2012

Relationship of Metabolic Costs of Aquatic Treadmill Versus Land Treadmill Running

Sarah Squires Blackwell
Utah State University

RELATIONSHIP OF METABOLIC COSTS OF AQUATIC TREADMILL

VERSUS LAND TREADMILL RUNNING

by

Sarah Squires Blackwell

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Health and Human Movement

Approved:

Dennis Dolny Major Professor	Gerald Smith Committee Member
Dale Wagner Committee Member	Mark R. McLellan Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2012

ABSTRACT

Relationship of Metabolic Costs of Aquatic Treadmill

versus Land Treadmill Running

by

Sarah Squires Blackwell, Master of Science

Utah State University, 2012

Major Professor: Dr. Dennis Dolny
Department: Health, Physical Education and Recreation

Running injuries are common, usually causing athletes to cease or significantly reduce participation in a particular sport. The recent development of aquatic treadmills (ATM), an alternative to land treadmill (LTM) running, provides another option. This study sought to examine the metabolic (VO_2) relationship between varying jet resistances and running speed on an ATM versus LTM. This was accomplished by developing two linear regression equations and a prediction equation. One linear regression represented the predicted VO_2 from a given speed and jet resistance setting in the water, the other linear regression predicted VO_2 on land from a given speed and the prediction equation was designed to match land speed to a VO_2 score derived from ATM running conditions. This study examined experienced runners (N = 18). Each subject completed an initial VO_2 peak test, three LTM trials, and 18 ATM trials. Each ATM trial consisted of running for three minutes at either a relatively slow, moderate, or somewhat fast speed while one of six ATM jet settings ranging from 0 to 100% jet capacity in 20% increments were assigned to the trial. Oxygen consumption (VO_2) and heart rate (HR) were measured during each trial while ratings of perceived exertion (RPE) were solicited immediately following each trial.

Resulting analysis produced an ATM linear regression for each jet resistance setting and a LTM linear regression equation of $VO_2 = 4.16 * \text{speed} + 7.39$. A prediction equation for each jet resistance setting was then determined from the linear regression equations for both the ATM and LTM conditions.

Results showed that at and between 0-40% jet resistances that there is not a marked difference in metabolic cost but from 40-100% jet resistances the VO_2 is influenced more strongly. These results demonstrate that ATM metabolic costs are not only influenced by jet resistance settings but at jet resistances of 40% or greater provide an intensity of exercise that mimics running faster on LTM. This provides an added benefit for those individuals who may be limited due to acute overuse-type injuries or returning to full LTM activity following lower extremity surgery.

(67 pages)

Public Abstract

Relationship of Metabolic Costs of Aquatic Treadmill versus Land Treadmill Running

Running injuries are common, usually causing athletes to cease or significantly reduce participation in a particular sport. The recent development of aquatic treadmills (ATM), an alternative to land treadmill (LTM) running, provides another option. The use of an ATM provides an individual the opportunity to run in an environment that creates much lower impact or ground contact forces compared to what is experienced on land. Forces 2-3 times that of a person's body weight may be experienced on land while in water these forces are about 1 times body weight. This cumulative reduction in force lowers the risk of overuse injury and decreases the possibility of lost time to exercise. Another consideration with ATM is whether the energy expenditure during running in an ATM is comparable to running on a land treadmill. Therefore, this study sought to examine the energy expenditure (oxygen consumption, VO_2) relationship between varying jet resistances and running speed on an ATM versus running on a level LTM.

Healthy subjects ran on a LTM at three self-selected running speeds while VO_2 was measured. In ATM subjects ran as speeds identical to LTM but water jet resistances corresponding to 0, 20, 40, 60, 80 and 100% jet capacity were used to provide additional resistance during running.

In terms of energy expenditure LTM was greater than ATM when 0 or 20% jets were used. By 40% jets energy expenditure was similar between LTM and from 60-100% jets ATM was greater than LTM. Knowing what jet resistance is used in ATM allows for the estimation of running speed on LTM to create similar amounts of energy expenditure.

These results allows someone with orthopedic restrictions to exercise in ATM and gain similar benefits of energy expenditure as LTM.

Sarah Squires Blackwell
Utah State University, 2012

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Injuries are common among runners with one of the most common causes being overuse injuries to the lower extremities. Although acute injuries do exist, overuse injuries are most problematic to the athlete. An accepted definition of an overuse injury is, "an injury of the musculoskeletal system resulting from combined fatigue effect over a period of time beyond the capabilities of a specific structure that has been stressed (Hreljac & Ferber, 2006)." These injuries are not limited to but include, achillies tendionopathy, anterior knee pain, and plantar fasciitis (Nobloch, Yoon, & Vogt, 2008). Overuse injuries require adequate rest and time for healing. From an athlete's perspective, rest and time are not things that an athlete likes to hear or adhere to. Injuries can set training back and cause the athlete to lose valuable gains already attained.

Injured runners are typically advised to discontinue running activities and instead cross train to allow for adequate healing. Aquatic running has been recommended as one of the best modes of cross training during a running hiatus (Reilly, Dowzer, & Cable, 2003). This is because the buoyancy effect of water reduces the amount of stress placed upon the joints. It also provides aerobic benefits, utilizes almost all muscles in the body, and most closely resembles that of land based running (Moening, Scheidt, Shepardson, & Davies, 1993). Water is more than 800 times as dense as air; therefore, the benefits of aquatic running are aided by the ability of the drag forces to facilitate an increase in energy expenditure (Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2005; Moening, et al., 1993).

The problem that exists for injured athletes is then being able to maintain fitness gains during injury while still being able to allow the body to recover. The use of aquatic running to impose comparable training intensities to the athlete with a reduction of stressors allows the athlete to maintain and increase his or her fitness level during recovery.

Research on aquatic running is becoming more extensive. Most aquatic research has been directed towards utilizing aquatic walking or running to elicit similar metabolic responses to those achieved on land. Previous studies have and are manipulating variables such as water depth, use of jets, and varying speeds to examine the physiological responses during aquatic running.

Deep water running utilizes a pool where participants run at a neck level water depth. Although this mode is still popular, research has shown varying metabolic responses. Shallow water running more closely resembles that of land running and is typically done in the shallow end of a swimming pool or on an aquatic treadmill (Frangolias, & Rhodes, 1996; Reilly et al., 2003). Shallow running not only combines resistance from locomotion through the water but also allows a reduction in ground reaction forces dependent on the depth.

Aquatic treadmill running has been utilized for individuals who are recovering from injury or surgery, are obese, have osteoarthritis, or are elderly. In all cases, the outcomes of participation in aquatic running or walking have proved successful with results eliciting similar heart rates and VO_2 values comparable to those on land (Greene et al., 2009; Rife et al., 2010; Rutledge, Silvers, Browder, & Dolny, 2007; Silvers, Rutledge, & Dolny, 2007). Gleim and Nicholas (1989) wrote one of the first studies to examine the metabolic costs of treadmill walking and running with those of shallow water walking and running at different depths and different temperatures. One finding of this study was that only at waist deep water and at speeds greater than 134.1 $m \cdot min^{-1}$ was the VO_2 similar to those on a land treadmill; otherwise, water trials resulted in greater VO_2 values than those on land. These results suggest that water depth and speed are important factors in achieving similar cardiorespiratory responses for land treadmill walking and running and aquatic treadmill walking and running.

To further the study of water depth and physiological responses, Pohl and McNaughton (2003) studied the differences in walking and running at thigh deep and waist deep water levels as compared to land trials and found that VO_2 values were greater in water than on land.

Although the results from the previous two studies show similarities, shallow water running research has been varied and somewhat inconsistent. This has been in part due to the varying depths of the water. With greater water depths there is an increase of the frontal resistance and a change in running mechanics and energy expenditure (Moening et al., 1993).

Aquatic treadmill running can alleviate this problem by reducing frontal resistance and allowing a more normal gait pattern. Previous research conducted utilizing an aquatic treadmill has produced more similar results. This was in part due to the fact that the water depth can be altered. Silvers et al. (2007) observed that a similar VO_2 max response can be obtained from both the aquatic treadmill (ATM) and land treadmill (LTM). Green et al. (2009) employed the aquatic treadmill and found that both aquatic treadmill and land treadmill are both capable of improving aerobic fitness. Both Rife et al. (2010) and Rutledge et al. (2007) found that both running on an aquatic treadmill, at chest height and level of the xiphoid, and on a land treadmill generate similar VO_2 responses. For all previously mentioned studies, water levels ranged between the fourth intercostal space and the xiphoid process.

Rutledge et al. (2007) matched land cardiorespiratory responses from those gained on the aquatic treadmill by examining what land speeds produce similar VO_2 responses to those in the water when speeds and water jets were altered. These results provide more information on how to match cardiorespiratory responses on an aquatic treadmill to those on a land treadmill. Still less information is available relating equivalent treadmill metabolic responses with other necessary aquatic treadmill parameters such as other jet resistances and speeds.

Rutledge et al. (2007) utilized aquatic treadmill speeds of 174 $m \cdot min^{-1}$ (6.5 mph), 201 $m \cdot min^{-1}$ (7.5 mph), and 228 $m \cdot min^{-1}$ (8.5 mph) and jet resistances of 0%, 50%, and 75%. Information is currently unavailable for the cardiorespiratory responses during aquatic treadmill running at 160.9 $m \cdot min^{-1}$ (6 mph), 187.8 $m \cdot min^{-1}$ (7 mph), 214.6 $m \cdot min^{-1}$ (8 mph), and other speeds with jet resistances of 40%, 60%, 80%, and 100%. These missing gaps would provide valuable information for understanding matched metabolic costs of aquatic running with those on land at common speeds providing practitioners, athletes, and others with more information in designing rehabilitation or training protocols on the aquatic treadmill.

Purpose

The purpose of this study was to match the metabolic responses of aquatic treadmill running (ATM) during selected running speeds and jet resistances to land treadmill (LTM) running speeds.

Hypotheses

1) It was hypothesized that running on an ATM would produce increased cardiorespiratory responses with increases in speeds and jet resistance settings.
2) The cardiorespiratory responses on a LTM would also increase with increasing speed.
3) The addition of jet resistances on an ATM at a particular speed would significantly increase the metabolic costs and reflect running at a greater speed on land.

Definitions

Aquatic running: For this study, the physical activity of running while partially submerged in water aided by the use of an aquatic treadmill.

Land running: The physical activity of running that takes place on land while on a treadmill.

Metabolic cost: The amount of energy consumed as the result of performing a given work task.

VO_2: The capacity of an individual to transport and use oxygen during exercise that reflects an individual's physical fitness and aerobic power. The volume of oxygen consumed per minute.

Heart rate: The number of heart beats per unit of time, normally expressed in beats per minute; the pulse of the body.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Both running and walking require the cooperation of various systems of the body to transport the body from one place to another. Walking is typically an exercise that people do on a daily basis. Running is also a popular means of exercise that challenges the body requiring it to meet the demands placed upon it. One such demand that is placed upon the body while running on land is that of the stress placed upon various joints, mainly the knee, ankle, and hip. Because of this increased strain placed upon the body during land running, aquatic running has provided an acceptable means for assisting in injury recovery, injury prevention, and as a way to cross train (Dale, 2007). The nature of running in water allows the body to not encounter the same amount of ground reaction forces as it does when running on land (Moening et al., 1993). For this reason, aquatic running has the possibility of contributing to the cardiovascular fitness of an individual without exposing him or her to injuries that are typically common with running on land.

This review of literature will examine (a) the health concerns with running on land, (b) previous research on the use of water as a means of exercise and the body's response to water exercise and, (c) previous research conducted using the underwater treadmill specifically addressing water depth and speed.

Health Concerns with Running on Land

Because of the nature of running on land it is one of the most demanding sports that the body can perform (Dowzer, Reilly, Cable, & Nevill, 1999). This is because of the activation of large muscles groups as well as the impact forces placed upon the skeletal system during running (Gross & Napoli, 1993). Due to this, running has been responsible for numerous injuries such as ankle strains, muscle strains, shin splints, stress fractures, and knee disorders resulting from overuse (Hreljac, & Ferber, 2006; Moening, et. al., 1993).

Overuse injuries are classified as any injury affecting the musculoskeletal system which has been stressed beyond capacity over time (Hreljac, & Ferber, 2006). This occurs when numerous small magnitude repetitive forces act on the muscle or tendon at a force greater than the tolerance threshold of the structure (Elliott, 1990; Stanish, 1984). Repeated stressors on the system are important to stimulate bone and muscle growth; however, once a stressor has reached above a certain tensile level it can start to be detrimental causing injuries that can interfere with training, performance, and everyday mobility (Elliott, 1990; Rolf, 1995; Stanish, 1984). The populations that these injuries affect varies from the elderly and overweight to the professional athlete because with time their bodies cannot uphold repetitive impact forces (Thompson, Gordon, & Pescatello, 2010).

The elderly population has been a topic of concern because as the body ages muscular and structural functions are altered allowing the body to be overloaded and stressed which can lead to injury (Kallinen, & Markku, 1995). The most common injuries found in elderly are those affecting the lower extremities. In treating the elderly it is important to avoid immobilization. Exercise and proper strength training are important for the elderly population (Kallinen, & Markku, 1995). However, sometimes due to a sedentary lifestyle or health concerns it is not always possible for elderly to sustain the weight bearing forces of walking or running on their joints and muscles. In a study that examined sport injuries in elderly athletes, it was found that most of the injuries that occurred in the elderly who were already active were due to overuse injuries (Kannus, Niittymaki, Jarvinen, & Lehto, 1989).

Obese or overweight individuals are also at risk for injury. This is in part due to the nature of the forces that act upon their lower extremities. Carrying extra weight around places additional forces on the musculoskeletal system, especially affecting the knee joint. If overuse continues in overweight or obese individuals it could lead to osteoarthritis (Wearing, Hennig, Byrne, Steele, & Hills, 2006).

Athletes also are at risk for overuse injuries. Running is one of the most common contributors to overuse injuries. Since most sports require the participant to run to some degree, many athletes are at risk for overuse injuries. The knee is the most common site of overuse injuries in athletes (Hreljac, & Ferber, 2006). The cause of overuse injuries in athletes is in part due to training and anatomical and biomechanical factors.

Most sports require a significant amount of loading on their musculoskeletal system. Highly competitive distance runners especially spend numerous hours training each week. Because of this they develop high levels of cardiovascular fitness but are also more prone to injury (Reilly et al., 2003). Injured athletes often suffer from a decrease in training time as well as a decrease in cardiovascular training (Rife et al., 2010). Previous research has shown after 6 weeks of non-training an athlete's cardiovascular fitness level decreases by 14% to 16% in VO_2max (Eyestone, Fellingham, George, & Fisher, 1993). A main concern for athletes with injuries then is sustaining the same fitness level during rehabilitation (Rife et al., 2010). Aquatic running provides a solution to this problem.

Aquatic Running

There are several types of aquatic running: deep water running (DWR), shallow water running (SWR), and running on an aquatic treadmill (ATM). Each modality has its pros and cons, and each modality elicits various responses from the body and therefore different outcomes. One of the main differences between the three different types of aquatic running is the water depth. Other differences include the ability to adjust speeds and water jets and the resemblance to land based walking or running. Adjustments of these variables allow the participant to receive desired results without compromising the rehabilitation process.

Deep Water Running

Deep water running is performed in the deep end of a swimming pool where the subject is tethered to a pulley system and a buoyant vest or belt (Silvers et al., 2007). The participant then tries to run in one spot mimicking the motion of land based running (Reilly et al., 2003). This has been found to be an appropriate form of exercise and is one of the most common forms, the physiological responses of which have been studied a great deal.

In a study examining the physiology between running on land compared to in water, runners were immersed in water at neck level and then preformed two tests, a submaximal and maximal VO_2 test. The results of this study showed that maximal oxygen uptake was significantly lower than that on a land with the mean differences being, 4.03 ± 0.13 $L \cdot min^{-1}$ vs 4.60 ± 0.14 $L \cdot min^{-1}$ (Svedenhag & Seger, 1992). For a given VO_2 the heart rate was 8-11 beats lower during aquatic running verses treadmill running.

Chu, Rhodes, Taunton, and Martin (2002) also reported similar results while examining the effects of deep water and treadmill running in young and older women. In the younger group the VO_2 max was 43.17 $mL \cdot kg^{-1} \cdot min^{-1}$ for DWR verses 47.06 $mL \cdot kg^{-1} \cdot min^{-1}$ for treadmill running (Chu et al., 2002). The results were similar for the older population with a measurement of 17.98 $mL \cdot kg^{-1} \cdot min^{-1}$ for DWR verses 23.07 $mL \cdot kg^{-1} \cdot min^{-1}$ for the treadmill running. These results are not unusual for DWR as DWR brings about a lower maximal heart rate and oxygen consumption than treadmill running on land (Brown, Chitwood, Beason, & McLemore, 1997).

Similar results were also published in a study that examined the differences in maximal VO_2 responses between DWR and treadmill running (Brown et al., 1997). In this study 24 moderately active individuals were used. The results indicated a lower maximal VO_2 for DWR than on the land treadmill as well as lower HR results in the water as compared to land. In order to maintain comparability between DWR and treadmill running a similar running cadence was set for each modality (Brown et al., 1997). This method helped maintain similarity between DWR and treadmill running, but the actual running form was still different between DWR and treadmill running.

Again in a study of metabolic responses to prolonged work during treadmill and water immersion running, subjects followed similar protocols for land and water running to obtain VO_2 max. The difference in VO_2 max for treadmill or immersion running were 59.7 $mL·kg^{-1}·min^{-1}$ and 54.2 $mL·kg^{-1}·min^{-1}$ (Frangolias, Rhodes, Taunton, Belcastro, & Coutts, 2000). Maximal heart rates also were lower in DWR and LTM (174.4 and 189.2 bpm). Frangolias et al. (2000) explained that the differences in VO_2 max in DWR may be due to the unfamiliarity of the runners with DWR, the inability of runners to reach a true VO_2 max, and also due to the muscle recruitment patters that differ between DWR and LTR (Reilly et al., 2003).

Reilly et al. (2003) explained that these changes in VO_2 max and HR while the body is immersed in water are partly attributed to the hydrostatic forces exerted on the body. Because of this increase in pressure on the thoracic cavity, there occurred a redistribution of blood volume by about 700 ml with 200 ml being accepted by the heart (Arborelius, Baildin, Lilja, & Lindgren, 1972). This increase of blood to the heart increases stroke volume, and therefore is associated with a lower HR. The increase in cardiac output is also associated with water depth (Reilly et al., 2003). Reilly also explained how hydrostatic pressure also affects lung function by decreasing its vital capacity by 3-9% when water depth is at the xiphoid process (Agostoni, Gurtner, Torri, & Rahn, 1966; Hong, Song, Pim, & Suh, 1967)

Shallow Water Running

Because of the altered technique in DWR, shallow water running (SWR) was introduced to more closely imitate land based running (Frangolias, & Rhodes, 1996; Reilly et al., 2003). In SWR the water depth varies from ankle depth to xiphoid or mid sternum. Ground reaction forces are increased in SWR and buoyancy is decreased depending on the water depth (Silvers et al., 2007). As the water level rises, there is more resistance and hence more workload placed upon the body. As a result, an increase in metabolic demand occurs because the body must push through more water in order to propel itself forward. Most previous studies have looked at the physiological responses between running on land verses SWR.

A study examining the loading of lower limbs when walking partially immersed showed that, while walking, maximum weight bearing force decreased as water emersion increased (Harrison, Hillman, & Bulstrode, 1992). This is in agreement with other studies that examined water depth and loading of lower limbs. The physiological responses of SWR however have varied. These variations have been due to the water level and frontal resistance (Pohl, & McNaughton, 2003; Silvers et al., 2007). This change in frontal resistance also causes a change in posture while running (Byrne, Craig, & Willmore, 1996).

Aquatic Treadmills

DWR typically causes a shorter stride and SWR causes a change in posture due to frontal resistance (Byrne et al., 1996). Aquatic treadmills (ATM) resolve the problems encountered by both DWR and SWR by enabling the individual to have a correct posture while running and overcome frontal resistance (Hall, MacDonald, Maddison, & O'Hare, 1998). Aquatic running also enables more adaptable changes to be made to the water depth and speed which then elicits metabolic responses that more closely resemble that of running on land (Silvers et al., 2007).

The ATM has been designed for training and rehabilitation (Alkurdi, Paul, Sadowski, & Dolny, 2010). There are two main types of ATM: one is a treadmill submerged in the bottom of a small pool, or one that integrates a flume that expels water at a force that is comparable to walking at a particular pace. Some ATMs combine a treadmill and a flume together in one pool. These are what have been typically used in rehabilitation. In these particular ATM, the pool floor can be raised or lowered to adjust the depth of the water. Differing depths elicit different responses from the body.

Water Depth

Water running helps alleviate overuse injuries by reducing the effects of gravity felt by the body because the human body is more buoyant in water, decreasing compressive joint forces (Barela & Duarte, 2008; Gleim, & Nicholas, 1989; Harrison et al., 1992). Ground reaction forces felt by the body are related to the water depth at which the subject either runs or walks (Alkurdi et al., 2010). In a study that examined water depths and ground reaction forces, Harrison et al. (1992) concluded that the percentage of weight bearing is dependent on the water depth and the speed at which the person is walking.

Water depth also imposes changes on the cardiovascular system therefore affecting a subject's VO_2. Previous research has been conducted examining the effects of running and walking at different water levels such as DWR which is usually at neck level, aquatic treadmill running (all depths), and SWR which usually ranges from ankle depth to xiphoid or mid sternum depth.

Harrison et al. (1992) examined the relationship between loading of the lower limbs when a subject is standing and walking at various speeds and at different water depths. Their results showed that the weight-bearing for an individual standing in water decreased with rise in water level. These results were similar for walking at a slower pace and at a faster pace. Since walking loads can increase up to 76% compared to standing, the faster walking resulted in greater weight bearing in general but still decreased with an increase in water level.

Other research has also examined the affects of water depth on aquatic running and walking. The results have varied based upon the mode of aquatic running or walking. The three main types of aquatic exercise that most exemplifies land based walking or running include, DWR, SWR, and ATM.

Alkurdi et al. (2010) studied the effects of water depth on energy expenditure. The depths which were tested were 10 cm above the xiphoid (+10), 10 cm below the xiphoid (-10), and at the xiphoid. The purpose was to see if smaller changes of 10 cm influenced metabolic responses (Alkurdi et al., 2010). The results of this study provided valuable information for determining the water depth that is most comparable with walking on land. Energy expenditure and heart rate were greater at -10 cm than at xiphoid, +10 cm, and on land. Land and +10 cm were not significantly different from each other providing insight into the balance between water depth (buoyancy) and resistance (Alkurdi et al., 2010). Because the subjects in this study had a BMI that ranged from 21.5 to 44.9 $kg \cdot m^{-2}$, with an average BMI of 29.0 ± 6.2 $kg \cdot m^{-2}$, the water level may have been higher for this population to compensate for the extra adipose tissue. The assistance of an aquatic treadmill has also contributed to a normal running pattern and comparable results between land and aquatic running in terms of energy expenditure.

The depth that has been considered to be the best at balancing between buoyancy and resistance is at the xiphoid. This level also produces comparable energy expenditure on land and water and allows for a normal running pattern (Rutledge et al., 2007). It has been shown that at this level limb loading is decreased by 72% (Hall, Figueroa, Fernhall, & Kanaley, 2004; Harrison et al., 1992). This balance is important if energy expenditure in ATM is to match that of LTM.

Speed

Walking Studies

One of the earliest ATM studies examined the metabolic and heart rate responses of walking on an ATM at different water depths (Gleim, & Nicholas, 1989). Their results showed that increasing water depth in ATM causes an increase in the work of walking and jogging. At speeds greater than or equal to 134.1 $m \cdot min^{-1}$, or a jogging pace, VO_2 in waist deep water was not significantly greater than dry jogging (Gleim, & Nicholas, 1989). Another interesting result of their study was that the VO_2 of walking at knee and mid-thigh levels were not significantly different. In fact walking at waist level produced a lower VO_2 than either knee or mid-thigh levels. This is due to the fact that the increased buoyancy due to the higher water level offset the frontal resistance.

In looking at the cardiorespiratory responses to underwater treadmill walking, Hall et al. (1998) examined eight healthy women as they preformed submaximal exercises on land and water treadmills in chest deep water. Five minute tests were preformed at varying speeds (3.5, 4.5 and 5.5 $km \cdot h^{-1}$). Two temperatures (28°C and 36°C) were also tested to see if temperature would influence cardiorespiratory responses. At a speed of 3.5 $km \cdot h^{-1}$, VO_2 was similar. For speeds 4.5 and 5.5 $km \cdot h^{-1}$, VO_2 was significantly higher in ATM than on land with no significant difference in water temperature. The temperature of water did influence HR, with HR being greater at 36°C.

The similarity of VO_2 responses for walking at a speed of 3.5 $km \cdot h^{-1}$ for the ATM and LTM can be explained by relating the resistance to the speed of the movement (Hall et al., 1998). Since the speed was slower it did not create enough drag forces to significantly change the VO_2. The overall conclusion of their study was that walking in chest deep water at a speed greater than 4 $km \cdot hr^{-1}$ required more energy than the same speed on land (Hall et al., 1998).

Hall et al. (2004) conducted a study examining the relationship between walking on land and water in people with rheumatoid arthritis. The goal of this study was to examine the cardiorespiratory responses and how they compared. This was accomplished by performing VO_2 tests on fifteen female patients walking at 2.5, 3.5, and 4.5 $km \cdot h^{-1}$ in two conditions: on land and on the ATM with the water level at the xiphoid process and water temperature being 34.5°C.

The results showed a lower VO_2 response for walking in water than land at 2.5 and 3.5 $km \cdot h^{-1}$. At 4.5 $km \cdot h^{-1}$ there was no difference between VO_2. As expected, HR increased on land and water as the treadmill speed increased. For speeds of 2.5 and 3.5 $km \cdot h^{-1}$ HR was significantly lower in water than on land. However, it was higher in water at 4.5 $km \cdot h^{-1}$.

These results showed that VO_2 in water is dependent upon the speed at which one walks. At lower speeds, results suggest that resistance to movement is minimal and the effects of buoyancy are felt to a greater extent (Hall et al., 2004). That then results in a lower metabolic demand. As speed increases, more resistance is felt to the extent that it overcomes the effects of buoyancy and requires a greater metabolic demand (Gleim & Nicholas, 1989; Hall et al., 1998;

Hall et al., 2004). It can be concluded that energy expenditure is linked to velocity.

Masumoto, Shono, Hotta, and Fujishima (2008) also tested the physiological responses of walking on a flowmill. A flowmill differs from other aquatic treadmills because the current that is applied to the subject in the pool matches the speed at which the subject is walking or running, whereas other aquatic treadmills allow varied adjustments in speed and water jets. In this particular study, nine healthy older female subjects preformed three tests walking on land at speeds of 2.4, 3.6, and 4.8 $km \cdot h^{-1}$ and in water at speeds of 1.2, 1.8, and 2.4 $km \cdot h^{-1}$. The speeds in water were different due to previous research that showed matched responses, to those on land, in heart rate, VO_2, and RPE when water speeds were decreased (Masumoto, Shono, Hotta, & Fujishima, 2004, 2005). The temperature was maintained at 31°C, and water level was at the xiphoid process.

At the moderate and fast speeds there was no significant difference in VO_2 between walking in water and walking on land. This was perhaps due to the adjustment in ATM speeds. At slow speed there was a significant difference in VO_2 between that of LTM and ATM. In general the VO_2 and HR were significantly higher while walking in water than on land at the same speeds. At the fastest speed, it is interesting to note that the VO_2 and HR for water walking compared to land walking were greater in water than on land. This was the opposite effect at the slow and moderate speeds. Masumoto et al. (2008)

validated previous research that had shown that walking in water at speeds half to that on land produces similar metabolic responses.

In a study done on walking and running in water at different depths, Pohl and McNaughton's (2003) participants walked and ran in two different water depths (thigh-deep and waist-deep water), and the researchers compared it to walking and running on land. The results showed that the VO_2 values for running at thigh-deep water level was significantly higher than running at waist-deep or running on land. For all tests running VO_2 was greater than walking VO_2. The VO_2 values from walking to running at thigh deep also increased at a greater rate than those VO_2 values on land and at waist deep (Pohl, & McNaughton, 2003). The HR responses varied with depth and mode with HR being the greatest in thigh deep water for running and walking.

An explanation for these varying results may be due to the buoyancy of water and the water resistance felt by the subject. Since VO_2 is proportional to the work load, the added resistance of running at thigh-deep and waist-deep water may have caused an increase in VO_2 when compared to land. The buoyancy of water and the stride frequency could explain the differences in VO_2 values between thigh-deep water and waist-deep water. For waist-deep water more of the body is supported by the water causing the flight phase to be prolonged (Dowzer et al., 1999). The buoyancy would not affect walking as much because there is not a flight phase (Pohl, & McNaughton, 2003).

It has been concluded that in order for metabolic values of aquatic running to resemble those of land based running there needs to be a balance between resistance and buoyancy. Pohl and McNaughton (2003), observed that the water depth is a key factor for achieving a particular desired VO_2 outcome.

ATM Training

Greene et al. (2009) compared LTM with ATM training in overweight and obese individuals. The purpose of the training was to examine the differences in body composition, weight loss, and cardiovascular fitness over a 12 week training program. Pre-tests of body composition, VO_2 max, and initial weight were assessed. Participants were instructed to maintain their normal diet. The participants were then randomly assigned to either LTM or ATM training groups. The exercise protocol consisted of meeting three times a week with intensity increasing from week to week. During ATM the depth of the water was at the fourth intercostal space and jets were directed at the umbilicus (Green et al., 2009).

The results showed no significant differences in reduction of percent body fat between both LTM and ATM groups, with both groups showing significant fat loss. Total body weight was also decreased for both groups, and lean body mass was maintained for the LTM exercise group. An interesting finding of this study showed an increase in lean body mass in the ATM group with an average increase of 0.6 ± 0.3 kg (3.2%). This increase, as Greene and associates explain, is approaching significance ($P = 0.0599$) (Greene et al., 2009). This study provides evidence of the effectiveness of using the ATM as a means for exercise training in overweight and obese individuals and possibly other populations as well.

Running Studies

Silvers et al. (2007) examined the effects of running on an ATM and on a LTM. Twenty-three collegiate runners preformed maximal tests in 28°C water with water depth at xiphoid process level. For this test, water jets were used at 40% capacity directed at the runner's torso. This was to help promote a normal running pattern (Silvers et al., 2007). The results of the maximal test on land and in water showed no difference in VO_2, HR, RER, RPE, and test time.

The results of this study showed that running on an ATM and on a LTM can both evoke similar peak cardiorespiratory responses (Silvers et al., 2007). These results also give encouragement for the use of water jets in combination with the ATM to help compensate for the effects of buoyancy. These findings are important as previous research has conflicted about the cardiorespiratory responses of ATM running and LTM running (Gleim, & Nicholas, 1989; Pohl, & McNaughton, 2003).

As mentioned previously, knowing the appropriate water depth and that it is possible to achieve the same cardiorespiratory responses by running in water as on land, precision in determining matching speeds and jet resistance to that of land based running is an area of research which Rutledge et al. (2007) sought to determine. Their study consisted of fifteen runners, tested in nine different trials. Three different ATM speeds were chosen (174, 201, and 228 $m \cdot min^{-1}$) and three different jet resistances were chosen (0%, 50%, and 75%). Participants ran on the ATM with the water level at their xiphoid and the jets aimed at the middle of their torso. There was no significant difference between the VO_2 for the ATM trials compared to the LTM. This implies that one can receive similar cardiorespiratory responses for ATM running as for LTM running. The metabolic cost for ATM running also increased with increased amount of jet resistance demonstrating that one can increase energy expenditure without having to increase speed.

In an attempt to establish ATM running parameters with land running cardiorespiratory responses, Rife et al. (2010) compared running in three different conditions: on land, on ATM without shoes, and on an ATM with water shoes. Eighteen trained subjects participated in this study and, after taking a maximal VO_2 test, preformed three other running tests at different intensities. Each submaximal test included running at 50%, 60%, 70%, and 80% of the VO_2 max. The running intensities were monitored through heart rate. As found in previous studies, running on an ATM elicited HR that were on average 7 bpm less than on land to achieve similar cardiorespiratory overload (Svedenhag, & Seger, 1992).

The results showed that at a comparable HR of 150 bpm, VO_2 was significantly less during land running than aquatic running with shoes and without shoes. Wearing the water shoes increased VO_2 by 4.12 $mL \cdot kg^{-1} \cdot min^{-1}$. This supports previous aquatic running studies. Running on the ATM has the potential to elicit similar and greater metabolic responses as running on land at similar speeds.

A similar study conducted by Greene, Greene, Carbuhn, Green, and Crouse (2011), examined the metabolic responses of ATM and LTM walking and jogging. Twenty-four participants preformed six separate exercise sessions including, a land trial at 0% grade, and five water trials in chest deep water at 0%, 25%, 50%, 75%, and 100% jet resistance. For all trials the speed was progressively increased every three minutes. Oxygen uptake and heart rate were measured throughout each trial.

The results showed that LTM VO_2 was greater than ATM VO_2 for all speeds with 0% jet resistance. Unless there was some jet resistance, LTM walking or running is more demanding than ATM. These results showed that unless there is added jet resistance there is not enough of a drag force to counter forward movement. The population that was used in this study was more overweight than other populations in previous studies that may explain the lower ATM VO_2 than on land because there was a greater buoyancy.

Summary

There are several different physiological responses from the varying forms of aquatic walking and running. Because of the many factors that influence the body's response, the research has tried to show the modality that elicits physiological responses most similar to those on land. In attempts to do this, water depth and speed have been adjusted to find a balance between buoyancy, gravity, and frontal resistance. The ATM provides the best controlled environment in which speed and water depth can be adjusted. The research has shown that this form of aquatic running elicits cardiorespiratory responses most similar to those on land while not compromising joint stress especially for elderly, obese, and those recovering from injury.

Although previous studies have compared the metabolic demands between LTM and ATM running there still remain a few gaps in the research at particular exercise intensities. Missing ATM speeds include 6 mph, 7 mph, and 8 mph with 40%, 60%, 80%, and 100% jet resistances. The purpose of this study is to fill in those missing gaps in an attempt to further compare and explain the physiological responses between LTM and ATM running. This is done in an attempt to assist with understanding between the two modalities and assist in gaining more specified exercise protocols for ATM to elicit results most similar to those on LTM.

CHAPTER III

METHODOLOGY

This chapter will explain the study design, participants, procedures, instrumentation, and statistics that will be used in this study. The purpose of this study is to further examine the cardiorespiratory responses of the body during selected speeds and jet resistances of aquatic treadmill (ATM) running compared to that on a land treadmill (LTM) in order to develop prediction equations to estimate land speed from aquatic conditions.

Research Design

This is a case controlled observational study in which participants know what treatment is being administered. It is case controlled because the sample includes individuals with a particular characteristic. It is considered an open label trial because the participants know what treatment is being allocated. The purpose of this study is to answer the following research questions:

1. What are the cardiorespiratory responses while running on an ATM at selected speeds and water jet resistances?
2. What are the cardiorespiratory responses while running on a LTM at selected speeds?
3. What LTM running speed corresponds with a particular ATM running speed and jet resistance?

Participants

The subject sample originally consisted of 20 subjects (13 males, 6 females); however, due to injury (one male) and inability to schedule test sessions (one female) a final sample of 18 individuals (12 males, 5 females) were subsequently used for data analysis. Table 1 shows the characteristics of the population used. All of the subjects were between the ages of 18 - 40 years (25.3 ± 6.8). Five of the participants were college athletes, two were from a local running club, and 11 were college students who were recreational runners. The runners were well conditioned and in shape with an average body fat percentage of 13% ± 6% and an average VO_2 peak of 53.8 ± 8.3 $mL \cdot kg^{-1} \cdot min^{-1}$.

All participation was voluntary. Participants were contacted initially by contacting members of local running clubs, university track and cross country athletes, and students in physical education classes on campus. Those with

Table 1.
Descriptive Statistics (*N* = 18)

	Min	Max	*M*	*SD*
Age (year)	18	40	25.3	6.8
Height (cm)	162.6	188.0	173.1	8.1
Weight (kg)	51.4	86.7	65.8	9.7
Body Fat %	6	33	13	6
$VO_{2\ peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	35.9	63.7	53.8	8.3

interest in participating were then e-mailed regarding the purpose and design of the study. They were also informed of the requirements to be in the study. Those who returned e-mails were then contacted by phone. All subjects were provided a letter describing the participation requirements and informed consent was acquired (Appendix B). This study was reviewed and approved by the Institutional Review Board (IRB) of Utah State University (Appendix A).

Requirements that the participants had to meet in order to be included in this study were; 1) having run consistently for the last six months with running an average of five times a week for an average of 30 minutes per session or a weekly average of 25 miles or more, 2) currently free of any acute injuries or orthopedic conditions or disabling injuries that would not allow them to run and were free of pain or any restrictions that would interfere with normal running mechanics, 3) good health, and 4) able to dedicate the needed time to participate in this study. Because of the nature of this study and the demanding protocol, it was important that the participants were in good health and had the endurance and muscular capabilities to allow them to run at high speeds with great resistance. For this reason it was important that participants were screened beforehand, therefore limiting the population of study.

Equipment

LTM procedures were performed on a standard land adjustable treadmill (FreeMotion Fitness, Colorado Springs, CO.). Expired air was analyzed using a True One 2400 automated metabolic system (ParvoMedics TrueOne, Consentius

Technologies, Sandy, UT) which was calibrated before each test. Heart rate chest straps (Polar T31, Polar Electro, Lake Success, NY,) were worn by participants to monitor heart rate (HR). Rate of perceived exertion (RPE) was also monitored using Borg's 15 point scale (Borg, 1982). ATM protocols were administered on a HydroWorx 2000 (HydroWorx Inc., Middletown, PA) which consisted of an 8' x 12' pool with moveable floor and adjustable jets.

Procedures

Each subject participated in three testing days over the period of two weeks. At the orientation session baseline information was collected such as age, height, weight, and body fat percentages using Jackson et al. (1980) three site skinfold equation. This was followed by a familiarization period in which subjects ran on the ATM for several minutes and were exposed to changes in running speed and jet resistances in the ATM.

Participants received a reminder phone call a few days before their scheduled data collection. During this phone call the participants were reminded to, 1) refrain from any strenuous exercise for the 24 hr leading up to their scheduled data collection, 2) to maintain their normal eating pattern prior to a 1 hr run, and 3) to bring the proper running attire depending on if the test that day would be on the LTM or ATM. For the LTM normal outdoor running attire was requested. For the ATM trials snug shorts and tops were asked to be worn to decrease drag. All testing occurred in the USU Dale Mildenberger Sports Medicine Center.

The entire data collection varied from an hour to an hour and a half depending on the particular test for that day. The participants were divided into three groups and tested in two week intervals. This not only helped with scheduling but also enabled there to be less time between tests allowing for less variability due to uncontrolled changes of fitness or health. These tests occurred in the USU sports medicine facility. The testing period lasted two weeks with two days of testing each week.

The first testing session consisted of an ATM familiarization session. This session included running on the treadmill in xiphoid deep water at various speeds and varying jet resistances in order to help the subject become comfortable running in the water and with jets.

As part of the first testing session all participants completed a VO_2 max test on an ATM to obtain peak aerobic capacity. An incremental treadmill protocol was used in order to obtain a base line. This protocol consisted of subjects running to exhaustion. The initial starting speed of the treadmill was self selected, based on individual's running capability, with 0% jet resistance. The speed was then increased every minute by 0.5 mph until the subject reached maximum comfortable running pace. Once that pace was reached the jet resistance was added starting at 40% jet resistance and increased by 10% every minute until voluntary exhaustion. HR and expired air were continuously monitored. Expired air was analyzed for volume, percent oxygen consumption, and carbon dioxide content for VO_2 determination. The criteria for meeting peak VO_2 was a leveling off of VO_2 (within 1.5 $mL \cdot kg^{-1} \cdot min^{-1}$ over consecutive minutes near the end of the test) with an increase in work rate, a HR close to age-predicted (220 – age) maximum HR, and a RER greater than 1.1 (Silvers et al., 2007). Results from previous research has shown that HR is typically lower on the ATM; therefore, if HR did not have to be within 10 bpm of HR max but rather show an increase with increasing work rate and a leveling off of HR as subject reached VO_2 max.

The mode for the next testing day was randomly selected. Individual trials were randomly assigned for each day. Each subject had 48 hr between each testing day to allow for adequate rest. There was one testing day on the ATM and one testing day on the LTM.

The aquatic conditions consisted of running on the ATM at three self selected speeds. During each speed jet resistances of 0, 20%, 40%, 60%, 80%, and 100% were applied. Two jet ports propelled water towards the torso of the individual running. These were adjusted based on an individual's height. Before each test these were adjusted to ensure that they targeted at the torso of the subject just above the umbilicus.

Subjects were positioned one meter in front of the jets to standardize the delivery of jet water flow throughout all testing conditions. Visual markers were set on the side and front of the pool to help the subject stay in front of the jets and at the proper distance from them. Underwater video cameras recorded frontal and sagittal views and displayed relative position on a TV screen for the subject to view and use to facilitate proper running position.

Each subject ran at a particular testing trial for at least three minutes until steady state conditions were achieved. VO_2 was taken by measuring expired air in 15 second increments. A subject was considered at steady state when VO_2 measurements remained within 1.5 $mL \cdot kg^{-1} \cdot min^{-1}$. HR and expired air were continuously monitored while RPE was solicited immediately after each trial was completed. Subjects received a three minute recovery period between each trial. Subjects completed a total of 18 trials during the ATM session.

The LTM running trials were conducted in a similar manner with each subject completing trials at the same three self selected ATM speeds. The subjects were instructed to select speeds that would represent an easy, medium, and hard effort.

Statistical Analyses

Data were analyzed using Excel (version 14.1.2). Mean and standard deviation were determined for participants age, height, weight, and body fat percentage. A linear regression equation was calculated for each jet resistance to determine the relationship of speed and VO_2 at each jet resistance. A linear regression equation was also determined for the relation between VO_2 values at different running speeds on the LTM. Finally, an equation was determined for land running speed for a given ATM speed and jet resistance by combining ATM VO_2 and LTM VO_2 linear regression equations. An r-squared value was determined for each regression equation.

CHAPTER IV

RESULTS

The purpose of this study was to examine the cardiorespiratory responses during ATM running at varying speeds and jet resistances, to observe changes in cardiorespiratory responses on a LTM, and to compare cardiorespiratory responses on an ATM to those on a LTM. This comparison between the two exercise modalities would allow for prediction equations to estimate VO_2 given certain ATM running conditions and then to estimate land speed at a similar metabolic cost.

The speeds selected by the subjects ranged from 4.5 mph to 8.2 mph with a mean and standard deviation for speed of 6.0 ± 0.9 mph. Table 2 and Figure 1 illustrate the mean and standard deviation results for ATM settings. Table 3 illustrates the mean and standard deviation results for the LTM settings.

Table 2.
Mean and SD results for ATM running speeds and jet resistances.

Jet Percentage	**Mean Slow VO_2**	**StDev Slow VO_2**	**Mean Medium VO_2**	**StDev Medium VO_2**	**Mean Fast VO_2**	**StDev Fast VO_2**
0	26.0	5.1	29.4	5.9	32.6	7.4
20	26.6	4.7	30.7	6.0	34.7	8.3
40	29.8	5.8	33.4	6.7	36.9	7.2
60	34.1	5.9	39.3	6.7	42.5	7.7
80	42.3	5.5	45.7	7.1	49.4	6.5
100	48.7	7.2	50.1	7.6	50.3	7.8

Note. VO_2 is in $ml \cdot kg^{-1} \cdot min^{-1}$

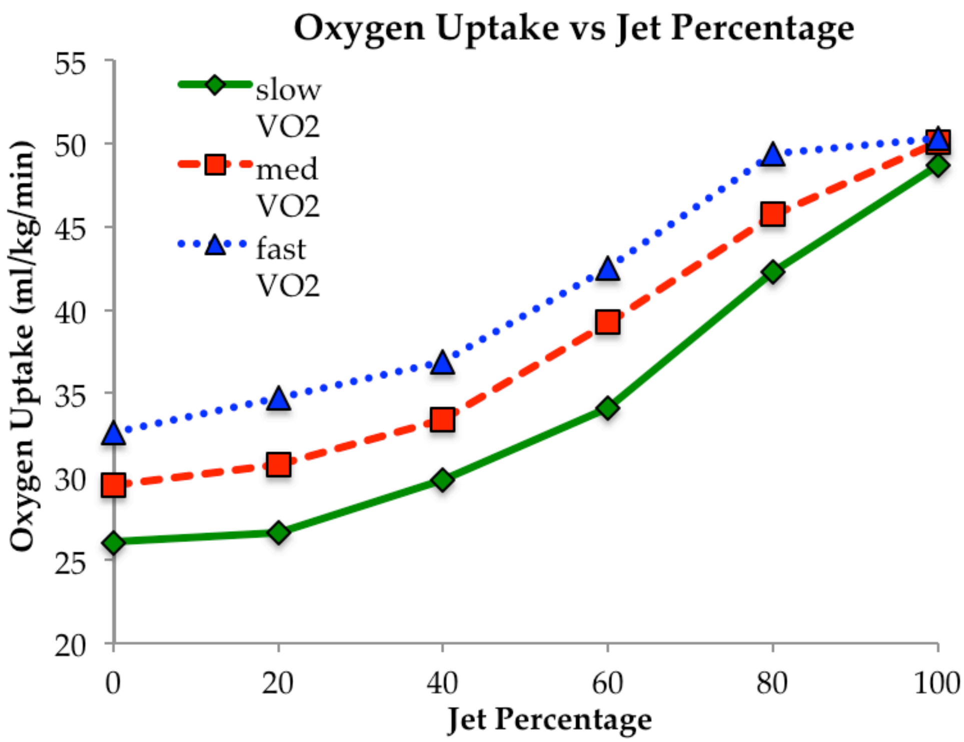

Figure 1. Relationship of jet resistance, speed and VO_2

Table 3.
Mean and SD results for ATM running speeds

Running Speed	**Average Speed**	**StDev Speed**	**Average VO_2**	**StDev VO_2**
Slow	5.29	0.63	29.15	4.88
Medium	6.01	0.65	32.77	4.88
Fast	6.79	0.73	35.43	5.26

The linear regression equation for each aquatic condition is seen in table 4. Each equation provides a predicted VO_2 for a given ATM condition. Measurement for VO_2 was in ml/kg/min^{-1} and running speed is in miles per hour. The varying jet resistance percentages are a percentage of the maximum jet flow for the ATM system. Figure 2 provides a graphical representation of these data.

Table 4.
Linear Regression Equations for each Jet Resistance Setting.

Jet Resistance	**Equation**	**R^2 Value**
0%	VO_2 = 4.4 (speed) + 3.0	.99
20%	VO_2 = 5.4 (speed) – 1.7	.99
40%	VO_2 = 4.7 (speed) + 5.0	.99
60%	VO_2 = 5.6 (speed) + 5.1	.98
80%	VO_2 = 4.7 (speed) + 17.3	.99
100%	VO_2 = 1.1 (speed) + 43.2	.81

Note. VO_2 is in $ml \cdot kg^{-1} \cdot min^{-1}$ and speed is in mph.

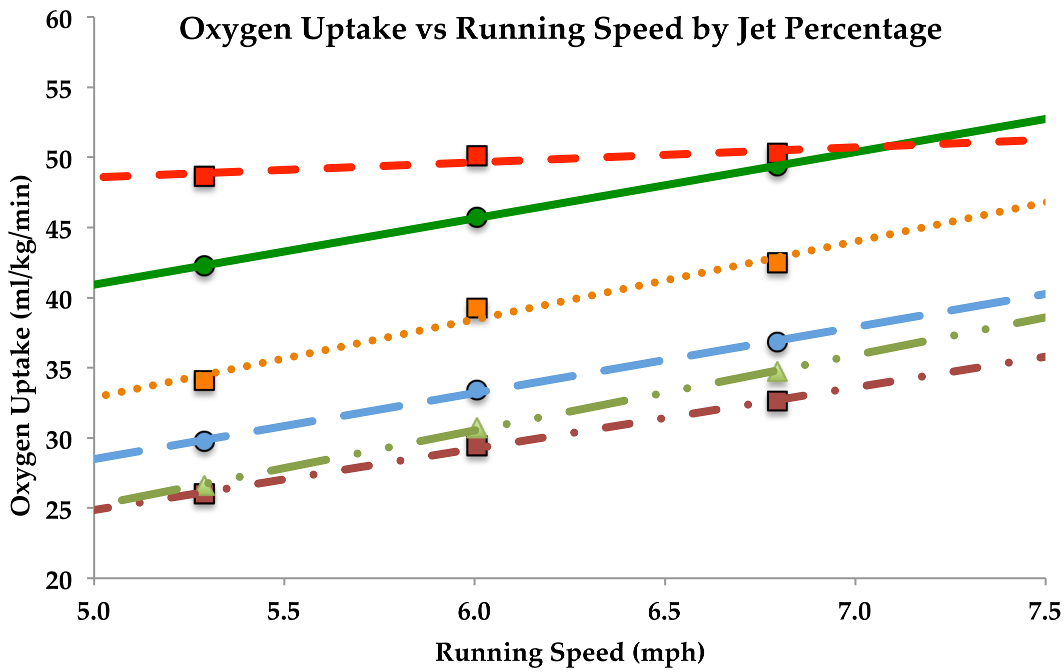

Figure 2. Linear relationship of ATM running speed, jet resistance and VO_2

The second part of the analysis included developing a similar prediction equation for predicting VO_2 during running on LTM. This resulted in the following prediction equation: $VO_2 = 4.2 \text{ (speed)} + 7.4$ with an r-squared value of .99. Figure 3 depicts this linear regression.

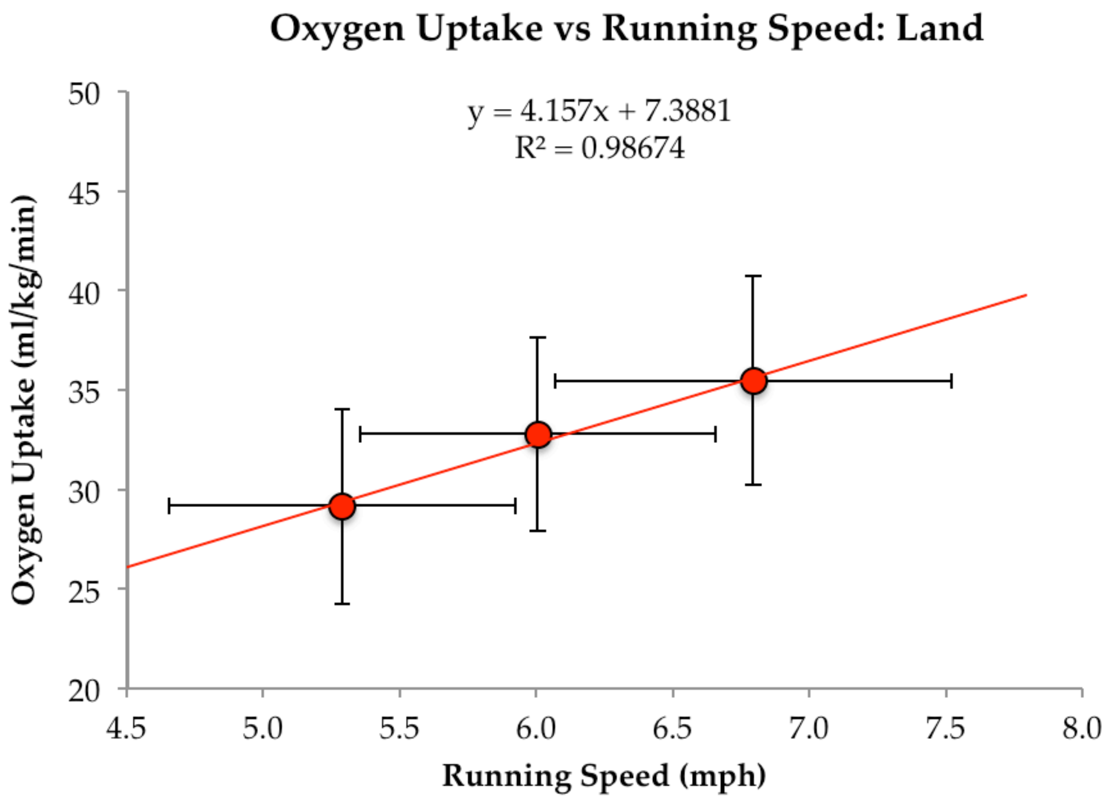

Figure 3. Relationship of land speed and VO_2

A combination of both ATM and LTM linear regression equations is used to predict a particular ATM condition given a LTM speed. This combination of linear regression equations can also be used to predict a particular land speed given an ATM condition. These comparisons are seen in tables 5 and 6, and figures 4 and 5.

Table 5.
Prediction Equations for ATM Speed and Jet Resistance

Jet Resistance	Prediction Equation
0%	Aquatic speed = 0.95 * land speed + 1.00
20%	Aquatic speed = 0.77 * land speed + 1.69
40%	Aquatic speed = 0.88 * land speed + 0.51
60%	Aquatic speed = 0.75 * land speed + .41
80%	Aquatic speed = 0.88 * land speed – 2.10
100%	Aquatic speed = 3.87 * land speed – 33. 40

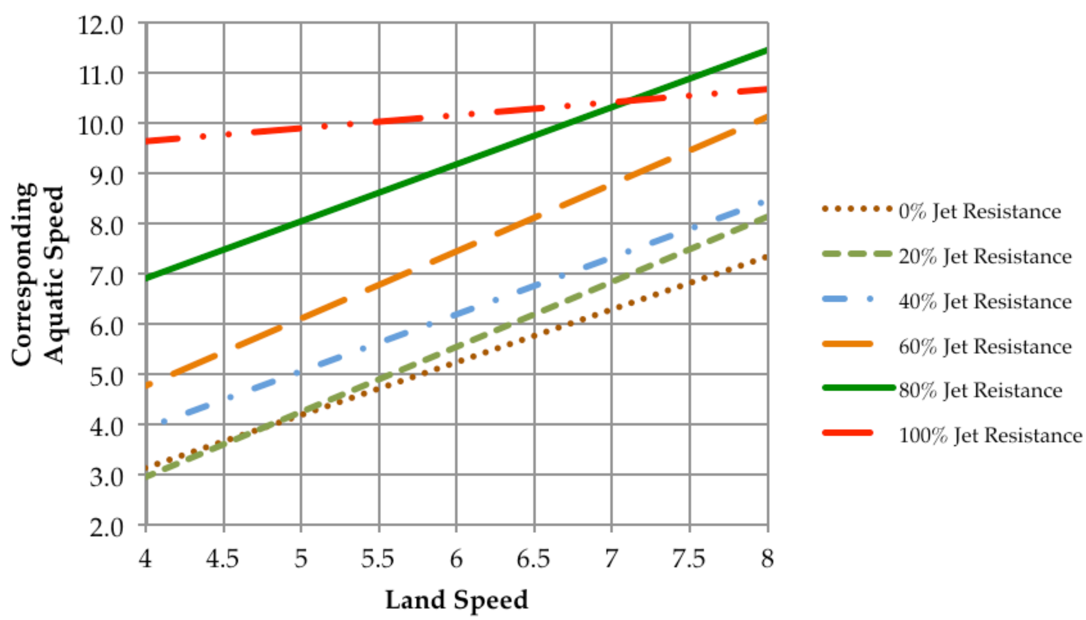

Figure 4. Land Speeds with Corresponding Aquatic Speeds and Jet Resistances

Table 6.
Prediction Equations for LTM Speeds

Jet Resistance	Prediction Equation
0%	Land Speed = 1.05 * aquatic speed – 1.05
20%	Land Speed = 1.29 * aquatic speed – 2.18
40%	Land Speed = 1.13 * aquatic speed – 0.58
60%	Land Speed = 1.34 * aquatic speed – 0.55
80%	Land Speed = 1.14 * aquatic speed + 2.39
100%	Land Speed = 0.26 * aquatic speed + 8.62

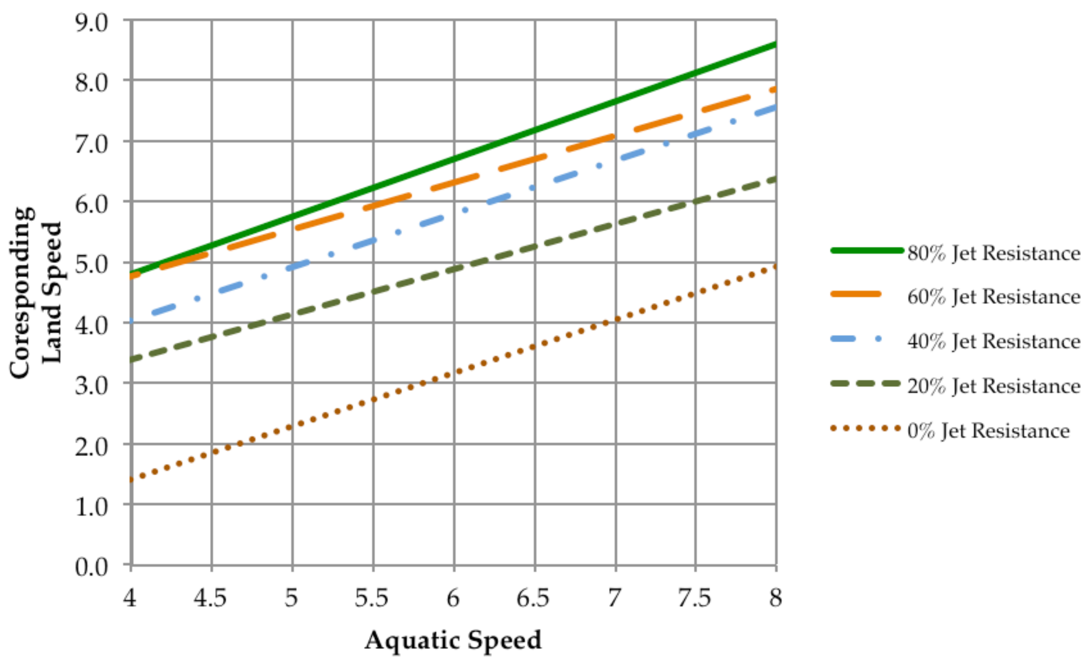

Figure 5. Aquatic Speeds and Jet Resistances with Corresponding Land Speed

CHAPTER V

DISCUSSION

The purpose of this study was three fold: 1) To examine the cardiorespiratory responses while running on an ATM at selected speeds and water jet resistances, 2) To examine the cardiorespiratory responses while running on a LTM at selected speeds, and 3) To understand what LTM running speeds correspond with a particular ATM running speed and jet resistance.

The results of this study support those of previous studies examining the metabolic cost of ATM running in that, increasing the speed and jet resistances increases the metabolic cost (Gleim & Nicholas, 1989; Rife, et al., 2010; Rutledge, et al., 2007). For example, Rutledge et al. (2007) reported with ATM at a set speed of 174 $m \cdot min^{-1}$ (6.48 mph), VO_2 averaged 33.97 $ml \cdot kg^{-1} \cdot min^{-1}$ at 0% jet resistance, 39.81 $ml \cdot kg^{-1} \cdot min^{-1}$ at 50% jet resistance, and 45.28 $ml \cdot kg^{-1} \cdot min^{-1}$ at 75% jet resistance. To exemplify this same pattern using the linear regression equations for each jet resistance setting (table 3), for a subject running at 6.0 mph with 0% jet resistance the resulting VO_2 would be 29.4 $ml \cdot kg^{-1} \cdot min^{-1}$. If the jet resistance was then increased to 60% and the speed was held constant at 6.0 mph the resulting VO_2 would be 38.7 $ml \cdot kg^{-1} \cdot min^{-1}$.

VO_2 during ATM also increased with increased running speed while maintaining 0% jet resistance. For example, one subject (Subject #10) self-selected 5, 6, and 7 mph (see appendix D). At the three different speeds and 0% jet resistance, VO_2 values of 23.74 $ml \cdot kg^{-1} \cdot min^{-1}$, 33.22 $ml \cdot kg^{-1} \cdot min^{-1}$, and 37.69 $ml \cdot kg^{-1} \cdot min^{-1}$ were observed. These findings are similar with those of Rutledge et al.

(2007) who reported at 174 $m{\cdot}min^{-1}$ (6.48 mph), 201 $m{\cdot}min^{-1}$ (7.49 mph) and 228 $m{\cdot}min^{-1}$ (8.50 mph) VO_2 increased from 33.97 to 37.96 to 43.63 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. Gleim and Nicholas (1989) observed similar responses as running speed increased from 120.7 $m{\cdot}min^{-1}$ (4.5 mph) to 160.9 $m{\cdot}min^{-1}$ (6 mph). The average change in VO_2 increased from 27.2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ to an average VO_2 of 33.4 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. Gleim and Nicholas's study used a water level at the umbilicus so the relationship between buoyancy and resistive drag forces would be different than those in the present study.

Comparing 0% jet resistance on the ATM and 0% incline on LTM for a similar speed yields interesting results. For example, the aquatic condition prediction equation for 0% jet resistance and 6 mph yields a VO_2 of 29.24 $ml{\cdot}kg^{-1}{\cdot}min^{-1.}$ If the prediction equation for the land condition is solved for VO_2 at the same speed, it would yield a VO_2 of 32.33 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, suggesting that in order to match the predicted aquatic equation it would not be necessary to run at as great of a speed, rather only a speed of 5.24 mph would be required. These results differ from those of Rutledge et al. (2007) who observed that running on land at 6.5, 7.5, and 8.5 mph yielded VO_2 values that were similar to ATM scores at the same speeds with 0% jets. Similar ATM systems, metabolic carts, and water depth were used in both studies. Differences in running economy may have partially contributed to these differences.

The results of adding jet resistances demonstrated that comparing 0% to 20% and 20% to 40% jet resistances did not substantially change the predicted land speed. The aquatic and land prediction equations show that once one reaches 40% jet resistance the speed on land required to match a similar VO_2 is greater than that in water and continues to increase with increasing jet resistance. However, as seen above, at lower jet resistances and no jet resistance a subject's predicted speed on land is lower than that in the water. At 20% jet resistance and 6 mph, an estimated VO_2 value of 30.54 $ml \cdot kg^{-1} \cdot min^{-1}$ is given. In order to match this same VO_2 value a subject would need to run 5.57 mph which is less than the ATM speed. At 40% jet resistance and 6 mph, an equivalent speed on land would be 6.14 mph. This is a similar trend found by Rutledge et al. (2007) at higher jet resistance. An average metabolic cost of running at 174 $m \cdot min^{-1}$ with 75% jet resistance produced similar VO_2 value as running on land at 228 $m \cdot min^{-1}$. Thus, at greater jet resistances a greater speed on land is needed to match a similar VO_2.

The water trials consisted of six different jet conditions, while the land trial only evaluated level running and did not add a second factor (slope or incline). Rife et al. (2010) did not develop a regression equation to predict VO_2 during ATM with no jets; however, a visual examination of Figure 5 in their manuscript appears to present a range of VO_2 values from ~25 – 45 $ml \cdot kg^{-1} \cdot min^{-1}$ during running trials ranging in speeds between ~5.5 to 7.0 mph. Therefore, it appears that the ability to predict VO_2 during ATM may be more challenging than on LTM.

This is not unusual when compared to other regression equation results from land studies. Hall et al. (2004) compared five different running prediction equations and calculated that most prediction equations overestimated or underestimated energy expenditure ranging from 3 - 10%. In a similar study, Ruiz and Sherman (1999) evaluated the American College of Sports Medicine metabolic equation for estimating the oxygen cost of running and discovered that it significantly overestimated VO_2 on average by 4.7 $ml \cdot kg^{-1} \cdot min^{-1}$, overestimating the oxygen cost of running in 88% of their subjects, comparable to an average error of 9%.

Previous research examining an increase in speed on land with increased metabolic cost shows similar results of those found in the LTM in the present study (Bassett, Giese, Nagle, Ward, Raab, & Balke, 1987; Jones, & Doust, 1996; Robergs, Wagner, & Skemp, 1997). Jones and Doust (1996) examined predicting a treadmill grade that most closely reflects the energy cost of outdoor running. Looking at six different speeds, they observed variability among the VO_2 values and an average standard deviation of 2.33 $ml \cdot kg^{-1} \cdot min^{-1}$. Jones and Doust (1996) also observed that their prediction equations on average yielded considerably lower VO_2 estimates than those of previous studies.

Another explanation for the interaction of jet resistances and speed is due to the buoyancy effect on different body compositions. Although the average subject's body fat percentage was 13 ± 6% and average weight was 65.83 kg ± 9.71, varying body shapes may have influenced the felt impact of jet resistances. For a smaller subject the amount of work required to stay at the proper distance from the jets at 80% and 100% jet resistances was harder than a larger subject at the same jet settings. The difference in torso surface area relative to overall body mass may be a factor that further investigations need to take into account. These discussions are currently ongoing in our laboratory.

The amount of buoyancy also decreases the metabolic demands of exercising in the water by increasing a subject's time in flight phase thereby decreasing energy expended (Rife et al. 2010). Previous studies have examined the effects of buoyancy and suggested that running at the level of the xiphoid as an appropriate balance of buoyancy and drag forces (Rutledge et al., 2007). The amount of buoyancy is affected by body composition and thus might influence energy expenditure differently based on the population of subjects studied. This relationship awaits further study.

Another explanation for the interaction of jet resistances and speed are seen in the results. At lower jet resistances (20% and 40%) there was a trend for smaller changes in VO_2 compared to the jet resistances at 60%, 80%, and 100%. This also suggests that the lower jet resistances have less of an effect on VO_2 thereby causing a decreased land speed requirement to meet similar aquatic VO_2. Preliminary estimates of drag forces experienced on the human body due to jet resistances remain quite low until jet resistances reach 40% (unpublished observations).

Limitations

One of the limitations of the prediction equations is that they are only applicable to a similar population of study. Although this population was a diverse set of runners, they still were limited in their representation of age, fitness level, and running experience. According to the literature reviewed similar populations have been studied in previous studies comparing ATM and LTM (Rife et al., 2010; Rutledge, et al., 2007; and Silvers, et al. 2007). Cross-validation of this equation with subjects of diverse characteristics is required to evaluate the equation's efficacy.

Another limitation of this study is that not all subjects were able to run against 100% jets, especially at their highest self-selected running speed. There were several subjects who had reached close to, if not at, their peak VO_2 at 100% jets while running at their greatest self-selected running speed. Therefore, there was an observed leveling off or plateau between the 80 and 100% jet condition. In general the water turbulence created by this maximum jet setting created what several subjects subjectively reported as an unstable running condition. They experienced difficulty not only in terms of effort but in attempting to maintain what they perceived to be typical running form. However, this does pose an interesting question. If running form tends to deteriorate at this jet setting, would it be prudent for therapists and/or sport coaches to have their participants train in this condition? Understanding any alterations in gait at this high jet resistance awaits further study.

Implications

These regression equations provide information for designing treatment protocols for athletes who want to maintain their fitness level while recovering from injury. They can help coaches and physical therapists who might be less familiar with ATM conditions develop a more precise training program. They also could be useful for recovering athletes when they are able to return to their sport. For example, knowing what speed and jet resistance one has been recovering at in the ATM can help the athlete predict an approximate land speed that stresses the cardiorespiratory system to the same extent.

These prediction equations may also be helpful for someone who is not injured wanting to cross train using an ATM. Although ATM currently are not easily accessible, being able to make predictions for aquatic conditions and know how ATM running and LTM running compare could be helpful for a first time user or athletes wanting to add variety to their training.

Conclusion

Based off our findings and current research, ATM running can elicit similar metabolic responses with those on land. The prediction equations may provide physical therapists with useful information when making treatment programs for their patients. Suggestions for future research include cross-validation of this equation and comparing metabolic costs of ATM employing jet resistance with inclined running with LTM.

REFERENCES

Agostoni, E. G., Gurtner, G., Torri, G., & Rahn, H. (1966). Respiratory mechanics during submersion and negative-pressure breathing. *Journal of Applied Physiology, 21*, 251-258.

Alkurdi, W., Paul, D. R., Sadowski, K., & Dolny, D. G. (2010). The effect of water depth on energy expenditure and perception of effort in female subjects while walking. *International Journal of Aquatic Research and Education, 4*, 49-60.

Arborelius, M., Baildin, U. I., Lilja, B., & Lindgren, C. E. G. (1972). Hemodynamic changes in man during immersion with the head above water. *Aerospace Medicine, 43*, 592-598.

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.

Bassett, D. R., Giese, M. D., Nagle, F. J., Ward, A., Raab, D. M., & Balke, B. (1985). Aerobic requirements of overground versus treadmill running. *Medicine and Science in Sports and Exercise, 17*, 477-481.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14*, 377-381.

Brown, S. P., Chitwood, L. F., Beason, K. R., & McLemore, D. R. (1997). Deep water running physiological responses: gender differences at treadmill-matched walking/running cadences. *Journal of Strength and Conditioning Research, 11*, 107-114.

Bryne, H. K., Craig, J. N., & Willmore, J. H. (1996). A comparison of the effects of underwater treadmill walking on oxygen consumption, heart rate, and cardiac output. *The Journal of Aquatic Physical Therapy, 4*, 4-11.

Chu, K. S., Rhodes, E. C., Taunton, J. E., & Martin, A. D. (2002). Maximal physiological responses to deep-water and treadmill running in young and older women. *Journal of Aging and Physical Activity, 10*, 306-313.

Dale, R. B. (2007). Deep water running for injured runners. *Athletic Therapy Today, 12*, 8-10.

Dowzer, C. N., Reilly, T., Cable, N. T., & Nevill, A. (1999). Maximal physiological responses to deep and shallow water running. *Ergonomics, 42*, 275-281.

Elliot, B. C. (1990). Adolescent overuse sporting injuries: A biomechanical review. *Australian Sports Commission Program*, *23*, 1-9.

Eyestone, E., Fellingham, G., George, J., & Fisher, G. (1993). Effect of water running and cycling on maximum oxygen consumption and 2-mile run performance. *American Journal of Sports Medicine*, *21*, 41-45.

Frangolias, D. D., & Rhodes, E. C. (1996). Metabolic responses and mechanisms during water immersion running and exercise. *Sports Medicine*, *22*, 38-59.

Frangolias, D. D., Rhodes, E. C., Taunton, J. E., Belcastro, A. N., & Coutts, K. D. (2000). Metabolic responses to prolonged work during treadmill and water immersion running. *Journal of Science and Medicine in Sport*, *3*, 476-492.

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.

Greene, N. P., Lambert, B. S., Greene, E. S., Carbuhn, A. F., Green, J. S., & Crouse, S. F. (2009). Comparative efficacy of water and land treadmill training for overweight or obese adults. *Medicine & Science in Sports & Exercise*, *41*, 1808-1815.

Greene, N. P., Greene, E. S., Carbuhn, A. F., Green, J. S., & Crouse, S. F. (2011). VO_2 prediction and cardiorespiratory responses during underwater treadmill training exercise. *Research Quarterly for Exercise and Sport*, *82*, 264-273.

Gross, M. L., & Napoli, R. C. (1993). Treatment of lower extremity injuries with orthotic shoe inserts. An overview. *Sports Medicine*, *15*, 66-70.

Hall, C., Figueroa, A., Fernhall, B., & Kanaley, J. A. (2004). Energy expenditure of walking and running: comparison with prediction equations. *Medicine & Exercise in Sports & Exercise*, *36*, 2128-2134.

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*, *77*, 278-284.

Harrison, R. A., Hillman, M., & Bulstrode, S. (1992). Loading of the lower limb when walking partially immersed: Implications for clinical practice. *Physiotherapy*, *78*, 164-166.

Hong, S. K., Song, S. H., Pim, P. K., & Suh, C. S. (1967). Seasonal observations on the cardiac rhythm during diving in the Korean ama. *Journal of Applied Physiology*, *23*, 18-22.

Hreljac, A., & Ferber, R. (2006). A biomechanical perspective of prediction injury risk in running. *International SportMed Journal*, *7*, 98-108.

Jackson, A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine & Science in Sports & Exercise 12*, 175-182.

Jones, A. M., & Doust, J. H. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sports Science, 14*, 321-327.

Kallinen, M., & Markku, A. (1995). Aging, physical activity and sport injuries. An overview of common sport injuries in the elderly. *Sports Medicine, 20*, 41-52.

Kannus, P., Niittymaki, S., Jarvinen, M., & Lehto, M. (1989). Sports injuries in elderly athletes: a three-year prospective, controlled study. *Age and Ageing, 18,* 263-270.

Masumoto, K., Shono, T., Hotta, N., & Fujishima, K. (2004). Electromyographic analysis of walking in water in healthy humans. *Journal of Physiological Anthropology and Applied Human Science*, *23,* 119-127.

Masumoto, K., Shono, T., Hotta, N., & Fujishima, K. (2005). Muscle activity and heart rate response during backward walking in water and on dry land. *European Journal of Applied Physiology*, *94,* 54-61.

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.

Miyoshi, T., Shirota, T., Yamamoto, S., Nakazawa, K., & Akai, M. (2005). Functional roles of lower-limb joint moments while walking in water. *Clinical Biomechanics, 20,* 194-201.

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.

Nobloch, K., Yoon, U., & Vogt, P. (2008). Acute and overuse injuries correlated to hours of training in master running athletes. *Foot & Ankle International / American Orthopedic Foot and Ankle Society & Swiss Foot and Ankle Society, 29*, 671-676.

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 Science, 21,* 959-972.

Rife, R. K., Myrer, J. W., Vehrs, P., Feland, J. B., Hunter, I., & Fellingham, G. W. (2010). Water treadmill parameters needed to obtain land treadmill intensities in runners. *Medicine & Science in Sports & Exercise, 42,* 733-738.

Robergs, R. A., Wagner, D. R., & Skemp, K. M. (1997). Oxygen consumption and energy expenditure of level verses downhill running. *The Journal of Sports Medicine and Physical Fitness, 37,* 168-174.

Rolf, C. (1995). Overuse injuries of the lower extremity in runners. *Scandinavian Journal of Medicine and Science in Sports, 5*, 181-190.

Ruiz, A., & Sherman, N. W. (1999). An evaluation of the accuracy of the American College of Sports Medicine metabolic equation for estimating the oxygen cost of running. *Journal of Strength and Conditioning Research, 13*, 219-223.

Rutledge, E., 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,* 131-146.

Silvers, W. M., Rutledge, E. R., & Dolny, D. G. (2007). Peak cardiorespirartory responses during aquatic and land treadmill exercise. *Medicine & Science in Sports & Exercise, 39,* 969-975.

Stanish, W. D. (1984). Overuse injuries in athletes: A perspective. *Medicine and Science in Sports and Exercise, 16,* 1-7.

Svedenhag, J., & Seger, J. (1992). Running on land and in water: comparative exercise physiology. *Medicine and Science in Sports and Exercise, 23*, 238-241.

Thompson, W. R., Gordon, N. F., Pescatello, L. S. (2010). ACSM's Guidelines for Exercise Testing and Perscription (Eighth Edition). Baltimore, MD., Philadelphia, PA: American College of Sports Medicine.

Wearing, S. C., Hennig, E. M., Byrne, N. M., Steele, J. R., & Hills, A. P. (2006). Musculoskeletal disorders associated with obesity: a biomechanical perspective. *Obesity Reviews, 7*, 239-250.

APPENDICES

APPENDIX A: IRB Approval

USU Assurance: FWA#00003308
Protocol # 2867
SPO #: AES #: UTA00

TO: FROM:
SUBJECT:
Dennis Dolny Sarah Squires, Ryan Porter
Richard D. Gordin, Acting IRB Chair True M. Fox, IRB Administrator
2/10/2011

Comparison of Metabolic Costs of Aquatic Running and Land Running at Varying Conditions and Speeds

Your proposal has been reviewed by the Institutional Review Board and is approved under expedite procedure #4 .

X There is no more than minimal risk to the subjects. There is greater than minimal risk to the subjects.
This approval applies only to the proposal currently on file for the period of one year. If your study extends beyond this approval period, you must contact this office to request an annual review of this research. Any change affecting human subjects must be approved by the Board prior to implementation. Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Institutional Review Board.
Prior to involving human subjects, properly executed informed consent must be obtained from each subject or from an authorized representative, and documentation of informed consent must be kept on file for at least three years after the project ends. Each subject must be furnished with a copy of the informed consent document for their personal records.
The research activities listed below are expedited from IRB review based on the Department of Health and Human Services (DHHS) regulations for the protection of human research subjects, 45 CFR Part 46, as amended to include provisions of the Federal Policy for the Protection of Human Subjects, November 9, 1998.

4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

APPENDIX B: Informed Consent

Introduction/ Purpose Professor Dolny in the Department of Health, Physical Education and Recreation at Utah State University is conducting a research study to find out more about the metabolic costs of aquatic running and how it compares to land running at different intensities and conditions. There will be approximately 30 total participants in this research.

Procedures If you agree to be in this research study, you will be asked to come to the Sports Medicine Complex on the campus of Utah State University four separate times. With each visit lasting about an hour with the four visits occurring within two weeks. The four visits will consist of the following:
1. VO2 max test on a land treadmill and an aquatic running familiarization period.
2. An hour of 3-4 minute running bouts on the aquatic treadmill with 3 minutes recovery in between.
3. An hour of 3-4 minute running bouts on the land treadmill with 3 minutes recovery in between.
For all tests, you will be attached to a metabolic cart which will analyze your oxygen and carbon dioxide inhaled and exhaled. This will require that the day before testing you do not participate in any strenuous exercise.

New Findings During the course of this research study, you will be informed of any significant new findings (either good or bad), such as changes in the risks or benefits resulting from participation in the research, or new alternatives to participation that might cause you to change your mind about continuing in the study. If new information is obtained that is relevant or useful to you, or if the procedures and/or methods change at any time throughout this study, your consent to continue participating in this study will be obtained again.

Risks Participation in this research study may involve some added risks or discomforts. These include
1. Dizziness due to exercising to exhaustion during the VO2 max test
(For studies involving experimental therapies, there should be a statement that unforeseen risks could occur. For studies involving sensitive issues (i.e. AIDS, drug use, alcohol abuse, criminal activity, etc.) there should be a statement that describes the risk of that information being released through legal methods. For studies with minimal risk, there should be a statement that there are no anticipated risks involved in the study.) Any risks involved with inadvertent disclosure of private records must be addressed. For research involving more than minimal risk to participants, add a statement if any compensation is available if injury occurs. If medical treatments are available if injury occurs, describe what it consists of or where further information may be obtained).

Benefits This study will provide you with knowledge of your VO2 which is an indicator of your cardiorespiratory endurance and aerobic fitness. It will also provide you with the opportunity to train on an aquatic treadmill. And your participation will help to contribute to research on the metabolic responses of aquatic running.

Explanation & offer to answer questions Dr Dolny and his research associates have explained this research study to you and answered your questions. If you have other questions or research-related problems, you may reach Professor Dolny at 797-7579

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits; simply inform the researchers of your desire to withdraw from the study.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only Dr. Dolny and research assistants Ryan Porter and Sarah Squires will have access to the data which will be kept in a locked file cabinet in a locked room. Personal, identifiable information will be destroyed following the final data analyses within a year of the completion of the study.

IRB Approval Statement The Institutional Review Board for the protection of human participants at USU has approved this research study. If you have any pertinent questions or concerns about your rights or a research-related injury, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu. If you have a concern or complaint about the research and you would like to contact someone other than the research team, you may contact the IRB Administrator to obtain information or to offer input.

Copy of consent You have been given two copies of this Informed Consent. Please sign both copies and retain one copy for your files.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

Signature of PI & student or Co-PI

____
Dr. Dennis Dolny
(435) 797-7579
dennis.dolny@usu.edu

____
Ryan Porter
Graduate Research Assistant
(phone number)

____
Sarah Squires Blackwell
Graduate Research Assistant
(801) 634-5651

Signature of Participant By signing below, I agree to participate.

______________________________ ______________________________
Participant's signature Date