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Effects of Underwater Treadmill Exercise on Mobility of People with Knee Osteoarthritis

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EFFECTS OF UNDERWATER TREADMILL EXERCISE ON MOBILITY OF

PEOPLE WITH KNEE OSTEOARTHRITIS

by

Jaimie Roper

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ABSTRACT

Effects of Aquatic Treadmill Exercise on Mobility of

People with Knee Osteoarthritis

by

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Gait, pain, and self-efficacy alterations in osteoarthritis (OA) patients may be precursors for pathological alterations and are important variables to examine in an aquatic therapy study aimed at improving mobility. A greater understanding of these alterations will be useful for the treatment of OA and the prevention of OA progression. The purpose of this thesis was twofold: to review the effects of certain land and aquatic therapies on gait kinematics and mobility of people with osteoarthritis, and to examine the effects of short-term aquatic treadmill exercise on gait kinematics, perception of pain, and mobility in OA patients. A direct comparison of water versus land treadmill exercise was used to determine the acute effectiveness of aquatic therapy on gait kinematics, pain, and self-efficacy. Fourteen participants diagnosed with osteoarthritis of the knee performed three consecutive exercise sessions for each mode of exercise. Gait kinematics, pain, and self-efficacy were measured before and after each intervention. Angular velocity gain score during stance for left knee extension was significantly higher for aquatic treadmill exercise compared to land treadmill exercise by 38.1% ($p = 0.004$). Similarly, during swing, the gain scores for angular velocity were also greater for left knee internal rotation and extension by 65% and 20%, respectively ($p = 0.004$, $p = 0.008$). During stance, the joint angle gain score for left hip flexion was greater for land exercise by 7.23% ($p = 0.007$). Similarly, during swing, the angular velocity gain score for right hip extension was significantly greater for aquatic exercise by 28% ($p = 0.01$). Only the joint angle gain score for left ankle abduction during stance was significantly higher for land exercise by 4.72% ($p = 0.003$). No other joint angle gain scores for either stance or swing were significantly different for either aquatic or land treadmill exercise ($p = 0.06$-0.96). Perceived pain was 100% greater for land than aquatic treadmill exercise ($p = 0.02$) and self-efficacy gain scores were not different between conditions ($p = 0.37$). The present study demonstrated that an acute training period on an aquatic treadmill did influence joint angular velocity and arthritis-related joint pain. Although acute effects of training (i.e., pain, angular velocity) improve after aquatic rather than land training, it is unclear whether or not aquatic exercise is a better long-term alternative to land exercise, and further longitudinal research is needed to examine gait kinematic changes after an increased training period of aquatic exercise.

(111 pages)

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I offer special thanks to my husband, family and friends for their patience, encouragement, and moral support from the initial proposal writing to this final document. I appreciate all of your kind thoughts and helpfulness along this journey.

Jaimie Roper

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CHAPTER 1

INTRODUCTION

Background

Osteoarthritis is a widespread disease and is also the most common form of arthritis in the elderly (Davis, Ettinger, Neuhaus, & Mallon, 1991; Felson et al., 1987; Hochberg, 1991). Osteoarthritis (OA) of the hip and knee is often distinguished by pain, stiffness, and decreased range of motion. People who have OA of the lower extremities are generally less active and have decreased physical conditioning and function. This reduction in mobility further decreases one's ability to carry out daily activities and complete regular physical exercise (Kaufman, Hughes, Morrey, Morrey, & An, 2001; Mangione, Axen, & Haas, 1996).

Clinical OA diagnosis involves joint symptoms and evidence of physical change, usually demonstrated with the use of a radiograph (Felson & Zhang, 1998). The most common symptoms include joint pain and stiffness (Arden & Nevitt, 2006). Physical examination typically reveals bony enlargements, pain upon palpation, and crepitus. Pain usually increases with weight bearing and physical activity, and improves with rest (American College of Rheumatology Subcommittee on Osteoarthritis Guidelines, 2000). Mechanical complications of OA are characterized by joint destruction, loss of cartilage, osteophytes (bone formation at the joint margins), weakening of muscles (i.e., quadriceps femoris), and in some cases inflammation (Hutton, 1989).

Along with physical examination and the aforementioned characteristics of OA, systemic and local risk factors can be used to determine the likeliness one will develop OA, and have been identified in reviews by Arden and Nevitt (2006) and Felson and Zhang (1998). Systemic risk factors may increase susceptibility for injury to the joints, either by directly damaging the tissue(s) or weakening the process of repair in damaged tissue. Such risk factors include age, gender, hormones, bone density, ethnicity, genetics and nutrition. Local risk factors are those that involve exposure of specific joints to injury and excess loading situations that can lead to joint degeneration. Risk factors include obesity, acute injuries, repetitive loading of the joint, deformity of the joint and muscle strength and weakness.

Patients with OA are commonly prescribed physical exercise regimens to aid in maintaining physical activity and daily functions. It has been reported that mechanical complications due to OA or pain in the lower joints may indirectly decrease walking capacity (Sutbeyaz, Sezer, Koseoglu, Ibrahimoglu, & Tekin, 2007). Early termination of exercise programs because of knee pain may prevent individuals from receiving the beneficial effects of aerobic training. Therefore, exercise programs intended to lessen knee pain could potentially enable those with OA to execute a longer, more strenuous workout, resulting in an advanced level of cardiovascular fitness and all of its subsequent benefits (Mangione et al., 1996).

Aquatic exercises may allow OA patients to engage in longer and more strenuous workouts as compared to land-based exercises (Hinman, Heywood, & Day, 2007). For example, patients with OA may have an easier time completing closed-chain exercises in an aquatic environment than on land because joint loading and pain across affected joints may be less (Barela, Stolf, & Duarte, 2006). Additionally, by adjusting the depth of the water, the percentage of body weight supported by the lower limbs can be incrementally decreased, to accommodate a person's pain tolerance (Silvers, Rutledge, & Dolny, 2007). Finally, the warmth and pressure of water may assist in decreasing joint swelling and pain, and allow for easier movement patterns (Hinman et al., 2007).

Research examining the effectiveness of aquatic therapy on mobility is limited in OA patients. For instance, in a recent review article by Bartels et al. (2007), 30 potential studies were retrieved, but only six were considered high quality. It was reported that out of these six, only five examined mobility as a functional outcome measure. Out of these five studies (Cochrane, Davey, & Matthes Edwards, 2005; Foley, Halbert, Hewitt, & Crotty, 2003; Patrick et al., 2001; Stener-Victorin, Kruse-Smidje, & Jung, 2004; Wang, Belza, Thompson, Whitney, & Bennett, 2007; Wyatt, Milam, Manske, & Deere, 2001), mobility was assessed with tests (e.g., 6-min walk test) that estimated improvements in gait kinematics. While these studies reported improvement in mobility after aquatic therapy, none examined specific gait kinematic parameters (e.g., step length, joint angle and velocity). An appreciation for how a therapy affects kinematic gait parameters may strengthen decisions made in treating those affected with OA and may assist in selecting appropriate therapies to combat OA symptoms.

Previous research examining the progressive decline of kinematic gait parameters on land in patients with OA has observed specific changes. Walker, Myles, Nutton, and Rowe (2001) utilized electrogoniometers to examine the minimum and maximum joint angles of the knee during various functional movements in 50 patients with OA of the knee and 20 age and gender matched controls. Some of the functional movements included walking on a level surface, and ascending and descending a slope. The researchers observed that the OA patients had significantly lower maximum knee extension angles for all activities and displayed only 70-80% of normal knee flexion when compared to the control group ($p = .004$). Their results were supported by Kaufman et al. (2001) who observed that OA patients walked slower and had 6° less peak knee motion than normal subjects ($p < 0.01$). In a review by Messier (1994), examining the effects of knee OA on gait, the researchers reported decreased knee range of motion in patients with OA of the knee. These kinematic observations have lead to the conclusion that changes in knee angle could be a strategy used by OA patients to reduce joint movement so that less pain is felt during weight bearing activities. These changes are important to examine because measurements of the mechanics of the disease are necessary for a greater understanding of the functional affects of treatment(s).

With progressive worsening of OA, changes in gait kinematics are often accompanied by progressive worsening in pain and perception of mobility. For example, Astephen, Deluzio, Caldwell, and Dunbar (2008) studied the differences in self-reported pain and function among three groups: asymptomatic participants and participants with moderate OA, and severe OA. All scores were higher in the moderate group than the asymptomatic group, and higher in the severe group than the moderate group. Similarly, Focht, Rejeski, Ambrosius, Katula, and Messier (2005) observed that OA patients involved in exercise have a higher self-efficacy for exercise than non-exercising controls. These results indicate that studies examining the effectiveness of physical therapy treatments for OA patients should include a measure of pain and self-efficacy.

Purpose

Gait, pain, and self-efficacy alterations in OA patients noted in the previous literature may be precursors for pathological alterations and would seem to be important variables to examine in an aquatic therapy study aimed at improving mobility. A greater understanding of these alterations will be useful for the treatment of OA and the prevention of OA progression. The purpose of the present study was twofold. The purpose of the review article was to determine the effects of certain land and aquatic therapies on gait kinematics and mobility of people with osteoarthritis. The purpose of the experimental study examined the effects of short-term aquatic treadmill exercise on gait kinematics and perception of pain and mobility in OA patients.

Hypothesis

For the experimental article of this thesis (Chapter 3), it was hypothesized that aquatic treadmill walking would elicit similar kinematic responses as land treadmill walking at the same speed. It was also hypothesized that pain levels would decrease after the aquatic treadmill intervention.

Authorship Contribution

The contributions of authorship for the manuscripts are as follows:

Non-Invasive Treatments of Osteoarthritis and their Effects on Function and Mobility

Roper, J. (90%) Bressel, E. (10%)

The Effects of Aquatic Treadmill Exercise on Mobility of People with Knee Osteoarthritis

Roper, J. (85%) Bressel, E. (15%)

Glossary of Terms

Osteoarthritis: A progressive disease of the joints caused by ongoing loss of cartilage and resulting in development of bony spurs and cysts at the joint margin

Aquatic exercise: A physical activity or treatment for an illness or disorder that takes place while submerged in a body of water

Land-based exercise: A physical activity or treatment for an illness or disorder that takes place while on land

Function: Characterized by balance, cardiopulmonary fitness, coordination, flexibility, mobility, muscle performance, neuromuscular control, postural control, postural stability, equilibrium, and stability.

Mobility: The ability of structures or segments to move or be moved in order to allow the occurrence of range of motion for functional activities

Kinematics: Branch of biomechanics that describes the motion and spatial position of objects without consideration of the forces involved

Step length: The rectilinear distance (usually measured in meters) between 2 successive placements of each foot

Step rate: The amount of steps taken in a specific amount of time

Joint angles: The angle between two adjacent body segments

Angular velocity: Angular speed of a rotating joint

Noninvasive: A technique that does not require a participant's body to be broken by incision, or any samples taken

Knee effusion: Excess fluid accumulation in or around the knee joint

CHAPTER 2

REVIEW ARTICLE

Noninvasive Treatments of Osteoarthritis and Their Effects on Function and Mobility

Abstract

The purpose of this paper was to review the literature examining noninvasive OA therapies on kinematics of gait. An appreciation of these findings may help clinicians in choosing the most efficacious therapy for improving mobility. Studies that utilize land-based exercises have improved basic function, walking speed, and joint space narrowing. Unfortunately while these land exercises have presented positive effects, other research has noted that palpable effusions, (excessive fluid accumulation around or in the knee joint) increased after training, and suggested the cause may be related to the mechanical loading of the joint. Aquatic training is an option for decreasing the chances of developing these effusions. Studies that have used aquatic training have noted improvements in physical function, mobility, stiffness and pain upon movement. Future biomechanical research is needed to evaluate benefits to aquatic training to better serve programs aimed at improving function and mobility for patients with OA.

Introduction

Osteoarthritis is a widespread disease and is also the most common form of arthritis in the elderly (Davis et al., 1991; Felson et al., 1987; Hochberg, 1991). Osteoarthritis (OA) of the hip and knee is often distinguished by pain, stiffness, and decreased range of motion. People who have OA of the lower extremities are generally less active and have decreased physical conditioning and function. This reduction in mobility further decreases one's ability to carry out daily activities and complete regular physical exercise (Kaufman et al., 2001; Mangione et al., 1996).

Clinical OA diagnosis involves joint symptoms and evidence of physical change, usually demonstrated with the use of a radiograph (Felson & Zhang, 1998). The most common symptoms include joint pain and stiffness (Arden & Nevitt, 2006). Physical examination typically reveals bony enlargements, pain upon palpation, and crepitus. Pain usually increases with weight bearing and physical activity, and improves with rest (American College of Rheumatology Subcommittee on Osteoarthritis Guidelines, 2000). Mechanical complications of OA are characterized by joint destruction, loss of cartilage, osteophytes (bone formation at the joint margins), weakening of muscles (i.e., quadriceps femoris), and in some cases inflammation (Hutton, 1989).

Along with physical examination and the aforementioned characteristics of OA, systemic and local risk factors can be used to determine the likeliness one will develop OA, and have been identified in reviews (Arden & Nevitt, 2006; Felson & Zhang, 1998). Systemic risk factors may increase susceptibility for injury to the joints, either by directly damaging the tissue(s) or weakening the process of repair in damaged tissue. Such risk factors include age, gender, hormones, bone density, ethnicity, genetics and nutrition. Local risk factors are those that involve exposure of specific joints to injury and excess loading situations that can lead to joint degeneration. Risk factors include obesity, acute injuries, repetitive loading of the joint, deformity of the joint and muscle strength and weakness (Arden & Nevitt, 2006; Felson & Zhang, 1998).

Previous studies have suggested that gait patterns of adults affected by OA are considerably different when compared to healthy adults (Gyory, Chao, & Stauffer, 1976; Messier, Loeser, Hoover, Semble, & Wise, 1992; Stauffer, Chao, & Gyory, 1977; Walker et al., 2001). For example, Gyory et al. (1976) used a goniometer to compare three dimensional knee angular kinematics of 29 normal participants to 65 OA participants and 30 with rheumatoid arthritis. The authors observed knee range of motion, stance phase knee flexion/extension, walking velocity, stride length, and cadence were reduced in the OA group. Similar results were reported by Walker et al. (2001) who observed that OA patients had significantly lower maximum knee extension angles for all activities and displayed only 70-80% of normal knee flexion when compared to the control group (p = .004). Stauffer et al. (1977) observed reduced sagittal plane knee range of motion, stance phase range of motion and 18% less internal and external knee rotation in the OA group. These previously mentioned kinematic observations have lead to the conclusion that changes in lower extremity kinematics could be a strategy used by OA patients to reduce joint movement so that less pain is felt during weight bearing activities. These changes are important to examine because measurements of the mechanics of the disease are necessary for a greater understanding of the functional affects of treatment(s), such as those that affect mobility. The purpose of this paper was to review the literature examining noninvasive OA therapies on function and mobility. An appreciation of these findings may help clinicians in choosing the most efficacious therapy for improving mobility, such as kinematics of gait. By improving gait kinematics, patients with OA may experience improved economy of gait and reduced secondary impairments to non-arthritic joints via the kinetic chain. This review is organized in the following manner: (a) strategies for literature search, (b) methods used to assess gait mobility with descriptions of specific tests used to address mechanical and painful complications of OA, and (c) various forms of noninvasive therapies used for treatment of OA and their effects on mobility (Tables 1 and 2).

Methods

The strategy used for the present literature review involved searching the following electronic databases: MEDLINE, PubMed, SPORT-DISCUS, and Google Scholar. The following key words were used in different compositions: gait, kinematics, function, osteoarthritis, therapy, exercise, aquatic, land-based, aquatic, mobility, rehabilitation, biomechanics, gait analysis. The selection of articles was executed in two successive screening stages. The first stage consisted of selecting articles based on title and abstract, and the second involved applying the selection criteria to the full-text articles.

The selection criteria for inclusion in this study were as follows: The study used at least one type of noninvasive therapy to treat OA, and at least one of the outcome measures was an assessment of gait, function and/or mobility, the studies were available in English and were published in a peer-reviewed journal, and/or the study provided additional information on noninvasive methods for treating OA. Seven articles from 1997 to 2009 were included (Tables 1 and 2).

Techniques Used to Measure Function and Mobility

In many studies mobility has been assessed using field tests that estimate gait kinematics (Cochrane et al., 2005; Foley et al., 2003; Patrick et al., 2001; Rogind et al., 1998; Stener-Victorin et al., 2004; Wang et al., 2007; Wyatt et al., 2001). For example, the 6-min walk test requires participants to walk for 6 min over a flat surface such as a running track, and measures the maximum distance a participant walked in 6-min. The purpose of the 6-min walk test is to measure exercise endurance. The Timed Up and Go (TUG) test is also timed, but measures the time it takes a participant to stand up from an armchair, walk a distance of 3 m, turn, walk back to the chair, and sit down (Podsiadlo & Richardson, 1991). The purpose of the timed up and go test is to provide a short test of balance and basic mobility skills for frail community-dwelling elderly participants.

Self reported physical function measures are also used to assess gait kinematics, the most popular being the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Stanford Health Assessment Questionnaire (HAQ) and the Jette Functional Status Index (JFSI) (Fransen, Crosbie, & Edmonds, 1997). The Stanford Health Assessment Questionnaire has two versions, a full version and a short version. The short version is most frequently used and most commonly known as HAQ. The short HAQ contains the HAQ Disability Index (HAQ-DI), the Visual Analog Scale (VAS) Pain

Scale, and the VAS Patient Global in a 2-page format (Bruce & Fries, 2003). The HAQ was created to represent a model of patient oriented outcome assessment and has influenced several diverse areas such as prediction of successful aging, inversion of the therapeutic pyramid in rheumatoid arthritis (RA), development of risk factor models for OA, and examination of mortality risks in RA. The HAQ has established itself as a worthy and effective instrument for measurement of health status. It has increased the credibility and use of validated self-report measurement techniques as a quantifiable set of hard data endpoints and has created a new appreciation of outcome assessment (Bruce & Fries, 2003). The WOMAC was developed to evaluate patients who had OA of the hip or the knee. The index contains three subscales: One for pain (five items), one for stiffness (two items), and one for disability (17 items). This questionnaire can be self-administered, and it is reportedly reliable and valid (Bellamy et al., 1997). The JFSI gives individual scores for degree of dependence, difficulty and pain during 18 activities. The JFSI consists of 10 items within three sections (gross mobility, hand activities, and personal care) scored on a 4-point scale from 1 = no pain to 4 = severe pain (Jette, 1980). The item scores are summed for a total score. The minimum possible score is 10; the maximum score (severe pain on every item) is 40. The reliability and validity of the JFSI have been examined and found to be adequate (Fillenbaum, George, & Blazer, 1988). It is helpful to use these types of measures when testing large clinical populations, as it is essential to keep the test short and easy to perform for both assessor and participant (Fransen et al., 1997).

Although the WOMAC, HAQ, and JFSI scales have been validated for those with OA of the lower limbs, they have not been validated for those who are in earlier phases of the disease (Fransen et al., 1997). Fransen et al. (1997) have suggested that it is possible gait changes take place before any functional loss scored by these scales occurs, or even before pain changes are recorded by self-reported ratings. The level of personal pain experienced is only possible to determine indirectly by self-reported ratings using uni-dimensional pain rating scales that may be used for various dimensions of pain, such as the Visual Analog Scale (VAS), which is one of the most common used scales for self-assessment of pain. Therefore it seems important for researchers to examine changes in both questionnaire(s) and specific gait kinematic variables (e.g., changes in knee joint angle), as the latter is a precursor to functional limitation for the OA population, and could prove useful when measuring the effectiveness of a therapeutic intervention.

Previous studies have suggested that OA patients compensate for their pain in their affected joint by increasing the work of other joints (Brinkmann & Perry, 1985; Kaufman et al., 2001; Messier, 1994; Stauffer et al., 1977; Walker et al., 2001). For example, Messier (1994) observed that OA patients increase hip angular velocity in order to counteract a decrease in knee angular velocity. These observations are made by directly measuring the kinematics of the joint during certain movements such as walking. The kinematics of gait requires the use of sophisticated laboratory equipment such as camera systems that compute three-dimensional motion or more simply electrogoniometry.

Three-dimensional motion analysis presents a distinct method for measuring lower extremity dynamics for physical activities such as walking. Motion analysis of the human body often involves using optical systems capable of measuring retro-reflective markers placed on a subject so segments can be analyzed. Trajectories are used to estimate positions of underlying bony segments, with the false assumption that markers and bones are rigidly connected (Stagni, Fantozzi, Cappello, & Leardini, 2005). Electrogoniometers allow a researcher to measure the range of motion about a joint. Electrogoniometry uses the relative positions of the thigh and leg to allow for quick measurements of relative joint angles and continuous knee joint motion in all planes of motion. Other techniques also exist for measuring joint kinematics during gait. For example, accelerometry, electromechanical switches (attached to the heel to identify timing of heel strike in gait), gyroscopes, and pedometers are also used to measure human movement.

Current Treatments and Therapies

Land-based treatments. General physical therapy has been helpful for osteoarthritis of the knee. Physical therapy (PT) practice involves applying cold and/or heat, ultrasound, and shortwave therapy, instruction in joint use and preservation of range of motion, supplying patients with canes or orthotic devices, and isometric exercises to prevent muscle atrophy (Cooke & Dwosh, 1986). Rogind et al. (1998) utilized a basic functional test, (which included activities such as a 20-m walking time, and time to walk up and down one flight of stairs) to compare the effects of a physical training program on 25 patients with bilateral OA of the knee, with controls that had similar diagnosis of the knee. The design of the study was a randomized control trial with a blinded observer. The program was overseen by an experienced physical therapist and concentrated on mobility, venous therapy, lower extremity and trunk muscle strength, flexibility of lower extremity soft tissue of lower extremity, and ability to balance and coordinate the body. Training was performed two times per week for three months. Assessments for the basic functional test were at baseline, the end of 3 months, and 1 year. At the end of one year, researchers observed that basic functional tests increased and walking speed was significantly improved (p = .05; Table 1).

Fisher, White, Yack, Smolinski, and Pendergast (1997) studied the before and after affects of a rehabilitation program on gait and function in adults with knee OA, by using a quantitative progressive exercise rehabilitation (QPER) program and motion analysis. The QPER program included isometric, isotonic, isotonic with resistance, and endurance and speed muscle contractions. Each subject completed the QPER program three times a week for 1 hr during the course of 2 months. Functional Performance was measured by a 50-foot walk time, the Jette Functional Status Index (JFSI) yielded individual values for the degrees of dependence, and difficulty and pain during 18 different activities, and observations recorded and scored during performances of activities of daily living (walking, rising from a chair, stair climbing, etc.), which yielded a single value for a specific activity observed. Gait analysis was assessed by using an inverse dynamics approach utilizing a bilateral, sagittal plane, linked-segment model. Reflective markers were placed over the fifth-metatarsal, heel, lateral malleolus, lateral femoral condyle, greater trochanter and acromion process. Markers were used to define segment anthropometrics and joint centers. Three repeated walking trials were averaged for each subject, and walking speed and stride length were normalized to subject height. Joint angles were expressed relative to their orientation for a standing anatomical posture. The results inferred that the QPER program did significantly improve walking time, which was reduced by 21% while functional assessment determined by observation of the activities of daily living was also improved by 13% ($p = .05$; Table 1). There were no significant changes in speed, cadence, or stride length after the intervention.

Muscular strength training is a therapeutic intervention that has benefited those with OA of the knee (Mikesky et al., 2006; Schilke, Johnson, Housh, & O'Dell, 1996). By utilizing the WOMAC questionnaire Mikesky et al. (2006) measured mobility of two groups of OA participants. The researchers conducted a 30-month, randomized, attention-controlled trial of the effects of lower-extremity strength training on the incidence and progression of knee OA in elderly adults. A screening assessment included a standing anteroposterior knee radiograph and administration of the WOMAC. Two-hundred and twenty-one adults were randomly assigned to strength training or range of motion training. The strength training group trained for twice a week at a training center and once a week at home for the first 3 months. The next 3 months strength training participants were asked to train twice a week at home and once a week at the training center. The last 3 months, they were required to train at the training center once a month, and perform the remainder of the workout sessions at home. The workout structure consisted of a warm-up period of walking for 5 min, followed by three sets of exercise in the resistance training session, followed by a 5-min cool-down. Resistance training exercises performed at the training center were the following: leg presses, leg curls, seated chest presses, and seated back rows. The home session exercises were similar, for example wall squats, standing leg curls, wall push-ups, and seated rows were all performed using rubber bands instead of machines.

The range of motion exercise group was used as controls and performed simple movement exercises with no external loading. The range of motion group followed a similar structure that consisted of a warm-up of walking for five minutes, followed by flexibility exercises and a five minute cool-down. Flexibility exercises were 10 repetitions each, and targeted the neck, shoulders, trunk, elbows, wrist, hips, knee, and ankles.

When assessing function with the WOMAC scale the authors observed those in the group that used strength training compared to the group that used range of motion training, and their results indicated a trend towards better function for the strength training group over the range of motion group (p = .088; Table 1).

From the previous research mentioned (Fisher et al., 1997; Mikesky et al., 2006; Schilke et al., 1996) it has been cited that atrophy and weakness of the quadriceps muscles are quite frequent and have been the source to disuse of the muscle because the patient reduces any painful weight-bearing activities. For patients with knee OA, pain is increased by load bearing and relieved by rest. Current clinical treatments for OA assume that modalities such as physical therapy and strength training that aim to improve muscular strength, coordination and flexibility, can improve overall mobility and reduce pain without causing further harm to the joint, even though mechanical loading is increased (Rogind et al., 1998). However, Rogind et al. (1998) observed an increase in palpable effusions after one year of physical training, and concluded that these negative side affects could lead to an increase in OA activity (p = .01). Land-based exercise and therapy may not decrease joint loads to a sufficient level so that pain is decreased and exercise is performed at adequate intensities. Because negative side affects such as effusions could increase the incidence of the disease of the affected joint, it may be important for therapists and clinicians to examine modalities that can reduce mechanical loading.

Aquatic-based treatments. Aquatic exercises as compared to land-based exercises may allow OA patients to engage in longer and more strenuous workouts (Hinman et al., 2007). For example, patients with OA may have an easier time completing closed-chain exercises in an aquatic environment than on land because joint loading and pain across affected joints may be less (Barela et al., 2006). Additionally by adjusting the depth of the water, the percentage of body weight supported by the lower limbs can be incrementally increased, to accommodate a person's pain tolerance (Silvers et al., 2007). Finally, the warmth and pressure of water may assist in decreasing joint swelling and pain, and allow for easier movement patterns (Hinman et al., 2007).

Research examining the effectiveness of aquatic therapy on mobility is limited in OA patients. For instance, in a recent review article by Bartels et al. (2007), 30 potential studies were retrieved, but only 6 were considered high quality. It was reported that out of these six, only five examined mobility as a functional outcome measure. Out of these five studies (Cochrane et al., 2005; Foley et al., 2003; Patrick et al., 2001; Stener-Victorin et al., 2004; Wang et al., 2007; Wyatt et al., 2001), mobility was assessed with field tests (e.g., 6-min walk test) that estimated improvements in gait kinematics.

Foley et al. (2003) directly compared a land-based resistance exercise program with an aquatic resistance exercise program among people with OA of the hip or knee to a control group, to evaluate whether one modality provided benefits in strength and mobility over the other. Each group had three exercise sessions a week for 6 weeks. Outcome assessments included the 6-min walk test, distance walked, and the WOMAC. The authors observed that both hydrotherapy and gym groups improved from baseline in walking speed and distance ($p < 0.001$). WOMAC pain scores were significantly declined from baseline in the hydrotherapy group ($p = 0.045$; Table 2), but not different between groups. The authors concluded that hydrotherapy may be more appropriate for aerobic based exercise programs.

Wyatt et al. (2001) also compared land-based exercise with aquatic exercise among patients with moderate OA of the knee. Participants were randomly assigned to either the aquatic or land condition. Both groups exercised three times a week for 6 weeks. Both exercise programs contained the following: two sets of manual resistance knee extension and flexion, four way straight leg raises, mini squats, and an 800-foot walk. The authors used a pretest/posttest design to detect differences in subject values for passive ROM utilizing a universal goniometer and time for a 1-mile walk. Total knee ROM and the 1-mile walk time improved for both groups between the pre and post measurements ($p \leq 0.05$; Table 2).

Hinman et al. (2007) tested the efficacy of a 6-week aquatic physical therapy program in people diagnosed with hip OA, knee OA, or both. An assessment was done immediately before treatment and immediately after treatment was completed, with a follow up assessment 6 weeks prior to the completion of the intervention. The aquatic physical therapy program completed functional weight bearing and progressive exercises twice a week for 45-60 min a session, including squats, calf raises, lunges and walking at water levels at the sternum and anterior superior iliac spine. Dependent variables included measurements with a VAS for pain upon movement in the primary OA joint, as well as subject-perceived global changes in pain and physical function, recorded on five-point Likert scales which ranged from one (much worse) to five (much better). A score of four or five were documented as showing improvement, scores of one, two, or three were documented as not showing improvement. The WOMAC was used to assess pain, stiffness, and physical function in the primary OA joint. Muscle strength was assessed bilaterally utilizing a Nicholas Manual Muscle Tester of the hip abductor muscles. Physical function was measured with the Timed Up and Go test to assess functional ability. Aquatic gait was assessed using the 6-min walk test to evaluate the distance participants could walk at a fast, comfortable pace. The authors hypothesized aquatic physical therapy would produce a greater improvement in pain and physical function than having no aquatic physical therapy. A secondary hypothesis was also formed that the aquatic physical therapy would also result in greater improvements in stiffness, quality of life, physical activity, and muscular strength. Participants of the aquatic physical therapy reported a mean reduction in pain on movement of 33% from baseline and had significantly less pain at 6 weeks than control participants ($p < .01$). Similarly, 75% of the intervention participants reported a global improvement in physical function ($p < .001$; Table 2). Outcomes that were not significantly different after intervention included quadriceps femoris muscle strength, and the Timed Up and Go test.

In both studies by Foley et al. (2003) and Wyatt et al. (2001) the researchers observed both land-based and aquatic-based exercise programs improve physical function. Improvements in gait are important for patients with OA so they may maintain independence and carry out activities of daily living. Functional independence of older adults is also associated with decreased mortality and decreased admission into nursing homes and hospitals (Sharkey, Williams, & Guerin, 2000). For self-reported outcomes, Foley et al. (2003) suggested that lack of change could have been due to participants overestimating their capabilities at baseline by assuming that they can do more than they actually can, and after 6 weeks of exercise they have a better understanding of their true physical capabilities and provide a more accurate reflection of this at the end assessment. The researchers also explained that it was necessary to match the exercise intensity between the two interventions as closely as possible. However, progressive overloading of the musculature and loading through the eccentric phase of muscle contraction is not possible in water as it is on land. Therefore, the exercise intensity would not have been as high in the water-based group and would explain increases seen in strength in the land-based groups. On the other hand the aquatic therapy group had an underlying aerobic training factor, higher and faster repetitions were used to increase the exercise intensity, and also worked nonstop for the full half hour session. Because OA patients usually have low cardiovascular fitness (Ettinger et al., 1997), the aquatic therapy program possibly produced an increase in aerobic capacity, which would explain the significant increase in physical function without the same increases in strength as observed on land.

Wyatt et al. (2001) recommended using a practical application of maintaining or increasing the present level of function of patients with OA. Reduced pain is associated with increased movement function as well as exercise adherence. The authors reported that the use of a monitored exercise program is effective for preventing potential loss of mobility, because exercise increases ROM, prevents thigh muscle atrophy, and decreases overall pain.

Denning, Bressel, and Dolny (2010) examined the acute effects of aquatic and land treadmill exercise on mobility by utilizing the TUG test, and assessing gait kinematics using a motion analysis system. Each participant performed three consecutive exercise sessions for 20 min each on an aquatic treadmill and on a land-based treadmill with the order of exercise mode randomly assigned. Water temperature was 30°C and air temperature was set at 24°C. The land treadmill exercise was performed in the same room and in the same manner as the aquatic treadmill exercise. Gait analyses were assessed at baseline (within 24 hr of beginning the exercise week) and within 24 hr of completing the third exercise session for each mode of exercise. The motion analysis system tracked retro-reflective markers placed on the subject over bony landmarks of the foot and leg (Vicon MX system, Vicon Motion Systems, Centennial, CO, USA). Participants walked four times at their preferred speed over a flat straight 10-m course using their normal walking shoes. From the position data, stride length and stride rate were both computed as a measure of mobility. TUG data were recorded at baseline and after completing the third exercise session for each mode of exercise. TUG scores were 240% greater after land compared with after aquatic treadmill exercise (p = 0.02; ES = 1.12; Table 2). Stride rate and stride length scores were not different between conditions. The authors concluded while future longitudinal research is needed; aquatic treadmill exercise may possibly also lead to greater improvements in mobility when compared to the same exercise completed on land. Although improvements in mobility were noted in the study, no differences in stride rate or stride length were found in the study. The improvements were based on TUG scores and not a kinematic analysis of joints.

Conclusion

Different modalities for treating OA may affect walking speed, stride length, stride rate, and function. Studies that train via land have improved basic function, walking speed, and joint space narrowing (Fisher et al., 1997; Mikesky et al., 2006; Rogind et al., 1998). Unfortunately while these land exercises have presented positive effects, Rogind et al. (1998) noted that palpable effusions (which may be caused by increased joint loading) increased after training, and suggested the cause may be related to the mechanical loading of the joint. One way to decrease the load of the joint is by exercising aquatic (Barela & Duarte, 2008). Studies that have used aquatic training have noted improvements in physical function, mobility, stiffness and pain upon movement. Studies that have examined land and aquatic training have observed improvements in range of motion and walking speed and distance. Future biomechanical research is

Table 1

Characteristics of Included Land-based Studies

needed to evaluate benefits to aquatic training to better serve programs aimed at improving function and mobility for patients with OA.

These gait, pain, and mobility alterations in OA patients noted in the previous literature may be precursors for pathological alterations and would seem to be important variables to examine in an aquatic therapy study aimed at improving mobility. A greater understanding of these alterations will be useful for the treatment of OA and the prevention of OA progression.

Reference	Participants	Intervention	Main outcome measures	Key findings
Rogind et al. 1998	Bilateral Knee OA	General fitness, balance, coordination, stretching and lower extremity muscle strength training, twice a week for 3 months. Assessments were at baseline, 3 months, and 1 year	Muscle strength, AFI, Pain (0 to 10 point scale), walking speed	By one year, AFI decreased 3.8 points (CI $_{2\alpha = .05}$, 1.0 to 7.0), pain decreased by 2.0 points (CI $_{2\alpha = .05}$, 0.0 to 4.0), and walking speed increased 13% (CI $_{2\alpha = .05}$, 4% to 23%)
Fisher et al. 1997	Women with Knee OA	QPER Program, 3 times a week for 2 months, 1 hr a day. Assessments were at baseline and post QPER	50-foot walk time, JFSI, and observations scored during the performance of daily living, gait analysis using video records at 60 hz	Walking time was significantly reduced by 21%, function determined by observation was improved by 13% (p = 0.05)
Mikesky et al. 2006	Knee OA	Randomized to strength training or range-of-motion exercises for 3 times a week for 12 weeks. Followed by transition to home training for 12 months Assessments at 30 months	Standing AP knee radiograph, WOMAC	JSN > 0.50 mm was more common in ST than in ROM (34% versus 19%; p – 0.038)

AFI = Algofunctional Index; QPER = Quantitative Progressive Exercise Rehabilitation; JFSI = Jette Functional Status Index; WOMAC =Western Ontario and McMaster Universities OA Index ; JSN = Joint Space Narrowing; ROM = Range of Motion; VAS = Visual Analog Scale; TUG = Timed Up and Go.

Table 2

Characteristics of Included Aquatic-based Studies

Reference	Participants	Intervention	Main outcome measures	Key findings

Foley et al. 2003	Knee or Hip OA	Randomized to hydrotherapy, gym, or control. Exercising groups had 3 sessions a week for 6 weeks. Assessments were at baseline and 6 weeks	Six minute walk test, WOMAC, Arthritis Self-Efficacy Scale	Both exercising groups improved in walking speed and distance ($p < 0.001$) Hydrotherapy improved in the WOMAC ($p = 0.006$)
Wyatt et al. 2001	Moderate Knee OA	Randomized to either aquatic or land, both groups exercised 3 times a week for 6 weeks. Knee extension, knee flexion, four way straight leg raises, mini squats, and an 800-foot walk were performed during exercises. Assessments were at baseline and at 6 weeks	Passive ROM assessed with a universal goniometer, timed 1-mile walk	Total knee ROM and 1-mile walk significantly improved ($p \leq 0.05$)

Reference	Participants	Intervention	Main outcome measures	Key findings

Hinman et al. 2007	Hip and/or Knee OA	Aquatic physical therapy program including exercises such as squats, calf raises, lunges, and walking at water levels at the sternum and ASIS, twice a week for 45 to 60 minutes, for 6 weeks. Assessments were at baseline and 6 weeks	VAS for pain upon movement, Likert scales for subject perceived global changes in pain and physical function, WOMAC, TUG, six-minute walk test	Pain on movement was reduced by 33% ($p < .01$). Physical function also improved ($p < .001$).
Denning et al. 2010	Knee, Hip, and/or Ankle OA	Utilized an aquatic treadmill and land-based treadmill. Each participant completed 3 sessions for 20 minutes on each treadmill. Assessments were done at baseline, and after the 3rd exercise for each mode of exercise.	TUG, gait kinematics via motion analysis, VAS pain scale	TUG scores were 240% greater for aquatic treadmill exercise ($p < .02$; *ES* = 1.12)

WOMAC =Western Ontario and McMaster Universities OA Index; ROM = Range of Motion; VAS = Visual Analog Scale; TUG = Timed Up and Go.

CHAPTER 3

EXPERIMENTAL PAPER

Effects of Aquatic Treadmill Exercise on Mobility in People with Knee Osteoarthritis

Abstract

This study examined the acute effects of aquatic and land treadmill exercise on gait kinematics, pain, and self-efficacy. Fourteen participants diagnosed with osteoarthritis of the knee performed three consecutive exercise sessions for each mode of exercise. Gait kinematics, pain, and self-efficacy were measured before and after each intervention. Step rate and step length were not different between conditions (p = 0.31-0.92), but the angular velocity gain score during stance for left knee extension was significantly higher for aquatic treadmill exercise by 38.1% (p = 0.004). Similarly, during swing the gain scores for angular velocity were also greater for left knee internal rotation and extension by 65% and 20%, respectively (p = 0.004, p = 0.008). During stance, the joint angle gain score for left hip flexion was greater for land exercise by 7.23% (p = 0.007). Similarly, during swing the angular velocity gain score for right hip extension was significantly greater for aquatic exercise by 28% (p = 0.01). Only the joint angle gain score for left ankle abduction during stance was significantly higher for land exercise by 4.72% (p = 0.003). No other joint angle gain scores for either stance or swing were significantly different for either condition (p = 0.06-0.96). Perceived pain was 100% greater for land than aquatic treadmill exercise (p = 0.02) and self-efficacy

gain scores were not different between conditions (p = 0.37). The present study demonstrated that an acute training period on an aquatic treadmill did influence joint angular velocity and arthritis related joint pain suggesting that for acute bouts of exercise, an aquatic treadmill may improve angular speed of the joint and pain related to OA. It is unclear whether or not aquatic exercise is a better alternative to land exercise, and further longitudinal research is needed to examine gait kinematic changes after an increased training period of aquatic exercise.

Introduction

Osteoarthritis is a widespread disease and is also the most common form of arthritis in the elderly (Davis et al., 1991; Felson et al., 1987; Hochberg, 1991). Osteoarthritis (OA) of the hip and knee is often characterized by pain, stiffness, and decreased range of motion. People who have OA of the lower extremities are generally less active and have decreased physical conditioning and function. This reduction in mobility further decreases one's ability to carry out daily activities and complete regular physical exercise (Kaufman et al., 2001; Mangione et al., 1996).

Patients with OA are commonly prescribed physical exercise regimens to aid in maintaining physical activity and daily functions. It has been reported that mechanical complications due to OA or pain in the lower joints may indirectly decrease walking capacity (Sutbeyaz et al., 2007). Early termination of exercise programs because of knee pain may prevent individuals from receiving the beneficial effects of aerobic training. Therefore exercise programs intended to lessen knee pain could potentially enable those with OA to execute a longer, more strenuous workout, resulting in an advanced level of cardiovascular fitness (Mangione et al., 1996).

Aquatic exercises may allow OA patients to engage in longer and more strenuous workouts as compared to land-based exercises (Hinman et al., 2007). For example, patients with OA may have an easier time completing closed-chain exercises in an aquatic environment than on land because joint loading and pain across affected joints may be less (Barela et al., 2006). Additionally, by adjusting the depth of the water, the percentage of body weight supported by the lower limbs can be incrementally decreased, to accommodate a person's pain tolerance (Silvers et al., 2007). Finally, the warmth and pressure of water may assist in decreasing joint swelling and pain, and allow for easier movement patterns (Hinman et al., 2007).

Research examining the effectiveness of aquatic therapy on mobility is limited in OA patients. For instance, in a recent review article by Bartels et al. (2007), 30 potential studies were retrieved, but only six were considered high quality. It was reported that out of these six, only five examined mobility as a functional outcome measure. Out of these five studies (Cochrane et al., 2005; Foley et al., 2003; Patrick et al., 2001; Stener-Victorin et al., 2004; Wang et al., 2007; Wyatt et al., 2001), mobility was assessed with tests (e.g., 6-min walk test) that estimated improvements in gait kinematics. While these studies reported improvement in mobility after aquatic therapy, none examined specific gait kinematic parameters (e.g., step length, joint angle and velocity). An appreciation for how a therapy affects kinematic gait parameters may strengthen decisions made in treating those affected with OA and may assist in selecting appropriate therapies to combat OA symptoms.

Previous research examining the progressive decline of kinematic gait parameters on land in patients with OA has observed specific changes. Walker et al. (2001) utilized electrogoniometers to examine the minimum and maximum joint angles of the knee during various functional movements in 50 patients with OA of the knee and 20 age- and gender-matched controls. Some of the functional movements included walking on a level surface, and ascending and descending a slope. The researchers observed that the OA patients had significantly lower maximum knee extension angles for all activities and displayed only 70-80% of normal knee flexion when compared to the control group ($p = .004$). Their results were supported by Kaufman et al. (2001) who observed that OA patients walked slower and had 6° less peak knee motion than normal subjects ($p < 0.01$). In a review by Messier (1994) examining the effects of knee OA on gait, the researchers reported decreased knee range of motion in patients with OA of the knee. These kinematic observations have lead to the conclusion that changes in knee angle could be a strategy used by OA patients to reduce joint movement so that less pain is felt during weight bearing activities. These changes are important to examine because measurements of the mechanics of the disease are necessary for a greater understanding of the functional affects of treatment(s).

With progressive worsening of OA, changes in gait kinematics are often accompanied by progressive worsening in pain and perception of mobility. For example, Astephen et al. (2008) studied the differences in self-reported pain and function among three groups: asymptomatic participants and participants with moderate OA, and severe OA. All scores were higher in the moderate group than the asymptomatic group, and higher in the severe group than the moderate group. Similarly, Focht et al. (2005) observed that OA patients involved in exercise have a higher self-efficacy for exercise than non-exercising controls. These results indicate that studies examining the effectiveness of physical therapy treatments for OA patients should include a measure of pain and self-efficacy.

These gait, pain, and self-efficacy alterations in OA patients noted in the previous literature may be precursors for pathological alterations and would seem to be important variables to examine in an aquatic therapy study aimed at improving mobility. A greater understanding of these alterations will be useful for the treatment of OA and the prevention of OA progression. The present study examined the effects of short-term aquatic treadmill exercise on gait kinematics and perception of pain and mobility in OA patients. An aquatic treadmill was chosen instead of more traditional aquatic therapy exercises (e.g., deep water running) because it applies the principle of specificity and allows for control over exercise intensity and buoyancy (Dolbow, Farley, Kim, & Caputo, 2008). A direct comparison of water versus land treadmill exercise was necessary to establish a control condition and to determine the acute effectiveness of aquatic therapy on gait kinematics, pain and self-efficacy.

In this study the authors have chosen to include ankle and hip kinematics in addition to knee kinematics to evaluate whether or not these joints are also affected by training, based on reasoning that the body acts as a kinetic chain, and that all segments of the body must act together to create human movement. If one component of the chain is not functioning properly it may affect another.

Methods

Participants

Potential participants for this study were recruited from the local community through flyers and informational sheets distributed through primary care physician offices. Prior to participating in the study, all participants read and signed an informed consent form approved by the University Institutional Review Board.

To be included in the study, participants had to be previously diagnosed with knee OA through clinical history, physical examination, and radiographic analysis. All diagnoses were made by a local rheumatologist and were confirmed for 'definite' OA based on the diagnostic algorithm reported by March, Schwarz, Carfrae, and Bagge (1998). Additionally, participants had to be over 35 years of age, able to walk a city block, and walk up stairs in a reciprocal manner. Participants were excluded if they currently exercised on an aquatic treadmill, had intra-articular corticosteroid injections in the past month, reported any neuromuscular disease such as Parkinson's disease, stroke, cardiovascular disorders or surgeries to the lower limb (except for exploratory arthroscopy), lavage of knee joint or partial meniscetomy at least one year prior to entry into study. Fourteen participants who responded to the request for subjects met these criteria. Physical characteristics and arthritis history for the participants are reported in Table 3.

Procedures

This preliminary study used a quasi-experimental crossover design to address the study purpose. Each participant was asked to perform three consecutive exercise sessions on an aquatic treadmill (Figure 1; HydroWorx 2000^{TM}, Middletown, PA) and on a land-based treadmill (Nordic Track 9600, ICON Fitness, Logan UT). Each exercise bout was separated by at least 24 hr, and was completed within 1 week. Each mode of exercise was separated by 1 week. The order of exercise mode was randomly assigned. It was determined from pilot testing that three exercise sessions were appropriate to provide familiarization of procedures and equipment and to realize any acute effects of mode exposure.

The amount of walking for each exercise bout was 20 min and consisted of four 5-min stages (Figure 1). The first stage (the self-selected pace) required participants to walk at a self-selected pace they considered "comfortable." The second stage was 0.13 m/s faster than the self-selected pace and the third stage was 0.26 m/s faster than the self-selected pace. The fourth stage speed was identical to the first phase speed (Figure 2). Participants performed the aquatic treadmill exercise with no shoes at a water depth equal to the xiphoid process. The temperature of the water was 30^{o} C with the air temperature set at 24^{o} C. The land treadmill exercise was performed in the same room and in the same manner as the aquatic treadmill exercise and required participants to wear their normal walking shoes along with typical exercise clothing. Treadmill incline was set at 0º for each mode of exercise. Treadmill speed settings of 0.89 m/s were compared between the aquatic and land treadmills using a video analysis. An interclass correlation coefficient (*ICC* = 0.99) performed on the analyzed data indicated nominal speed settings were similar between treadmills.

Measurements

Gait kinematics. Gait analyses were assessed at two baselines (within 24 hr of beginning the exercise week) and within 24 hr of completing the third exercise session for each mode of exercise. Gait kinematics were assessed using a motion analysis system that tracked retro-reflective markers placed on the participant (Vicon MX system, Vicon Motion Systems, Centennial, CO, USA). Participants walked four times at their preferred speed over a flat straight 10 m course using their normal walking shoes (Figure 3). Seven Vicon T-20 cameras sampling at 100 Hz tracked low mass (2.2 g) retro-reflective markers placed on the skin according to the lower extremity plug-in gait model provided by Vicon. Skin markers were placed on the toe, heel, lateral malleolus, mid-shank, lateral aspect of the knee, mid-thigh, anterior superior iliac crest, and posterior superior iliac crest, for both lower limbs. Three-dimensional position data from each reflective marker were computed from direct linear transformations using Vicon Nexus software. Position data gaps were filled by performing a cubic spline interpolation operation to correct any errors or inconsistencies in the reconstructed and labeled data. Average number of gaps filled per participant was 29.4, and average number of gaps filled per marker was 2.36. The three-dimensional data were filtered using a Visual3D (C-Motion, Inc, Germantown, MD, USA) low-pass Butterworth filter with a cutoff frequency (8 Hz) based on a residual analysis (Winter, 1990; Appendix A) using Microsoft Excel (2007) software .

From the position data, step length, step rate, joint angles, and velocities were calculated. Step length was computed as the rectilinear distance (m) between two successive placements of each foot. Step rate was computed as the difference in frames between two successive placements of each foot divided by the recording rate of the cameras. Maximum and minimum joint angles and angular velocities of the hip, knee, and ankle were calculated for stance and swing phases from the position data using finite difference equations provided by Visual3D. Stance phase was defined as the time between heel strike and toe-off, and swing phase was determined as the time between toe-off to heel strike. Heel strike was defined as the moment at which the heel marker was at its lowest point in the vertical direction, and toe-off was defined as the moment at which the toe marker was at its lowest point in the vertical direction.

Hip joint centers were estimated based on a regression equation and data presented by Bell, Pedersen, and Brand, (1990). On average, all kinematic descriptors were computed from six consecutive steps for both limbs. Variability for each stride was calculated for knee flexion during stance and the median coefficient of variation was 1% (Appendix B). Joint angles were expressed relative to their orientation for a standing anatomical posture and the positive and negative convention for each measure is illustrated in Figure 4. Angular velocities were defined as the rate of change of the angular position of the joint angle and expressed as degrees per second.

Pain scale. The perception of joint pain was assessed within 24 hr before the first exercise session and within 24 hr after the third exercise session using a continuous visual analog scale. The scale was 12 cm in length and was modeled after pain scales described previously by Carlsson (1983). The left end of the scale was labeled “no pain” and the right end was labelled “very severe pain.” To improve consistency of implementing the pain scale, we provided written instructions to each participant before they rated their pain. The instructions were, “please mark the line to indicate the arthritis related joint pain that you have felt during the past week; the farther to the right, the more discomfort/pain you feel.” Visual analog scales, such as the one used in this study, are reported to be reliable assessments of pain perceptions and are more precise than ordinal scales that rank responses (Carlsson, 1983; Gramling & Elliott, 1992; McCormack, Horne, & Sheather, 1988). The pain scales were analyzed by measuring the distance from the left of the scale to the vertical mark drawn by each subject. This distance was measured to the nearest millimeter. All pre- and post-exercise pain scores were averaged to yield a single mean pain score before the first and after the last exercise.

Self-efficacy scale. Participants were asked to rate the level of certainty that they could complete a certain amount of laps around the gymnasium. Participants circled the number on a confidence ladder that represented their level of confidence to walk around the gymnasium two times without stopping. This measurement was repeated for anticipated distances of four laps, six laps, eight laps, 10 laps, and 12 laps without stopping. Walking self-efficacy scores were determined by summing the participants’ confidence scores across the six levels of difficulty and multiplying by two. This measurement procedure was consistent with the protocol developed by Bandura (1977) and has previously presented acceptable psychometric properties in previous studies (Focht et al., 2005; Rejeski, Craven, Ettinger, McFarlane, & Shumaker, 1996; Rejeski, Ettinger, Martin, & Morgan, 1998).

Statistical Analyses

Self-selected treadmill speeds for the aquatic and land treadmills were compared with a paired-samples *t* test and arthritis history information (e.g., time since diagnosis) was analyzed descriptively. The independent variable in this study was mode of exercise (aquatic treadmill or land treadmill) and the dependent variables were gait kinematics (maximum and minimum joint angles and angular velocity, step length, and step rate), perceived pain, and the Self-Efficacy scale. A gain score was computed and used for statistical comparisons between conditions. Gain scores may provide reliable insight into individual differences between conditions and are appropriate when variability may be high within participants (Williams & Zimmerman, 1996; Zimmerman & Williams, 1982). For example, OA patients often display high variability in perceived pain between days (Hochberg et al., 1995), preventing a stable base for comparisons. In the present study, negative gain scores will indicate that pretest scores are greater than posttest scores and positive gain scores will indicate the opposite.

The nonparametric Wilcoxon signed rank test was used to compare gait kinematics, perceived pain, and self-efficacy scores between conditions. This nonparametric test was selected because of the small sample size and because of the arthritis related variability among participants and the probable effect this variability had on the normal distribution of scores. Significant differences for pain and self-efficacy scores were based on an alpha level set at 0.05. However, a Holm's correction to the

0.05 level was made for kinematic comparisons because of the large number of comparisons (i.e., 432) (Lundbrook, 1998) and the risk this poses on misinterpreting a true Type I error (Knudson, 2009). To help clinicians better interpret any significant or non-significant results, the median difference in gain scores between conditions and their 95% confidence intervals (CI) were calculated.

Results

Data from all participants were used in the statistical analyses, although some data (i.e., post aquatic treadmill data) were missing from one participant that was unable to complete testing do to scheduling conflicts. Pairwise comparisons of the self-selected speeds during exercise indicated they were not different between aquatic (0.76 ± 0.24 m/s) and land (0.80 ± 0.26 m/s) treadmill exercise ($p = 0.13$). The descriptive results from arthritis history questionnaire revealed that, on average, the amount of time between the diagnosis and testing in our laboratory was 7.88 (± 6.73) yrs and that the knee was the primary arthritic joint (Table 3).

Joint Angles and Angular Velocity

Joint angle and angular velocity gain scores that were significantly different at the $p = 0.05$ level are shown in Tables 4-6. A typical joint angle pattern for the gait cycle at the ankle, knee, and hip are shown in Figures 5-10. After adjusting *p* values using the Holm's correction, the angular velocity gain score during stance for left knee extension was significantly higher for aquatic treadmill exercise by 38.1% ($p = 0.004$; Table 7). Similarly during swing the gain scores for angular velocity were also greater for left knee internal rotation and extension by 65% and 20%, respectively (*p* = 0.004, *p* = 0.008; Tables 8, 9). During stance, the joint angle gain score for left hip flexion was greater for land exercise by 7% (*p* = 0.007; Table 10). Similarly during swing the angular velocity gain score for right hip extension was significantly greater for aquatic exercise by 28% (*p* = 0.01; Table 8). Only the joint angle gain score for left ankle abduction during stance was significantly higher for land exercise by 4.72% (*p* = 0.003; Table 10). No other joint angle gain scores for either stance or swing were significantly different for either condition (*p* = 0.06-0.96; Tables 11-14).

Confidence Intervals

Table 4-6 presents the confidence intervals (95% CI) for all kinematic variables reaching the alpha level of 0.05. Not surprising, the width of confidence intervals computed were high given the small sample. More specifically, it may be observed in Table 4-6 that there is a 95% chance that the confidence intervals calculated (left knee extension angular velocity for stance, left knee internal rotation angular velocity for swing, right knee extension angular velocity for stance, left ankle abduction angular velocity during stance, left hip flexion during stance, and right hip flexion angular velocity during swing (29.1, 88.2), (-190, -52.6), (20.6, 109), (3.89, 19.8), (3.23, 15.2), (-48.7, -11.2)) contains the true population median difference.

Perceived Pain, Self-Efficacy, and Step Rate and Length

Perceived pain was 100% greater for land than aquatic treadmill exercise (*p* = 0.02; Table 15) and self-efficacy gain scores were not different between conditions (*p* =

0.37). Step rate and step length gain scores were not different between conditions (p = 0.31 - 0.92; Table 16).

Discussion

Although physical therapists provide numerous exercises for patients with OA of the knee, there is little scientific evidence to confirm whether certain modalities of exercise are more advantageous than others for treatment of the disease (Callaghan & Oldham, 1995). Many studies have compared knee kinematic gait variables, pain, and self-efficacy of adults with OA with normal, healthy, controls (Huang, Lin, Yang, & Lee, 2003; Kaufman et al., 2001). The unique aspect of the present study is that the authors examined the effectiveness of aquatic therapy on gait kinematics before and after aquatic training using a three-dimensional approach analyzing changes at not just the knee, but also at the hip and ankle.

Hip, knee, and ankle kinematics were affected over the course of the acute training periods (Tables 3-11) and our gait kinematic values were consistent with previous research measuring joint kinematics of patients with OA (Al-Zahrani & Bakheit, 2002; Messier, 1994; Walker et al., 2001). For example, Walker et al. (2001) reported an average knee extension angle of 177°, which is consistent with our max knee extension values (171°; Table 10). Huang et al. (2008) reported an average value for hip extension during stance of 170°, which is also consistent with our hip extension values (165°; Table 10). It should be noted that studies used for comparisons did not use an intervention, such as the present study.

Surprisingly, hip flexion gain scores were significantly greater for land exercise than water, proposing that land treadmill exercise may be more likely to increase hip flexion. However, this result may also suggest that after an acute bout of land exercise compensatory deviations, such as excessive hip flexion, take place to overcome limited range of motion at the knee and ankle. An increase in hip flexion would allow the patient to overcome problems caused by the disease or difficulties the patient cannot control. These findings may indicate that land exercise decreases knee rehabilitation (Los Amigos Research and Education Institute, 2001).

Angular velocity gain scores for knee extension during stance, knee internal rotation during swing, and knee extension during swing were significantly greater for aquatic exercise over land. Similarly, angular velocity gain scores for ankle abduction during stance, and hip flexion during swing were also greater for aquatic exercise over land. These increases in angular velocity are important because the values may be close to those of a normal population. The present study observed maximal knee angular velocity during swing after aquatic exercise to be 337 °/s. These findings suggest that aquatic therapy may be more beneficial for improving the angular velocity of a joint, such as the knee, hip, or ankle. Radin, Yang, Riegger, Kish, and O'Connor (1991) observed angular velocity scores during natural gait for a normal healthy population. The authors reported maximal knee angular velocity during swing to be 403 °/s.

The mechanism for increasing angular velocity could be due to the unique environment of the aquatic exercise, when aquatic, there is an increased resistance to movement due to the drag force exerted by water against the segments of the body

(Barela & Duarte, 2008). Barela et al. suggested that to maintain a constant speed aquatic it is necessary to generate an impulse to overcome the drag force in the horizontal direction. The participants in the present study walked on an aquatic treadmill versus walking in a pool, which meant that only limbs were moving through the water rather than limbs plus their body, which lowered the overall fluid resistance. The aquatic environment could perhaps strengthen the neuromuscular aspects of certain muscles that affect lower limb kinematics, such as the quadriceps in effort to overcome this increase in fluid resistance that influences joint angular velocity. Previous studies (Huang et al., 2003; Marks, 1993) have demonstrated that strengthening the quadriceps musculature with resistance exercise was associated with significant improvements in pain and function.

Although significant differences were found in joint velocity and angle gain scores between land and aquatic exercises, no differences were found between step rate and step length, which suggest the differences found in angles and angular velocities, had no influence on the step length or step rate during walking. In a similarly designed study, Denning et al. (2010) observed mobility, based on Timed Up and Go scores, improved after an acute bout of aquatic training as opposed to land training, but also found no differences between stride rate and stride length. These similar findings could infer that neuromuscular aspects of the body and balance improved, rather than walking speed and step length. It should be noted that the present study was not designed to encourage walking speed. The participants were asked to walk at their own comfortable speed, had the study also included another condition in which participants were asked to walk as fast as possible, there may have been differences in step rate and step length.

Results of this study indicated that patients with OA of the knee might have less arthritis related joint pain by training on an aquatic treadmill as opposed to a land-based treadmill. Wang et al. (2007) and Patrick et al. (2001) studied the effects of aquatic exercise on self-reported pain, and did not observe changes in pain. This disagreement between studies may be due to differences in several reasons, such as how and when an assessment was administered, and the type of assessment. The current study targeted pain only related to knee OA. Previous studies investigating the effectiveness of aquatic therapy have also demonstrated decreases in arthritis related joint pain after therapy. For example, Denning et al. (2010) detected perceived joint pain was less immediately after aquatic versus land exercise, utilizing a visual analog scale, and was 140% greater after aquatic exercise versus land. The present study also detected improvements in perceived joint pain after three bouts of aquatic training compared to land, by 100%. Although the exact mechanism for the reduction in pain is unknown, previous authors have concluded that the benefits may be related to buoyancy, warmth, and pressure of the water (Barela & Duarte, 2008; Denning et al., 2010; Hinman et al., 2007)

This preliminary study failed to find any difference between the two modalities of training for improvements in self-efficacy gain scores. Prior studies have on the contrary; found that exercise therapy can increase scores in self-efficacy (Ahern, Nicholls, Simionato, Clark, & Bond, 1995; Focht et al., 2005). Focht et al. (2005) observed significant improvements after a four-day study in self-efficacy. It is possible that in the current study the participants overestimated their potential in walking a certain number of laps around the gym, and assumed they could complete more than they could prior to starting the physical exercise. After the bouts of exercise, they may have had a more accurate idea of their physical capabilities at follow up, and therefore had no significant differences between scores.

There are a number of limitations of the study that may have influenced the results and application of results. Skin motion, particularly in participants who are overweight or obese, causes marker motion relative to the underlying bone. This movement affects the estimation of the gait kinematics, and is considered the most critical source of error in human movement analysis (Leardini, Chiari, Della Croce, & Cappozzo, 2005). Of the lower limb segments, the thigh is the greatest source of this soft tissue artifact. Leardini et al. (2005) have recommended motion about other axes other than the flexion/extension axis should be observed carefully, as this artifact can produce false effects with magnitudes comparable to the amount of motion actually occurring at the joint. Therefore, due to the effects of soft tissue artifact the authors of the present study suggest interpreting the results of the kinematics section with caution. Also, patients with OA completed measurements before and after only three exercise sessions. Increasing the length of the training period may produce alternative outcomes that would affect the gait kinematics and self-efficacy of the participants. While this was a limitation, three exercise sessions were long enough for neuromuscular changes to take place, and these results are supported by Denning et al. (2010) who demonstrated that VO_2 leveled of after the second exercise session.

It should be noted that in addition to kinematic and self-reported measurements, participants in the present study gave subjective comments and all had preference to the aquatic treadmill over the land treadmill. Generally the participants stated they enjoyed how they felt in the water and were interested in continuing the aquatic exercise after ending the study. However, due to the lack of aquatic treadmills in the community at the time, most participants were unable to continue the training, which could be considered a temporary shortcoming for aquatic treadmill training.

Conclusion

The present study demonstrated that an acute training period on an aquatic treadmill tended to increase select joint angular velocities and decrease arthritis related joint pain. Although some acute effects of training (i.e., pain, angular velocity) improved after aquatic training compared to land, it is unclear whether or not aquatic exercise is a better long-term alternative to land exercise as further longitudinal research is needed to examine gait kinematic changes after an increased training period of aquatic exercise.

Table 3

Physical Characteristics and Osteoarthritis (OA) Descriptives for All Participants (n = 14)

Characteristic	Mean	*SD*	Range
Age (yr)	57.4	7.4	43 – 64
Gender	2 male, 12 female		
Height (cm)	168.8	8.89	157 – 188
Body mass (kg)	93.2	22.8	59 – 145
Involved limb (s)	12 knee, 1 hip/knee, 1 knee/ankle		
Duration of OA (yr)	8.85	6.62	3 - 24

Table 4

Knee Kinematic Variables Significant at the 0.05 Level and the 95% Confidence Interval

Comparisons	*p* value	Holm's adjusted value	95% CI
Land vs aquatic stance max angular velocity for left knee (Sagittal)	0.004	0.05/8 = 0.006	60.8 (29.1, 88.2)*
Land vs aquatic swing min angular velocity for left knee (Transverse)	0.004	0.05/7 = 0.007	-125 (-190, -52.6)*
Land vs aquatic swing max angular velocity for left knee (Sagittal)	0.008	0.05/6 = 0.008	62.4 (20.6, 109)*
Land vs aquatic stance max angular velocity for right knee (Sagittal)	0.02	0.05/5 = 0.01	42.6 (10.7, 73.7)
Land vs aquatic swing min angular position for left knee (Sagittal)	0.02	0.05/4 = 0.01	-6.46 (-15.6, -0.38)
Land vs aquatic stance max angular position for right knee (Frontal)	0.04	0.05/3 = 0.02	36.3 (3.47, 67.9)
Land vs aquatic stance min angular position for right knee (Frontal)	0.05	0.05/1 = 0.05	-3.91 (-8.70, -0.11)

* significant at the adjusted level

Table 5

Ankle Kinematic Variables Significant at the 0.05 Level and the 95% Confidence Interval

Comparisons	*p* value	Holm's adjusted value	95% CI
Land vs aquatic stance max angular position for left ankle (Frontal)	0.003	0.05/11 = 0.005	9.75 (3.89, 19.8)*
Land vs aquatic stance min angular velocity for right ankle (Frontal)	0.006	0.05/10 = 0.005	214 (72.0, 401)
Land vs aquatic swing min angular velocity for right angle (Transverse)	0.01	0.05/9 = 0.006	32 (12.1, 53.1)
Land vs aquatic stance max angular velocity for right ankle (Frontal)	0.01	0.05/8 = 0.006	213 (401, 72.0)
Land vs aquatic stance min angular velocity for left ankle (Transverse)	0.016	0.05/7 = 0.007	-104 (-196, -22.9)
Land vs aquatic stance min angular velocity for left ankle (Transverse)	0.023	0.05/6 = 0.008	21.8 (6.01, 35.4)
Land vs aquatic swing max angular velocity for right ankle (Transverse)	0.03	0.05/5 = 0.01	168 (28.5, 320)
Land vs aquatic stance max angular position for the right ankle (Transverse)	0.034	0.05/4 = 0.01	7.07 (1.20, 19.4)

Comparisons	*p* value	Holm's adjusted value	95% CI
Land vs aquatic swing min angular velocity for right ankle (Transverse)	0.04	0.05/2 = 0.03	-114 (-226, -38.6)
Land vs aquatic stance max angular velocity for right ankle (Transverse)	0.04	0.05/3 = 0.02	-183 (-320, 32.9)
Land vs aquatic swing max angular position for left ankle (Frontal)	0.05	0.05/1 = 0.05	9.75 (0.27, 16.8)

* significant at the adjusted level

Table 6

Hip Kinematic Variables Significant at the 0.05 Level and the 95% Confidence Interval

Comparisons	*p* value	Holm's adjusted value	95% CI
Land vs aquatic stance max angular position for left hip (Sagittal)	0.007	0.05/6 = 0.008	9.88 (3.23, 15.2)*
Land vs aquatic swing min angular velocity for right hip (Sagittal)	0.01	0.05/5 = 0.01	-28.9 (-48.7, -11.2)*
Land vs aquatic stance max angular velocity for left hip (Sagittal)	0.02	0.05/4 = 0.01	19.4 (3.06, 45.5)
Land vs aquatic swing max angular position for right hip (Sagittal)	0.02	0.05/3 = 0.02	-5.25 (-8.93, -0.73)
Land vs aquatic swing max angular position for left hip (Frontal)	0.04	0.05/2 = 0.03	-2.14 (-4.12, -0.09)
Land vs aquatic stance max angular velocity for right hip (Transverse)	0.04	0.05/1 = 0.05	-19.1 (-43.8, -0.92)

* significant at the adjusted level

Table 7

Maximum Joint Angular Velocity (°/s, mean ±SD) for the Stance Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	276 (37.5)	265 (85.7)	282 (52.6)	249 (42.7)	5.44 (59.1)	-16.2 (75.0)
Left	263 (74.1)	266 (88.0)	278 (52.2)	240 (72.2)	31.2 (63.0)	0.20 (57.2)
Knee (Sagittal)						
Right	212 (45.1)	226 (88.7)	263 (35.2)	221 (48.7)	41.6 (31.1)	-2.08 (48.7)
Left	207 (47.3)	226 (88.7)	251 (36.2)	188 (51.4)	44.3 (57.4)	-23.7 (58.8)*
Hip (Sagittal)						
Right	133 (55.8)	143 (44.9)	150 (19.6)	142 (18.1)	-1.17 (32.7)	-15.9 (25.4)
Left	133 (34.7)	132 (36.9)	139 (17.8)	150 (19.6)	6.53 (39.2)	-16.9 (24.8)
Ankle (Frontal)						
Right	263 (114)	395 (341)	371 (139)	316 (219)	82.7 (101)	-72.0 (191)
Left	233 (112)	224 (136)	335 (182)	241 (148)	56.8 (143)	17.0 (191)
Knee (Frontal)						
Right	118 (72.4)	147 (130)	130 (26.3)	134 (80.6)	26.9 (56.0)	-8.31 (31.5)
Left	131 (69.5)	139 (75.4)	129 (41.2)	126 (40.8)	-1.84 (78.8)	1.97 (47.4)
Hip (Frontal)						
Right	90.1 (37.8)	82.5 (32.1)	82.3 (16.1)	72.4 (18.8)	-0.24 (23.4)	-5.42 (23.1)
Left	99.4 (36.0)	90.4 (32.1)	72.6 (9.16)	71.5 (28.1)	-26.8 (36.9)	-3.78 (24.6)
Ankle (Transverse)						
Right	433 (116)	547 (257)	552 (147)	524 (249)	119 (155)	-66.1 (130)
Left	389 (148)	513 (274)	446 (185)	369 (142)	56.6 (213)	-73.4 (213)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	382 (113)	398 (257)	461 (74.9)	457 (254)	53.0 (70.0)	83.8 (129)
Left	337 (114)	363 (136)	366 (152)	331 (125)	28.8 (168)	-32.1 (147)
Hip (Transverse)						
Right	156 (43.1)	158 (68.8)	129 (45.5)	142 (35.7)	-39.0 (45.8)	-16.3 (50.6)
Left	156 (53.2)	181 (71.0)	150 (32.8)	149 (58.5)	-5.86 (62.0)	-14.9 (75.7)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 8

Minimum Joint Angular Velocity (°/s, mean ± SD) for the Swing Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	265 (80.4)	247 (76.6)	247 (54.4)	213 (54.5)	-17.4 (86.1)	-33.9 (78.6)
Left	212 (92.2)	218 (69.3)	234 (62.5)	225 (81.9)	22.1 (70.7)	21.7 (52.3)
Knee (Sagittal)						
Right	335 (39.9)	364 (79.2)	357 (42.4)	332 (47.9)	9.54 (27.8)	-15.8 (69.3)
Left	293 (34.8)	326 (69.3)	354 (27.5)	301 (72.6)	60.5 (73.5)	1.89 (37.2)
Hip (Sagittal)						
Right	107 (22.6)	120 (34.8)	128 (17.3)	110 (26.6)	20.4 (26.9)	-9.33 (41.0)*
Left	107 (34.8)	116 (28.8)	119 (28.5)	107 (30.7)	12.2 (35.7)	-9.05 (40.2)
Ankle (Frontal)						
Right	175 (45.4)	276 (182)	191 (43.1)	255 (163)	16.9 (50.9)	-66.9 (208)
Left	172 (58.0)	177 (55.9)	205 (56.9)	185 (71.0)	35.8 (41.9)	21.4 (56.4)
Knee (Frontal)						
Right	192 (110)	178 (112)	168 (42.4)	171 (42.4)	-5.08 (31.9)	-9.01 (69.5)
Left	178.6 (92.0)	175 (89.7)	200 (67.5)	170 (63.9)	22.1 (81.7)	21.1 (42.2)
Hip (Frontal)						
Right	67.6 (34.4)	69.4 (38.1)	49.3 (8.00)	59.5 (24.1)	-7.96 (20.2)	-9.91 (43.2)
Left	67.6 (47.7)	59.0 (26.7)	64.8 (28.1)	44.5 (16.7)	-7.52 (30.5)	-6.99 (24.3)
Ankle (Transverse)						
Right	335 (130)	441 (268)	416 (144)	345 (151)	69.0 (82.8)	-69.1 (122)
Left	425 (236)	417 (274)	499 (230)	354 (141)	73.5 (333)	53.0 (106)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	223 (69.8)	262 (131)	243 (83.2)	216 (125)	20.1 (92.9)	-49.9 (101)
Left	201 (95.4)	224 (107)	293 (109)	181 (88.8)	91.4 (93.9)	-27.6 (56.2)*
Hip (Transverse)						
Right	95.9 (58.6)	96.3 (34.4)	86.7 (23.5)	92.3 (36.9)	4.17 (41.4)	6.01 (38.4)
Left	102 (53.7)	111 (57.1)	110 (48.0)	95.3 (36.5)	8.53 (78.0)	-15.5 (61.2)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 9

Maximum Joint Angular Velocities (°/s, mean ± SD) for the Swing Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	249 (64.6)	258 (84.4)	253 (55.7)	219 (61.8)	3.53 (73.2)	-23.0 (63.5)
Left	211 (82.4)	224 (64.2)	252 (60.1)	223 (70.4)	26.1 (51.8)	6.42 (48.3)
Knee (Sagittal)						
Right	323 (61.3)	338 (81.4)	332 (56.3)	318 (39.8)	-2.93 (22.0)	-6.06 (37.8)
Left	299 (72.1)	315 (71.1)	337 (33.7)	292 (74.0)	38.1 (76.7)	-25.5 (47.1)*
Hip (Sagittal)						
Right	109 (43.8)	111 (27.2)	106 (31.5)	109 (30.9)	-2.61 (35.6)	-13.5 (21.1)
Left	105 (43.8)	106 (27.2)	99.8 (31.5)	95.4 (30.9)	-5.39 (57.4)	-21.2 (13.3)
Ankle (Frontal)						
Right	175 (49.5)	243 (128)	194 (41.5)	254 (151)	35.5 (37.6)	-34.2 (158)
Left	161 (47.4)	190 (53.7)	197 (35.4)	171 (50.0)	35.4 (53.7)	-5.05 (39.5)
Knee (Frontal)						
Right	195 (107)	183 (110)	155 (45.4)	182 (86.5)	-24.3 (66.2)	-5.64 (75.4)
Left	194 (119)	184 (92.9)	202 (70.2)	166 (60.4)	8.03 (117)	8.97 (53.7)
Hip (Frontal)						
Right	60.5 (39.5)	58.5 (39.0)	54.8 (11.8)	56.6 (26.4)	1.94 (24.3)	3.54 (19.7)
Left	66.7 (32.3)	59.7 (25.7)	53.5 (16.5)	48.2 (14.7)	-13.2 (27.5)	-3.36 (18.2)
Ankle (Transverse)						
Right	345 (151)	394 (244)	489 (209)	330 (164)	99.4 (174)	-115 (214)
Left	295 (165)	413 (285)	493 (209)	353 (136)	198 (235)	16.8 (185)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	211 (89.9)	259 (63.5)	247 (170)	249 (181)	22.6 (52.9)	-28.3 (89.5)
Left	203 (76.0)	210 (63.5)	278 (125)	209 (55.2)	74.9 (117)	24.1 (56.1)
Hip (Transverse)						
Right	156 (68.0)	163 (91.3)	159 (69.4)	125 (32.8)	9.43 (60.9)	-24.7 (70.4)
Left	166 (103)	150 (74.0)	137 (44.6)	110 (48.9)	-8.37 (70.7)	-39.8 (38.4)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 10

Maximum Joint Angles (degrees, mean ± SD) for the Stance Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	126 (5.45)	120 (16.9)	124 (4.09)	123 (7.65)	-1.69 (6.00)	3.22 (15.5)
Left	123 (9.17)	123 (15.32)	124 (6.86)	126 (12.9)	1.41 (8.47)	-0.39 (7.21)
Knee (Sagittal)						
Right	173 (5.00)	170 (10.3)	170 (3.77)	172 (3.79)	-1.27 (4.29)	-0.01 (6.01)
Left	171 (8.19)	171 (9.89)	168 (7.95)	171 (6.97)	-2.85 (9.59)	0.63 (7.20)
Hip (Sagittal)						
Right	167 (5.42)	165 (4.59)	164 (3.98)	168 (5.63)	-3.48 (3.67)	0.17 (6.11)
Left	167 (7.20)	165 (7.24)	161 (4.82)	171 (8.65)	-6.33 (6.22)	2.97 (8.81)*
Ankle (Frontal)						
Right	170 (11.9)	168 (8.26)	173 (3.18)	173 (6.11)	1.15 (6.27)	5.73 (8.18)
Left	173 (7.38)	167 (9.52)	170 (4.17)	172 (6.69)	-4.30 (3.01)	4.88 (11.9)*
Knee (Frontal)						
Right	173 (4.74)	174 (4.42)	175 (3.51)	174 (3.23)	1.93 (4.42)	0.03 (3.27)
Left	172 (3.49)	174 (3.32)	175 (3.84)	174 (4.19)	2.12 (2.73)	-0.44 (3.74)
Hip (Frontal)						
Right	178 (1.96)	177 (1.76)	177 (1.56)	177 (1.84)	-1.10 (2.07)	-0.70 (2.43)
Left	175 (2.31)	176 (2.45)	176 (2.30)	176 (1.76)	1.59 (2.25)	-0.13 (2.53)
Ankle (Transverse)						
Right	173 (8.35)	153 (43.0)	172 (1.48)	173 (5.00)	-3.15 (3.98)	9.62 (16.2)
Left	172 (8.98)	158 (45.2)	169 (8.21)	173 (3.07)	-3.71 (2.63)	-0.26 (6.14)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	173 (9.19)	174 (4.88)	174 (4.27)	172 (8.08)	-1.55 (3.98)	-2.83 (7.90)
Left	175 (3.36)	173 (4.92)	175 (2.49)	173 (5.04)	0.28 (3.02)	-1.10 (4.16)
Hip (Transverse)						
Right	171 (8.38)	167 (10.5)	171 (4.19)	174 (4.54)	-1.12 (7.68)	3.99 (7.18)
Left	173 (6.49)	169 (8.04)	174 (3.29)	173 (3.52)	1.04 (7.75)	6.90 (12.4)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 11

Minimum Joint Angular Velocity (°/s, mean ± SD) for the Stance Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	274 (74.2)	242 (103)	234 (39.4)	237 (61.6)	-56.7 (81.1)	-29.4 (85.3)
Left	255 (98.7)	258 (75.4)	249 (51.4)	231 (79.53)	-21.71 (81.05)	-11.46 (44.41)
Knee (Sagittal)						
Right	205 (65.0)	199 (72.2)	222 (44.0)	216 (50.6)	-11.3 (46.2)	-29.0 (29.5)
Left	188 (64.0)	201 (71.3)	207 (47.3)	167 (50.4)	19.2 (80.6)	-44.0 (55.4)
Hip (Sagittal)						
Right	142 (36.5)	138 (18.0)	170 (20.5)	144 (18.0)	21.4 (15.7)	6.69 (37.8)
Left	137 (33.2)	137 (45.4)	148 (18.8)	123 (29.9)	10.6 (36.7)	-13.5 (39.5)
Ankle (Frontal)						
Right	248 (118)	390 (379)	364 (110)	237 (144)	115 (105)	-80.0 (237)
Left	224 (74.4)	241 (176)	283 (95.5)	237 (144)	36.8 (100)	-4.11 (108)
Knee (Frontal)						
Right	116 (69.1)	152 (145)	123 (20.1)	149 (82.0)	22.3 (46.8)	12.2 (39.6)
Left	131 (60.5)	146 (74.7)	118 (35.6)	107 (47.4)	8.15 (44.4)	-24.4 (41.0)
Hip (Frontal)						
Right	87.5 (41.7)	80.6 (39.1)	81.8 (13.7)	78.0 (23.0)	3.33 (19.2)	-2.60 (29.4)
Left	91.9 (42.4)	87.4 (32.2)	70.4 (8.27)	71.3 (22.9)	-14.4 (33.7)	-8.12 (24.4)
Ankle (Transverse)						
Right	255 (101)	317 (213)	321 (99.2)	375 (189)	35.5 (52.4)	57.8 (242)
Left	267 (90.1)	306 (164)	348 (106)	284 (140)	81.2 (84.4)	22.3 (119)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	261 (131)	281 (136)	284 (109)	298 (125)	37.0 (82.1)	31.9 (144)
Left	266 (124)	276 (152)	303 (80.7)	265 (156)	36.1 (94.1)	13.3 (139)
Hip (Transverse)						
Right	116 (39.1)	128 (29.9)	124 (43.1)	123 (51.4)	7.87 (62.0)	-14.8 (37.1)
Left	125 (44.4)	158 (62.7)	126 (20.8)	133 (52.8)	-6.64 (38.5)	-38.7 (64.1)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 12

Maximum Joint Angles (degrees, mean ± SD) for the Swing Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	126 (7.10)	124 (15.8)	124 (4.82)	126 (14.4)	-2.46 (8.09)	-0.22 (14.0)
Left	125 (13.2)	126 (15.5)	125 (9.68)	127 (13.3)	-0.46 (11.7)	-2.77 (16.0)
Knee (Sagittal)						
Right	172 (4.26)	169 (10.6)	168 (3.92)	170 (3.27)	-4.87 (6.11)	-1.75 (7.85)
Left	172 (6.98)	169 (10.7)	167 (8.27)	172 (5.89)	-4.48 (10.5)	2.99 (8.55)
Hip (Sagittal)						
Right	170 (7.34)	171 (10.6)	173 (3.15)	173 (5.36)	3.35 (3.15)	-0.94 (7.05)
Left	171 (6.56)	168 (13.7)	167 (8.28)	172 (6.41)	-3.81 (8.53)	0.78 (5.94)
Ankle (Frontal)						
Right	170 (9.07)	169 (6.99)	172 (3.74)	174 (4.94)	0.64 (4.11)	4.31 (9.88)
Left	172 (6.05)	168 (7.82)	171 (2.22)	171 (6.71)	-4.69 (3.60)	4.56 (6.71)
Knee (Frontal)						
Right	174 (4.24)	173 (4.56)	175 (2.07)	175 (2.75)	0.70 (4.44)	1.84 (4.94)
Left	173 (3.77)	173 (3.51)	175 (3.11)	174 (4.28)	2.58 (3.5)	0.50 (3.94)
Hip (Frontal)						
Right	175 (2.43)	174 (3.02)	174 (2.62)	172 (2.65)	-0.72 (4.01)	-2.00 (4.67)
Left	173 (3.10)	176 (3.63)	174 (3.85)	175 (2.66)	1.40 (2.67)	-1.06 (2.16)
Ankle (Transverse)						
Right	174 (6.24)	159 (26.70)	174 (4.58)	172 (8.36)	-1.45 (2.33)	6.70 (17.4)
Left	173 (9.94)	160 (43.9)	173 (8.31)	175 (5.50)	-0.74 (4.20)	2.84 (14.2)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	171 (10.0)	175 (4.91)	175 (2.61)	174 (3.64)	1.75 (5.12)	-0.79 (4.71)
Left	175 (5.00)	174 (4.64)	173 (1.51)	174 (5.15)	-3.99 (4.18)	0.01 (6.36)
Hip (Transverse)						
Right	173 (7.12)	168 (9.71)	174 (2.77)	174 (4.23)	-1.40 (3.85)	5.43 (10.9)
Left	171 (5.84)	169 (6.47)	174 (3.95)	172 (3.42)	2.81 (7.13)	2.26 (7.39)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 13

Minimum Joint Angles (degrees, mean ± SD) for the Stance Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	93.5 (7.91)	88.9 (13.7)	93.0 (1.51)	90.0 (4.95)	1.01 (6.22)	1.11 (14.2)
Left	92.2 (7.28)	92.4 (13.4)	92.4 (5.00)	96.0 (18.7)	-1.27 (6.92)	0.00 (6.54)
Knee (Sagittal)						
Right	144 (11.6)	148 (13.1)	144 (3.01)	142 (6.96)	-0.09 (11.7)	-6.02 (12.7)
Left	143 (8.05)	144 (10.6)	146 (8.05)	146 (12.3)	0.85 (7.40)	-0.50 (6.26)
Hip (Sagittal)						
Right	154 (8.62)	152 (14.2)	158 (6.24)	154 (6.98)	3.65 (4.40)	-1.35 (7.10)
Left	154 (11.7)	150 (14.7)	158 (7.85)	154 (10.4)	3.77 (8.99)	3.58 (12.8)
Ankle (Frontal)						
Right	158 (8.74)	153 (14.3)	156 (5.15)	157 (11.7)	-1.94 (8.30)	4.28 (19.6)
Left	158 (8.54)	163 (10.0)	153 (6.78)	155 (11.4)	-4.72 (10.6)	-5.45 (10.5)
Knee (Frontal)						
Right	166 (6.10)	166. (6.40)	169 (3.72)	166 (5.43)	2.67 (5.98)	-2.97 (3.32)
Left	167 (7.89)	167 (7.69)	168 (5.52)	167 (6.34)	1.43 (5.23)	0.72 (3.84)
Hip (Frontal)						
Right	171 (2.45)	170 (3.15)	171 (3.24)	168 (3.28)	-0.31 (4.16)	-1.26 (4.40)
Left	170 (4.49)	171 (3.34)	169 (4.45)	171 (4.46)	-0.51 (4.52)	0.79 (2.82)
Ankle (Transverse)						
Right	159 (11.53)	136 (31.5)	148 (10.5)	154 (15.7)	-13.6 (9.39)	10.9 (30.3)
Left	158 (13.8)	148 (34.8)	151 (11.5)	158 (11.2)	-6.68 (16.3)	1.29 (23.5)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	166 (6.46)	160 (9.55)	162 (3.49)	160 (10.9)	-4.03 (7.31)	0.24 (15.7)
Left	161 (7.20)	163 (12.5)	161 (11.3)	155 (11.7)	2.99 (5.70)	-7.65 (15.2)
Hip (Transverse)						
Right	168 (5.42)	171 (4.59)	172 (3.98)	168 (5.63)	1.61 (3.67)	-3.20 (6.11)
Left	170 (7.20)	170 (7.24)	169 (5.63)	167 (8.65)	-0.85 (6.22)	-2.71 (6.11)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 14

Minimum Joint Angles (degrees, mean ± SD) for the Swing Phase of Gait. Quantified before (pre) and after (post) aquatic and land treadmill exercise. The difference between post and pre values (gain) for the left and right legs are displayed for the ankle, knee and hip joints

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Ankle (Sagittal)						
Right	103 (6.95)	100 (13.6)	102 (2.30)	96.2 (10.9)	0.51 (4.79)	-2.92 (12.0)
Left	103 (12.3)	104 (14.1)	101 (4.95)	105 (16.7)	-1.85 (3.92)	-4.08 (14.8)
Knee (Sagittal)						
Right	128 (8.03)	132 (8.45)	131 (5.02)	131 (6.84)	1.80 (5.30)	-1.35 (11.9)
Left	130 (8.76)	132 (13.7)	134 (9.88)	131 (12.4)	6.06 (8.53)	-4.07 (10.4)
Hip (Sagittal)						
Right	153 (8.58)	151 (8.58)	157 (6.18)	152 (6.82)	4.16 (4.24)	-1.16 (6.61)
Left	153 (9.70)	150 (13.6)	156 (8.24)	153 (10.3)	3.57 (8.06)	-1.10 (5.26)
Ankle (Frontal)						
Right	159 (7.93)	152 (7.82)	157 (5.21)	157 (15.8)	-2.13 (7.94)	5.21 (22.9)
Left	160 (7.79)	163 (9.55)	153 (8.84)	152 (13.8)	-5.50 (12.8)	-8.07 (11.5)
Knee (Frontal)						
Right	165 (8.01)	163 (9.04)	167 (4.23)	165 (6.65)	-0.70 (4.45)	1.89 (10.3)
Left	165 (8.85)	166 (8.53)	164 (7.42)	164 (9.34)	-1.3 (7.36)	-2.22 (5.75)
Hip (Frontal)						
Right	170 (3.25)	169 (2.94)	170 (3.37)	167 (3.99)	0.17 (4.79)	-0.77 (4.33)
Left	168 (4.74)	170 (3.49)	169 (4.30)	170 (4.48)	2.10 (3.50)	0.71 (4.02)
Ankle (Transverse)						
Right	156 (14.2)	131 (32.2)	141 (12.0)	149 (19.4)	-15.3 (18.1)	17.3 (37.3)
Left	153 (13.8)	144 (35.1)	147 (15.3)	153 (13.0)	-2.69 (20.1)	9.45 (41.1)

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Knee (Transverse)						
Right	162 (6.50)	158 (12.6)	161 (3.36)	161 (10.0)	-1.21 (7.62)	2.5 (17.2)
Left	159 (9.36)	162 (10.4)	160 (11.9)	153 (9.91)	3.50 (6.75)	-9.38 (14.9)
Hip (Transverse)						
Right	169 (5.35)	174 (4.35)	172 (3.50)	168 (7.21)	3.10 (4.95)	-6.08 (7.42)
Left	173 (7.01)	170 (7.58)	169 (6.14)	168 (8.72)	-3.55 (8.62)	-1.98 (8.62)

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic treadmill exercise, $p < .05$.

Table 15

Self-Efficacy and Pain scores (mean ± SD) for Aquatic and Land Treadmill Exercise

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Self Efficacy	92.0 (34.3)	92.0 (34.7)	96.0 (34.6)	86.3 (39.8)	-4.89 (34.6)	-4.57 (27.7)
Pain	40.0 (24.1)	37.2 (25.0)	37.4 (23.4)	25.5 (25.2)	0.13 (19.2)	-15.4 (20.7)*

Note. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic exercise, $p < .05$

Table 16

Step Length and Step Rate Gain Scores (mean ± SD) for the Right and Left Limbs for Aquatic and Land Treadmill Exercise

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
SL (m)						
Right	0.64 (0.11)	0.62 (0.11)	0.64 (0.08)	0.62 (0.11)	0.01 (0.05)	-0.001 (0.07)
Left	0.66 (0.10)	0.65 (0.11)	0.62 (0.09)	0.63 (0.10)	-0.03 (0.04)	-0.01 (0.06)
SR (step/s)						
Right	0.54 (0.06)	0.54 (0.05)	0.62 (0.09)	0.62 (0.11)	-0.42 (0.07)	-0.001 (0.07)
Left	0.51 (0.15)	0.54 (0.04)	0.55 (0.03)	0.54 (0.04)	-0.04 (0.05)	-0.02 (0.07)

Note. SL = step length and SR = step rate. Gain scores were computed as the difference between pretest and posttest values.

*significantly different from aquatic exercise, p<.05

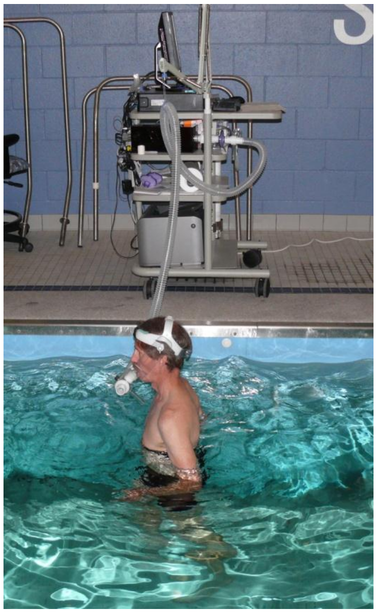


Figure 1. Experimental setup for the aquatic treadmill mode.

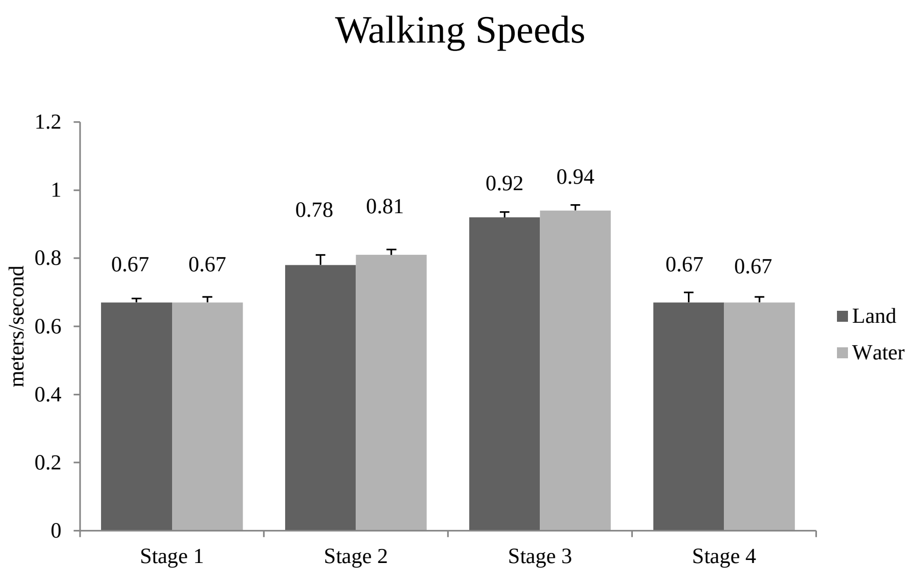


Figure 2. Average walking speeds at different stages for land and water conditions.

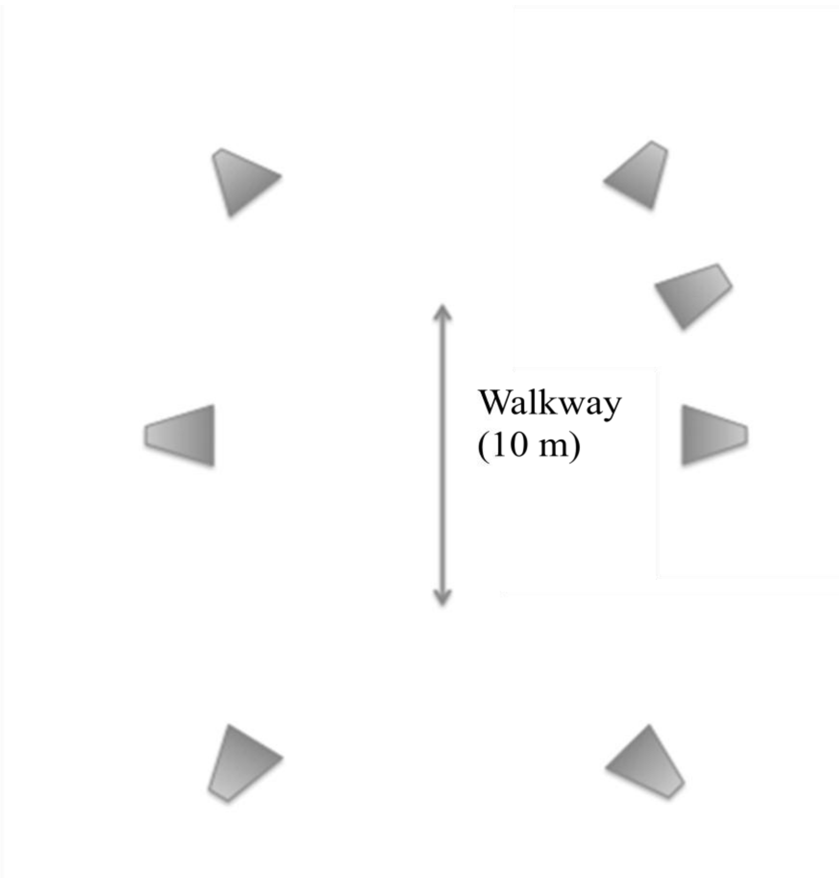
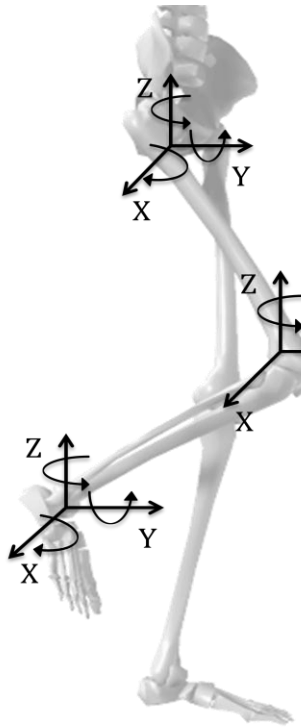


Figure 3. Aerial view of experimental setup for collecting gait kinematic data. The participants walked six times over a 10 m walkway while marker position data were recorded from seven high-speed cameras.



Hip	x	y	z
Maximum Angles	Extension	Abduction	External Rotation
Minimum Angles	Flexion	Adduction	Internal Rotation
Knee			
Maximum Angles	Extension	Abduction	External Rotation
Minimum Angles	Flexion	Adduction	Internal Rotation
Ankle			
Maximum Angles	Plantarflexion	Abduction	External Rotation
Minimum Angles	Dorsiflexion	Adduction	Internal Rotation

Figure 4. Joint coordinate system used for determining positive and negative joint angles. The curved arrows indicate the positive directions for joint angular displacements and velocities.

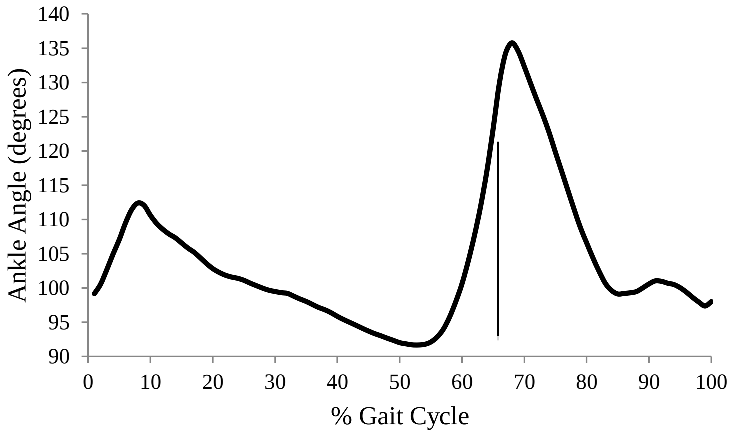


Figure 5. Sagittal plane ankle angle during complete gait cycle for left limb. An ankle angle of zero degrees indicates complete dorsiflexion. The curve is a representative sample taken during the pre-aquatic assessment while walking over a flat 10-m walkway. The vertical line represents beginning of the swing phase (toe-off) in gait.

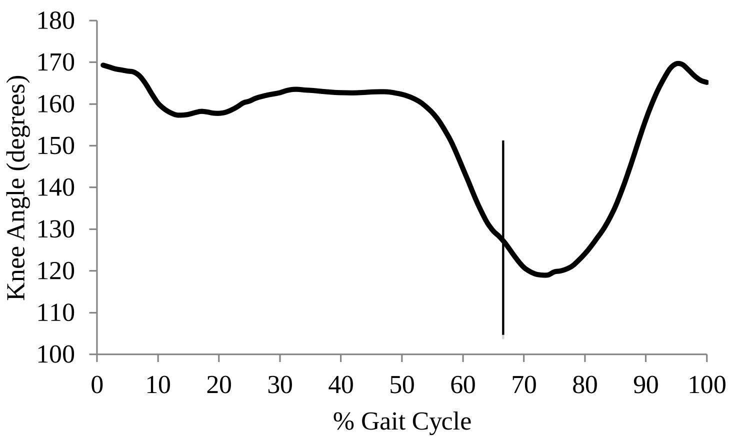


Figure 6. Sagittal plane knee angle during complete gait cycle for left limb. A knee angle of zero degrees indicates complete flexion. The curve is a representative sample taken during the pre-aquatic assessment while walking over a flat 10-m walkway. The vertical line represents beginning of the swing phase (toe-off) in gait.

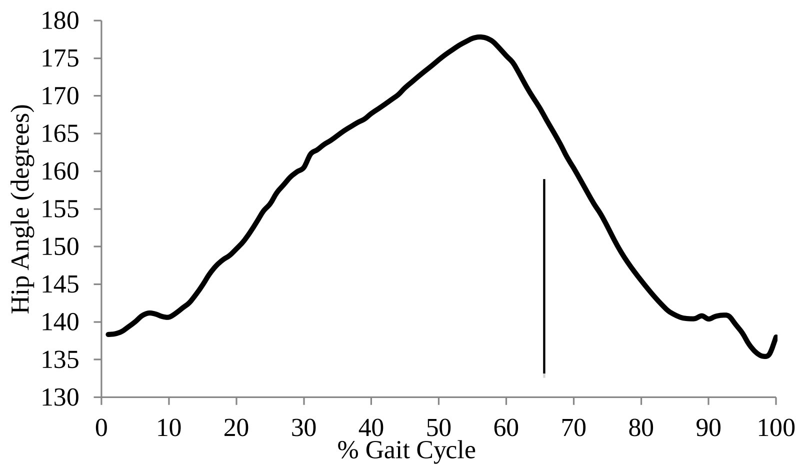


Figure 7. Sagittal plane hip angle during complete gait cycle for left limb. A hip angle of zero degrees indicates complete flexion. The curve is a representative sample taken during the pre-aquatic assessment while walking over a flat 10-m walkway. The vertical line represents beginning of the swing phase (toe-off) in gait.

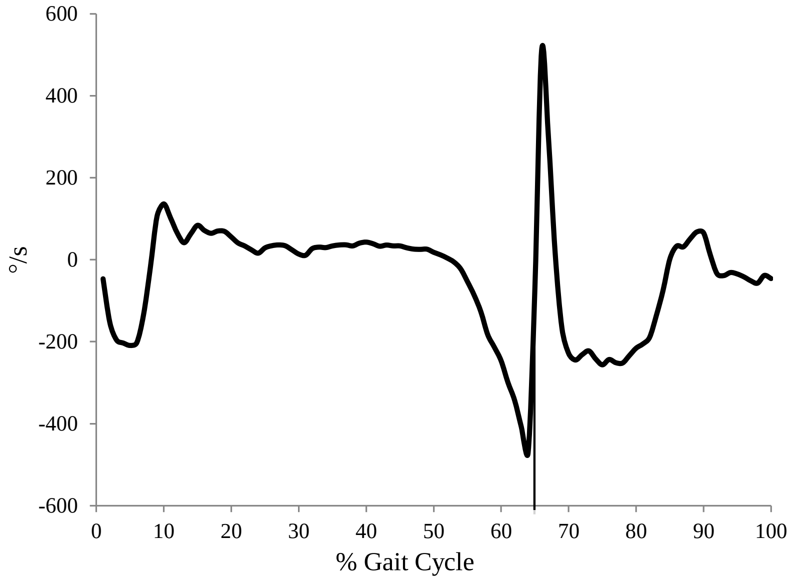


Figure 8. Sagittal plane ankle angular velocity during complete gait cycle for left limb. The curve is a representative sample taken during the pre-aquatic assessment while walking over a flat 10-m walkway. The vertical line represents beginning of the swing phase (toe-off) in gait.

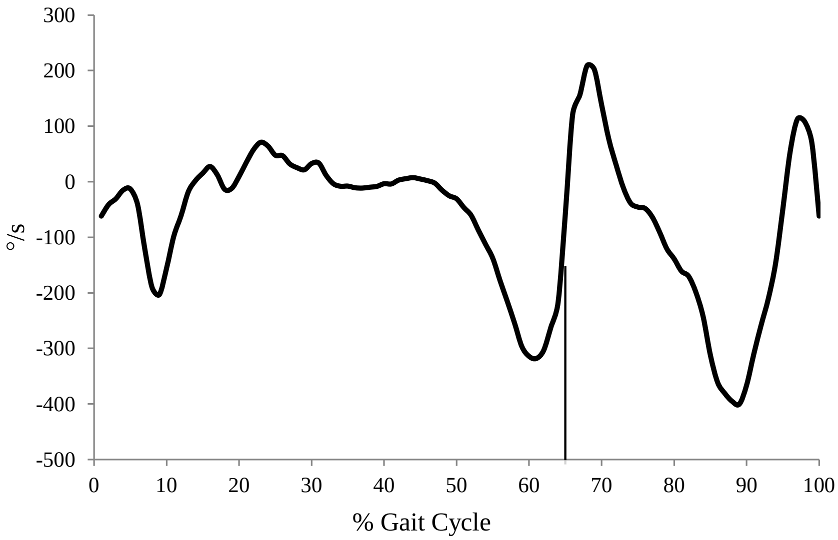


Figure 9. Sagittal plane knee angular velocity during complete gait cycle for left limb. The curve is a representative sample taken during the pre-aquatic assessment while walking over a flat 10-m walkway. The vertical line represents beginning of the swing phase (toe-off) in gait.

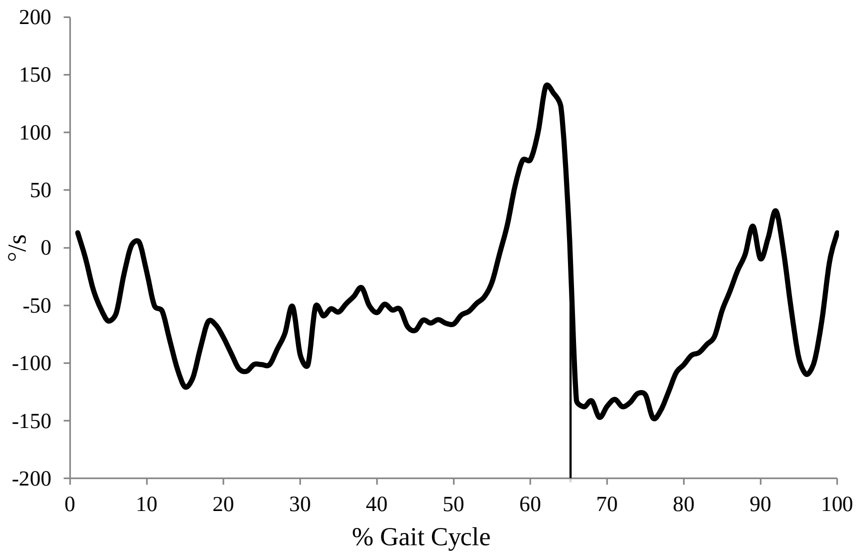


Figure 10. Sagittal plane hip angular velocity during complete gait cycle for left limb. The curve is a representative sample taken during the pre-aquatic assessment while walking over a flat 10-m walkway. The vertical line represents beginning of the swing phase (toe-off) in gait.

CHAPTER 4

SUMMARY AND CONCLUSION

Review Article (Chapter 2)

Previous studies have suggested that gait patterns of adults affected by OA are considerably different when compared to healthy adults. Researchers have observed differences in knee range of motion, stance phase knee flexion/extension, walking velocity, stride length, and cadence when compared to a normal, healthy population (Gyory et al., 1976; Messier et al., 1992; Stauffer et al., 1977; Walker et al., 2001).

These kinematic observations have lead to the conclusion that changes in lower extremity kinematics could be a strategy used by OA patients to reduce joint movement so that less pain is felt during weight bearing activities. These changes are important to examine because measurements of the mechanics of the disease are necessary for a greater understanding of the functional effects of treatment(s).

The purpose of this paper was to review the literature examining noninvasive OA therapies on kinematics of gait. An appreciation of these findings may help with clinicians in choosing the most efficacious therapy for improving mobility. This review was organized in the following approach, methods used to assess gait mobility with descriptions of specific tests used to address mechanical and painful complications of OA, and various forms of noninvasive therapies used for treatment of OA and their effects on mobility.

The selection criteria for inclusion in this study were as follows: the study used at least one type of noninvasive therapy to treat OA, and at least one of the outcome measures was an assessment of gait and/or mobility, the studies were available in English and were published in a peer-reviewed journal, and/or the study provided additional information on non-invasive methods for treating OA. Seven articles from 1997 to 2009 were included.

Different modalities for treating OA may affect walking speed, stride length, stride rate, and function.   Studies that train via land have improved basic function, walking speed, and joint space narrowing (Rogind et al., 1998; Fisher et al., 1997; Mikesky et al., 2006). Unfortunately while these land exercises have presented positive affects, Rogind et al. (1998) noted that palpable effusions (which may be caused by increased joint loading) increased after training, and suggested the cause may be related to the mechanical loading of the joint. One way to decrease the load of the joint is by exercising aquatic (Barela & Duarte, 2008). Studies that have used aquatic training have noted improvements in physical function, mobility, stiffness and pain upon movement. Studies that have examined land and aquatic training have observed improvements in range of motion and walking speed and distance. Future biomechanical research is needed to evaluate benefits to aquatic training to better serve programs aimed at improving function and mobility for patients with OA.

These gait, pain, and mobility alterations in OA patients noted in the previous literature may be precursors for pathological alterations and would seem to be important variables to examine in an aquatic therapy study aimed at improving mobility. A greater understanding of these alterations will be useful for the treatment of OA and the prevention of OA progression.

Experimental Paper (Chapter 3)

Osteoarthritis is a widespread disease and is also the most common form of arthritis in the elderly (Davis et al., 1991; Felson et al., 1987; Hochberg, 1991). Osteoarthritis (OA) of the hip and knee is often characterized by pain, stiffness, and decreased range of motion. People who have OA of the lower extremities are generally less active and have decreased physical conditioning and function. This reduction in mobility further decreases one's ability to carry out daily activities and complete regular physical exercise (Kaufman et al., 2001; Mangione et al., 1996).

Aquatic exercises may allow OA patients to engage in longer and more strenuous workouts as compared to land-based exercises (Hinman et al., 2007). For example, patients with OA may have an easier time completing closed-chain exercises in an aquatic environment than on land because joint loading and pain across affected joints may be less (Barela et al., 2006). Additionally, by adjusting the depth of the water, the percentage of body weight supported by the lower limbs can be incrementally decreased, to accommodate a person's pain tolerance (Silvers et al., 2007). Finally, the warmth and pressure of water may assist in decreasing joint swelling and pain, and allow for easier movement patterns (Hinman et al., 2007).

Previous research examining the progressive decline of kinematic gait parameters on land in patients with OA has observed specific changes. Prior studies examining people with OA have detected decreased walking speed, and lower maximum knee extension angles (Kaufman et al., 2001; Walker et al., 2001). With progressive worsening of OA, changes in gait kinematics are also often accompanied by progressive worsening in pain and perception of mobility (Astephen et al., 2008). The purpose of the experimental study examined the effects of short-term aquatic treadmill exercise on gait kinematics and perception of pain and mobility in OA patients.

Fourteen participants with OA of the knee performed three consecutive exercises (20 min each) on an aquatic treadmill and on a land-based treadmill. The order of exercise mode was randomized and completed within 1 week. Gait kinematics (step rate, step length, min and max joint angles and angular velocity at the hip, knee, and ankle), pain and self-efficacy measures were all recorded before (pre) and after (post) completion of the aquatic and land-based treadmill.

Joint angles and angular velocity gain scores that were significantly different at the $p = 0.05$ level are shown in Tables 4-6. After adjusting p values using the Holm's correction, the angular velocity gain score during stance for left knee extension was significantly higher for aquatic treadmill exercise by 38.1% ($p = 0.004$; Table 7). Similarly during swing the gain scores for angular velocity were also greater for left knee internal rotation and extension by 65% and 20%, respectively ($p = 0.004$, $p = 0.008$; Tables 8, 9). During stance, the joint angle gain score for left hip flexion was greater for land exercise by 7.23% ($p = 0.007$; Table 10). Similarly during swing the angular velocity gain score for right hip extension was significantly greater for aquatic exercise by 28% ($p = 0.01$; Table 8). Only the joint angle gain score for left ankle abduction during stance was significantly higher for land exercise by 4.72% (p = 0.003; Table 8). No other joint angle gain scores for either stance or swing were significantly different for either condition (p = 0.06-0.96; Tables 11-14).

Confidence Intervals

Table 4-6 presents the confidence intervals (95% CI) for all kinematic variables reaching the alpha level of 0.05. Not surprising, the width of confidence intervals computed were high given the small sample. More specifically, it may be observed in Table 4-6 that there is a 95% chance that the confidence intervals calculated for the kinematic variables contain the true population median difference.

Perceived Pain, Self-Efficacy, and Step Rate and Length

Perceived pain was 100% greater for land than aquatic treadmill exercise (p = 0.02; Table 15) and self-efficacy gain scores were not different between conditions (p = 0.37). Step rate and step length gain scores were not different between conditions (p = 0.31 - 0.92; Table 16).

The unique aspect of the present study is that the authors examined the effectiveness of aquatic therapy on gait kinematics before and after aquatic training using a complete three-dimensional study analyzing changes at not just the knee, but also at the hip and ankle. The present study demonstrated that an acute training period on an aquatic treadmill did influence joint angular velocity and arthritis related joint pain. It is unclear whether or not aquatic exercise is a better alternative to land exercise, and further longitudinal research is needed to examine gait kinematic changes after an increased training period of aquatic exercise.

Conclusions

Review Article (Chapter 2)

Within the limitations of the review, it may be concluded that when compared to a similar land-based treatment:

- Aquatic exercise may decrease the affected joint pain and improve mobility
- Aquatic and land exercise may both improve physical function, range of motion, walking speed and distance

Experimental Article (Chapter 3)

Within the limitations of this study, it may be concluded that when compared to a similar land-based treatment:

- OA patients displayed greater joint angular velocities after aquatic treadmill exercise for the following:
  - Left knee extension during stance
  - Left knee internal rotation and extension during swing
  - Right hip extension during swing
- OA patients displayed greater joint angles after land treadmill exercise for the following:
  - Left hip flexion during stance

  - Left ankle abduction during stance
- Patients diagnosed with OA may have improved pain after training on an aquatic treadmill when compared to a land-based treadmill
- Step rate and step length tend to be not different after aquatic or land treadmill intervention

- **L**

Comment [EB1]: ?

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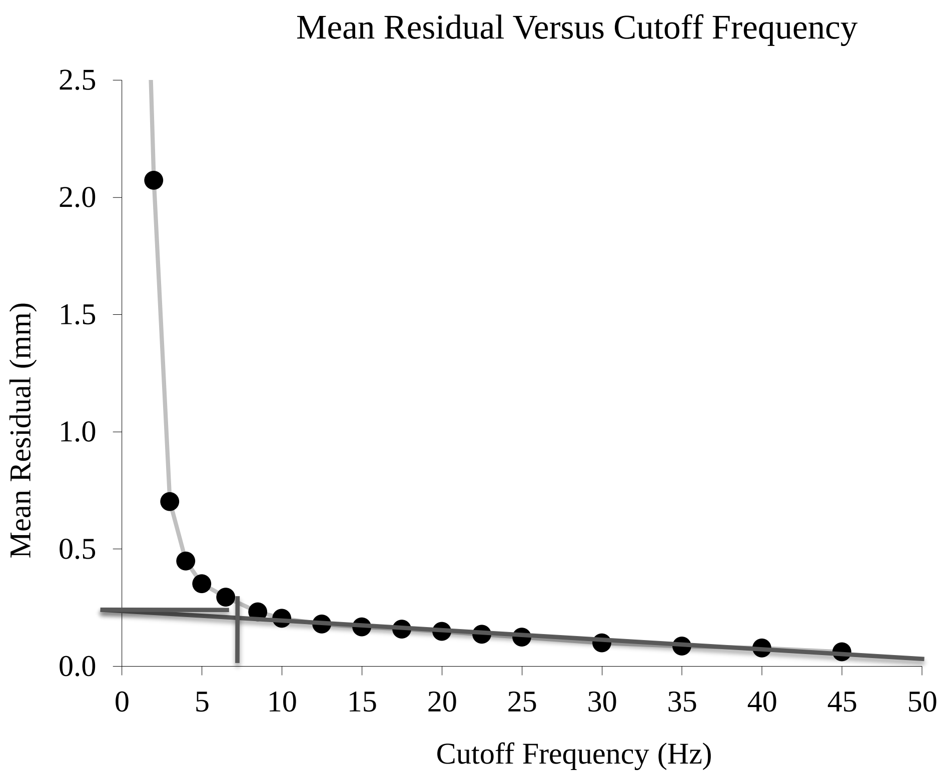
APPENDICES

Appendix A

Mean Residual Analysis



Appendix A. Sample data demonstrating the selection of optimal cutoff frequency for filtering.

Appendix B

Coefficient of Variation

Appendix B

Representation of Coefficient of Variation for all patients and the knee in stance phase. Six steps were used to calculate the average and standard deviation was divided by the average to calculate the Coefficient of Variation.

Participant	Knee Angle	Coefficient of Variation (%)
1	133 (1.20)	0.90
2	138 (1.11)	0.80
3	140 (1.58)	1.13
4	143 (25.7)	18.0
5	145 (2.55)	1.75
6	130 (1.30)	0.99
7	144 (21.1)	14.6
8	137 (1.07)	0.78
9	142 (1.64)	1.15
10	141 (1.57)	1.11
11	143 (2.72)	1.91
12	146 (2.51)	1.72
13	142 (0.82)	0.58
14	157 (13.0)	8.25