

THE EFFECTS OF AQUATIC EXERCISE ON PHYSIOLOGICAL
AND BIOMECHANICAL RESPONSES

by

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ABSTRACT

The Effects of Aquatic Exercise on Physiological
and Biomechanical Responses

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Due to recent advances in aquatic research, technology, and facilities, many modes of aquatic therapy now exist. These aquatic modes assist individuals (e.g., osteoarthritis patients) in the performance of activities that may be too difficult to complete on land. However, the biomechanical requirements of each aquatic therapy mode may elicit different physiological and functional responses. Therefore, the purpose of this thesis was to: (a) provide a review of the physiological and biomechanical differences between aquatic and land based exercises, and (b) examine the acute effects of underwater and land treadmill exercise on oxygen consumption (VO_2), rating of perceived exertion (RPE), perceived pain, mobility, and gait kinematics for patients with osteoarthritis (OA). Methods consisted of the retrieval of experimental studies examining the physiological and biomechanical effects of deep water running (DWR), shallow water running (SWR), water calisthenics, and underwater treadmill therapy. The methods also

examined the physiological and biomechanical effects on 19 participants during and after three consecutive exercise sessions on an underwater treadmill and on a land-based treadmill. Based on the studies reviewed, when compared to a similar land-based mode, VO_2 values are lower during both DWR and SWR, but can be higher during water calisthenics and underwater treadmill exercise. RPE responses during DWR are similar during max effort, and stride frequency and stride length are both lower in all four aquatic modes than on land. Pain levels are no different between most water calisthenics, and most studies reported improvements in mobility after aquatic therapy, but no difference between the aquatic and land-based modes. The OA participants achieved VO_2 values that were not different between conditions during moderate intensities, but were 37% greater during low intensity exercise on land than in water ($p = 0.001$). Perceived pain and Time Up & Go scores were 140% and 240% greater, respectively, for land than underwater treadmill exercise ($p = 0.01$). Patients diagnosed with OA may walk on an underwater treadmill at a moderate intensity with less pain and equivalent energy expenditures compared to walking on a land-based treadmill.

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Matt Denning

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CHAPTER 1

INTRODUCTION

The use of water for cleansing and religious means existed among the Greeks, Romans and Egyptians. The fathers of healing, Pythagoras (B.C. 530) and Hippocrates (B.C. 460), used water with friction and rubbing for the treatment of gout and rheumatism (Metcalf, 1898). Presently, research aims to investigate the affects of aquatic therapy on the human body in many capacities such as joint flexibility, functional ability (Templeton, Booth, & O'Kelly, 1996), muscle strength, and aerobic fitness (Wang, Belza, Thompson, Whitney, & Bennett, 2007). Aquatic therapy is becoming more popular due to the therapeutic benefits of water. These physical properties of water may provide increased relaxation, ease of movement, resistance, and support (McNeal, 1990), with the added benefit of lower impact forces (Barela & Duarte, 2008) and pain levels (Hinman, Heywood, & Day, 2007). Research has even argued that exercises performed in water may even give individuals a better workout, indicating a higher amount of oxygen consumption during aquatic treatment (Gleim & Nicholas, 1998; Hall, Macdonald, Maddison, & O'Hare, 1998).

Due to the added benefits of water, many forms of aquatic therapy now exist. Each mode of aquatic therapy and exercise introduces a variety of treatment and rehabilitative exercise programs. Four of the most popular forms of aquatic therapy and exercise are (a) deep water running (DWR), where the individual is suspended in water with the use of a buoyancy device; (b) shallow water running (SWR), where the individual either runs or walks in the shallow end of a pool; (c) water calisthenics, where

the individual participates in a variety of exercises staying stationary in the pool; (d) underwater treadmill exercise, where the individual runs or walks on an underwater treadmill at various speeds and depths.

The diverse techniques for each aquatic therapy mode make it possible that the physiological and functional responses differ from one mode to the next. Dowzer, Reilly, Cable, and Nevill (1999), for example, investigated the oxygen consumption (VO_2) response during DWR, SWR, and land based running. The results indicated that peak VO_2 during SWR and DWR averaged 83.7% and 75.3% of land treadmill running, respectively. This result may in part be due to the lack of ground contact during DWR. If the goal of a clinician was to prescribe an aquatic exercise mode that more closely resembled land VO_2 , SWR may be an appropriate mode of aquatic exercise over DWR. However, Dowzer et al. (1999) only takes into consideration two forms of aquatic treatment. There are many other forms of aquatic treatment which also need to be examined. To our knowledge, research has never compared more than two forms of aquatic exercise to a similar land based mode. A comparison of the physiological and biomechanical differences between the four different modes of aquatic therapy and exercise would benefit the clinician in prescribing a program to best assist their patients in reaching the desired therapeutic goals.

Many individuals may benefit from aquatic therapy and exercise including those suffering from pain, arthritis, orthopedic dysfunctions, fibromyalgia, or anything that makes land based exercise too strenuous (Assis et al., 2006; Cassady & Nielsen, 1992; Hinman et al., 2007). Because patients diagnosed with osteoarthritis (OA) often exhibit

compromised mobility (Cichy & Wilk, 2006) and balance (Hinman, Bennell, Metcalf, & Crossley, 2002), while suffering from joint pain, stiffness, and muscle weakness (Hinman et al., 2007), aquatic therapy may be an ideal form of treatment for these individuals. Recent literature suggests that aquatic therapy does assist in improving the condition of OA symptoms (Foley, Halbert, Hewitt, & Crotty, 2003; Hinman et al., 2007; Wyatt, Milam, Manske, & Deere, 2001), however, mixed results have been reported due to the inability to control water depth and speed of gait (Hinman et al., 2007; Lund et al., 2008; Wang et al., 2007). Most underwater treadmills have the ability to adjust the treadmill speed and the depth of the water giving an added advantage in controlling exercise intensity during aquatic therapy. There is, however, a lack of research investigating the physiological and functional differences between underwater and land treadmill treatment for individuals suffering from OA. If OA patients experience decreased pain levels and increased mobility after underwater treadmill treatment, while reaching VO_2 values comparable to land treatment, this mode of aquatic therapy may greatly assist in the treatment of OA.

Purpose Statement

The purpose of this thesis is twofold:

- 1) to provide a review of the physiological and biomechanical differences between aquatic and land based exercises
and

- 2) to examine the acute effects of underwater and land treadmill exercise on VO_2 , rate of perceived exertion, perceived pain, mobility, and gait kinematics for patients with OA.

Hypothesis

For the experimental article of this thesis (Chapter 3), it was hypothesized that underwater treadmill walking would elicit the same VO_2 and RPE response as land treadmill walking at the same speed. It was also hypothesized that pain levels would decrease after the underwater treadmill intervention and mobility and gait kinematics would remain the same after both the aquatic and land based interventions. There was no hypothesis for the first paper (Chapter 2), as this paper was a review article.

Outline of Thesis

This thesis is composed of two manuscripts, a review manuscript, followed by an experimental manuscript. The review manuscript aims to assist the clinician in prescribing the most beneficial mode of aquatic therapy and exercise. It will inform the clinician of the physiological and functional differences during and/or after four different aquatic modes compared to a similar land based mode. This review article was written to provide clinicians with a single source reference that may be used to better prescribe aquatic exercise for achieving the desired goal of the therapy. The experimental manuscript aims to indicate the physiological and biomechanical differences between underwater and land treadmill treatment in adults with osteoarthritis. Because individuals with osteoarthritis experience joint pain, this paper also investigated perceived pain after

both the aquatic and land treadmill treatments to indicate which mode of exercise educated less pain. The goal of this paper was to examine if underwater treadmill treatment would elicit the same physiological components as land but produce less pain and increase mobility. Both of the manuscripts will then be followed by a summary/conclusion chapter to summarize the findings.

Authorship Contribution

The contributions of authorship for the manuscripts are as follows:

A review of the physiological and biomechanical differences between four different modes of aquatic therapy and exercise

Denning, W. (85%) Bressel, E. (10%) Dolny, D. (5%)

Underwater treadmill exercise as a potential treatment for adults with osteoarthritis

Denning, W. (70%) Bressel, E. (25%) Dolny, D. (5%)

Glossary of Terms

The following terms will be used in the thesis:

Aquatic Therapy and Exercise: any form of therapy or an exercise program which takes place in water. Different forms of aquatic therapy and exercise consist of, but not limited to, shallow water walking, deep water running, water calisthenics, underwater treadmill, and swimming.

Land Based Therapy and Exercise: any form of therapy or an exercise program which takes place on land. This can also consist of therapy or exercise which takes place on a land treadmill.

Oxygen Consumption (VO_2): the rate at which oxygen is used by the body. It is usually expressed in L/min or ml/kg/min.

Peak VO_2 (VO_2 max): the maximum rate at which the body uses oxygen. This is used as a measure of physical fitness.

Rate of Perceived Exertion (RPE): a quantitative scale which indicates the intensity of an exercise.

Stride Length (SL): the rectilinear distance (m) between two successive placements of either the left or right heel.

Step Length: the rectilinear distance (m) between two successive placements of each foot.

Stride Frequency (SF): the numbers of strides taken during an amount of time. It is usually expressed in strides per second.

Timed Up & Go (TUG): a test given to assess basic mobility and balance.

Gait: the manner of movement during walking or running

Kinematics: A component of biomechanics describing motion. Common kinematic variables are stride length, stride frequency, and joint angles.

CHAPTER 2

REVIEW ARTICLE

A Review of the Physiological and Biomechanical Differences Between Four Different Modes of Aquatic Exercise

Abstract

Four of the most popular modes of aquatic therapy and exercise are: deep water running (DWR), shallow water running (SWR), water calisthenics, and underwater treadmill exercise. The biomechanical requirements of each aquatic therapy mode may elicit different physiological and functional responses. The purpose of this paper was to provide a review of the physiological and biomechanical differences between aquatic and land based exercises. The physiological variables included oxygen consumption (VO_2) and rating of perceived exertion (RPE). The biomechanical variables include stride length (SL), stride frequency (SF), pain, and mobility. Based on the studies reviewed, when compared to a similar land based mode, VO_2 values were lower during both DWR and SWR, but, depending on water depth and exercise performed, may be higher during water calisthenics and underwater treadmill exercise. RPE responses during DWR are similar to land during max effort, and stride frequency and stride length were both lower in all four aquatic modes than on land. Pain levels were no different between most water calisthenics and land exercise, but may decrease after underwater treadmill exercise. Most studies reported improvements in walk timed tests after aquatic therapy, but no difference between the aquatic and land based modes.

Introduction

The popularity of aquatic therapy and exercise is becoming more prevalent, given the therapeutic properties of water and the increased accessibility of pool facilities. Many clinicians now use aquatic therapy for rehabilitation purposes which include strength gains and functional activities in a low weighted environment. Individuals suffering from rheumatism, pain, orthopedic dysfunctions, or who have any difficulty performing an exercise on land, may benefit from this form of therapy (Cassady & Nielsen, 1992). Hinman, Heywood, and Day (2007) indicated that aquatic physical therapy may assist in ease of movement, swelling reduction, and pain relief due to the pressure and warmth of water. Others have noted that the effects of water resistance causes greater energy expenditures (Gleim & Nicholas, 1989; Hall, Macdonald, Maddison, & O'Hare, 1998) while reducing impact forces on the lower extremity joints (Barela & Duarte, 2008; Barela, Stolf, & Duarte, 2006).

Due to recent advances in aquatic research, technology and facilities, many modes of aquatic therapy now exist. Deep water running, shallow water running, water calisthenics, and underwater treadmill exercise are some of the most popular forms of aquatic therapy and exercise, with underwater treadmill use being the most recent. The biomechanical requirements of each aquatic therapy mode may elicit different physiological and functional responses. Deep water running, for example, does not include ground contact (Reilly, Dowzer, & Cable, 2003), which is different from shallow water running, underwater treadmill running, and water calisthenics. This difference may be one reason why oxygen consumption (VO_2) is lower during deep water running when

compared to shallow water running (Town & Bradley, 1991). Also, the variations between the different modes of aquatic therapy and exercise make it difficult for the clinician to know which mode of exercise will achieve the desired therapeutic goal. For instance, if the goal of the clinician was to prescribe an aquatic exercise that most closely mimics the oxygen consumption demands of land based exercise then an understanding of the physiological responses of aquatic exercise is imperative. If the goal of the clinician is to prescribe an aquatic exercise that would rehabilitate mobility impairments most closely to a land based exercise then an understanding of the biomechanical and pain responses are also as equally important. The knowledge of the different physiological and functional responses during aquatic therapy and exercise will assist clinicians to prescribe the most beneficial form of treatment for their patients. To our knowledge, no research has examined these responses during deep water running, shallow water running, water calisthenics, and underwater treadmill exercise.

The purpose of this paper is to review the scientific evidence for four different modes of aquatic therapy and report their physiological and biomechanical differences compared to a similar land based mode. The physiological variables include oxygen consumption (VO_2) and rating of perceived exertion (RPE), with stride length (SL) and stride frequency (SF) being the biomechanical variables. Because many rehabilitation patients experience pain and range of motion impairments, we also reviewed how each mode of exercise affected pain and mobility after the aquatic and land exercise treatment. The articles included in this review compared these different variables during and/or after both the aquatic and land based therapy exercise. This was done in order to meet the

principle of specificity and to help clinicians know which type of exercise (i.e., land or water) would be most advantageous for their patients. If the aquatic mode elicits the same physiological and biomechanical responses with the added benefits of increased relaxation, ease of movement, and support (McNeal, 1990), while decreasing pain (Hinman et al., 2007) and impact forces (Barela & Duarte, 2008) clinicians will be able to prescribe an aquatic treatment that would best fit the needs of the patient. Also, the studies needed a base measurement in order to make comparisons between the different aquatic modes. Similar land based treatments were chosen as a base line measure. This review is outlined as follows:

- Brief history of aquatic therapy
- Definition of the four aquatic modes reviewed
- Physiological responses (oxygen consumption and rating of perceived exertion) of each aquatic mode compared to a land based mode
- Biomechanical and Pain Responses (stride frequency, stride length, pain, and mobility) of each aquatic mode compared to a land based mode
- Summary

History of Aquatic Therapy

The use of water for cleansing and religious means existed among the Greeks, Romans, and Egyptians. The fathers of healing, Pythagoras (B.C. 530) and Hippocrates (B.C. 460), used water with friction and rubbing for treatment of gout and rheumatism. Water for healing continued to last until the time of Galen (A.D. 131-200), a firm

believer in the treatment, but not much was recorded after his time until two Arabian physicians, Rhazes (A.D. 923) and Avicenna (A.D. 1036) promoted cold water for illness such as small pox and diarrhea. The introduction of new drugs, however, took precedence over water treatment, and it was not until the beginning of the 18th century that aquatic therapy arose again. Many books such as “The History of Cold Bathing,” “The Power and Effect of Cold Water,” and many others appeared (Metcalf, 1898).

In the early 1800s, Vincent Priessnitz, known as the father of hydrotherapy, was able to further develop water treatment. When someone had a bruise, dislocation, sprain, or other external injury, Priessnitz wasted no time recommending cold water as a cure. As his popularity spread, people suffering from diseases came from all around the world to seek relief from their ailments (Metcalf, 1898).

To our knowledge, research on the beneficial effects of aquatic therapy started in the early 1900’s when hydrotherapy for rheumatism and gout was investigated (Crees, 1906; Sanderson, 1904). Presently, research still aims to investigate the affects of aquatic therapy on the human body. Aquatic therapy has been shown to be an effective mode of increasing joint flexibility and functional ability while decreasing pain in individuals with rheumatic diseases (Templeton, Booth, & O’Kelly, 1996). Aquatic therapy not only helps people with rheumatic diseases, but it can benefit many other populations as well.

Defining the Different Aquatic Modes

There are many different modes of aquatic exercise and therapy. The four modes focused on are as follows: deep-water running (DWR), shallow-water running (SWR), water calisthenics, and underwater treadmill exercise.

Technique of DWR takes place in water deep enough for patients to be submersed to the neck. The use of flotation aids, such as a buoyancy vest or belt are used to suspend the patient so a lack of ground contact occurs during the exercise (Reilly et al., 2003).

Technique of SWR is performed in shallow water typically below the xiphoid level (Dowzer, Reilly, Cable, & Nevill, 1999), where participants run/walk propelling themselves through the water (Gappmaier, Lake, Nelson, & Fisher, 2006). Flotation devices are not often used, as participants are able to make contact with the ground.

Water calisthenics are achieved by performing a variety of aerobic conditioning and resistance training exercises usually in the shallow end of a pool so ground contact is possible (Cassady & Nielsen, 1992). This mode of aquatic exercise includes any exercise performed in the shallow end of the pool excluding walking and running. Underwater treadmill exercise uses a treadmill belt submersed in water (Gleim & Nicholas, 1989). Some underwater treadmills have the capability to use water jets (Silvers, Rutledge, & Dolny, 2007) and adjust water depth and treadmill speed in order to manipulate the amount of water buoyancy and resistance forces applied to the body. The control of water depth and treadmill speed is imperative to control exercise intensity which other forms of aquatic therapy and exercise do not offer (Denning, Bressel, & Dolny, 2010).

Physiological Responses

Each mode of aquatic therapy and exercise has its own physiological response. Each study reviewed in this section investigated VO_2 and/or RPE during comparable aquatic and land based modes.

Oxygen Consumption

Oxygen consumption is frequently used to indicate the level of aerobic intensity allowing for an objective comparison between modes (Johnson, Stromme, Adamczyk, & Tennoe, 1977). Oxygen consumption is the product of cardiac output (stroke volume x heart rate) and arterial-venous oxygen difference (a-v O₂ diff), and is linearly related to caloric energy expenditure. Several studies have examined VO₂ during DWR, and it has been indicated that maximum oxygen consumption (VO₂ max) responses during this mode of exercise is lower when compared to land treadmill running (Table 2-1). There is, however, a wide range of results, ranging from only a 10% decrease (Butts, Tucker, & Greening, 1991a) to a 27% decrease (Nakanishi, Kimura, & Yokoo, 1999b). Although some females obtained a max VO₂ lower than males (Butts, Tucker, & Greening, 1991), both genders display lower values in the water compared to land. This would indicate that gender is not a contributor to the lower VO₂ max values during DWR. Nakanishi et al. (1999b) evaluated the VO₂ responses in young and old males. The results of this study indicated that even though the younger males had a lower percent decrease, 21% compared to 27%, age was also not an indicator of the lower VO₂ response. A number of factors may contribute to the lower VO₂ response during DWR. It is believed that water temperature, the cardiovascular responses to hydrostatic pressure and different muscle activity may contribute to the VO₂ differences (Butts et al., 1991a; Butts, Tucker, & Smith, 1991b; Nakanishi et al., 1999b).

Although few studies have examined the VO₂ responses during SWR, these studies also have indicated a lower VO₂ max response when compared to land treadmill

running (Table 2-1). Dowzer et al. (1999) investigated the relationship between SWR and land treadmill running for fifteen male runners, and found that during SWR, VO_2 max averaged 83.7% compared to what was achieved on land. Another study by Town and Bradley (1991) observed that the VO_2 responses during SWR were only 10% less than land treadmill running. This small difference between SWR and land treadmill running indicates that SWR may be a sufficient mode of exercise to elicit similar metabolic responses when compared to land running. Interesting to note that both studies mentioned above also investigated the difference between SWR and DWR. The results indicated that VO_2 values during SWR were greater than during DWR. One reason SWR VO_2 might more closely resemble land VO_2 is that the force of buoyancy is less and the push off of a hard surface is more similar to land treadmill running (Dowzer et al., 1999; Town & Bradley, 1991). Another reason for this result may be due to the greater relative velocity of the fluid during SWR. It has been contended that as relative velocity increases, water resistance also increases, counteracting the effects of buoyancy. The higher the water resistance and lower the buoyancy forces, the greater the energy expended. This contention is supported by previous research which revealed that when walking speeds are greater than 0.97 m/s, limb velocities increase and fluid resistance offsets buoyancy leading to similar or greater energy expenditure values during aquatic exercise (Denning et al., 2010; Gleim & Nicholas, 1989; Hall, Grant, Blake, Taylor, & Garbutt, 2004; Hall et al., 1998; Rutledge, Silvers, Browder, & Dolny, 2007). On the contrary, when walking speeds are less than 0.97 m/s, buoyancy dominates over the low

fluid resistance and relative velocities, causing lower energy expenditure in water (Hall et al., 2004).

Several studies have examined the effect of water calisthenics on oxygen consumption, which have reported contradicting results (Table 2-1). Cassady and Nielsen (1992), Darby and Yaekle (2000), and Johnson et al. (1977) have reported higher VO_2 values, and Barbosa, Garrido, and Bragada (2007) and Hoeger, Hopkins, and Barber (1995) have reported lower VO_2 values during water calisthenics compared to similar land exercises or land treadmill VO_2 max tests. Due to the vast variation in the types of calisthenics possible, it is difficult for researchers to compare oxygen consumption values. For example, Barbosa et al. (2007) had participants perform a “rocking horse” exercise which consists of moving both the upper and lower extremities at the same time. Johnson et al. (1977), however, examined two different types of exercise, one using the upper extremities, and one using the lower extremities. Darby and Yaekle (2000) took a different approach by measuring leg only exercise and both arm/leg exercise separately while changing the cadence of the exercise according to the participant’s heart rate. Mixed results may have occurred due to the different types of exercise performed. Clinicians may need to be aware that different exercises performed in water may elicit different oxygen consumption responses during water calisthenics.

The relationship between VO_2 and underwater treadmill exercise has also been widely investigated (Table 2-1). It has been argued that underwater treadmills are able to better control for exercise intensity due the control of treadmill speed and water depth (Denning et al., 2010). Speed and depth are two vital variables when considering an

underwater treadmill exercise. For example, Hall et al. (1998) found that when treadmill speeds were 0.97 m/s, VO_2 values were similar between aquatic and land conditions in healthy females. When speeds were 1.25 and 1.23 m/s, however, VO_2 values were higher during underwater treadmill running compared to land treadmill running. Another study by Hall et al. (2004), indicated that VO_2 was significantly lower in patients with rheumatoid arthritis when speeds were lower than 0.97 m/s.

Pohl and McNaughton (2003) investigated the effect of water depth and indicated that the highest VO_2 values for underwater treadmill running occurred during thigh-deep water levels followed by waist-deep water levels, with land treadmill running having the lowest VO_2 values. The VO_2 response at ankle depth and knee depth has also been researched. Gleim and Nicholas (1989) revealed that the lowest VO_2 values occur during land treadmill walking, increasing values at ankle depth, and even higher values at the water depth just below the knee, but lower values when the water was at waist level. It would seem that as water treadmill speed increases, water resistance elicits higher VO_2 values, and as water depth increases, water buoyancy produces lower VO_2 values. Whether the VO_2 response would be lower, higher, or equal to a similar land based running may depend on the combination of both treadmill speed and water depth.

Rating of Perceived Exertion (RPE)

There has been a variety of studies investigating RPE, a quantitative scale indicating the intensity of an exercise (Borg, 1982), during DWR (Table 2-1). The results of these studies revealed that during maximal effort, there are no differences in RPE between DWR and land based running (Butts et al., 1991b; Nakanishi, Kimura, &

Yokoo, 1999a; Nakanishi et al., 1999b). However, Matthews and Airey (2001) measured RPE at a sub-maximal effort. Here, RPE was measured at 60, 70, and 80% of heart rate reserve, and the results indicated that during the three different intensities, RPE scores were 1.4, 2.3, and 2.8 points greater during DWR, respectively.

Two studies examining the RPE response during water calisthenics reported mixed results (Table 2-1). Barbosa et al. (2007) investigated RPE at two different water depths and found that RPE at hip depth was significantly higher when compared to breast depth ($p = 0.03$) and land exercise ($p < 0.01$). There was no significant difference between breast depth and land exercise. Hoeger et al. (1995) contradicts this last finding by indicating lower RPE levels during water calisthenics when the participants are immersed to the arm pit. This contradiction may partly be attributed to the differences in exercise procedures requiring different levels of muscle activation. With so many varieties of water calisthenics, it is difficult to compare RPE outcomes for aquatic and land based calisthenics.

The studies examining RPE during underwater treadmill exercise can be found in Table 2-1. There are slight fluctuations for this measurement which seems to be dependent on the speed of gait, primarily because research has kept the water depth fairly constant at the xiphoid process. Rutledge et al. (2007) used three different speeds (2.9, 3.35, and 3.8 m/s), and three different percents of water jet resistance (0%, 50%, 75%). Their results revealed that RPE was greater for land treadmill exercise when compared to underwater treadmill exercise with 50% and 75% jet resistance. Hall et al. (2004) reported that at speeds greater than 0.7 m/s RPE in the legs was greater in water than on

land. Below this speed, there was no significant difference. These results contradict the finding by Denning et al. (2010) which revealed no significant difference in RPE with speeds greater than 0.7 m/s.

Biomechanical and Pain Responses

The studies reviewed in this section will compare the different biomechanical responses during the four aquatic modes to a similar land based mode. Stride frequency, stride length, and pain and mobility in special populations (i.e., rheumatoid arthritis, osteoarthritis, fibromyalgia, and lower back pain) are included.

Stride Frequency

It has been suggested that lower extremity kinematics during DWR are different from land running (Kilding, Scott, & Mullineaux, 2007; Killgore, Wilcox, Caster, & Wood, 2006; Moening, Scheidt, Shepardson, & Davies, 1993), and it is widely known that the stride frequency is lower in DWR when compared to land based running (Table 2-2). Additionally, it has been suggested that stride frequency during DWR can be close to half of what it is on a land (Masumoto, Delion, & Mercer, 2009). Killgore et al. (2006) examined two different styles of DWR and found that both styles, a cross country style and a high-knee style, elicited a lower stride frequency, although the cross country style of DWR was found to be more similar to land running than the high-knee style. The lack of ground support and increased water resistance during DWR may account for the stride frequency difference.

The research investigating stride frequency during SWR is somewhat limited. Research has found that stride frequency is significantly lower in adults and elderly individuals (Barela & Duarte, 2008; Barela et al., 2006). Town and Bradley (1991) compared stride frequency during both DWR and SWR and noted that stride frequency was $108.2 \text{ strides} \cdot \text{min}^{-1}$ during SWR and $83.9 \text{ strides} \cdot \text{min}^{-1}$ during DWR.

The biomechanical characteristics during underwater treadmill walking/running has been widely investigated (Table 2-2). As with DWR, stride frequency can be nearly 50% lower during underwater treadmill walking when compared to land treadmill walking (Shono, Fujishima, Hotta, Ogaki, & Masumoto, 2001). Hall et al. (1998) reported a 27 stride/min deficit during underwater treadmill walking in healthy females. A common finding among many underwater treadmill studies is lower stride frequencies regardless of the speeds used (Hall et al., 1998, 2004; Kato, Onishi, & Kitagawa, 2001). One study, however, contended that the main difference in stride frequency occurs during running and not during walking (Pohl & McNaughton, 2003).

Stride Length

There is a lack of research comparing the stride length differences between aquatic and land based therapy. To our knowledge, mixed results have been reported on the two studies comparing stride length during SWR (Table 2-2). Barela and Duarte (2008) indicated lower stride lengths occur during SWR with elderly individuals (i.e., approximately 70 years of age), however, an earlier study by Barela et al. (2006) reported no difference in stride length in healthy adults (i.e., approximately 29 years of age). This may indicate age as a possible factor to lower stride lengths during SWR. Both studies

included in the review examining stride or step length during underwater treadmill exercise reported longer strides or steps during this form of exercise when compared to walking on land at the same speed (Masumoto, Shono, Hotta, & Fujishima, 2008; Shono et al., 2007). These results may have been influenced by the buoyant force causing the participants to “float” for an extended period of time.

Due to the lower stride frequencies reported and the mixed reports on stride length, it would seem that for these two variables, the principle of specificity is not met; stride frequency and stride length during aquatic exercise is not similar to land based exercise.

Mobility

Even though stride frequency and stride length may be lower during aquatic exercise, the therapeutic results do not have to be. Mobility measurements indicate the effectiveness of the treatment. In reviewing the studies for mobility, a quantitative measurement (i.e. time up & go test (TUG), 1-mile walk time, 100 m walk time) had to be present.

The majority of the studies reviewed measured mobility after treatment with water calisthenics (Table 2-3). Jentoft, Kvalvik, and Mengshoel (2001) tested mobility in women with fibromyalgia with a 100-m walk time test. The study reported no difference in walk time between the aquatic and land based interventions, although both groups improved. These improvements in walk time remained after a 6-month followup. Sjogren, Long, Storay, and Smith (1997) also used a 100-m walk test to measure mobility in participants with chronic low back pain, and reported the same findings. There was no

significant difference in walk times between the aquatic and land based groups, even though both groups improved. Although water calisthenics did not statistically improve mobility more than land based exercise, it would seem that water calisthenics improved mobility in special populations equally as well as land based treatments. This contention is also supported by other research that used different mobility tests and different populations (Foley et al., 2003; Green, McKenna, Redfern, & Chamberlain, 1993; Minor, Hewett, Webel, Anderson, & Kay, 1989; Wyatt, Milam, Manske, & Deere, 2001).

There is a lack of research measuring mobility after DWR, SWR, and underwater treadmill running. To our knowledge, no study has compared mobility differences to after DWR and land based running, and no study has compared mobility differences after SWR and land based running. Denning et al. (2010), the only study in this review to compare mobility after underwater and land treadmill treatment, measured mobility using TUG scores before and after the aquatic and land interventions. It was reported that TUG scores were 240% greater after land treatment when compared to underwater treadmill treatment. This indicates a significant improvement in mobility after underwater treadmill walking.

Pain

Many studies have researched the effects of aquatic exercise on pain for special populations (Table 2-3). The majority of the studies reviewed compared pain during water calisthenics. Most of these studies concluded that there is no difference in pain between the aquatic and land based mode (Foley et al., 2003; Green et al., 1993; Jentoft et al., 2001; Minor et al., 1989; Sjogren et al., 1997; Sylvester, 1990). Two studies,

Wyatt et al. (2001) and Evcik, Yigit, Pusak, & Kavuncu (2008), however, did find a significant reduction in pain levels after the aquatic treatment. In fact, Evcik et al. (2008) indicated that there was a 40% decrease in pain scores after the aquatic treatment and only a 21% decrease after the land based treatment. In contrast, Hall, Skevington, Maddison, and Chapman (1996) was the only study to report a significant difference between groups with a decrease in pain levels after the land based treatment. Each study examined in this review paper reported improved pain levels after the aquatic treatment indicating water calisthenics as a good option to reduce pain in special populations. Clinicians should be aware, however, that this notion may not be fully supported by research, as some studies, which do not compare the aquatic mode to a land based mode, found contradicting results (Lund et al., 2008; Wang, Belza, Thompson, Whitney, & Bennett, 2007). Also, some of the studies examining water calisthenics included different modes of aquatic exercise (i.e. shallow water walking) in their methods (Evcik et al., 2008; Minor et al., 1989; Sylvester, 1990).

Although there is limited research investigating pain during DWR and underwater treadmill exercise, the results appear to be congruent with that of water calisthenics. There was no significant difference in pain levels between the aquatic and land based groups during DWR, although Assis et al. (2006) revealed an average decrease in pain of 36%. Denning et al. (2010), the only study investigating pain during underwater treadmill treatment, reported a significant improvement in pain after only a short aquatic intervention in participants with osteoarthritis.

Summary and Clinical Relevance

If the goal of the clinicians is to prescribe an aquatic mode with similar physiological and functional responses to land, the clinician should be aware of the following:

- Water calisthenics can elicit lower or higher VO_2 values, as three studies reported higher values and two studies reported lower values.
- Underwater treadmill exercise can elicit lower, equal, or higher VO_2 values depending on treadmill speed and water depth.
- Three studies indicated that DWR elicits similar RPE responses during maximal effort.
- Stride frequency is lower in all aquatic modes reviewed
- Two studies reported higher stride lengths during underwater treadmill exercise, and two studies reported mixed results for stride length during SWR.
- Six studies reported no significant difference in pain levels during water calisthenics, two studies reported a significant decrease, and one study reported lower pain levels during land exercises.
- Two studies found no significant difference in pain levels during DWR, and one study indicated lower pain levels after underwater treadmill walking.
- One study reported an improvement in mobility after underwater treadmill treatment.

The knowledge of the physiological and biomechanical responses for the different modes of aquatic exercise examined gives clinicians essential information for prescribing the most beneficial form of aquatic exercise.

Table 2-1

Description of Studies Reviewed Comparing RPE and VO₂ Responses During Different Aquatic Modes to a Similar Land Based Mode

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO ₂ Outcome
Butts et al. (1991a)	DWR	12 trained men and 12 trained women	Starting cadence of 100 beats/min increasing 20 beats/min every 2 minutes	Neck level	29°C		VO ₂ max was 16% lower in water for women and 10% lower in water for men.
Butts et al. (1991b)	DWR	12 high school cross country females	Starting cadence of 100 beats/min increasing 20 beats/min every 2 minutes	Neck level	29°C	No significant difference	Peak VO ₂ values were 17% lower ($p > .001$) in response to DWR
Mercer & Jensen (1997)	DWR	12 women and 14 men	1-min stages adding 0.57 kg each min to a bucket and pulley system	Neck level	27°C		Lower mean peak VO ₂ values during DWR
Nakanishi et al. (1999a)	DWR	20 healthy non-smoker males	48 cycles/min warm up for 4 min followed by 66 cycles/min increased by 3 to 4 cycles/min every 2 minutes		32.5°C	No significant difference at max effort	VO ₂ max values were approximately 20% lower in DWR when compared to Land running ($p < 0.001$)
Nakanishi et al. (1991b)	DWR	14 young and 14 middle aged males	48 cycles/min warm up for 4 min followed by 66 cycles/min increased by 3 to 4 cycles/min every 2 minutes		32.5°C	No significant difference at max effort	Middle aged group was 27% lower during DWR, young group was 21% lower

(Continued)

Table 2-1

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO ₂ Outcome
Glass et al. (1995)	DWR	10 men and 10 women	Started at 80 rpm and increased 12 rpm until voluntary exhaustion	Neck level			VO ₂ max values were 11% lower during DWR
Matthews & Airey (2001)	DWR	6 males and 4 females	60%, 70%, and 80% of heart rate reserve	Stero-clavicular level	30°C	Significantly greater for each speed	
Dowzer et al. (1999)	DWR & SWR	15 trained male runners	DWR- 120 strides/min SWR- 132 strides/min Each increased 12 strides/min then 8 strides/min until exhaustion	DWR- between chin and nose level SWR- waist level	29°C		Peak VO ₂ averaged 83.7% and 75.3% of land treadmill running during SWR and DWR respectively
Town & Bradly (1991)	DWR & SWR	7 male and 2 female runners	Increased each minute, final 2 minutes represented max exertion	DWR- 2.5-4m SWR – 1.3m			VO ₂ max values were 90.3% and 73.5% during SWR and DWR respectively
Cassady & Nielson (1992)	WC	20 Men and 20 Women	Exercises performed at 60, 80, and 100 counts per minute	Shoulder level	29°C		VO ₂ responses were greater during water exercises than exercises performed on land.

(Continued)

Table 2-1

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO ₂ Outcome
Johnson et al. (1977)	WC	4 men and 4 women	66 beats/ min and 58 beats/ min	Shoulder level	26 - 26.5°C		VO ₂ values were greater during water exercises when compared to the same exercises on land
Hoeger et al. (1995)	WC	19 males and 11 females	Cadence of 80, 88, 92, 100, and 108 beats/min for 7 two minute stages for various exercises	Armpit level	28 °C	Significantly lower	Peak VO ₂ was approximately 15% lower
Darby & Yaekle (2000)	WC	20 college-aged females	Cadence increased every 3 minutes according to heart rate	Chest deep	30 °C		VO ₂ was approximately 2-6 ml*kg ⁻¹ *min ⁻¹ greater
Gleim & Nicholas (1989)	UT	6 Men and 5 Women	Started at 0.67 m/s and increased 0.22 m/s every 2 minutes	Ankle, below knee, midthigh, and waist deep	30.5 and 36.1°C		At speeds equal to or lower than 0.89 m/s, VO ₂ was significantly elevated. At speeds equal to or greater than 2.24 m/s VO ₂ of waist deep running was not significantly greater.
Pohl & McNaughton (2003)	UT	6 students	1.11 m/s and 1.94 m/s	Both thigh and waist	33 °C		Highest VO ₂ at thigh-deep exercise, followed by waist-deep, and then land.

(Continued)

Table 2-1

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO ₂ Outcome
Hall et al. (2004)	UT	15 females with rheumatoid arthritis	0.69, 0.97, and 1.25 m/s	Xiphoid process	34.5 °C	For a given VO ₂ , RPE for legs are 15-20% higher in water	Below 0.69 m/s VO ₂ was lower in water. At 1.25m/s there was no difference in VO ₂ .
Hall et al. (1998)	UT	8 healthy females	0.97, 1.25, and 1.53 m/s	Xiphoid process	28 and 36 °C		At 1.25 and 1.53 m/s VO ₂ was higher in water with similar VO ₂ values at 0.97 m/s.
Rutledge et al. (2007)	UT	8 men and 8 women	2.9, 2.35, and 3.8 m/s, plus 0%, 50%, and 75% water-jet resistance	Xiphoid process	28 °C	Higher in Land at only two speeds	Similar VO ₂ responses for each speed until water-jets were introduced.
Silvers et al. (2007)	UT	23 college runners (12 male and 11 female)	Started at own pace, increased 0.22 m/s every 4 min. Water jet resistance was constant at 40%	Xiphoid process	28°C	No significant difference	No difference in peak VO ₂
Shono et al. (2001)	UT	6 healthy elderly women	0.33, 0.5, and 0.67 m/s (land speeds were double each water speed)	Xiphoid process	30.7°C		No difference at 0.5 or 0.67 m/s, VO ₂ at 0.33 m/s was significantly lower

(Continued)

Table 2-1

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO ₂ Outcome
Fujishima & Shimizu (2003)	UT	9 healthy elderly men	20 min of walking at a RPE of 13	Xiphoid process	31 and 35 °C		No significant difference
Denning et al. (2010)	UT	19 adults osteoarthritis	Self selected, Self selected + .13m/s, Self selected + .26m/s	Xiphoid process	30 °C	No Significant difference	No difference at fastest speed, 37% lower at self selected speed.

Note. DWR = deep water running, SWR = shallow water running, WC = water calisthenics, and UT = underwater treadmill

Table 2-2

Description of Studies Reviewed Comparing Stride Length and Stride Frequency During Different Aquatic Modes to a Land Based Mode

Study	Mode	Sample	Speed	Depth	Temp	Stride Length	Stride Frequency
Masumoto et al. (2008)	UT	9 older females	0.33, 0.5, and 0.67 m/s, Land speeds were doubled	Xiphoid process	31°C	Significantly higher at matched speeds	Significantly lower at all speeds
Shono et al. (2007)	UT	8 Elderly Women	0.33, 0.5, and 0.67 m/s, land speeds were doubled	Xiphoid process	30.7 °C	Step length was significantly higher at matched speeds	Significantly lower at matched speeds.
Shono et al. (2001)	UT	6 elderly women	0.33, 0.5, and 0.67 m/s, land speeds were doubled	Xiphoid process	30.7 °C		Nearly half compared to land
Kato et al. (2001)	UT	6 males	0.56 m/s, starting speed, increased by 0.56 m/s to 3.33 m/s	Waist level	29 °C		Significantly lower at speeds of 1.11, 2.22, 2.78, and 3.33 m/s.
Hall et al. (2004)	UT	15 females with rheumatoid arthritis	0.69, 0.97, and 1.25 m/s	Xiphoid process	34.5 °C		Approximately 21.9 strides/min lower at all speeds

(Continued)

Table 2-2

Study	Mode	Sample	Speed	Depth	Temp	Stride Length	Stride Frequency
Hall et al. (1998)	UT	8 healthy females	0.97, 1.25, and 1.53 m/s	Xiphoid process	28 and 36 °C		27 strides/min slower at all speeds
Pohl & McNaughton (2003)	UT	6 students	1.11 m/s and 1.94 m/s	Thigh and waist	33 °C		Similar at all conditions during walking, but 20 strides/min lower for the waist deep running
Barela & Duarte (2008)	SWR	10 elderly (6 male, 4 female)	Self selected	Xiphoid process		Significantly shorter	Significantly lower
Barela et al. (2006)	SWR	10 healthy adults, (4 male, 6 female)	Self selected	Xiphoid process		No significant difference	Significantly lower
Town & Bradley (1991)	SWR and DWR	9 trained runners (7 males, 2 females)	Increased each minute, final 2 minutes represented max exertion	DWR- 2.5-4m SWR – 1.3m			Significantly greater turnover in SWR compared to DWR

(Continued)

Table 2-2

Study	Mode	Sample	Speed	Depth	Temp	Stride Length	Stride Frequency
Kilgore et al. (2006)	DWR	20 distance runners	60% of maximal treadmill VO ₂	3.96m	27.2°C		High knee style and cross country style both significantly lower, although high knee style is more similar to land.
Masumoto et al. (2009)	DWR	7 healthy subjects (3 male, 4 female)	RPE of 11, 13, and 15	Deep enough so no foot contact occurred	28 °C		Increased as RPE levels increased, but was approximately 49% lower
Frangolias & Rhodes (1995)	DWR	13 elite distance runners (8 male, 5 female)	Starting load of 500 and 750g increasing by 400 g/min. Load was added to a bucket	Neck level	28 °C		Significantly lower

Note. DWR = deep water running, SWR = shallow water running, WC = water calisthenics, and UT = underwater treadmill

Table 2-3

Description of Studies Reviewed Comparing Pain and Mobility During Different Aquatic Modes to a Similar Land-Based Mode

Study	Mode	Sample	Exercise Program	Depth	Temp	Pain	Mobility
Minor et al. (1989)	WC	120 subjects with Rheumatoid and Osteoarthritis	One hour, three times a week for 12 weeks exercising at 60-80% of heart rate max	Chest level		No significant difference although both groups improved	No significant difference although both groups improved
Hall et al. (1996)	WC	139 subjects with chronic rheumatoid arthritis	30 min sessions, twice weekly for 4 weeks			Significantly decreased in pain level for the land mode although both groups improved	
Jentoft et al. (2001)	WC	47 females with fibromyalgia	Twice a week for 20 weeks, exercising within 60-80% heart rate maximum		34 °C	No significant difference although both groups improved	No significant difference although both groups improved
Foley et al. (2003)	WC	105 subjects with osteoarthritis	30 minutes, three times a week for 6 weeks			No significant difference although both groups improved	No significant difference although both groups improved
Sjogren et al. (1997)	WC	60 subjects with chronic low back pain	Two group sessions a week for 6 weeks			No significant difference although both groups improved	No significant difference although both groups improved

(Continued)

Table 2-3

Study	Mode	Sample	Exercise Program	Depth	Temp	Pain	Mobility
Wyatt et al. (2001)	WC	46 subjects with knee osteoarthritis	Three times a week for 6 weeks	5 feet	32.2 °C	Significantly improved in pain level	No significant difference although both groups improved
Evcik et al. (2008)	WC	63 subject with fibromyalgia	Three times a week for 5 weeks		33 °C	Aquatic and land groups reduced pain score by 40% and 21% respectively	
Green et al. (1993)	WC	47 subject with osteoarthritis in the hip	Twice weekly for 6 weeks in pool but 18 weeks total			No significant difference although both groups improved	No significant difference although both groups improved
Sylvester et al. (1990)	WC	14 subjects with osteoarthritis in the hip	30 minutes, twice a week for 6 weeks			No significant difference although both groups improved	
Assis et al. (2006)	DWR	60 sedentary women with Fibromyalgia	60 minutes, three times a week for 15 weeks	Neck level	28-31 °C	No significant difference between groups, although both decreased pain scored by 36%	

(Continued)

Table 2-3

Study	Mode	Sample	Exercise Program	Depth	Temp	Pain	Mobility
Melton-Rogers et al. (1996)	DWR	8 women with class II and III rheumatoid arthritis	Max test on stationary bike, DWR started at 92 beats/min increasing 6 steps every 2 minutes	Neck level	33 °C	No significant difference at peak VO ₂ or at 60% of peak	
Denning et al. (2010)	UT	19 subjects with osteoarthritis	Self selected pace, Self selected + .13m/s, Self selected + .26m/s	Xiphoid process	30 °C	Significantly improved in pain level	Significantly improved

Note. DWR = deep water running, SWR = shallow water running, WC = water calisthenics, and UT = underwater treadmill

Table 2-4

Summary of the Effects of the Four Different Aquatic Modes Compared to Similar Land Treatments

	VO ₂	RPE	SF	SL	Pain	Mobility
Deep Water Running	--	=	--		=	
Shallow Water Running	--		--	±		
Water Calisthenics	±	±			=	=
Underwater Treadmill	±	±	--	+	--	+

Note. Symbol (=) means effects equal to that of land; symbol (--) means effects less than that of land; symbol (±) means uncertain effects compared to land, lower, equal to, or higher; symbol (+) means effects greater than that of land; VO₂ = oxygen consumption; RPE = rating of perceived exertion; SF = stride frequency; SL = stride length.

CHAPTER 3

EXPERIMENTAL ARTICLE

Underwater Treadmill Exercise as a Potential Treatment
for Adults with Osteoarthritis¹

Abstract

This study examined the acute effects of underwater and land treadmill exercise on oxygen consumption (VO_2), perceived pain, and mobility. Nineteen participants diagnosed with osteoarthritis performed three consecutive exercise sessions for each mode of exercise. VO_2 and perceived pain were recorded during each exercise session and Timed Up & Go (TUG) scores were measured before and after each intervention. VO_2 values were not different between conditions during moderate intensities, but were 37% greater during low intensity exercise on land than in water ($p = 0.001$). Perceived pain and TUG scores were 140% and 240% greater, respectively, for land than underwater treadmill exercise ($p = 0.01$). Patients diagnosed with OA may walk on an underwater treadmill at a moderate intensity with less pain and equivalent energy expenditures compared to walking on a land based treadmill. Unexpectedly, OA patients displayed greater mobility after underwater than land treadmill exercise when assessed with the TUG.

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Introduction

An estimated 15 % of Americans have some form of arthritis with osteoarthritis being the most common form (Lawrence et al., 2008). Osteoarthritis (OA) begins when joint cartilage breaks down, sometimes leaving a bone-on-bone joint. The joint then loses shape and bony growths develop. This degenerative process causes symptoms of pain and stiffness leading to difficulty in mobility, for example, when rising from a chair, climbing stairs, and walking. Generally, OA is an incurable disease with few effective treatments (Nieman, 2007).

Physical therapy treatment for OA patients aims at reducing pain and improving muscle strength, balance and joint coordination, and joint range of motion (Hurley, 2003). Physical therapy on land is a common treatment for OA; however, in recent years more attention has been devoted to evaluating the effectiveness of aquatic therapy. Research indicates there are many potential benefits of aquatic physical therapy compared to land-based therapy. For example, Hinman, Heywood, and Day (2007) noted that aquatic exercise may assist in pain relief, swelling reduction, and ease of movement due to the pressure and warmth of water. Hinman et al. also noted that patients with OA may be able to perform exercises that are too difficult on land because buoyancy may reduce pain across the affected joints. Some have argued the effects of water resistance make it possible to expend greater amounts of energy (Gleim & Nicholas, 1989; Hall, Macdonald, Maddison, & O'Hare, 1998) while still reducing stress and impact forces on the lower extremity joints (Barela & Duarte, 2008; Barela, Stolf, & Duarte, 2006).

There are many forms of aquatic exercise including deep-water running, where runners are suspended in the water with a buoyancy vest or belt; shallow-water running, where participants run/walk in the shallow end of the pool; aerobic aquatic therapy, where participants perform a variety of calisthenics in the shallow or deep end of a pool; and, the most recent type of exercise, underwater treadmill exercise where the water depth and treadmill speed are adjustable.

There are obvious benefits to being able to control water depth and treadmill speed, which are primary determinants of exercise intensity. For example, being able to objectively control exercise intensity between two modes of exercise (e.g., water versus land) may allow researchers to determine if differences in therapy outcomes are due to the environmental intervention itself or due to differences in exercise intensity. Previous research examining the effectiveness of aquatic therapy exercise in comparison to land based exercise in OA patients have not used an underwater treadmill, and therefore, have not been able to control water depth and gait speed (Ahern, Nicholls, Simionato, Clark, & Bond, 1995; Cochrane, Davey, & Matthes-Edwards, 2005; Foley, Halbert, Hewitt, & Crotty, 2003; Hinman et al., 2007; Lund et al., 2008; Norton, Hoobler, Welding, & Jensen, 1997; Wang, Belza, Thompson, Whitney, & Bennett, 2007; Wyatt, Milam, Manske, & Deere, 2001). We would postulate that some of the mixed results reported in the literature (Hinman et al., 2007; Lund et al., 2008; Wang et al., 2007) may in part be related to this lack of control over exercise intensity. This contention is supported by Gleim and Nicholas (1989) who observed that different water levels contribute to

different energy expenditures in healthy adults. Currently, the effectiveness of using an underwater treadmill as a therapy protocol in patients with OA has not been tested

One of the challenges with prescribing underwater treadmill exercise in OA patients is determining a gait speed that may lead to therapeutic gains. Hall et al. (1998) reported that at treadmill speeds of 1.25 and 1.53 m/s, oxygen consumption (VO_2) was greater in water than on land for healthy females; and when walking speeds are below 0.97 m/s, VO_2 values were lower in water than on land in patients with rheumatoid arthritis (Hall, Grant, Blake, Taylor, & Garbutt, 2004). Due to pain and other demobilizing factors of OA, it is unknown if OA patients will be able to produce the same VO_2 response on an underwater treadmill versus a land treadmill matched for speed. Additionally, it is important to standardize walking speeds between land and water to truly compare the cardiorespiratory and perceived pain responses during underwater and land treadmill exercise.

In view of these limitations of previous research, the purpose of this study was to examine the acute effects of underwater and land treadmill exercise on VO_2 and perceived pain in OA patients. Because functional measurements are essential for determining the efficacy of any treatment, and because mobility is often compromised in OA patients (Cichy & Wilk, 2006; Hinman, Bennell, Metcalf, & Crossley, 2002), we also examined how each mode of exercise influenced gait kinematics and Timed Up & Go performance. It was hypothesized that underwater treadmill walking would elicit the same VO_2 response as land treadmill walking at the same speed. This hypothesis is based on the observations by Rutledge, Silvers, Browder, and Dolny (2007), who observed that

VO₂ values in healthy adults are no different between land and underwater treadmill running when the water depth was set to the xiphoid process. Regarding pain and mobility, we hypothesized that pain would decrease after walking on the underwater treadmill, and mobility would remain the same after both the aquatic and land exercise interventions. This hypothesis is based on the observations by Barela and Duarte (2008) who reported a lower ground reaction force and a slower stride frequency for elderly individuals while wading in water immersed to the xiphoid process. If OA patients experience less pain and greater mobility after underwater treadmill walking with comparable VO₂ values than land treadmill walking, this mode of aquatic physical therapy may be suitable for treating OA patients.

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 International Review Board.

To be included in the study, participants had to be previously diagnosed with knee, hip or ankle 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 a diagnostic algorithm (March, Schwarz, Carfrae, & 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 underwater 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 meniscectomy at least one year prior to entry into study. Nineteen participants who responded to the request for subjects met these criteria. Physical characteristics and arthritis history for the participants are reported in Table 3-1.

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 underwater treadmill (Figure 3-1; HydroWorx 2000TM, Middletown, PA) and on a land based treadmill (Nordic Track 9600, ICON Fitness, Logan UT). Each exercise bout was separated by at least 24 hrs, and was completed within one week. Each mode of exercise was separated by one week. The order of exercise mode was randomly assigned. It was determined from pilot testing that three exercise sessions were appropriate to provide familiarization with 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 (Table 3-2). 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 stage speed. Participants

performed the underwater treadmill exercise with no shoes at a water depth equal to the xiphoid process. The temperature of the water was 30° C with the air temperature set at 24°C. The land treadmill exercise was performed in the same room and in the same manner as the underwater treadmill exercise and required participants to wear their normal walking shoes along with typical exercise clothing. Treadmill incline was set at 0° for each mode of exercise. To assess the relationship in nominal speed settings between the underwater and land treadmills a video analysis of belt speeds were examined. An interclass correlation coefficient ($ICC = 0.99$) performed on the analyzed data indicated nominal speed settings were similar between treadmills.

Measurements

Cardiorespiratory. The VO_2 was recorded during the third exercise session of each mode of exercise using a computerized metabolic measurement system (Figure 3-1; Parvomedics True One 2400, Sandy UT). Calculations of VO_2 ($l \cdot \text{min}^{-1}$ STPD) were made from expired air samples taken from participants breathing through a two-way valve mouthpiece (Hans Rudolph 700 series, Kansas City MO). Measurements of VO_2 from the third exercise session were calculated every 15 s during the third and fourth stage of the 20 min exercise bout and were averaged over the last 2 min of each stage. Before each testing session, O_2 and CO_2 analyzers from the metabolic system were calibrated with known gas mixtures and the pneumotach was calibrated with a 3 l syringe using manufacturer guidelines. As a supplement to the VO_2 data, rating of perceived exertion (RPE) was recorded during the third exercise session for all stages using the 10 point Borg scale (Borg, 1982).

Pain scale. The perception of joint pain was assessed immediately before and after each exercise session using a continuous visual analog scale. The scale was 12 cm in length and was modeled after pain scales described previously (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 feel right now; the further 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-exercise pain scores were averaged, and all post-exercise pain scores were averaged, to yield a single mean pain score before and after each mode of exercise.

Gait kinematics. Gait analyses were assessed at baseline (within 24 hrs of beginning the exercise week) and within 24 hrs of completing the third exercise session for each mode of exercise. Gait kinematics was assessed using a motion analysis system that tracked retro-reflective markers placed on the subject (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. Seven Vicon T-20 cameras sampling at 100 Hz tracked the low mass (2.2 g) retro-reflective markers

placed on the skin over select bony landmarks of the foot and leg. Three-dimensional position data from each reflective marker were computed from direct linear transformations using Vicon Nexus software. From the position data, stride length was computed as the rectilinear distance (m) between 2 successive placements of the same foot and stride rate was computed as the frequency of the stride (strides/s). On average, six consecutive strides for both limbs were averaged and recorded.

Timed Up & Go (TUG). The TUG is a simple method to assess basic mobility and balance (Podsiadlo & Richardson, 1991). We recorded TUG data at baseline and after completing the third exercise session for each mode of exercise. Instructions for how to complete the test were first given to the participant and then demonstrated by an investigator. The instructions were to stand up from an armed chair with a seat of 45 cm from the floor, walk 3 m at a comfortable speed, cross a line on the floor, turn around, walk back, and sit down again. The TUG was timed in seconds using an ordinary stopwatch with timing commencing when the participant's back was no longer in contact with the back of the chair and stopping when their buttocks touched the seat of the chair when they returned. The TUG has been reported to be a reliable and valid tool for mobility and balance assessments (Podsiadlo & Richardson, 1991; Shumway-Cook, Brauer, & Woollacott, 2000).

Statistical Analyses

Self selected treadmill speeds for the underwater and land treadmill 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 (underwater treadmill or land treadmill) and the dependent variables were VO_2 , RPE, perceived pain, gait kinematics (stride length and stride rate), and TUG. When pre and post measures were available, 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, positive gain scores will indicate that pretest scores are greater than posttest scores and negative gain scores will indicate the opposite.

The nonparametric Wilcoxon signed rank test was used to compare VO_2 , RPE, perceived pain, gait kinematics, and TUG scores between conditions with an alpha set at 0.05. Effect sizes (ES) were also quantified to appreciate the meaningfulness of any statistical differences. The ES were calculated with the following formula: $\text{ES} = (\text{high value} - \text{low value}) / (\text{standard deviation of high value})$, and Cohen's (1988) convention for effect size interpretation was used ($< 0.41 = \text{small}$, $0.41 - 0.7 = \text{medium}$, and $> 0.7 = \text{large}$).

Results

Data from all participants were used in the statistical analyses, although some data (i.e., post underwater treadmill data) were missing from one participant who was unable to complete testing due to scheduling conflicts. Pairwise comparisons of the self selected speeds indicated they were not different between underwater (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 $7.88 (\pm 6.73)$ yrs and that the knee was the primary arthritic joint (Table 3-1).

The VO_2 values were not different between conditions during stage 3 ($p = 0.08$), but were 37 % greater during the preferred walking speed (stage 4) on land than in water ($p = 0.001$; ES = 1.24; Table 3-2). The RPE scores followed a similar trend to the VO_2 values but were not different between conditions ($p = 0.59$; Table 3-2). Perceived pain and TUG gain scores were 140 % and 240 % greater, respectively, after land compared to after underwater treadmill exercise ($p = 0.01, 0.02$; ES = 0.49, 1.12; Table 3-3) and gait kinematic (i.e., stride rate and stride length) gain scores were not different between conditions ($p = 0.16 - 0.74$; Table 3-4).

Discussion

The unique aspect of this study was the control over the type, intensity, and dosage of exercise between water and land conditions. Most previous studies have not controlled for these confounding factors, which makes valid comparisons difficult. Results of this preliminary study indicated that patients diagnosed with OA may walk on an underwater treadmill at a moderate intensity with less pain and equivalent energy expenditures compared to walking on a land based treadmill at a similar moderate intensity. Unexpectedly, OA patients displayed greater mobility and balance levels after underwater than land treadmill exercise when assessed with the TUG test.

It should be noted that energy expenditures (VO_2) were actually lower during underwater than land treadmill exercise at the participant's preferred walking speed. This result suggests the fluid resistance of water was not substantial enough at the slower walking speeds to counteract the cardiorespiratory relief created by the force of buoyancy. This contention is supported by previous research which indicated that walking at speeds less than 0.97 m/s, buoyancy dominates and less energy is expended in water than land because fluid resistance is relatively low due to low limb velocities (Hall et al., 2004). When speeds are greater than 0.97 m/s, limb velocities increase and fluid resistance may offset buoyancy and lead to similar energy expenditures during water and land treadmill exercise (Gleim & Nicholas, 1989; Hall et al., 1998, 2004; Rutledge et al., 2007). The results of the present study support this observation. An important application of these results is that underwater treadmill exercise may help with weight regulation in OA patients since this mode of exercise does not seem to diminish energy expenditure when speeds approach 1.04 m/s (Table 3-2).

One of the most important outcome measures in determining the efficacy of any physical therapy treatment for OA patients is reduced pain (Edmonds, 2009; Hurley, 2003). It was observed in the present study that perceived joint pain was less after aquatic versus land exercise suggesting that underwater treadmill exercise may be efficacious for OA patients. The mechanism for this reduced pain is unknown but may be related to aquatic factors such as buoyancy, hydrostatic pressure, and temperature. Prior studies examining the effectiveness of aquatic therapy have not always observed reductions in pain after physical therapy (Lund et al., 2008; Wang et al., 2007).

Discrepancies between studies may be related to a number of factors including the type of assessment and when it was administered. For example, visual analog scales are commonly used scales but vary in respect to the targeted pain. That is, bodily pain (Wang et al., 2007), pain during rest and walking (Lund et al., 2008), and joint specific pain (Cochrane et al., 2005; Hinman et al., 2007) have all been assessed with different outcomes. The present study assessed the joint specific pain immediately before and after the exercise. It is possible the acute nature of this study and the specific versus general pain targeted, may account for some discrepancies.

In addition to joint pain, OA patients often display compromised mobility in comparison to controls (Cichy & Wilk, 2006). For example, knee and hip OA patients often display compromised balance scores (Hinman et al., 2002) and reduced gait speeds secondary to decreased step lengths when compared to controls (Messier, 1994). We observed that mobility, based on the TUG, is improved after short term underwater versus land treadmill exercise. The results could not be explained by improvements in stride length and stride rate as these measures were not different between conditions. Researchers have previously noted that success of the TUG is related to strength and balance changes (Podsiadlo & Richardson, 1991). In this respect, the gains we observed may be similar to the acute neuromuscular gains observed after starting a resistance training program and would suggest that aquatic gait may produce greater acute effects in strength and balance than land treadmill exercise.

The results of the present study should be interpreted in light of the limitations of the study. For example, OA participants were tested before, during, and after only three

exercise sessions; a longer training period may result in physiological and biomechanical adaptations that may change the outcomes of the study. It was clear from pilot testing that participants felt more comfortable after the second visit for each condition and that VO_2 and RPE measures were lower during the third visit, suggesting that a total of 40 min was a sufficient familiarization period.

Subjective comments from the participants of the study were all in favor of the underwater versus land treadmill exercise. Most participants commented that they felt good in the water and generally wanted to continue training on the underwater treadmill after the study ended. Unfortunately, due to the sparse access to underwater treadmills, most participants were unable to continue. We feel this is perhaps a temporary negative aspect of underwater treadmill therapy, in that OA patients may benefit from this form of exercise but are unable to find or have access to an underwater treadmill facility.

Conclusion

We concluded that patients diagnosed with OA will display similar energy expenditures during short-term exercise on an underwater versus land treadmill when speeds are greater than preferred. This finding along with the perceived pain findings would indicate that patients with OA may receive the same aerobic conditioning during underwater treadmill exercise with less joint pain than performing the same exercise on land. While future longitudinal research is needed, underwater treadmill exercise may also lead to greater improvements in mobility when compared to the same exercise performed on land.

Table 3-1

Physical Characteristics for All Participants (n = 19, 3 Male and 16 Female)

Characteristic	Mean	SD	Range
Age (yr)	59.4	7.4	43 – 70
Height (cm)	106.3	8.22	157 – 188
Body mass (kg)	90.8	21.8	54.5 – 145
Involved limb (s)	2 hip, 12 knee, 2 ankle, 1 hip/knee, 1hip/ankle, 1 knee/ankle		
Duration of OA (yr)	7.88	6.73	2 – 24

Table 3-2

Rating of Perceived Exertion (RPE) and Volume of Oxygen Consumed (VO₂; mean ± SD) During Each 5 min Stage of the 20 min Exercise for Underwater (Aquatic) and Land Treadmill Exercise

	RPE		VO ₂ (l·min ⁻¹)	
	Aquatic	Land	Aquatic	Land
Stage 1 (≈ 0.78 m/s)	1.41 (1.20)	1.50 (1.07)		
Stage 2 (≈ 0.91 m/s)	2.68 (1.64)	2.60 (1.15)		
Stage 3 (≈ 1.04 m/s)	3.74 (1.84)	3.77 (1.24)	1.00 (0.32)	1.15 (0.23)
Stage 4 (≈ 0.78 m/s)	1.88 (1.59)	2.17 (1.05)	0.71 (0.22) ^a	0.97 (0.21)

Note. All values are recorded from the third exercise session. Stage 1 = self selected pace; Stage 2 = self selected pace + 0.13 m/s; Stage 3 = self selected pace + 0.26 m/s; Stage 4 = same speed as stage 1. ^asignificantly different from land treadmill exercise, $p < 0.05$.

Table 3-3

Perceived Pain and Timed Up & Go (TUG) Scores (mean \pm SD) During Underwater (Aquatic) and Land Treadmill Exercise

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Pain (mm)	24.5 (19.7)	17.3 (15.0)	19.8 (16.4)	26.1 (13.3)	3.36 (10.3) ^a	-8.19 (10.3)
TUG (s)	12.3 (6.32)	11.2 (3.99)	11.4 (3.98)	11.7 (5.15)	0.83 (2.85) ^a	-0.55 (1.38)

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

^asignificantly different from land treadmill exercise, $p < 0.05$.

Table 3-4

Gait Kinematic Gain Scores (mean \pm SD) for the Right and Left Limbs During Underwater (Aquatic) and Land Treadmill Exercise

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
SL (m)						
Right	1.15 (0.44)	1.09 (0.44)	1.17 (0.24)	1.09 (0.21)	-0.03 (0.31)	-0.15 (0.42)
Left	1.13 (0.42)	1.09 (0.41)	1.20 (0.24)	1.21 (0.21)	-0.10 (0.33)	0.00 (0.65)
SR (strides/s)						
Right	0.90 (0.32)	0.91 (0.10)	0.89 (0.13)	0.88 (0.11)	0.42 (1.13)	0.03 (0.06)
Left	0.89 (0.11)	0.91 (0.10)	0.88 (0.13)	0.88 (0.11)	-0.01 (0.03)	0.12 (0.29)

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



Figure 3-1. Experimental setup for the underwater treadmill mode.

CHAPTER 4

SUMMARY AND CONCLUSION

Summary of Introductions

Review Article (Chapter 2)

Due to recent advances in aquatic research, technology and facilities, many modes of aquatic therapy now exist. Deep water running (DWR), shallow water running (SWR), water calisthenics, and underwater treadmill exercise are some of the most popular forms of aquatic therapy and exercise. The biomechanical requirements of each aquatic therapy mode may elicit different physiological and functional responses. Also, the variations between the different modes of aquatic therapy and exercise make it difficult for the clinician to know which mode of exercise will achieve the desired therapeutic goal. Because many clinicians now use aquatic therapy and exercise as a form of therapeutic treatment, an understanding of the physiological and biomechanical responses of these different modes is imperative.

The purpose of Chapter 2 was to provide a review of the physiological and biomechanical differences between aquatic and land based exercises. The physiological variables included oxygen consumption (VO_2) and rating of perceived exertion (RPE), with stride length (SL) and stride frequency (SF) being the biomechanical variables. Because many rehabilitation patients experience pain and range of motion impairments, we also reviewed how each mode of exercise affected pain and mobility after the aquatic and land exercise treatment. This review article was written to provide clinicians with a

single source reference that may be used to better prescribe aquatic exercise for achieving the desired goal of the therapy.

Experimental Article (Chapter 3)

Patients diagnosed with osteoarthritis (OA) often exhibit compromised mobility (Cichy & Wilk, 2006) and balance (Hinman, Bennell, Metcalf, & Crossley, 2002), while suffering from joint pain, stiffness, and muscle weakness (Hinman, Heywook, & Day, 2007). The therapeutic benefits of water may assist in a possible treatment for individuals suffering from this incurable disease. Recent literature suggests that aquatic therapy and exercise does improve the condition of OA symptoms (Foley, Halbert, Hewitt, & Crotty, 2003; Wyatt, Milam, Manske, & Deere, 2001; Hinman et al., 2007), however, mixed results have been reported (Hinman et al., 2007; Lund et al., 2008; Wang, Belza, Thompson, Whitney, & Bennett, 2007). The inconsistency in these findings may in part be due to the lack of control for exercise intensity involved during different modes of aquatic therapy. Underwater treadmills have the capability to control water depth and treadmill speed, which are primary determinates of exercise intensity. Being able to control exercise intensity between two modes of exercise (e.g., aquatic versus land) may allow researchers the ability to determine the differences in therapy with more precision. Currently, the effectiveness of using an underwater treadmill as a therapy protocol in patients with OA has not been tested.

The purpose of the experimental manuscript in Chapter 3 was to examine the acute effects of underwater and land treadmill exercise on VO_2 , rate of perceived exertion, perceived pain, mobility, and gait kinematics for patients with OA. The goal of

this paper was to examine if underwater treadmill treatment would elicit the same physiological components as land but produce less pain and increase mobility. It was hypothesized that underwater treadmill walking would elicit the same VO_2 and RPE response as land treadmill walking at the same speed. It was also hypothesized that pain levels would decrease after the underwater treadmill intervention and mobility and gait kinematics would remain the same after both the aquatic and land based interventions.

Summary of Methods

Review Article (Chapter 2)

The methods for the review manuscript consisted of the retrieval of experimental studies examining the physiological and biomechanical effects of aquatic therapy and land based therapy. Retrieval of these studies included searches in Pub Med, Google Scholar, and several library databases at Utah State University. Studies were included in the review if the research compared at least one physiological response (oxygen consumption or rate of perceived exertion) or at least one biomechanical response (stride length, stride frequency, pain, or mobility) during or after an aquatic mode and a similar land based mode. If the study included more than one physiological response, more than one biomechanical response, or more than one aquatic mode compared to a similar land based mode, it too was included. Studies were not included if the physiological or biomechanical variables were not examined, or if there was not a comparison of the aquatic mode to a similar land based mode. After the compilation of research articles were gathered, a summary of the article were put together in tabular format before the text was written.

Experimental Article (Chapter 3)

Nineteen participants diagnosed with osteoarthritis participated in the study. The participants were asked to perform three consecutive exercise sessions on an underwater treadmill and on a land based treadmill. Each bout consisted of four 5 minute stages. 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 stage speed. Each exercise bout was separated by at least 24 hours, and was completed within one week. Each mode of exercise was separated by one week. Participants performed the underwater treadmill exercise with no shoes at a water depth equal to the xiphoid process. The order of the exercise modes was randomly assigned. Oxygen consumption was recorded during the third exercise session of each mode during the last two stages of walking. Rate of perceived exertion was gathered during the third exercise session of each mode during the entire four stages of walking using the 10 point Borg scale. Joint pain was assessed immediately before and after each exercise session using a continuous visual analog scale. Gait analyses were assessed at baseline and within 24 hr of completing the third exercise session for each mode of exercise. Stride length and stride rate were computed using a motion analysis system that tracked retro-reflective markers placed on the subject. The Timed Up & Go instructed participants to stand up from an armed chair with a seat of 45 cm from the floor, walk 3 m at a comfortable speed, cross a line on the floor, turn around, walk back, and sit down again. Self selected treadmill speeds for the

underwater and land treadmill were compared with a Paired-Samples *t* test and arthritis history information (e.g., time since diagnosis) was analyzed descriptively. When pre and post measures were available, a gain score was computed and used for statistical comparisons between conditions. The nonparametric Wilcoxon signed rank test was used to compare VO₂, RPE, perceived pain, gait kinematics, and TUG scores between conditions with .05 set as the alpha level.

Summary of Results/Discussions

Review Article (Chapter 2)

It was observed from the literature that DWR elicits lower VO₂ values when compared to land based running. In addition, walking or running in shallow water also elicits a lower VO₂ when compared to land based running, even though these differences are much smaller when compared to DWR. Mixed results have been reported about water calisthenics depending on water level and the exercise performed. The underwater treadmill mode also revealed mixed results due to varying treadmill speeds and water heights. It is important for clinicians to understand that underwater treadmill exercises and water calisthenics can give VO₂ results similar to land based exercise. The similarities in VO₂ values gives clinicians the ability to prescribe decreased weight bearing programs (i.e., aquatic therapy), and still have a similar aerobic workout. A consideration regarding water depth, treadmill speed, and chosen callisthenic exercise is important, as these variables may change the VO₂ response.

The RPE response during DWR is the same as it is on land during maximal efforts, but could possibly be higher if measured at sub-maximal levels. There is a lack

of research investigating RPE response during SWR, as no study in this review examined this variable. The RPE response results for water calisthenics are mixed. This mode may be difficult to assess due to the variability of exercises. The research examining the underwater treadmill mode also displayed mixed results depending on the speed and depth of the treadmill, or if jet resistance was used. There is a need for future research during aquatic therapy and exercise on RPE due to the lack of research for SWR, and the mixed results reported during water calisthenics and underwater treadmill exercise. Further investigation during these modes of aquatic therapy and exercise would enhance the comparison between the different modes, allowing the clinician to know which mode is most applicable.

As indicated by the studies reviewed, stride frequency can be as low as 50% less during DWR, although the high-knee style is more similar to land stride frequency. A lower stride frequency is also found in SWR, even though this mode of aquatic exercise elicits greater stride frequency than DWR. To our knowledge, no study has investigated stride frequency during water calisthenics, as this variable is not an important measure for this mode of aquatic exercise. As with DWR, and SWR, underwater treadmill exercise also elicits a lower stride frequency. The lower stride frequencies in each aquatic mode reviewed alludes to the fact that no aquatic mode is similar to the stride frequencies found on land. Depending on the goal of the clinician, and if the clinician is trying to meet the principle of specificity, these aquatic modes may not be appropriate. However, if congruency between aquatic and land based modes is irrelevant, and if a patient needed a

lower stride frequency for injury rehabilitation purposes, each mode of aquatic therapy would be suitable.

Stride length measurements are also lower during SWR and during underwater treadmill running. However, the main difference in underwater treadmill running seems to be in older populations. There is a lack of research in this area so any predictions based on this research should be limited. Future research should focus on both SWR and underwater treadmill running as these two modes move through the water making contact with the ground.

Pain and mobility for special populations (i.e., rheumatoid arthritis, osteoarthritis, fibromyalgia, and lower back pain) does not seem to be different between aquatic and land based modes during water calisthenics. All studies reviewed, however, did report improvements in both pain and mobility after the water callisthenic intervention. DWR indicated similar results for pain, but to our knowledge, no study has investigated the affects of DWR on mobility. Pain and mobility significantly improved during underwater treadmill exercise compared to land based exercise, but this consensus is limited based on the limited research available. There is a great need for future research in the area of pain and mobility during DWR, SWR, and underwater treadmill exercise as many special populations suffer from pain and decreased mobility. Future research may want to examine these different modes of aquatic therapy to assess the effectiveness in improving these variables. This knowledge would be of great benefit for individuals seeking relief.

Experimental Article (Chapter 3)

Results of the experimental manuscript indicated that VO_2 values were not different between conditions during stage 3 ($p = 0.08$), but were 37% greater during the preferred walking speed (stage 4) on land than in water ($p = 0.001$). The RPE scores followed a similar trend to the VO_2 values but were not different between conditions ($p = 0.59$). Perceived pain and TUG gain scores were 140% and 240% greater, respectively, after land compared with after underwater treadmill exercise ($p = 0.01, 0.02$) and gait kinematic (i.e., stride rate and stride length) gain scores were not different between conditions ($p = 0.16\text{--}0.74$). It should be noted that energy expenditures (VO_2) were actually lower during underwater than land treadmill exercise at the participant's preferred walking speed. This result suggests the fluid resistance of water was not substantial enough at the slower walking speeds to counteract the cardiorespiratory relief created by the force of buoyancy. It was also observed in the current study that perceived joint pain was less after aquatic versus land exercise, suggesting that underwater treadmill exercise may be efficacious for OA patients. The mechanism for this reduced pain is unknown but may be related to aquatic factors such as buoyancy, hydrostatic pressure, and temperature. The improved mobility based on the TUG may be similar to the acute neuromuscular gains observed after starting a resistance training program and would suggest that aquatic gait may produce greater acute effects in strength and balance than land treadmill 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:

- Underwater treadmill exercise and water calisthenics can elicit lower, equal to, or higher VO_2 values depending on water depth, treadmill speed, and the exercise performed.
- DWR elicits similar RPE responses during maximum effort
- Stride frequency is lower in all aquatic modes
- Stride length is lower during all aquatic modes
- Pain levels are no different during water calisthenics, although two studies reported a significant decrease
- Improvements in pain and mobility occurred after underwater treadmill treatment

Experimental Article (Chapter 3)

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

- patients diagnosed with OA may walk on an underwater treadmill at a moderate intensity with less pain and equivalent energy expenditures
- VO_2 values tend to be lower during underwater treadmill exercise at the participant's preferred walking speed

- Rating of perceived exertion scores during underwater treadmill walking are no different
- Stride rate and stride length tend to be not different after the underwater treadmill intervention
- OA patients displayed greater mobility measured by the Time Up & Go Test after underwater treadmill exercise

REFERENCES

- Ahern, M., Nicholls, E., Simionato, E., Clark, M., & Bond, M. (1995). Clinical and psychological effects of hydrotherapy in rheumatic diseases. *Clinical Rehabilitation, 9*, 204-212.
- Assis, M. R., Silva, L. E., Alves, A. M., Pessanha, A. P., Valim, V., Feldman, D., et al. (2006). A randomized controlled trial of deep water running: clinical effectiveness of aquatic exercise to treat fibromyalgia. *Arthritis and Rheumatism, 55*, 57-65.
- Barbosa, T. M., Garrido, M. F., & Bragada, J. (2007). Physiological adaptations to head-out aquatic exercises with different levels of body immersion. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association, 21*, 1255-1259.
- Barela, A. M., & Duarte, M. (2008). Biomechanical characteristics of elderly individuals walking on land and in water. *Journal of Electromyography and Kinesiology, 18*, 446-454.
- Barela, A. M., Stolf, S. F., & Duarte, M. (2006). Biomechanical characteristics of adults walking in shallow water and on land. *Journal of Electromyography and Kinesiology, 16*, 250-256.
- Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sport and Exercise, 14*, 377-381.

- Butts, N. K., Tucker, M., & Greening, C. (1991a). Physiologic responses to maximal treadmill and deep water running in men and women. *The American Journal of Sports Medicine, 19*, 612-614.
- Butts, N. K., Tucker, M., & Smith, R. (1991b). Maximal responses to treadmill and deep water running in high school female cross country runners. *Research Quarterly for Exercise and Sport, 62*, 236-239.
- Carlsson, A. M. (1983). Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. *Pain, 16*, 87-101.
- Cassady, S. L., & Nielsen, D. H. (1992). Cardiorespiratory responses of healthy subjects to calisthenics performed on land versus in water. *Physical Therapy, 72*, 532-538.
- Cichy, B., & Wilk, M. (2006). Gait analysis in osteoarthritis of the hip. *Medical Science Monitor, 12*, CR507-513.
- Cochrane, T., Davey, R. C., & Matthes-Edwards, S. M. (2005). Randomised controlled trial of the cost-effectiveness of water-based therapy for lower limb osteoarthritis. *Health Technology Assessment, 9*, 1-114.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.
- Crees, R. (1906). Diet and hydrotherapy in treatment of rheumatism and gout. *California State Journal of Medicine, 4*, 194-195.

- Darby, L. A., & Yaekle, B. C. (2000). Physiological responses during two types of exercise performed on land and in the water. *The Journal of Sports Medicine and Physical Fitness*, 40, 303-311.
- Denning, W. M., Bressel, E., & Dolny, D. G. (2010). Underwater treadmill exercise as a potential treatment for adults with osteoarthritis. *International Journal of Aquatic Research and Education*, 4, 70-80.
- Dowzer, C. N., Reilly, T., Cable, N. T., & Nevill, A. (1999). Maximal physiological responses to deep and shallow water running. *Ergonomics*, 42, 275-281.
- Edmonds, S. (2009). Therapeutic targets for osteoarthritis. *Maturitas*, 63, 191-194.
- Evcik, D., Yigit, I., Pusak, H., & Kavuncu, V. (2008). Effectiveness of aquatic therapy in the treatment of fibromyalgia syndrome: a randomized controlled open study. *Rheumatology International*, 28, 885-890.
- Foley, A., Halbert, J., Hewitt, T., & Crotty, M. (2003). Does hydrotherapy improve strength and physical function in patients with osteoarthritis--a randomised controlled trial comparing a gym based and a hydrotherapy based strengthening programme. *Annals of the Rheumatic Diseases*, 62, 1162-1167.
- Frangolias, D. D., & Rhodes, E. C. (1995). Maximal and ventilatory threshold responses to treadmill and water immersion running. *Medicine and Science in Sports Exercise*, 27, 1007-1013.
- Fujishima, K., & Shimizu, T. (2003). Body temperature, oxygen uptake and heart rate during walking in water and on land at an exercise intensity based on RPE in

elderly men. *Journal of Physiological Anthropology and Applied Human Science*, 22, 83-88.

Gappmaier, E., Lake, W., Nelson, A. G., & Fisher, A. G. (2006). Aerobic exercise in water versus walking on land: Effects on indices of fat reduction and weight loss of obese women. *The Journal of Sports Medicine and Physical Fitness*, 46, 564-569.

Glass, B., Wilson, D., Blessing, D., & Miller, E. (1995). A physiological comparison of suspended deep water running to hard surface running. *Journal of Strength and Conditioning Research*, 9, 17-21.

Gleim, G. W., & Nicholas, J. A. (1989). Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. *The American Journal of Sports Medicine*, 17, 248-252.

Gramling, S. E., & Elliott, T. R. (1992). Efficient pain assessment in clinical settings. *Behaviour Research and Therapy*, 30, 71-73.

Green, J., McKenna, F., Redfern, E. J., & Chamberlain, M. A. (1993). Home exercises are as effective as outpatient hydrotherapy for osteoarthritis of the hip. *British Journal of Rheumatology*, 32, 812-815.

Hall, J., Grant, J., Blake, D., Taylor, G., & Garbutt, G. (2004). Cardiorespiratory responses to aquatic treadmill walking in patients with rheumatoid arthritis. *Physiotherapy Research International*, 9, 59-73.

- Hall, J., Macdonald, I. A., Maddison, P. J., & O'Hare, J. P. (1998). Cardiorespiratory responses to underwater treadmill walking in healthy females. *European Journal of Applied Physiology and Occupational Physiology*, 77, 278-284.
- Hall, J., Skevington, S. M., Maddison, P. J., & Chapman, K. (1996). A randomized and controlled trial of hydrotherapy in rheumatoid arthritis. *Arthritis Care and Research*, 9, 206-215.
- Hinman, R. S., Bennell, K. L., Metcalf, B. R., & Crossley, K. M. (2002). Balance impairments in individuals with symptomatic knee osteoarthritis: A comparison with matched controls using clinical tests. *Rheumatology*, 41, 1388-1394.
- Hinman, R. S., Heywood, S. E., & Day, A. R. (2007). Aquatic physical therapy for hip and knee osteoarthritis: Results of a single-blind randomized controlled trial. *Physical Therapy*, 87, 32-43.
- Hochberg, M. C., Altman, R. D., Brandt, K. D., Clark, B. M., Dieppe, P. A., Griffin, M. R., . . . Schnitzer, T. J. (1995). Guidelines for the medical management of osteoarthritis. Part I. Osteoarthritis of the hip. American College of Rheumatology. *Arthritis and Rheumatism*, 38, 1535-1540.
- Hoeger, W., Hopkins, D., & Barber, D. (1995). Physiologic responses to maximal treadmill running and water aerobic exercise. *The National Aquatics Journal*, 11, 4-7.
- Hurley, M. V. (2003). Muscle dysfunction and effective rehabilitation of knee osteoarthritis: What we know and what we need to find out. *Arthritis and Rheumatism*, 49, 444-452.

- Jentoft, E. S., Kvalvik, A. G., & Mengshoel, A. M. (2001). Effects of pool-based and land-based aerobic exercise on women with fibromyalgia/chronic widespread muscle pain. *Arthritis and Rheumatism*, *45*, 42-47.
- Johnson, B. L., Stromme, S. B., Adamczyk, J. W., & Tennoe, K. O. (1977). Comparison of oxygen uptake and heart rate during exercises on land and in water. *Physical Therapy*, *57*, 273-278.
- Kato, T., Onishi, S., & Kitagawa, K. (2001). Kinematical analysis of underwater walking and running. *Sports Medicine, Training and Rehabilitation*, *10*, 165-182.
- Kilding, A. E., Scott, M. A., & Mullineaux, D. R. (2007). A kinematic comparison of deep water running and overground running in endurance runners. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *21*, 476-480.
- Killgore, G. L., Wilcox, A. R., Caster, B. L., & Wood, T. M. (2006). A lower-extremities kinematic comparison of deep-water running styles and treadmill running. *Journal of Strength and Conditioning Research*, *20*, 919-927.
- Lawrence, R. C., Felson, D. T., Helmick, C. G., Arnold, L. M., Choi, H., Deyo, R. A., . . . Kremers, H. M. (2008). Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis and Rheumatism*, *58*, 26-35.
- Lund, H., Weile, U., Christensen, R., Rostock, B., Downey, A., Bartels, E. M., et al. (2008). A randomized controlled trial of aquatic and land-based exercise in

- patients with knee osteoarthritis. *Journal of Rehabilitation Medicine*, 40, 137-144.
- March, L. M., Schwarz, J. M., Carfrae, B. H., & Bagge, E. (1998). Clinical validation of self-reported osteoarthritis. *Osteoarthritis and Cartilage / OARS, Osteoarthritis Research Society*, 6, 87-93.
- Masumoto, K., Delion, D., & Mercer, J. A. (2009). Insight into muscle activity during deep water running. *Medicine and Science in Sports and Exercise*, 41, 1958-1964.
- Masumoto, K., Shono, T., Hotta, N., & Fujishima, K. (2008). Muscle activation, cardiorespiratory response, and rating of perceived exertion in older subjects while walking in water and on dry land. *Journal of Electromyography and Kinesiology*, 18, 581-590.
- Matthews, M., & Airey, M. (2001). A comparison of ratings of perceived exertion during deep water running and treadmill running: Considerations in the prescription of exercise intensity. *Research in Sports Medicine*, 10, 247-256.
- McCormack, H. M., Horne, D. J., & Sheather, S. (1988). Clinical applications of visual analogue scales: a critical review. *Psychological Medicine*, 18, 1007-1019.
- McNeal, R. L. (1990). Aquatic therapy for patients with rheumatic disease. *Rheumatic Diseases Clinics of North America*, 16, 915-929.
- Melton-Rogers, S., Hunter, G., Walter, J., & Harrison, P. (1996). Cardiorespiratory responses of patients with rheumatoid arthritis during bicycle riding and running in water. *Physical Therapy*, 76, 1058-1065.

- Mercer, J. A., & Jensen, R. L. (1997). Reliability and validity of a deep water running graded exercise test. *Measurement in Physical Education and Exercise Science, 1*, 213-222.
- Messier, S. P. (1994). Osteoarthritis of the knee and associated factors of age and obesity: Effects on gait. *Medicine and Science in Sports and Exercise, 26*, 1446-1452.
- Metcalfe, R. (1898). *Life of Vincent Priessnitz, founder of hydrotherapy*. London: Simpkin, Marshall, Hamilton, Kent & CO.
- Minor, M. A., Hewett, J. E., Webel, R. R., Anderson, S. K., & Kay, D. R. (1989). Efficacy of physical conditioning exercise in patients with rheumatoid arthritis and osteoarthritis. *Arthritis and Rheumatism, 32*, 1396-1405.
- Moening, D., Scheidt, A., Shepardson, L., & Davies, G. J. . (1993). Biomechanical comparison of water running and treadmill running. *Isokinetics and Exercise Science, 3*, 207-215.
- Nakanishi, Y., Kimura, T., & Yokoo, Y. (1999a). Maximal physiological responses to deep water running at thermoneutral temperature. *Applied Human Science, 18*, 31-35.
- Nakanishi, Y., Kimura, T., & Yokoo, Y. (1999b). Physiological responses to maximal treadmill and deep water running in the young and the middle aged males. *Applied Human Science, 18*, 81-86.
- Nieman, D. C. (2007). *Exercise testing and prescription: A health-related approach* (Sixth ed.). New York, NY: McGraw-Hill.

- Norton, C. O., Hoobler, K., Welding, A. B., & Jensen, G. M. (1997). Effectiveness of aquatic exercise in the treatment of women with osteoarthritis. *The Journal of Aquatic Physical Therapy, 5*, 8-15.
- Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society, 39*, 142-148.
- Pohl, M. B., & McNaughton, L. R. (2003). The physiological responses to running and walking in water at different depths. *Research in Sports Medicine, 11*, 63-78.
- Reilly, T., Dowzer, C. N., & Cable, N. T. (2003). The physiology of deep-water running. *Journal of Sports Sciences, 21*, 959-972.
- Rutledge, E. R., Silvers, W. M., Browder, K., Dolny, D. (2007). Metabolic-cost comparison of submaximal land and aquatic treadmill exercise. *International Journal of Aquatic Research and Education, 1*, 118-133.
- Sanderson, A. J. (1904). Hydrotherapy in rheumatism. *California State Journal of Medicine, 2*, 287-289.
- Shono, T., Fujishima, K., Hotta, N., Ogaki, T., & Masumoto, K. (2001). Cardiorespiratory response to low-intensity walking in water and on land in elderly women. *Journal of Physiological Anthropology and Applied Human Science, 20*, 269-274.
- Shono, T., Masumoto, K., Fujishima, K., Hotta, N., Ogaki, T., & Adachi, T. (2007). Gait patterns and muscle activity in the lower extremities of elderly women during

- underwater treadmill walking against water flow. *Journal of Physiological Anthropology*, 26, 579-586.
- Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Physical Therapy*, 80, 896-903.
- Silvers, W. M., Rutledge, E. R., & Dolny, D. G. (2007). Peak cardiorespiratory responses during aquatic and land treadmill exercise. *Medicine and Science in Sports and Exercise*, 39, 969-975.
- Sjogren, T., Long, N., Storay, I., & Smith, J. (1997). Group hydrotherapy versus group land-based treatment for chronic low back pain. *Physiotherapy Research International*, 2, 212-222.
- Sylvester, K. L. (1990). Investigation of the effect of hydrotherapy in the treatment of osteoarthritic hips. *Clinical Rehabilitation*, 4, 223-228.
- Templeton, M. S., Booth, D. L., & O'Kelly, W. D. (1996). Effects of aquatic therapy on joint flexibility and functional ability in subjects with rheumatic disease. *The Journal of Orthopaedic and Sports Physical Therapy*, 23, 376-381.
- Town, G. P., & Bradley, S. S. (1991). Maximal metabolic responses of deep and shallow water running in trained runners. *Medicine and Science in Sports and Exercise*, 23, 238-241.
- Wang, T. J., Belza, B., Thompson, F.E., Whitney, J. D., & Bennett, K. (2007). Effects of aquatic exercise on flexibility, strength and aerobic fitness in adults with osteoarthritis of the hip or knee. *Journal of Advanced Nursing*, 57, 141-152.

Williams, R. H., & Zimmerman, D. W. (1996). Are simple gain scores obsolete?

Applied Psychological Measurement, 20, 59-69.

Wyatt, F. B., Milam, S., Manske, R. C., & Deere, R. (2001). The effects of aquatic and

traditional exercise programs on persons with knee osteoarthritis. *Journal of*

Strength and Conditioning Research / National Strength & Conditioning

Association, 15, 337-340.

Zimmerman, D. W., & Williams, R. H. (1982). Gain scores in research can be highly

reliable. *Journal of Educational Measurement, 19*, 149-154.

APPENDIX

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