**Post-Training**	**Baseline**	**Post-Training**	**Baseline**	**Post-Training**
6MWT (m)	459.7 ± 72.2	473.8 ± 55.4	421.2 ± 77.4	431.6 ± 67.3	501.9 ± 114.0	507.2 ± 118.7
TUG (sec)	9.5 ± 1.4	*8.0 ± 1.4**	9.2 ± 2.1	*8.1 ± 1.8**	8.1 ± 1.9	7.5 ± 1.4
SCD (sec)	18.7 ± 9.5	14.8 ± 4.3	19.5 ± 8.1	17.3 ± 8.0	16.4 ± 9.7	16.9 ± 10.4
Maximum Isometric Flexion (N m)	43.82 ± 19.87	46.86 ± 19.06	39.33 ± 29.43	40.45 ± 34.19	58.83 ± 31.87	59.31 ± 25.45
Maximum Isometric Extension (N m)‡	80.86 ± 31.96	84.07 ± 34.74	91.39 ± 51.50	86.03 ± 52.61	124.32 ± 58.34	106.56 ± 50.50*

6MWT = 6-minute walk test, TUG = timed up-and-go, SCD = stair climb and descent

* - Significantly different from baseline.

‡- Significant difference in the training effect between strength training and control groups.

Table 4. WOMAC sub-scale scores at baseline and post-training.

	Strength Training		Taiji		Control	
	Baseline	**Post-Training**	**Baseline**	**Post-Training**	**Baseline**	**Post-Training**
Pain	155 ± 110	*71 ± 100**	169 ± 135	141 ± 107	170 ± 86	157 ± 96
Stiffness†	91 ± 52	*23 ± 24**	89 ± 60	82 ± 61	67 ± 46	57 ± 40
Physical Function	494 ± 265	*240 ± 249**	694 ± 361	552 ± 392	547 ± 396	475 ± 282

WOMAC = Western Ontario and MacMaster Universities Osteoarthritis Index

* - Significantly different from baseline.

† - Significant difference in the training effect between strength training and Taiji groups.

post-training for any of the initial stance peak variables. During the terminal stance peak, the t-test showed that the CON participants had a significantly smaller KMX_t after training (t=3.525, p=0.017). None of the paired t-tests were significant for KMY_t, but the one-way ANOVA of the difference scores for KMY_t found a significant difference among the groups ($F(2, 28) = 4.133$, $p = 0.027$). The post hoc comparisons showed that the TJ group reduced the KMY_t more than the ST group (p=0.022), but neither group was significantly different from the CON group.

Effect Sizes

The effect size for each outcome variable was also calculated (Table 6). Since the confidence intervals for each effect size crosses 0, these values were used, in conjunction with the paired t-tests, one-way ANOVAs, and values available in the literature, to aid in the interpretation of the results in the discussion.

DISCUSSION

It appears that both the strength training and Taiji training programs were effective for improving the participants' mobility. Although neither intervention was effective in improving the 6MWT distance of the participants, both training groups saw a significant improvement in the TUG. Also, both groups had moderate to large effect sizes for both the TUG (ES: -0.68 for TJ and -0.80 for ST) and SCD (ES: -0.77 for TJ and

Table 5. Kinematic and kinetic gait parameters at baseline and post-training.

	Strength Training		Taiji		Control	
	Baseline	**Post-Training**	**Baseline**	**Post-Training**	**Baseline**	**Post-Training**
Knee Angle Excursion (deg)	9.2 ± 4.4	8.8 ± 4.5	6.9 ± 4.7	7.7 ± 5.1	10.0 ± 4.2	10.6 ± 6.5
Initial Stance Peak						
GRF_i (N)	837.16 ± 189.60	830.59 ± 193.49	919.11 ± 173.82	921.62 ± 181.87	860.36 ± 242.10	862.49 ± 249.56
AMX_i (N m)	-4.56 ± 12.74	-3.08 ± 10.80	-0.29 ± 11.97	1.99 ± 12.37	-8.04 ± 8.58	-7.16 ± 10.56
KMX_i (N m)	36.82 ± 20.50	33.44 ± 19.32	39.90 ± 25.66	42.76 ± 24.31	43.05 ± 21.93	39.08 ± 20.03
KMY_i (N m)	-28.11 ± 19.88	-28.51 ± 22.25	-27.06 ± 21.58	-24.74 ± 24.62	-37.28 ± 19.85	-34.14 ± 17.89
Terminal Stance Peak						
GRF_t (N)	782.63 ± 136.36	782.32 ± 143.85	883.15 ± 191.16	861.20 ± 167.63	775.96 ± 159.13	793.11 ± 162.29
AMX_t (N m)	-102.83 ± 17.11	-103.00 ± 16.09	-114.33 ± 27.60	-111.40 ± 27.81	-102.49 ± 27.64	-104.46 ± 25.81
KMX_t (N m)	5.75 ± 13.38	3.67 ± 13.91	5.10 ± 21.21	6.84 ± 23.57	*6.08 ± 18.99*	*-0.36 ± 19.98**
KMY_t (N m)†	-14.74 ± 18.05	-18.36 ± 16.96	-21.38 ± 24.57	-17.84 ± 21.97	-30.09 ± 15.96	-28.94 ± 16.81

GRF = ground reaction force, AMX = sagittal plane ankle moment, KMX = sagittal plane knee moment, KMY = frontal plane knee moment, i = initial stance peak, t = terminal stance peak
* - Significantly different from baseline.
† - Significant difference in the training effect between strength training and Taiji groups.

Table 6. Estimated effect sizes.

Variable (Desired Direction of Change)	Strength Training	Taiji
WOMAC		
Pain (↓)	-0.86	-0.14
Stiffness (↓)	-1.16	0.04
Difficulty Performing Daily Activities (↓)	-0.58	-0.17
Performance Tests		
6MWT (↑)	0.23	0.12
TUG (↓)	-0.80	-0.68
SCD (↓)	-0.77	-0.90
Peak Isometric Moments		
Flexion (↑)	0.29	0.06
Extension (↑)	1.95	0.87
Knee Angle Excursion (↑)	-0.42	0.09
Initial Stance Peak		
GRF_i (↑)	-0.20	0.01
AMX_i (↑)	0.13	0.27
KMX_i (↑)	0.07	0.50
KMY_i (↑)	-0.75	-0.11
Terminal Stance Peak		
GRF_t (↑)	-0.74	-1.23
AMX_t (↓)	0.30	0.75
KMX_t (↑)	0.70	0.75
KMY_t (↑)	-0.89	0.40

WOMAC = Western Ontario and MacMaster Universities Osteoarthritis Index, 6MWT = 6-mintue walk test, TUG = timed up-and-go, SCD = stair climb and descent, GRF = ground reaction force, AMX = sagittal plane ankle moment, KMX = sagittal plane knee moment, KMY = frontal plane knee moment, i = initial stance peak, t = terminal stance peak

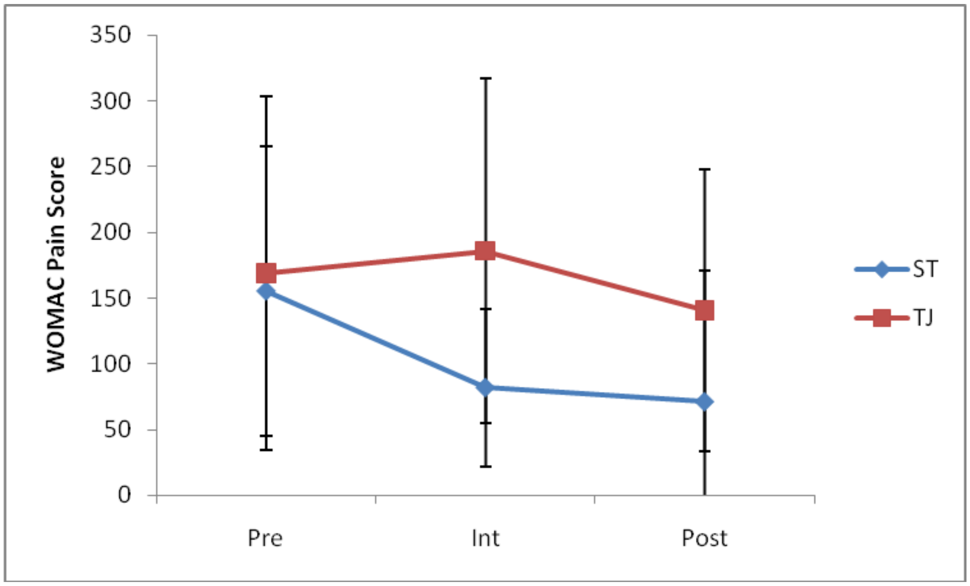
-0.90 for ST) compared to the control group, which appears to be in line with values reported in the literature. Effect sizes calculated from data reported in a study of participants in a 12-week 24-form Tai Chi for Arthritis class were 2.46 and 2.52 for the TUG and ST test, respectively (29). The participants in a resistance training program improved their TUG by 10%, and participants in Taiji improved by 12% (10), both of which are similar to the improvements found in this study. Topp et al. (22) reported improvements of their participants in stair ascending and descending performance by approximately 15% after a program of resistance training and pain medication, while the strength training participants in this study improved by 20.8%. It is unclear why the 6MWT did not improve. One possibility is that the 6MWT is more aerobic in nature than the TUG and SCD, and neither intervention stressed the participants' aerobic systems sufficiently to cause an adaptation.

The effectiveness of knee OA treatments has often been evaluated through the use of surveys and questionnaires, such as the WOMAC (30, 96, 108, 109). The WOMAC results of this study suggest that the Taiji intervention had no effect on the participants' OA symptoms. While, to the best of the author's knowledge, this is the only study to show no effect for a Taiji intervention, there are some similarities between these results and the literature. Brismée et al. (27) had 22 participants complete a 12-week Taiji program and complete a WOMAC questionnaire every 3 weeks. Their participants had significant improvements on both the pain and physical function sub-scales that were also significantly different from the control group beginning at week 9. There was also a significant difference from baseline in the stiffness sub-score which was not significantly different from controls. A study by Fransen et al. (29) with 52 participants in the Taiji group found that there was a mean of improvement on the WOMAC pain sub-score of 5.2 (on a 100 point scale) beyond the change seen by the control group, which was not statistically significant. They also found an improvement of 9.7 (also on a 100 point scale) on the physical function sub-scale beyond the control group, which was statistically significant and, according to the authors, of moderate clinical significance. Those results were both incorporated into a 2009 systematic review which estimated the effect of Taiji in reducing musculoskeletal pain to be approximately 10.1 points on a 100 point scale, but they were unsure if that was a clinically significant improvement (108).

The strength training intervention in this study, on the other hand, appears to have been strikingly effective. The ST group had a significant improvement on all three WOMAC sub-scales, with strong effect for pain and stiffness (ES = -0.86 and -1.16, respectively) and a moderate effect for physical function (ES = -0.58). Estimates of effect size in the literature for pain, stiffness, and physical function range from -0.21, -0.18, and -0.25 respectively (110) to -3.17, -2.74, and -3.58 (22). There is a great deal of variability in these numbers, likely due to the large variety of modalities, durations, and intensities employed. Attempts to find a study which also utilized an open-chained mode of training with progressive resistance as we did in this study for a meaningful comparison were unsuccessful. Figure 2 show the changes in the WOMAC pain and stiffness sub-scales from baseline to post-training, including an intermediate point that the participants completed after 5 weeks of training. It looks as though most of the improvements made by the ST group occurred in the first of 5 weeks of training.

Neither intervention was able to alter the participants gait in a meaningful way. Neither group had any change in knee flexion excursion (KEXC), which it was

A.)



B.)

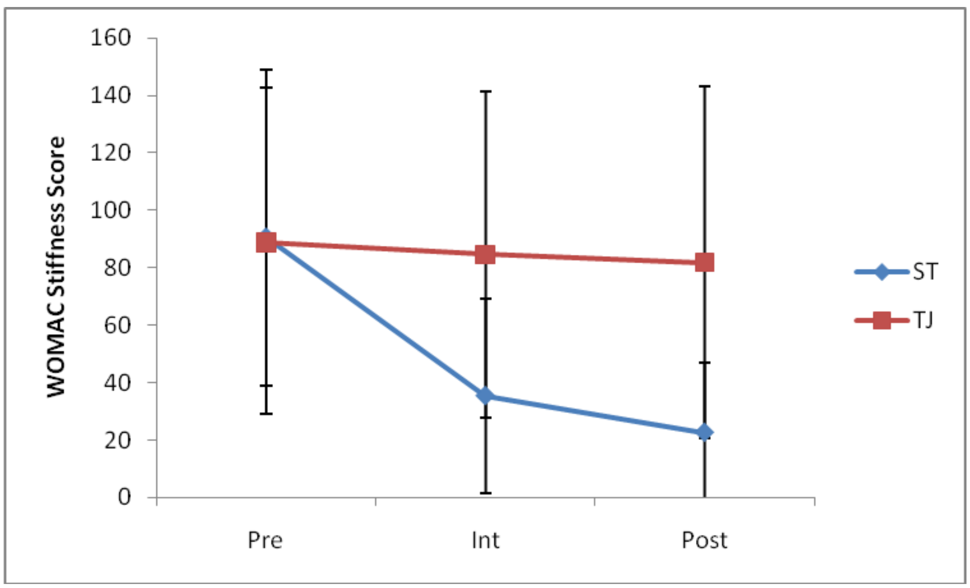


Figure 3. Comparison of the change in WOMAC scores between strength training (ST) and Taiji (TJ) groups. A.) WOMAC pain sub-scale. B.) WOMAC stiffness sub-scale.

hypothesized would increase (3, 33-35). Neither group had a change in the knee extension moment (KMX_i) or knee abduction moment (KMY_i) during the initial stance peak, or the sagittal plane knee moment during the terminal stance peak (KMX_t). Among those variables, it was hypothesized that KMX_i would increase (5, 34, 35) while KMY_i and KMX_t would both decrease in magnitude (5, 14, 16, 34-39). There was a significant difference between the ST and TJ groups in the difference scores of the knee abduction moment during the terminal stance peak (KMY_t). Compared to CON, ST had a strong effect for increasing the magnitude of KMY_t (ES = -0.89) while TJ had a weak effect for decreasing the magnitude of KMY_t (ES = 0.40). However, in light of the lack of a change in KMY_i, it is unclear if either of these changes in KMY_t represents a trend towards healthy gait (5, 35).

Using the ground reaction force (GRF_i) and knee extension moment (KMX_i) as the criteria, it appears that there was no change in tibiofemoral loading during the initial stance peak for either training group. Likewise, using GRF_t and the ankle plantarflexion moment (AMX_t) during terminal stance as the criteria, neither intervention appears to have had an effect on the tibiofemoral loading during the terminal stance peak.

There are several limitations that should be considered when weighing these results. There were two cohorts of strength training and Taiji groups that were conducted in different locations, on different days of the week, and taught by different instructors. Since the groups were small, the two cohorts were analyzed as one. However, both strength training and Taiji groups followed the same programs and the instructors were trained simultaneously to minimize the potential difference. Also, the small size of the control group may also limit the ability to detect differences between the two training groups and the control group.

Another limitation is that all of the K/L grade 4 patients were assigned to the Taiji intervention. Since OA severity is known to affect the rates of cartilage catabolism and anabolism (6), the skewed distribution of OA severity, while not statistically significant, may have predisposed the TJ group to improving slowly, or to not improving at all. Figure 4 shows the WOMAC scores both at baseline and post-training, broken down by K/L grade. Although the sample size is very small, it appears that the TJ participants that were K/L grades 2 or 3 may have made some improvement. Conversely, while the ST group showed large improvements in WOMAC scores, it is not known if strength training would be as effective if the participants had more severe knee OA.

Of the two interventions, the open-chain strength training with ankle weights appears to be the more promising therapy for people with knee OA. Although it was not specifically addressed in this study, there could be a simple underlying mechanism that makes open-chain strength training better for knee OA than closed-chain exercises and other weight bearing activities. It is known that metabolism of cartilage depends partly on its mechanical environment (6). In a closed-chain activity, such as Taiji, the peak quadriceps activation and peak tibiofemoral contact forces occur when the knee is flexed (23). During an open-chain exercise, peak tibiofemoral contact force occurs when the knee is fully extended (23). When the knee is flexed in the open-chain exercises, the ankle weight is essentially pulling the knee into traction. This mechanical difference could explain why the ST group in this study saw an improvement when many other studies have not. Further research is warranted to determine if open-chain strength training can result in changes in cartilage health, measured through either MRI imaging or biomarkers.

In conclusion, both open-chain strength training and Taiji were effective in improving the mobility of seniors with OA. However, the Taiji group saw no improvement in their OA symptoms, while strength training had a strong effect for reducing both pain and stiffness. Neither intervention made any meaningful changes to the participants walking gait. Further research is warranted to determine if open-chain strength training can be effective at relieving OA symptoms for a broader population of OA patients.

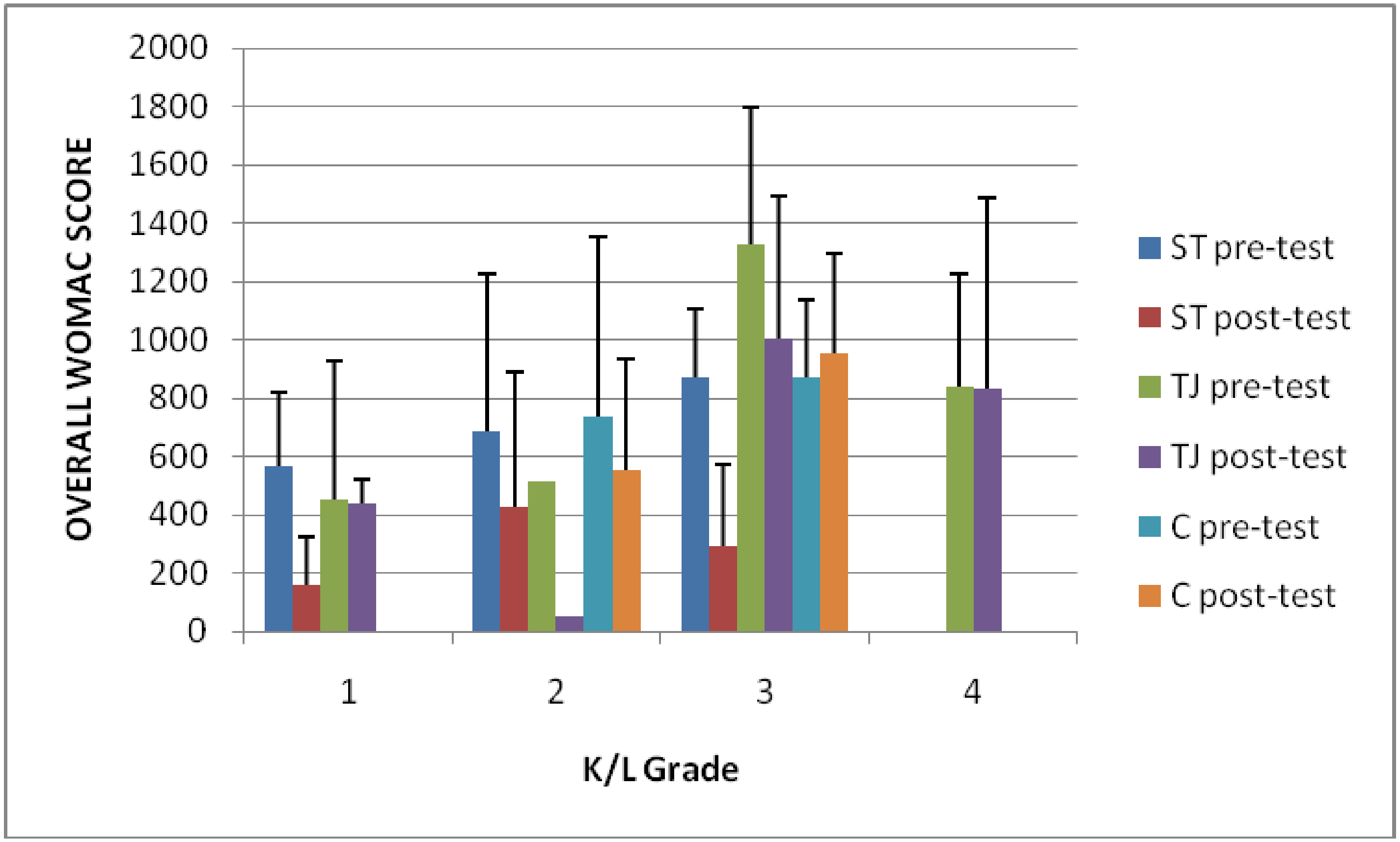


Figure 4. Baseline and post-test Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC) scores by group and Kellgren/ Lawrence (K/L) grade.

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APPENDIX

APPENDIX A

INDIVIDUAL SUBJECT DATA

Table 7. Participant Data.

Subject #	Group	Cohort	Age (years)	Gender	Analyzed Knee	Height (m)	Mass (kg)	
							Baseline	Post-Training
8	TJ	1	63.1	F	R	1.54	56.56	
9	TJ	1	69.1	F	R	1.69	79.02	78.77
14	TJ	1	76.5	M	L	1.82	72.05	
16	TJ	1	64.7	F	L	1.65	118.29	119.39
17	TJ	1	66.0	F	R	1.61	104.38	104.21
18	TJ	1	66.9	F	L	1.57	83.08	81.47
21	TJ	1	61.6	F	L	1.66	70.25	
24	TJ	2	74.7	F	R	1.55	59.82	58.53
29	TJ	2	76.1	F	R	1.64	96.43	94.56
33	TJ	2	77.3	F	L	1.52	80.27	81.57
34	TJ	2	64.7	M	L	1.79	117.50	117.72
41	TJ	2	65.4	F	L	1.53	93.49	93.40
42	TJ	2	68.1	M	R	1.72	123.03	122.14
44	TJ	2	60.8	M	R	1.92	126.36	123.11
47	TJ	2	62.9	F	R	1.60	71.56	76.54
2	ST	1	72.8	F	R	1.59	54.74	55.44
4	ST	1	72.4	F	R	1.66	85.70	86.32
10	ST	1	76.0	F	L	1.61	75.53	75.23
12	ST	1	78.2	M	L	1.79	92.09	88.17
13	ST	1	65.8	F	R	1.68	121.32	125.57
15	ST	1	68.6	F	R	1.51	54.79	55.04
20	ST	1	73.9	F	L	1.68	72.44	
22	ST	1	67.1	M	L	1.83	80.34	80.31
23	ST	1	62.6	F	R	1.67	91.86	94.41
31	ST	2	62.6	F	L	1.58	79.22	74.55
36	ST	2	82.5	M	R	1.76	80.90	78.48
40	ST	2	70.7	M	L	1.79	100.82	96.90
43	ST	2	63.3	F	R	1.69	93.38	92.46
45	ST	2	60.6	F	R	1.59	98.17	99.50

Table 7. Participant Data (continued).

Subject #	Group	Cohort	Age (years)	Gender	Analyzed Knee	Height (m)	Mass (kg)	
							Baseline	Post-Training
26	CON	2	66.5	F	R	1.63	79.32	
27	CON	2	63.0	F	R	1.52	59.20	58.69
28	CON	2	74.6	F	L	1.61	97.02	97.10
30	CON	2	65.9	F	L	1.67	81.69	82.40
32	CON	2	67.2	M	L	1.79	89.29	
35	CON	2	75.2	F	L	1.66	60.91	60.84
37	CON	2	70.6	M	R	1.75	114.27	114.25
38	CON	2	73.8	M	R	1.81	93.39	92.76
46	CON	2	71.0	F	R	1.64	78.99	

TJ = Taiji, ST = strength training, CON = control,

F = female, M = male, L = left, R = right

Table 8. Physical Performance Tests.

Subject #	Group	Cohort	6MWT (m)		TUG (s)		SCD (s)	
			Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training
8	TJ	1	373.5		11.1		18.9	
9	TJ	1	486.8	473.9	6.5	6.0	12.8	10.3
14	TJ	1	470.5		8.6		15.4	
16	TJ	1	287.4	312.2	13.0	12.3	31.0	35.2
17	TJ	1	373.5	434.3	8.3	7.7	20.7	21.6
18	TJ	1	453.0	433.5	8.0	7.5	13.2	13.9
21	TJ	1	500.0		7.5		13.3	
24	TJ	2	375.9	406.5	10.2	8.7	23.5	18.7
29	TJ	2	430.0	445.4	9.0	8.3	19.3	15.2
33	TJ	2	401.6	385.5	9.0	8.2	16.8	17.9
34	TJ	2	520.5	550.0	7.8	6.8	13.9	11.0
41	TJ	2	311.2	329.7	12.6	9.7	37.5	29.6
42	TJ	2	418.6	495.5	10.1	8.1	20.7	14.0
44	TJ	2	451.8	479.2	9.7	8.4	13.8	10.9
47	TJ	2	543.8	433.2	5.9	5.2	10.2	9.9
2	ST	1	584.5	538.4	9.0	6.1	14.3	9.6
4	ST	1	397.0	399.0	11.5	8.4	40.0	17.0
10	ST	1	439.0	450.7	8.6	9.2	14.9	15.6
12	ST	1	473.5	436.2	8.3	8.5	11.9	12.2
13	ST	1	399.0	418.3	11.4	8.6	37.6	25.9
15	ST	1	431.0	482.7	8.7	7.2	9.5	14.4
20	ST	1	424.0		8.3		24.8	
22	ST	1	481.0	500.0	9.6	6.3	17.0	11.0
23	ST	1	460.0	466.8	8.0	7.4	13.9	13.7
31	ST	2	511.7	498.5	8.6	8.3	12.5	11.5
36	ST	2	401.0	425.1	11.3	10.3	18.1	16.2
40	ST	2	598.4	608.3	8.1	6.0	13.1	11.5
43	ST	2	450.0	473.9	11.3	9.8	19.1	15.3
45	ST	2	350.0	461.9	8.6	7.4	20.6	19.0

Table 8. Physical Performance Tests (continued).

Subject #	Group	Cohort	6MWT (m)		TUG (s)		SCD (s)	
			Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training
26	CON	2	529.6		7.5		16.0	
27	CON	2	666.8	616.3	6.1	6.6	7.5	10.0
28	CON	2	342.6	302.0	10.8	9.0	35.2	37.4
30	CON	2	419.4	467.3	9.8	9.1	16.3	16.5
32	CON	2	619.3		5.7		9.1	
35	CON	2	497.6	498.2	7.6	7.2	14.4	15.0
37	CON	2	509.0	533.2	8.6	7.8	14.3	12.9
38	CON	2	576.0	625.9	6.0	5.4	10.7	9.6
46	CON	2	521.4		8.5		12.6	

TJ = Taiji, ST = strength training, CON = control, 6MWT = 6-minute walk test,

TUG = timed up-and-go, SCD = stair climb and descent

Table 9. Radiographic Data.

Subject #	Group	Cohort	Side	K/L Grade (0-4)		Osteophytes (0-4)			Joint Space (0-4)			Alignment
				ipsilateral	contralateral	Medial	Lateral	Patellofemoral	Medial	Lateral	Patellofemoral	
8	TJ	1	R	2	0	2	2	2	2	1	2	N
9	TJ	1	R	2	1	3	1	1	2	0	0	N
14	TJ	1	L	2	1	1	3	0	0	1	0	N
16	TJ	1	L	3	3	3	0	0	3	0	0	VAR
17	TJ	1	R	3	3	4	3	4	2	3	-	N
18	TJ	1	L	4	3	4	4	4	3	0	0	VAL
21	TJ	1	L	2	2	2	0	1	2	0	0	N
24	TJ	2	R	1	0	2	0	0	0	0	0	N
29	TJ	2	R	3	2	2	3	0	0	3	0	N
33	TJ	2	L	3	2	1	3	2	0	2	0	N
34	TJ	2	L	3	3	2	2	2	3	2	0	N
41	TJ	2	L	4	4	3	3	3	4	0	2	VAR
42	TJ	2	R	4	3	3	4	4	4	2	-	N
44	TJ	2	R	1	1	0	1	1	0	0	0	N
47	TJ	2	R	4	2	4	4	4	3	0	2	VAR

TJ = Taiji, ST = strength training, CON = control, L = left, R = right, K/L = Kellgren/Lawrence,

N = neutral, VAR = varus, VAL = valgus

Table 9. Radiographic Data (continued).

Subject #	Group	Cohort	Side	K/L Grade (0-4)		Osteophytes (0-4)			Joint Space (0-4)			Alignment
				ipsilateral	contralateral	Medial	Lateral	Patellofemoral	Medial	Lateral	Patellofemoral	
2	ST	1	R	1	1	0	0	0	1	0	0	N
4	ST	1	R	3	3	4	4	4	2	0	1	VAR
10	ST	1	L	2	1	1	2	1	0	2	0	VAL
12	ST	1	L	3	2	2	3	3	3	0	0	VAR
13	ST	1	R	3	3	4	3	4	3	1	2	N
15	ST	1	R	2	1	2	2	2	0	0	3	N
20	ST	1	L	3	1	3	2	2	2	0	0	N
22	ST	1	L	2	0	1	1	1	1	2	0	N
23	ST	1	R	3	2	2	3	2	0	3	1	N
31	ST	2	L	1	1	1	1	1	0	0	0	N
36	ST	2	R	2	1	3	2	0	2	0	-	N
40	ST	2	L	3	1	3	3	1	3	0	0	-
43	ST	2	R	2	2	1	2	1	2	2	-	N
45	ST	2	R	2	2	2	3	3	1	0	1	N
26	CON	2	R	3	1	3	2	1	3	0	0	N
27	CON	2	R	2	1	2	2	2	1	0	0	N
28	CON	2	L	3	3	3	3	4	2	0	3	N
30	CON	2	L	2	1	2	2	1	2	0	1	N
32	CON	2	L	1	1	1	1	1	0	0	0	N
35	CON	2	L	3	3	3	3	3	3	0	3	N
37	CON	2	R	2	2	1	2	2	0	1	0	N
38	CON	2	R	2	2	2	1	2	1	0	0	N
46	CON	2	R	3	1	2	2	2	2	0	0	N

Table 10. Maximum Isometric Knee Strength.

Subject #	Group	Cohort	Side	Flexion Moment (N m)		Extension Moment (N m)	
				Baseline	Post-Training	Baseline	Post-Training
8	TJ	1	R	30.2		47.1	
9	TJ	1	R	49.0	36.1	95.8	90.1
14	TJ	1	L	56.5		69.9	
16	TJ	1	L	10.9	10.8	64.3	37.0
17	TJ	1	R	26.4	15.8	30.0	52.5
18	TJ	1	L	42.8	39.2	62.4	60.1
21	TJ	1	L	46.2		52.4	
24	TJ	2	R	23.7	21.7	66.0	40.1
29	TJ	2	R	33.2	37.2	90.3	98.7
33	TJ	2	L	11.9	16.0	41.7	30.5
34	TJ	2	L	95.5	101.0	189.1	157.1
41	TJ	2	L	25.0	18.0	59.9	50.9
42	TJ	2	R	40.6	46.1	120.1	120.7
44	TJ	2	R	98.1	117.7	188.0	201.6
47	TJ	2	R	15.0	25.9	89.2	93.1
2	ST	1	R	35.0	32.2	52.8	56.0
4	ST	1	R	38.0	42.3	67.4	70.6
10	ST	1	L	28.8	30.0	53.0	47.4
12	ST	1	L	83.4	77.9	141.7	147.4
13	ST	1	R	11.0	18.6	60.8	81.5
15	ST	1	R	37.2	37.9	49.9	49.0
20	ST	1	L	23.4		62.4	
22	ST	1	L	73.0	83.6	111.8	136.6
23	ST	1	R	38.3	36.6	93.9	84.2
31	ST	2	L	29.9	39.2	64.5	74.2
36	ST	2	R	59.1	49.8	94.1	102.6
40	ST	2	L	60.8	68.4	128.5	128.5
43	ST	2	R	32.8	48.5	42.0	44.8
45	ST	2	R	42.5	44.3	90.7	70.1

Table 10. Maximum Isometric Knee Strength (continued).

Subject #	Group	Cohort	Side	Flexion Moment (N m)		Extension Moment (N m)	
				Baseline	Post-Training	Baseline	Post-Training
26	CON	2	R	34.9		65.6	
27	CON	2	R	57.7	55.4	107.8	88.5
28	CON	2	L	34.7	47.6	94.9	83.7
30	CON	2	L	45.9	50.4	84.0	76.8
32	CON	2	L	63.5		110.5	
35	CON	2	L	21.1	29.0	68.0	57.3
37	CON	2	R	93.9	69.7	174.3	140.2
38	CON	2	R	99.7	103.8	216.9	192.9
46	CON	2	R	45.9		98.2	

TJ = Taiji, ST = strength training, CON = control, L = left, R = right

Table 11. WOMAC Scores.

Subject #	Group	Cohort	Baseline			Intermediate			Post-Training		
			Pain	Stiffness	Physical Function	Pain	Stiffness	Physical Function	Pain	Stiffness	Physical Function
8	TJ	1	303.0	179.0	970.5						
9	TJ	1	60.5	64.5	390.0	8.0	2.0	39.0	32.5	2.0	15.0
14	TJ	1	154.0	84.0	378.5	114.0	92.0	459.0			
16	TJ	1	376.5	145.0	1323.0	344.0	131.0	1140.0	301.0	170.0	1224.0
17	TJ	1	275.0	164.0	874.0	120.0	113.0	660.0	92.5	52.0	691.0
18	TJ	1	47.0	80.0	434.0	230.0	98.0	703.0	302.0	140.0	1054.0
21	TJ	1	371.0	188.0	1542.0	422.0	187.0	1562.0			
24	TJ	2	21.0	7.0	89.5	67.0	15.0	186.0	78.0	25.0	279.0
29	TJ	2	27.0	25.0	512.0	108.0	38.0	444.0	54.0	38.0	258.5
33	TJ	2	219.5	192.5	985.5	260.0	167.0	978.0	147.0	132.0	806.5
34	TJ	2	403.5	109.5	1000.5	406.0	120.0	1233.0	293.0	154.0	621.0
41	TJ	2	208.0	20.5	861.5	160.0	112.0	587.0	73.0	51.0	372.5
42	TJ	2	182.5	98.0	970.5	34.0	9.0	139.0	20.5	7.0	65.0
44	TJ	2	164.0	40.5	586.5	143.0	65.0	455.0	92.5	72.0	331.0
47	TJ	2	39.5	120.0	303.5	350.0	145.0	1080.0	202.0	139.0	909.0

TJ = Taiji, ST = strength training, CON = control, WOMAC = Western Ontario and MacMaster Universities Osteoarthritis Index

Table 11. WOMAC Scores (continued).

Subject #	Group	Cohort	Baseline			Intermediate			Post-Training		
			Pain	Stiffness	Physical Function	Pain	Stiffness	Physical Function	Pain	Stiffness	Physical Function
2	ST	1	69.0	20.0	300.5	54.0	25.0	166.0	38.5	23.5	213.0
4	ST	1	153.0	124.0	542.0	107.0	14.0	361.0	33.0	9.5	84.5
10	ST	1	35.0	21.5	108.5	42.0	26.0	188.0	28.0	22.0	214.0
12	ST	1	177.0	132.0	709.5	69.0	61.0	389.0	117.0	67.5	582.0
13	ST	1	128.0	44.0	503.5	27.0	36.0	94.0	74.5	7.5	135.5
15	ST	1	133.5	92.0	637.0	117.0	14.0	478.0	27.0	0.0	127.0
20	ST	1	232.0	193.0	778.0						
22	ST	1	322.0	132.0	495.5	204.0	41.0	651.0	374.0	19.0	820.5
23	ST	1	235.5	120.0	845.5	88.0	26.0	256.0	12.0	7.0	39.0
31	ST	2	122.0	102.0	521.0	20.0	4.0	54.0	9.0	2.0	35.0
36	ST	2	6.0	0.0	8.0	0.0	0.0	0.0	11.5	5.0	92.0
40	ST	2	72.5	96.5	482.0	141.0	38.0	366.0	56.0	33.0	194.0
43	ST	2	169.0	142.0	325.0	43.0	41.0	136.0	11.5	21.0	39.0
45	ST	2	395.0	153.0	942.5	154.0	134.0	633.0	134.0	77.0	546.0
26	CON	2	64.0	42.5	258.5						
27	CON	2	6.5	1.5	3.0				55.0	19.0	44.0
28	CON	2	257.0	74.0	730.5				262.0	28.0	422.0
30	CON	2	195.5	123.5	1199.5				90.5	33.0	505.5
32	CON	2	19.0	28.0	331.0						
35	CON	2	212.0	25.0	448.5				258.0	123.0	814.0
37	CON	2	161.5	73.0	481.5				207.0	82.5	739.0
38	CON	2	185.5	104.0	420.5				68.0	58.0	324.0
46	CON	2	123.0	83.0	528.5						

Table 12. Knee Flexion Excursion (° ± STD).

Subject	Group	Cohort	Baseline	Post-Training
8	TJ	1	5.8 ± 2.1	
9	TJ	1	12.6 ± 2.2	11.1 ± 2.1
14	TJ	1	8.6 ± 1.6	
16	TJ	1	-0.4 ± 0.7	0.3 ± 1.4
17	TJ	1	3.7 ± 0.6	5.2 ± 0.8
18	TJ	1	7.9 ± 1.3	4.2 ± 1.6
21	TJ	1	9.5 ± 1.5	
24	TJ	2	12.3 ± 1.6	15.6 ± 1.7
29	TJ	2	5.8 ± 2.0	8.4 ± 2.1
33	TJ	2	10.9 ± 1.7	14.6 ± 1.4
34	TJ	2	6.0 ± 1.2	5.7 ± 1.5
41	TJ	2	1.1 ± 0.7	2.2 ± 1.2
42	TJ	2	3.4 ± 0.6	5.1 ± 1.3
44	TJ	2	14.2 ± 1.3	14.3 ± 1.4
47	TJ	2	4.7 ± 0.8	5.4 ± 0.4
2	ST	1	10.5 ± 1.6	10.5 ± 0.9
4	ST	1	3.8 ± 2.7	5.4 ± 2.2
10	ST	1	9.2 ± 1.4	9.5 ± 2.0
12	ST	1	13.2 ± 1.5	9.0 ± 1.4
13	ST	1	6.5 ± 0.9	7.1 ± 0.7
15	ST	1	3.6 ± 1.7	2.9 ± 1.8
20	ST	1	11.5 ± 1.1	
22	ST	1	12.3 ± 0.4	11.4 ± 1.6
23	ST	1	5.2 ± 1.8	4.7 ± 1.5
31	ST	2	19.3 ± 1.9	20.8 ± 1.2
36	ST	2	12.4 ± 1.5	10.7 ± 1.7
40	ST	2	6.4 ± 3.0	4.8 ± 1.9
43	ST	2	9.4 ± 1.9	10.5 ± 1.3
45	ST	2	7.8 ± 0.7	7.3 ± 2.5

Table 12. Knee Flexion Excursion (° ± STD) (continued).

Subject	Group	Cohort	Baseline	Post-Training
26	CON	2	6.8 ± 1.9	
27	CON	2	10.6 ± 1.9	15.3 ± 3.0
28	CON	2	7.9 ± 0.8	6.6 ± 1.1
30	CON	2	7.9 ± 0.9	7.1 ± 1.5
32	CON	2	10.0 ± 5.4	
35	CON	2	5.5 ± 2.7	1.3 ± 1.0
37	CON	2	10.6 ± 1.0	16.2 ± 1.7
38	CON	2	17.5 ± 2.9	17.0 ± 1.6
46	CON	2	10.6 ± 1.6	

TJ = Taiji, ST = strength training, CON = control

Table 13. Initial Stance Peak.

Subject	Group	Cohort	GRF_i (N) ± STD		AMX_i (N m) ± STD		KMX_i (N m) ± STD		KMY_i (N m) ± STD	
			Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training
8	TJ	1	551.6 ± 22.7		-4.2 ± 6.5		8.4 ± 1.0		-21.3 ± 1.3	
9	TJ	1	808.4 ± 50.9	665.2 ± 16.6	-2.6 ± 7.8	0.4 ± 1.4	51.7 ± 6.3	31.9 ± 3.5	-34.7 ± 4.2	-28.4 ± 4.7
14	TJ	1	651.6 ± 26.2		-3.4 ± 2.1		29.3 ± 3.9		-20.4 ± 2.2	
16	TJ	1	961.9 ± 15.5	1018.9 ± 27.3	11.0 ± 2.6	17.4 ± 1.6	11.8 ± 3.3	24.1 ± 4.5	-53.5 ± 7.0	-62.3 ± 3.9
17	TJ	1	983.5 ± 20.4	1018.3 ± 17.2	-30.1 ± 2.2	-22.1 ± 3.1	74.0 ± 4.5	84.8 ± 2.4	2.3 ± 0.9	6.7 ± 1.5
18	TJ	1	814.7 ± 44.8	803.7 ± 23.1	2.9 ± 8.1	-3.7 ± 6.2	24.1 ± 1.7	17.4 ± 2.7	5.3 ± 9.0	-1.2 ± 4.3
21	TJ	1	629.0 ± 30.8		8.9 ± 1.6		19.1 ± 2.6		-11.2 ± 2.3	
24	TJ	2	593.8 ± 11.3	599.4 ± 20.2	-1.4 ± 1.2	2.2 ± 3.0	22.4 ± 1.8	29.0 ± 7.4	-21.8 ± 1.8	-18.9 ± 2.7
29	TJ	2	996.7 ± 77.8	976.3 ± 34.7	-17.7 ± 18.3	-17.6 ± 6.5	29.8 ± 7.9	65.7 ± 7.2	-2.2 ± 0.6	3.6 ± 4.6
33	TJ	2	920.5 ± 40.7	975.2 ± 23.3	6.1 ± 4.2	6.4 ± 2.7	50.6 ± 7.5	53.0 ± 6.7	-10.6 ± 4.5	-1.5 ± 3.7
34	TJ	2	1098.6 ± 72.6	1124.0 ± 34.3	3.7 ± 7.1	13.8 ± 5.1	41.9 ± 5.8	41.8 ± 4.9	-51.4 ± 7.6	-61.8 ± 4.6
41	TJ	2	897.2 ± 26.5	959.7 ± 60.5	9.2 ± 3.6	17.5 ± 5.3	23.0 ± 2.7	34.0 ± 4.4	-26.0 ± 8.8	-19.3 ± 13.1
42	TJ	2	1018.0 ± 52.2	987.6 ± 105.8	4.6 ± 4.7	6.0 ± 17.2	5.5 ± 4.8	1.5 ± 6.4	-43.0 ± 5.1	-21.7 ± 17.3
44	TJ	2	1236.4 ± 21.3	1194.8 ± 14.1	6.2 ± 3.0	5.4 ± 3.3	92.5 ± 5.4	68.8 ± 5.4	-38.1 ± 2.4	-45.1 ± 1.6
47	TJ	2	699.6 ± 5.0	736.4 ± 20.2	4.7 ± 3.3	-1.8 ± 5.1	51.3 ± 2.1	61.2 ± 4.7	-51.0 ± 1.2	-47.0 ± 2.0

TJ = Taiji, ST = strength training, CON = control, GRF = ground reaction force, AMX = sagittal plane ankle moment,

KMX = sagittal plane knee moment, KMY = frontal plane knee moment

Table 13. Initial Stance Peak (continued).

Subject	Group	Cohort	GRF_i (N) ± STD		AMX_i (N m) ± STD		KMX_i (N m) ± STD		KMY_i (N m) ± STD	
			Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training
2	ST	1	541.9 ± 20.0	550.4 ± 30.3	-0.9 ± 1.7	-4.6 ± 4.9	25.7 ± 3.3	23.2 ± 2.2	-21.9 ± 2.0	-17.3 ± 4.1
4	ST	1	774.6 ± 42.6	779.1 ± 24.7	-3.5 ± 4.3	-8.3 ± 3.1	31.8 ± 3.6	28.8 ± 5.3	7.0 ± 2.4	1.2 ± 2.5
10	ST	1	724.7 ± 66.1	736.5 ± 52.1	3.9 ± 4.3	2.9 ± 1.5	39.6 ± 5.7	37.1 ± 4.5	3.5 ± 1.3	7.3 ± 2.6
12	ST	1	921.2 ± 31.1	907.8 ± 29.3	-2.0 ± 12.6	2.3 ± 10.8	39.7 ± 7.0	47.7 ± 7.9	-54.8 ± 4.1	-59.8 ± 3.7
13	ST	1	1137.7 ± 40.0	1209.1 ± 48.8	-26.9 ± 4.9	-21.8 ± 3.2	88.0 ± 7.3	76.8 ± 1.4	-44.8 ± 1.6	-43.3 ± 5.0
15	ST	1	457.4 ± 29.3	467.7 ± 25.0	8.4 ± 2.6	8.3 ± 1.6	6.0 ± 3.6	5.1 ± 2.4	-18.1 ± 2.9	-15.3 ± 2.4
20	ST	1	676.7 ± 4.9		6.3 ± 3.9		42.4 ± 3.3		-10.5 ± 4.7	
22	ST	1	778.1 ± 46.3	825.1 ± 48.5	5.2 ± 6.6	8.5 ± 3.8	36.1 ± 5.5	50.0 ± 6.1	-44.8 ± 5.3	-53.0 ± 5.9
23	ST	1	937.8 ± 36.6	937.5 ± 31.0	10.6 ± 4.7	4.0 ± 3.1	57.3 ± 1.9	50.9 ± 4.6	-17.0 ± 3.1	-18.4 ± 4.4
31	ST	2	856.4 ± 41.5	785.9 ± 30.0	-13.3 ± 8.8	-6.7 ± 4.6	50.9 ± 7.9	38.8 ± 4.9	-21.1 ± 3.7	-17.9 ± 2.1
36	ST	2	838.5 ± 12.2	764.5 ± 24.5	-31.6 ± 6.5	-26.8 ± 3.3	35.9 ± 4.2	17.8 ± 4.8	-33.3 ± 1.0	-34.2 ± 4.9
40	ST	2	1003.9 ± 55.5	968.9 ± 60.1	-3.4 ± 4.9	3.6 ± 6.1	29.4 ± 6.0	23.1 ± 4.1	-48.5 ± 7.8	-55.3 ± 3.2
43	ST	2	865.1 ± 60.7	831.3 ± 69.9	2.0 ± 9.0	1.6 ± 12.6	20.8 ± 4.9	18.6 ± 3.6	-22.4 ± 7.0	-13.9 ± 9.4
45	ST	2	1045.7 ± 35.8	1033.9 ± 7.7	-7.7 ± 5.8	-3.1 ± 8.4	17.5 ± 6.5	16.9 ± 1.6	-49.4 ± 3.5	-50.7 ± 2.4
26	CON	2	796.3 ± 19.5		5.2 ± 2.0		35.9 ± 1.8		-49.8 ± 2.0	
27	CON	2	611.1 ± 16.7	643.2 ± 9.8	-14.5 ± 2.0	-10.8 ± 1.8	20.9 ± 3.3	33.1 ± 4.2	-19.9 ± 1.9	-14.7 ± 1.5
28	CON	2	1086.5 ± 29.7	1057.0 ± 40.5	-13.4 ± 3.9	-7.2 ± 3.3	71.5 ± 3.6	52.3 ± 1.8	-67.7 ± 4.1	-61.1 ± 2.2
30	CON	2	781.3 ± 21.2	694.8 ± 61.3	-2.8 ± 7.0	2.9 ± 7.9	20.1 ± 1.9	12.5 ± 3.6	-25.0 ± 2.5	-21.2 ± 2.7
32	CON	2	885.6 ± 31.8		-11.5 ± 6.8		16.3 ± 16.6		-17.5 ± 8.4	
35	CON	2	605.6 ± 24.1	641.8 ± 10.2	2.0 ± 6.0	3.8 ± 4.4	32.0 ± 4.5	24.4 ± 4.3	-29.4 ± 5.5	-26.4 ± 2.3
37	CON	2	1188.7 ± 23.8	1246.9 ± 30.1	-18.9 ± 6.8	-25.1 ± 7.5	62.9 ± 5.3	68.3 ± 8.4	-24.9 ± 5.0	-31.1 ± 3.0
38	CON	2	888.9 ± 36.5	891.2 ± 23.3	-0.7 ± 5.8	-6.6 ± 9.5	50.8 ± 8.1	43.7 ± 4.4	-56.7 ± 6.3	-50.3 ± 2.4
46	CON	2	774.9 ± 30.6		-7.6 ± 5.9		25.2 ± 2.5		-38.8 ± 1.5	

Table 14. Terminal Stance Peak.

Subject	Group	Cohort	GRF_t (N) ± STD Baseline	GRF_t (N) ± STD Post-Training	AMX_t (N m) ± STD Baseline	AMX_t (N m) ± STD Post-Training	KMX_t (N m) ± STD Baseline	KMX_t (N m) ± STD Post-Training	KMY_t (N m) ± STD Baseline	KMY_t (N m) ± STD Post-Training
8	TJ	1	537.2 ± 13.9		-70.5 ± 1.9		-12.1 ± 3.7		-11.1 ± 2.5	
9	TJ	1	758.0 ± 14.9	757.1 ± 7.1	-106.8 ± 3.1	-109.2 ± 1.7	6.6 ± 3.7	0.9 ± 2.1	-35.0 ± 1.7	-27.7 ± 1.8
14	TJ	1	691.0 ± 18.3		-93.5 ± 3.3		-9.9 ± 2.9		-20.7 ± 0.6	
16	TJ	1	1005.4 ± 13.3	902.3 ± 44.2	-129.4 ± 2.1	-112.8 ± 5.9	-6.5 ± 3.6	7.2 ± 3.5	-34.6 ± 2.1	-18.5 ± 5.4
17	TJ	1	883.9 ± 8.4	900.9 ± 10.2	-120.4 ± 2.1	-124.6 ± 1.2	52.9 ± 2.3	50.6 ± 1.9	14.4 ± 4.4	19.2 ± 1.3
18	TJ	1	820.0 ± 13.2	760.9 ± 10.9	-99.0 ± 2.1	-86.0 ± 1.6	-3.2 ± 1.8	-8.8 ± 2.5	9.9 ± 1.1	2.7 ± 1.7
21	TJ	1	680.9 ± 15.2		-80.5 ± 1.0		3.6 ± 1.5		-5.1 ± 1.1	
24	TJ	2	607.7 ± 18.1	622.4 ± 7.9	-82.4 ± 2.9	-77.3 ± 1.7	-6.3 ± 1.6	-3.7 ± 3.2	-26.0 ± 1.0	-20.7 ± 2.5
29	TJ	2	916.2 ± 14.2	878.4 ± 15.3	-118.6 ± 1.9	-112.7 ± 2.3	8.2 ± 2.4	39.3 ± 2.4	9.7 ± 2.0	8.4 ± 1.3
33	TJ	2	782.7 ± 15.6	786.4 ± 5.6	-83.1 ± 7.0	-90.8 ± 0.9	21.6 ± 5.4	3.7 ± 2.4	-2.9 ± 3.0	1.6 ± 1.3
34	TJ	2	1104.0 ± 22.1	1063.0 ± 29.5	-146.9 ± 1.9	-140.3 ± 4.2	6.9 ± 6.7	-2.3 ± 5.9	-60.0 ± 1.8	-53.6 ± 2.4
41	TJ	2	760.1 ± 9.1	744.5 ± 11.2	-92.1 ± 1.8	-82.5 ± 1.6	-9.8 ± 1.4	4.8 ± 3.8	-19.8 ± 0.9	-16.6 ± 2.8
42	TJ	2	1158.0 ± 53.6	1121.9 ± 20.7	-148.5 ± 5.8	-151.4 ± 1.9	-33.7 ± 4.7	-34.9 ± 2.5	-48.4 ± 2.5	-39.6 ± 2.5
44	TJ	2	1165.6 ± 20.3	1118.5 ± 17.8	-160.7 ± 3.4	-159.7 ± 5.0	2.1 ± 1.7	-7.9 ± 2.7	-21.0 ± 3.5	-32.0 ± 3.8
47	TJ	2	636.0 ± 8.2	678.2 ± 10.5	-83.8 ± 1.5	-89.5 ± 2.1	22.4 ± 2.7	33.2 ± 1.2	-42.9 ± 1.6	-37.4 ± 2.4

TJ = Taiji, ST = strength training, CON = control, GRF = ground reaction force, AMX = sagittal plane ankle moment, KMX = sagittal plane knee moment, KMY = frontal plane knee moment

Table 14. Terminal Stance Peak (continued).

Subject	Group	Cohort	GRF_t (N) ± STD		AMX_t (N m) ± STD		KMX_t (N m) ± STD		KMY_t (N m) ± STD	
			Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training	Baseline	Post-Training
2	ST	1	554.7 ± 14.1	557.5 ± 15.5	-71.3 ± 1.9	-74.5 ± 2.8	-5.9 ± 1.4	-2.4 ± 2.3	-16.2 ± 1.6	-16.4 ± 1.0
4	ST	1	783.8 ± 8.4	795.3 ± 16.1	-97.4 ± 1.3	-112.2 ± 4.3	0.3 ± 2.2	-3.3 ± 2.9	12.7 ± 3.1	-2.2 ± 1.8
10	ST	1	722.6 ± 28.1	718.8 ± 8.0	-89.5 ± 3.1	-90.5 ± 2.0	0.6 ± 3.8	-5.3 ± 1.7	3.2 ± 2.4	-1.0 ± 1.2
12	ST	1	810.1 ± 5.8	782.1 ± 8.5	-115.2 ± 3.4	-110.4 ± 3.3	15.3 ± 1.7	18.9 ± 1.9	-32.1 ± 3.0	-39.3 ± 4.0
13	ST	1	966.7 ± 11.0	1037.6 ± 14.8	-119.7 ± 1.2	-122.3 ± 1.6	30.1 ± 1.6	24.2 ± 3.7	-16.1 ± 1.1	-14.7 ± 1.3
15	ST	1	569.9 ± 9.1	569.4 ± 12.6	-75.8 ± 1.1	-76.8 ± 0.6	-4.1 ± 2.1	2.5 ± 1.7	-14.7 ± 0.9	-9.7 ± 0.8
20	ST	1	627.9 ± 5.2		-55.3 ± 1.3		7.9 ± 1.4		-21.7 ± 1.4	
22	ST	1	704.3 ± 18.4	697.2 ± 6.8	-98.7 ± 2.3	-106.7 ± 1.3	-1.3 ± 2.8	2.1 ± 1.3	-36.1 ± 2.0	-47.5 ± 3.0
23	ST	1	843.6 ± 13.3	873.6 ± 20.6	-113.6 ± 0.7	-116.9 ± 3.3	21.0 ± 2.3	22.9 ± 5.5	19.3 ± 2.9	6.7 ± 2.9
31	ST	2	682.0 ± 44.4	671.4 ± 15.1	-91.1 ± 4.2	-85.0 ± 2.2	23.3 ± 3.5	9.1 ± 3.1	-10.0 ± 4.3	-6.3 ± 1.9
36	ST	2	744.5 ± 13.1	727.3 ± 5.8	-105.7 ± 2.7	-103.5 ± 2.3	0.4 ± 2.5	-14.6 ± 3.4	-23.4 ± 1.6	-24.4 ± 2.2
40	ST	2	945.4 ± 8.3	903.6 ± 14.2	-122.9 ± 3.0	-111.6 ± 2.0	-6.3 ± 4.3	-14.5 ± 3.0	-36.3 ± 1.9	-40.7 ± 1.8
43	ST	2	913.9 ± 15.7	901.7 ± 10.1	-119.0 ± 2.5	-120.7 ± 2.8	-12.6 ± 2.4	-10.7 ± 3.2	-9.2 ± 2.5	-12.1 ± 2.6
45	ST	2	932.6 ± 17.0	934.7 ± 13.0	-116.9 ± 4.2	-107.9 ± 1.7	14.1 ± 4.2	18.8 ± 1.7	-32.7 ± 1.4	-31.0 ± 2.1
26	CON	2	787.5 ± 5.4		-100.4 ± 0.7		6.3 ± 2.9		-33.1 ± 2.2	
27	CON	2	607.4 ± 9.0	614.5 ± 10.6	-75.6 ± 1.3	-79.4 ± 0.7	-8.3 ± 2.7	-9.7 ± 1.4	-15.6 ± 1.0	-15.9 ± 1.1
28	CON	2	829.9 ± 15.0	873.8 ± 6.6	-106.1 ± 2.9	-109.0 ± 1.3	39.5 ± 6.9	36.6 ± 1.6	-38.8 ± 1.9	-36.7 ± 4.1
30	CON	2	758.4 ± 11.2	781.4 ± 11.7	-94.5 ± 1.1	-102.2 ± 1.5	3.3 ± 3.7	-10.0 ± 2.2	-27.6 ± 2.2	-20.9 ± 2.3
32	CON	2	853.3 ± 20.9		-119.5 ± 1.4		-3.6 ± 3.4		-10.3 ± 1.2	
35	CON	2	589.6 ± 12.8	605.1 ± 15.6	-71.8 ± 1.8	-73.9 ± 2.0	8.0 ± 4.0	-2.1 ± 2.2	-21.7 ± 1.6	-18.6 ± 2.0
37	CON	2	1004.2 ± 15.6	1024.1 ± 31.4	-142.5 ± 1.7	-143.8 ± 3.4	9.3 ± 4.8	3.9 ± 1.3	-18.7 ± 1.6	-21.7 ± 1.3
38	CON	2	866.2 ± 21.8	859.7 ± 11.5	-124.4 ± 4.5	-118.4 ± 2.0	-15.3 ± 6.4	-21.0 ± 6.8	-58.1 ± 2.9	-59.9 ± 3.8
46	CON	2	774.7 ± 19.8		-92.6 ± 2.8		-2.6 ± 3.3		-25.6 ± 1.4	

APPENDIX B

THE TAIJI PROGRAM

Taiji, also spelled Tai Chi, is a martial art that has its origins in 16th century China. Through the years it has evolved from martial art for self defense into a form of exercise for health and meditation. The movements in Taiji have been described in qualitative studies as slow, smooth, and dance-like with a semi-squatting posture (24).

The Taiji program used in this study had 12 basic movements adapted from the Yang style, and was designed by Taiji Master Larry Brown, MS, CTRS, CAS, who has had 35 years of Taiji training and teaching experience. When designing this 12-movement routine, the main considerations were the suitability of the movements for knee OA patients and ease with which the participants could learn the routine.

The Taiji participants met twice a week for 60 minutes for 10 weeks, and were asked not to practice outside of class time. This was done in an attempt to ensure that all participants practiced the same amount. Progression was defined primarily in terms learning new movements. Each meeting was divided into four parts. The 15 minute warm-up period had light calisthenics and an emphasis on the different stances of Taiji. Next there was a review period, followed by a time to learn a new movement. The final 10 minutes of the time was reserved for quiet, meditative practice. The following is a list of the twelve movements taught to the Taiji participants. For more details on how the moves were performed, see *Body Mechanics of Tai Chi Chuan* by William C.C. Chen (111).

TWELVE MOVEMENTS

1. Preparation
2. Beginning
3. Ward Off with Left Hand
4. Ward Off with Right Hand
5. Roll Away
6. Press
7. Push
8. Single Whip
9. Snake Creeps Down
10. Golden Pheasant Stands on Left Leg
11. Golden Pheasant Stands on Right Leg
12. Ending

APPENDIX C

THE STRENGTH TRAINING PROGRAM

The strength training program was designed specifically for the knee OA patients following the position stand of American College of Sports Medicine (2009) and the guidelines of the American Geriatric Society (2001). The program was designed by John Krusenklaus, an experienced physical therapist who has had extensive experiences treating lower extremity injuries and diseases.

THE EXERCISE ROUTINE

1) Warm Up

- 5 minute walk (laps around room)
- 5 minute "range of motion" exercises (continued movement to music)

2) Weight Training with Ankle Weights (2-3 sets of 8-12 reps)

- Sitting Leg Extension
- Standing Hamstring Curl
- Straight Leg Raise
- Standing Abduction
- Standing Adduction
- Standing Hip Flex
- Standing Calf Raise (pointing toes)

3) Cool down

- Stretching (seated and standing)
- Fill in Exercise Log (sets, reps, weights, possible weights for next session)
- Encourage to ice
- Speak about different topics each session (time permitting)

The progression for strength training was accomplished by first increasing the number of reps in two sets, and then later adding a third set. The participants were also permitted to increase the weight they were lifting when it became too easy. They were instructed to adjust the weight so that the last two repetitions were effortful or lightly challenging.

PROGRESSION

Week 1	2x8
Week 2	2x10
Week 3	2x10-12 (depending on progress)
Week 4	2x12
Week 5	2x12
Week 6	3x8 (add weight if necessary – approximately 1 pound)
Week 7	3x10
Week 8	3x10-12 (depending on progress)
Week 9	3x 12
Week 10	3x12

APPENDIX D

INFORMED CONSENT FORM

Investigators: Songning Zhang, Ph.D. and Michael Wortley, MS
Address: Biomechanics/Sports Medicine Lab
The University of Tennessee
1914 Andy Holt Avenue
Knoxville, TN 37996
Phone: (865) 974-2091

Introduction
You are invited to participate in a research study entitled, "Effects of Tai Ji and strength training interventions on knee osteoarthritis of older adults." The purpose of this research study is to estimate the effectiveness of Tai Ji and strength training on improving the functional capacity of daily living, gait biomechanics, leg strength, knee joint range of motion, joint pain, and stiffness among the older adults with knee osteoarthritis (OA). This consent form may contain words that you do not understand. Please ask the study staff to explain any words or information that you do not clearly understand. Before agreeing to be in this study, it is important that you read and understand the following explanation of the procedures, risks, and benefits.

Testing Protocol and Duration
You will be randomly assigned to one of three groups: a control group, Tai Ji (Tai Chi) group, or strength training group. If you are assigned to the control group, you will be asked to keep doing what you are doing in your physical activity (no more than twice per week). At the conclusion of the training programs, the participants in the control group will be provided with choices of attending a couple training sessions of Tai Ji or strength training. If you are assigned to one of the two training groups, you will be asked to participate in one of the free 10 week training program based upon your assignment. Each week you will attend two 60-minute training sessions of either Tai Ji or strength training for 10 weeks at the O'Conner Senior Center; you will be asked not to participate in any other physical activity during the 10-week period so that we can determine the effects of Tai Ji and strength training on knee OA. Each training session will be conducted by a qualified instructor. You will be asked not to change dose and type of medications during the study, and attend two testing session: a pre-test one or two weeks prior to the training program, and a post-test one or two weeks after the training program.

At the beginning of the testing session, you will first fill out a survey form about your current physical activity and a survey form about you pain, stiffness, and physical function in the affected knee joint. This will take approximately 5 – 10 minutes. You will then be asked to perform two daily function tests. For the 6-minute walk test you will be asked to walk at a quick but safe speed for 6 minutes, and the distance you cover will be recorded. You will be also asked to climb one flight of stairs, turn around, and descend the same flight of stairs. You will be permitted to use the hand rails for support, but not to push or pull yourself up the stairs.

Next, your knee range of motion and your maximum knee flexion and extension strength will be tested. The range of motion test will be measured with you sitting on a testing chair. The measurement will be repeated three times. For the knee strength tests, you will be asked to sit in a custom built chair that has been adjusted to fit your height, and your thighs and torso will be fastened to the chair with straps that are similar to the seat belts in an automobile. A chord which is anchored to the wall will be fastened to your ankle, and on command you will be asked to attempt to flex or straighten your knee as forcefully as possible for 3 seconds.

For the final test we will perform a 3-dimensional gait analysis. Reflective markers will be applied to your legs and feet, and then you will be asked to walk through the lab recording area five times at a speed of 1.1 m/s, a common self-selected speed amongst seniors with osteoarthritis. During the testing, a 3-D motion capture system will record the movement of the reflective markers as you walk. No part of this system will impede your ability to engage in normal and effective motions during the test. If you have any further questions, interests or concerns about any instrumentation, please feel free to ask the investigator.

Potential Risks

Risks associated with this study are minimal. Considerations has been taken in designing the Tai Ji and strength training programs to ensure that the movements are safe and suitable for participants with knee OA. In general, Tai Ji exercise is slow, low impact, and easy to maintain balance. The strength training exercises are designed for older adults with knee OA, include light ankle weights and elastic resistant bands, and have been shown to be safe for frail populations.

During the testing sessions, the investigator or a qualified research assistant will be stationed close to you and provide assistance in case you lose balance. Should any injury occur during the course of testing, standard first aid procedures will be administered as necessary. At least one researcher with a basic knowledge of athletic training and/or first aid procedures will be present at each test session. The University of Tennessee or the O'Conner Senior Center does not "automatically" reimburse subjects for medical claims or provide other compensation. If physical injury is suffered in the course of research, please contact Dr. Songning Zhang (974-2091).

Benefits of Participation

Your benefits include the opportunity to be evaluated by a rheumatologist about your knee OA status, and possibly learning a Tai Ji or the strength training exercise that can improve your physical fitness, and may also provide pain relief and improve physical function.

Compensation

You will be paid $40 upon completion of both the pre-test session and post-test session as compensation for travelling and time for attending the testing sessions.

Voluntary Participation and Withdrawal

Your participation is entirely voluntary and your refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. It is your obligation to ask questions regarding any aspect of this study that you do not understand. You may stop participating in this study voluntarily or may be asked to stop if you fail to follow the study procedures or if the Investigator feels that it is in your best interest to stop.

Confidentiality

Your identity will be held in strict confidence through the use of a coded subject number during the training program, data collection, data analysis, and in all references made to the data, both during and after the study, and in the reporting of the results. The results will be disseminated in the form of presentations at conferences and publications in journals. The consent form containing your identity information will be destroyed three years after the completion of the study. If you decide to withdraw from the study, your information sheet and consent form with your identity and injury history will be destroyed at the conclusion of the study.

Contact Information

If you have any questions at any time about the study you can contact Dr. Songning Zhang. Questions about your rights as a participant can be addressed to Research Compliance Services in the Office of Research at the University of Tennessee at (865) 974-3466.

Consent Statement

The study has been explained fully to my satisfaction and I agree to participate as described. I have been given the opportunity to discuss all aspects of this study and to ask questions. Answers to such questions, if any, were satisfactory. I am qualified for the study and freely give my informed consent to serve as a subject. By signing this consent form, I have not given up any of my legal rights as a participant.

APPENDIX E

PARTICIPANT INFORMATION SHEET

Part 1. Basic Information

Name:____

Gender: Male Female Date of Birth (Month/

Day/Year):________________________

Mailing Address: ____

____

____

Daytime Phone Number: ____________________________________

Evening Phone Number: ____________________________________

Part 2. Medical History

1. Has a doctor ever said that you have

a. rheumatoid arthritis or inflammatory arthritis	YES	NO
b. osteoarthritis/degenerative arthritis in the knee	YES	NO
c. osteoarthritis/degenerative arthritis in the hip	YES	NO
d. osteoarthritis/degenerative arthritis in the hand/finger	YES	NO
e. osteoarthritis/degenerative arthritis in the back/neck	YES	NO
f. osteoarthritis/degenerative arthritis in some other joint	YES	NO
g. gout	YES	NO
h. any other type of arthritis	YES	NO

2. Are you currently seeing a doctor or other health care professional for arthritis?

3. Are you currently taking any medication for pain, aching, or stiffness related to osteoarthritis?

a. Acetaminophen (Tylenol)	YES	NO
b. nonprescription NSAIDs (Asprin, Ibuprofen)	YES	NO
c. prescription NSAIDs (Ibuprofen, Diciofenac)	YES	NO
d. COXIBs (Bextra, Celebrex)	YES	NO
e. strong prescription pain medications (narcotics)	YES	NO
f. SAMe (S-adenosylmethionine)	YES	NO
g. MSM (methylsulfonylmethane)	YES	NO
h. Doxycycline (Vibra-Tabs, Doryx, Adoxa)	YES	NO
i. Chondroitin Sulfate	YES	NO
j. Glucosamine	YES	NO

4. Have you had any knee injections for treatment of arthritis in the past 6 months?

a. Hyaluronic Acid	YES	NO
b. Streoids injections (cortisone/corticosteroid)	YES	NO

5. Have you ever injured either knee badly enough that you had difficulty walking for at least a full week? YES NO

6. In the past year, have you injured either knee badly enough that you had difficulty walking for at least 2 days? YES NO

7. Have you ever had any type of knee surgery?	YES	NO
a. arthroscopic surgery	YES	NO
b. ligament repair surgery	YES	NO
c. meniscectomy	YES	NO
d. joint replacement surgery	YES	NO

8. Have you ever had a hip replacement surgery? YES NO

VITA

Micheal Wortley has a B.S. in biomedical engineering from Johns Hopkins University and an M.S. in human performance and sports studies from the University of Tennessee. He has an interest in sports and sports injuries stemming from his 24 years as a competitive runner and swimmer, and as a coach of youth athletes. In his time as a graduate student he has taught many physical education courses, and was the teaching assistant for exercise science courses. He is the co-author of eight peer-reviewed publications, and counting.