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Caloric expenditure and substrate utilization in underwater treadmill running versus land-based treadmill running

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Caloric Expenditure and Substrate Utilization in Underwater Treadmill Running Versus

Land-Based Treadmill Running

by

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ABSTRACT

The objective of this study is to compare the caloric expenditure and oxidative sources of underwater treadmill running and land-based treadmill running at maximal and submaximal levels. Underwater running has emerged as a low load bearing form of supplementary training for cardiovascular fitness, as a way to promote recovery from strenuous exercise while maintaining aerobic fitness, and as a way to prevent injury. Prior studies have reported conflicting results as to whether underwater treadmill running elicits similar cardiorespiratory responses to land-based running. It is important to further investigate the similarities and differences between the two to determine if underwater running is as efficient as land-based running for maintenance of fitness and for rehabilitative purposes. Purpose: To compare the caloric expenditure and oxidative sources of underwater treadmill running and land treadmill running during both maximal treadmill trials to exhaustion and during 30 minute submaximal treadmill trials. Methods: 11 volunteer experienced male triathletes, ages 18-45 were recruited as participants. Each completed 6 trials total which included a maximal and submaximal oxygen consumption trial for each of three conditions: running on a water treadmill with AQx® water running shoes, running on a water treadmill without shoes, and running on a land-based treadmill.

Data analysis: Data was analyzed using repeated measures ANOVAs, paired t-tests, pairwise comparisons with bonferroni adjustments, and descriptive statistics were reported. Results: For maximal oxygen consumption trials VO_2, RPE, RER, and BP were not significantly different between modalities. Maximal HR was found to be significantly different between modalities, and was shown to be greater on land than in the water. For submaximal VO_2 trials HR, RPE, RER, and post BP were not found to be significantly different between modalities. Average VO_2, total calories expended, and pre systolic BP were found to be significantly different, and were shown to be greater on land than in water. Conclusions: While maximal exertion running on underwater treadmills seems to elicit similar cardiorespiratory responses to running on land-based treadmills, differences were seen at submaximal exertion levels. It remains unclear whether underwater treadmill running can elicit similar training stimuli as land running at submaximal levels.

Chapter One

Introduction

Rationale

The purpose of the present study was to investigate the caloric expenditure and oxidative sources for underwater treadmill running in comparison to land-based treadmill running, at both maximal and submaximal exertions. Underwater running has emerged as a low loadbearing form of supplementary training for cardiovascular fitness, as a way to promote recovery from strenuous exercise while maintaining aerobic fitness, and as a way to prevent injuries (Reilly & Dowzer, 2003). It provides a method of decreasing the running impact forces and the negative effects of excessive mileage when used in supplement to a runner's regular training program, while at the same time maintaining a training stimulus. Underwater running has been reported to reduce spinal and joint compressive loading which decreases the likelihood of incurring running-related musculoskeletal injuries, especially overuse injuries such as plantar fascitis, tendonitis, and stress fractures (Silvers, Rutledge, & Dolny, 2007). It has traditionally been used for aerobic conditioning during rehabilitation, but whether it elicits a cardiovascular and metabolic training stimulus comparable to that of land-based running is seemingly unclear. Previous literature has reported conflicting results possibly due to differences in the nature and protocol of each study, methods used to run under water, and training status and running style of the participants. This study aims to further investigate whether underwater treadmill running elicits similar cardiorespiratory and metabolic responses to land-based treadmill running, specifically in terms of caloric expenditure and substrate utilization (in percentage of fats and carbohydrates utilized).

Background

In the past underwater running has been performed primarily through deep water running (DWR) utilizing a buoyancy device to run in the deep end of a pool. This method of underwater running allows the athlete to reproduce the pattern of limb movement used during land-based running, without the ground support phase which eliminates the impact. Silvers et al. (2007) states that while this is the most common form of underwater running used in the past, DWR has been shown to be quite different from land-based running pertaining to muscle recruitment and kinematics of the lower extremities. Another form of underwater running that has emerged to more closely mimic land-based running is shallow water running (SWR), where the individual will run in the shallow end of a swimming pool, typically at a waist deep water level. SWR adds a ground reaction force component while still allowing for reduced impact. If the water level during SWR is raised it increases the amount of water resistance, therefore presumably increasing the cardiorespiratory demand for a given workload, but at the same time increasing the frontal resistance of forward movement in water which may degrade overall running mechanics (Silvers et al., 2007). With DWR and SWR posing certain limitations in their ability to resemble land-based running, underwater treadmills have more recently emerged. Underwater treadmills eliminate forward movement and therefore resistance through water allowing for a more natural gait pattern, and incorporate a reduced impact ground support phase which may enhance the specificity of underwater training (Silvers et al., 2007). With this being possible, underwater running should more effectively produce metabolic responses similar to those seen during land-based running. Previous literature has investigated whether underwater running actually does elicit similar metabolic responses to those seen on land in order to provide a foundation for the value and effectiveness of underwater running as a training modality.

In recent years, AQx Sports Deep Water Running shoes have been designed specifically to enhance deep water running. They are designed to simulate running on land without the associated impact of running on land, and are thought to be more similar to land-based running than running in the water barefoot. There is an added weight when wearing the shoes, and they also have “gills” on the sides, which create additional water resistance. The additional grip on the bottom of the shoes allows for greater traction when running on the bottom of the pool, which in turn allows for a larger range of motion that more closely resembles running on land. Research performed by the makers of AQx shoes during deep water running found that using the shoe enhanced the participant’s kinesthetic perception and allowed the deep water gait pattern to be more similar to land-based running and walking. However, research has not been conducted to evaluate the physiological effects of the use of the AQx shoes during underwater treadmill walking or running. If these shoes allow for deep water running that is more similar to land-based running, it seems logical to assume that the physiological advantages of the shoes used would also be found to be enhanced with use of an underwater treadmill. Further establishing (or refuting) the effectiveness of AQx water running shoes as a mechanism to enhance running on an underwater treadmill will lend additional research to what is already known regarding both water treadmill running in general as well as water treadmill running utilizing these shoes.

Hypotheses:

Null hypotheses (Ho):

(*Ho1)*: There is no significant difference in the caloric expenditure during underwater treadmill running (with or without AQx water running shoes) compared to land-based treadmill running at submaximal exercise intensities equivalent to 70 percent of maximum VO_2.

(*Ho2)*: There is no significant difference in the substrate utilization (percent of fats and carbohydrates utilized as determined by RER) during underwater treadmill running (with or without AQx water running shoes) compared to land-based treadmill running at submaximal exercise intensities equivalent to 70 percent of maximum VO_2.

Alternative hypotheses (Ha):

*(Ha*1): Underwater treadmill running (with or without AQx water running shoes) will elicit a greater caloric expenditure than land-based treadmill running at the same submaximal exercise intensities equivalent to 70 percent of maximum VO_2.

*(Ha*2): Underwater treadmill running (with or withour AQX water running shoes) will have a greater utilization of calories from carbohydrates than land-based treadmill running at submaximal exercise intensities equivalent to 70 percent of maximum VO_2.

Chapter Two

Review of the Literature

It is important to consider the hydrostatic effect associated with underwater running which in itself causes cardiorespiratory adjustments prior to discussing what previous literature has reported in terms of underwater running and its effect on metabolic responses. Upon immersion in water a hydrostatic vascular gradient occurs causing a shift in blood volume compartments, which when combined with the adjusted intra-thoracic pressures relative to the surrounding water pressure, contributes to an increased central blood volume as peripheral blood volume is displaced to the central core (Reilly et al., 2003). Much of the cardiorespiratory changes that occur in water are due to the extra pressure placed on the thoracic cavity and abdomen affecting the heart and the lungs. Due to the increased central blood volume, there is also an enhanced diastolic filling which leads to an elevated stroke volume, and in turn an increase in cardiac output (Arborelius, Balldin, Lilja, & Lindgren, 1972). The increased arterial pressure induced from the hydrostatic effect of water causes a rise in heart rate (HR), as well as stroke volume (Farhi & Linnarsson, 1997). Lung function is hindered by the pressure that water places on the body, counteracting inspiratory muscle function by compressing the abdomen and raising the diaphragm to near full expiration. This reduces lung and vital capacities, leading to an increased breathing frequency and rate, and therefore higher minute ventilation (Ve) to produce oxygen consumption (VO_2)

equivalent to that of exercise on land (Reilly et al., 2003). With the combination of an increased central blood volume and reduced inspiratory force there is a noted decrease in functional residual capacity and expiratory reserve volume (Reilly et al., 2003). With these changes associated with the hydrostatic effect of water encountered during underwater running, you would expect the metabolic responses during DWR, SWR, and underwater treadmill running to vary from those seen during land-based running. The majority of the previous literature has investigated this through the utilization of DWR. Fewer studies have investigated metabolic responses to SWR and underwater treadmill running, as they are newer means to perform underwater running (Dowzer et al., 1999, Pohl & McNaughton, 2003, Silvers et al., 2007). In this review of the literature all three types of underwater running will be discussed.

Previous literature has produced mixed results regarding the cardiorespiratory and metabolic responses to underwater running. This could be due to the type of protocol used, the training level of the participants, what in specific is being investigated, and the variations seen among the different types of underwater running (such as DWR, SWR, or running on underwater treadmills). The majority of prior studies utilizing buoyancy vests in pool running seem to have noted a decrease in maximal VO_2 as well as a decrease in HR. Butts, Tucker, & Greening (1991) conducted a study to investigate the maximal physiological responses to treadmill running on land and deep water running using a flotation device. The participants included 12 trained men and 12 trained women. Maximal aerobic capacity (VO_2 max), HR, and respiratory exchange ratio (RER) were measured. While men elicited slightly higher maximal VO_2 capacities than women and were similar across all other variables, both genders demonstrated significantly lower maximal VO_2 capacities and HR during underwater running in comparison to land-based treadmill running. The RER did not vary significantly in either gender between modes. This study's findings were supported by another study done by Frangolias & Rhodes (1995). This study compared the metabolic responses of treadmill running and water immersion running using a buoyancy device. Participants included 13 trained male endurance runners who were familiar with non-weight bearing water immersion running. Each participant completed tests at ventilatory threshold as well as at maximal intensity, both on land and during water immersion. VO_2 max, HR max, RER, VO_2 at ventilatory threshold, and HR at ventilatory threshold were all reported to be lower during water immersion running. With a decrease in VO_2 at ventilatory threshold there would also be a decrease in caloric expenditure as the number of calories expended per minute is dependent upon the liters of oxygen consumed per minute. If there is a lower rate of oxygen consumption, then a lesser number of calories are being expended. This leads to an overall lesser training stimulus. Minute ventilation, rating of perceived exertion (RPE), and RER were not different between modalities and intensities. Reporting that RER at ventilatory threshold was not found to be different between modalities indicates that substrate utilization (percent of fats and carbohydrates utilized during exercise) for both types of running was similar also, as substrate utilization can be determined based off of the RER value. Both of these studies indicate that aerobic capacity and heart rate are lower during underwater running. It is thought that with decreased limb loading along with added buoyancy of a flotation device seen in this type of underwater running, workload is decreased to a point that would reduce maximal cardiorespiratory as well as metabolic responses in water (Silvers et al., 2007).

Similar results to those found by Butts, et al. (1991) and Frangolias, et al. (1995), were observed in three subsequent studies, all of which also utilized DWR with buoyancy devices. Dowzer, Reilly, Cable, & Nevill (1999) compared the maximal physiological responses to treadmill running, SWR, and DWR. Participants included 15 trained male runners who each completed maximal intensity exercise tests on a land-based treadmill, during SWR, and during DWR using a flotation device. Both the SWR and DWR tests elicited a lower maximal VO_2 and HR in comparison to land-based running, with DWR eliciting lower values than SWR for both measures. RER was found to be similar across all three modalities. Frangolias, Coutts, Rhodes, & Taunton (2000) completed a study which further supported the findings of a lower VO_2 and HR during underwater running utilizing flotation devices. Their study compared physiological responses to treadmill and water immersion to the neck. Participants included 10 male endurance runners who performed treadmill and water immersion running maximal VO_2 tests during each as well as submaximal tests at ventilatory threshold. The immersion test was completed using a flotation belt with the water level at the neck. VO_2 was found to be lower during underwater running in comparison to the treadmill on land during submaximal tests, although it was found to be similar during maximal tests. HR was similar at and above ventilatory threshold, but was lower during prolonged underwater running exercise below the threshold when compared to land-based values. Ve and RPE were both reported to be similar during both modalities. The third study reporting lower VO_2 and HR values during underwater treadmill running was completed by Svedenhag &Seger (1992), and investigated the effect of water immersion on cardiorespiratory responses during running. Participants included 10 trained male runners, mean age of 26 years old, who each ran in water at four different submaximal loads at the target HRs of 115, 130, 145, and 155bpm wearing a buoyancy vest, as well as at maximal exercise intensity. Values were obtained for land-based treadmill running at the same submaximal and maximal loads for comparison. HR for a given VO_2 was seen to be lower during underwater running compared to land-based treadmill running, irrespective of intensity. Maximal VO_2 and maximal HR were also seen to be lower during underwater running. RPE and RER were seen to be higher during underwater running in comparison to land treadmill running, while Ve was seen to be the same across modalities. Svedenhag & Seger (1992) postulate that the results found in their study are likely due to water immersion inducing acute cardiac adjustments extending to maximal exercise intensities, external hydrostatic load, and altered running technique adding to an increased anaerobic metabolism during water running. These studies cumulatively reported a decreased VO_2 at both maximal and submaximal levels during water immersion running in comparison to land-based running. The cases reporting VO_2 at submaximal levels to be lower indicate a decreased caloric expenditure as well. These studies also cumulatively reported RER to be similar for both types of running at both maximal and submaximal levels, which indicates that there is no difference in the substrate utilization seen during water running in comparison to land running.

In contrast to the previously discussed studies, another study physiologically comparing deep water running using a flotation device to land-based treadmill running by DeMaere & Ruby (1997) did not find VO_2 and HR to be lower during underwater running. This study utilized DWR with flotation devices in the deep end of a university pool. Participants included 8 seasonally trained male cross country runners, who each completed a treadmill maximal VO_2 test followed by treadmill submaximal test and deep water run at heart rates equivalent to 60 percent and 80 percent of the land-based treadmill VO_2s. Pertaining to the protocol of this study, most authors writing on related topics caution against using land-based VO_2 to prescribe water based exercise intensities. This is because prior studies have shown conflicting results as to whether the modalities elicit similar responses, so there may be a difference in modalities that do not allow for prescribing one type of exercise based off of the other. Ve, RER, and carbohydrate oxidation were found to be greater during underwater running than treadmill running, while VO_2 and RPE did not differ significantly between modalities. This study did not observe VO_2 during water running to be any different than that observed during land-based treadmill running.

Other studies investigating underwater running using alternative methods to flotation devices have elicited contrasting results from the previously literature, as well. Most, if not all prior studies pertaining to this topic area utilizing underwater treadmills have not reported VO_2 and HR to be lower in any case. This would suggest that if the VO_2 is not lower, then the caloric expenditure for water treadmill running also will not be lower. Pohl & McNaughton (2003) compared the physiological responses of walking and running at ventilatory threshold utilizing a land treadmill to water treadmill responses at two different depths. Participants included six males who each completed five minute walking and running trials on both land treadmills and water treadmills. The water-based trials were complete at both thigh high and waist deep water levels. Walking and running on the underwater treadmill elicited a higher VO_2 and HR in comparison to the land-based treadmill. VO_2 and HR were seen to be higher during thigh deep running in water than during waist deep water running. The authors state that water-based running and walking appear to elicit a greater physiological cost than land-based exercise, possibly attributed to the elevated cost of moving in water due to increased resistance. The most recently published study investigating underwater running in comparison to land-based treadmill running was done by Silvers et al., (2007) and aimed to determine the cardiovascular responses elicited during maximal effort protocols using an underwater treadmill and land-based treadmill. This investigation was done to delve into the question of whether underwater running is able to elicit comparable cardiorespiratory stress compared to land exercise, as it is a subject area that remains unclear. The participants included 23 college runners, who performed two continuous, incremental maximal VO_2 protocols to exhaustion. VO_2, HR, RER, RPE, and ventilatory thresholds were all found to be not significantly different between modalities, while Ve was the only variable seen to be significantly greater during underwater treadmill running. The conclusions drawn by this study, as stated by the authors, indicate that the fluid resistance created by water and jets that are part of underwater treadmill utilization elicit peak cardiorespiratory responses comparable with those seen during land-based treadmill running. This suggests that underwater treadmill running may be just as effective as land treadmill running for aerobic conditioning in fit individuals, from which it could be assumed that caloric expenditure and substrate utilization would be similar between the two modalities. The results of the present study are expected to most closely resemble the results of the Silvers et al., (2007) study just discussed, as it used similar parameters and utilized an underwater treadmill (Hydroworx 2000®) similar to that used in the present study (Hydroworx 1000®).

While the vast majority of the research that has been conducted on underwater running in comparison to land-based running has utilized DWR with flotation devices which seems to elicit lower VO_2 and HR values than on land, there is still a broad area of underwater running using alternative modalities such as underwater treadmills which seems to elicit different responses warranting further research. SWR in comparison to DWR also elicit differing metabolic responses to each other, which both further differ from underwater treadmill running. Based off of the findings of Pohl & McNaughton (2003) and Dowzer et al., (1999), the lower the water level, the higher the VO_2 and HR responses that are elicited will be during buoyancy aided underwater running. Dowzer et al. (1999) states that this may be due to buoyancy counteracting the resistance of water, which lowers the physiological cost of movement in water.

Metabolic and mechanical functions are altered when the body is submersed in water, and therefore differ during underwater running compared to land-based running. Cardiorespiratory and metabolic responses seen during underwater running vary from that of land running, and also vary between types of underwater running. Underwater treadmill running is thought to account for more of the differences encountered in water in order to elicit metabolic responses and gait performance closer in similarity to that observed on land. DWR with the aid of flotation devices on the other hand, does not as closely imitate land locomotion during running, and therefore elicits responses further from that of land-based running. According to the majority of the literature, DWR is associated with lower VO_2 (and therefore caloric expenditure) and HR values than that of land-based running, and underwater treadmill running is associated with values that are not significantly different than land-based running. These concepts are still inconclusive though, and have not been consistent across all of the prior studies done in this area. It remains unclear whether underwater running is as efficient and effective a modality as land-based running. The goal of the present study is to gain further insight into the metabolic costs of underwater treadmill running in comparison to land-based treadmill running, specifically in terms of caloric expenditure and substrate utilization (percent of fats and carbohydrates utilized), at both maximal and submaximal levels.

Chapter Three

Methods

Participants

Eleven volunteer participants were recruited from local triathlete training groups in the Tampa Bay area, primarily through word of mouth describing the nature of the study. One participant dropped out during the course of the study due to scheduling conflicts, and his data were omitted during statistical analysis. A second participant completed the water trials only, for a total of 4 of the 6 trials. His data were used where appropriate. The final sample consisted of 10 experienced male triathletes, ages 20-46. “Experienced triathlete” was defined by having completed at least two triathlons in the last year or having completed more than 5 triathlons in their lifetime, and participants also were required to be currently training a minimum of 10 hours per week. No monetary compensation was offered to the participants; however their incentive for participating was to gain the knowledge of their maximal oxygen capacity to be used for training purposes. Prior to including any participant in the study they were required to fill out an informed consent approved by the University of South Florida’s IRB, as well as a medical and training history questionnaire administered by a licensed physician.

The average age, height, weight, and body mass index of the participants was 32.7 years (±10.6), 182.4 centimeters (±5.2), 79.3 kg (±11.8) , and 23.9 BMI (±2.9), respectively. The average number of Sprint Triathlons, Olympic Triathlons, Half Iron

Men, and Full Iron Men completed was 13.1 (±23.5), 4.4 (±5.4), 1.9 (±3.3), and 1.4 (±2.3) respectively, and the average number of years training was 8.2 (±7.1). During the year prior to participating in the study the average miles ran per week was 22.9 (±10.6), the average hours biked each week was 6.5 (±4.7), and the average hours swam each week was 2.5 (±1.7). Table 1 provides demographic data for the participants.

Table 1

Participant Demographics (n=10)

	Mean (SD)	*Minimum*	*Maximum*
Age (yrs)	32.7 (10.6)	20	46
Height (cm)	182.4 (5.2)	174	190.5
Weight (kg)	79.3 (11.8)	56.8	94.5
BMI	23.9 (2.9)	17.96	28.26
Years Training	8.2 (7.1)	2	25
Sprint Triathlons	13.1 (23.5)	0	75
Olympic Triathlons	4.4 (5.4)	0	15
Half Iron Man	1.9 (3.3)	0	10
Full Iron Man	1.4 (2.3)	0	7
Miles Ran (per wk.)	22.9 (10.6)	10	40
Hrs Biked (per wk.)	6.5 (4.7)	2	15
Hrs Swam (per wk.)	2.5 (1.7)	1	6

Experimental Design

The research design used was a quasi experimental, 2 x 3 repeated measures design. 2 (maximal and submaximal aerobic capacity tests) x 3 (modalities: water treadmill barefoot, water treadmill with shoes, land treadmill). It was designed to investigate the effects of underwater treadmill running with and without shoes in comparison to land-based treadmill running.

Protocol

Each of the 10 participants completed six experimental trials, with the exception of one participant who completed only four trials. Three of the six trials were maximal VO_2 tests and three were submaximal aerobic capacity (VO_2 submax) tests performed at 70 percent of maximal VO_2. One maximal and one submaximal trial were completed for each of the three modalities being compared which included running on a Hydroworx underwater treadmill barefoot, running on a Hydroworx underwater treadmill with AQx® brand water running shoes, and running on a land-based treadmill in a mostly random order (Table 2). The participant completing only four trials completed two maximal and two submaximal tests, one each for underwater barefoot as well as underwater with shoes. Maximal trials were completed prior to their corresponding submaximal trials and were used to establish the workloads for the submaximal trials. AQx® brand deep-water training shoes were used during the appropriate trials in this study in order to determine their effectiveness in comparison to running on water treadmills barefoot, as well as on land-based treadmills. These shoes are designed to simulate running on land without the associated impact of running on land, and are thought to be more similar to land running than running in the water barefoot. The present study utilizes one aspect of a second study investigating these shoes. While the main purpose of the present study was to compare caloric expenditure and oxidative sources of underwater treadmill running in general to land-based running, the AQx® water running shoes were included as a variable of interest to further establish their effectiveness as a mechanism to enhance water running. Inclusion of the AQx® shoes also lends additional research literature to what is currently known regarding water treadmill running.

Table 2

Trial Conditions Completed by Each Participant

	Max. Trial	*Submax. Trial @70% VO_2 max*
Land-Based		
UW with shoes		
UW without shoes		

Prior to completing their first trial, each participant met with a licensed physician who is also an investigator of the study to complete their medical and training history questionnaire as well as their University of South Florida Institutional Review Board approved informed consent. The purpose and procedures of the study were also explained to them, as well as their right to withdraw from the study without consequences at any time should they choose. At the beginning of each participant's first trial on the Hydroworx® underwater treadmill, they completed a 5 minute familiarization bout to acclimate them to the underwater treadmill as well as to the AQx® underwater running shoes. Upon completion of the familiarization bout, they rested for approximately 2 minutes and then completed the trial. Note that no participants had experienced running on an underwater treadmill prior to this study. Maximal trials were completed prior to their corresponding submaximal trials of the same modality, as the workload for the submaximal tests were based on a percentage (70%) of the aerobic capacity found during the maximal trials.

Participants were requested to refrain from doing any type of exercise at any intensity for 12 hours prior to each trial, to refrain from doing any strenuous exercise 24 hours prior to each trial, and to refrain from eating 4 hours prior to each trial. They were instructed to come to each trial fully hydrated (as interpreted by each individual participant). Participants were also instructed to complete a 3-day food and exercise diary prior to each trial in order to account for any dietary intake that may affect their performance. Each trial was separated by at least 48 hours, and was not supposed to be separated for more than one week; however due to unforeseeable events there were some trials that were separated by more than a week.

Maximal tests

Maximal trials were conducted using an incremental protocol to volitional exhaustion. The land-based treadmill tests were started at a self-selected, moderately vigorous pace that was held constant for the duration of the test. This pace was determined just prior to beginning the test during a brief warm up period lasting 1 to 5 minutes. The treadmill grade was increased by 2% every two minutes until exhaustion occurred. The maximum speed reached for land-based treadmill trials was 8.7mph with an average of 7.43 mph (±1.17), and the maximum grade reach was 12% with an average of 9.5% (±2.2).

The maximal underwater treadmill tests were done using a modified Astrand ramp protocol, similar to that used in an underwater treadmill study utilizing a Hydroworx 2000® treadmill by Silvers, et al. (2007). Prior to beginning the trial, the water level in the Hydroworx® pool was adjusted to be just below the participant’s xiphoid process while standing in the pool. The jets in the front of the pool were set at 40% resistance to start, as determined by Silvers, et al (2007) to promote normal running gait and minimize float time over the treadmill belt. The participants began the trial at a self-selected, moderately vigorous pace determined during the brief warm up period lasting 1 to 5 minutes just prior to completing the test. For the first 4 minutes of the test, treadmill speed was increased .5mph every 1 minute while maintaining 40% jet resistance throughout. At the end of minute 4, jets were increased 10% every 1 minute until volitional exhaustion was reached. In some cases, the maximum jet resistance (100%) possible was reached prior to the participant reaching exhaustion. In these cases speed was increased .5mph per minute until the participant then reached exhaustion, or the Hydroworx® treadmill's maximum speed of 7.5mph was reached and maintained for a full minute. The average speed of the underwater trials barefoot and with the AQx® shoes were 7.27mph (.45) and 7.21mph (1.17) respectively, the average jet resistance was 95% (8.5) for barefoot, and 95% (7.1) with AQx® shoes. Six participants reached maximum speed and jet resistance during their underwater VO_2 maximal tests; however only 2 participants thought they may have been able to continue if it were possible to increase speed or jets any further. For these 6 participants, 5 met the criteria for reaching a maximal effort for the variable of HR (HR was greater than 90% of age predicted maximal) and 4 met the criteria for RPE (were at a score of 19 or 20 on Borg 6 – 20 scale). Only 2 participants met the criteria for maximal exertion for RER (RER greater than 1.15); however, all of the participants had an RER greater than 1.0. (Note: No flotation devices or tethering systems were used for the water trials).

Prior to each VO_2 maximal test resting heart rate (HR), resting blood pressure (pre BP), and weight were measured. Participants were allowed to warm up for 1 to 5 minutes at their discretion, and then the trials took place. During the final minutes of the trials, verbal encouragement was employed to help ensure that a maximal effort was reached. After reaching exhaustion, participants were allowed to cool down for 1 to 5 minutes at their discretion, and then resting post blood pressure (post BP) was measured. During each maximal trial HR and physiological data including oxygen consumption and RER was measured continuously. HR was recorded every minute, RPE was assessed every 2 minutes, and blood pressure was measured pre and post test. Blood pressure during maximal trials was only taken pre and post test and not throughout the duration, as it was not feasible to obtain accurate readings during the trials specifically during running on the underwater treadmill.

Table 3

Maximal VO2 Trial Protocols

	Incremental Protocol	*Speed Mean (SD)*	*Workload Mean (SD)*
Water Treadmill (barefoot)	40% jet resistance; moderately vigorous pace. Increase speed .5mph/min for 4 min. then increase jets 10%/min. until exhaustion	7.3mph (.34)	95%jets (8.5)
Water Treadmill (with AQx shoes)	40% jet resistance; moderately vigorous pace. Increase speed .5mph/min for 4 min. then increase jets 10%/min. until exhaustion	7.2mph (.45)	95%jets (7.1)
Land Treadmill	moderately vigorous pace constant speed increase grade 2%/min. until exhaustion	7.4mph (1.17)	9.5%grade (2.2)

Submaximal Tests

Each submaximal trial was performed for 30 minutes at a workload that was calculated to be 70 percent of the participant's respective maximal aerobic capacity:

- Land-based submaximal treadmill trial was done at 70 percent of the maximal VO_2 found during land-based maximal treadmill trial.

-Underwater with shoes submaximal trial was done at 70 percent of the maximal VO2 found during underwater with shoes maximal trial.

-Underwater without shoes submaximal trial was done at 70 percent of the maximal VO2 found during underwater without shoes maximal trial.

The speed and workload of the submaximal trials was determined based off of the participant's corresponding maximal test data. The maximal VO_2 value was multiplied by .7 to determine 70 percent, and the resulting value was compared to the maximal test data output to determine what workload the participant was at when they reached 70 percent. This was the workload then used for the duration of the corresponding submaximal trial. Since it was difficult to set a workload that was precisely 70 percent of an individual's maximal VO_2, there was a variation from 70 percent that was on average .2ml/kg/min, .4ml/kg/min., and 3.41ml/kg/min for the barefoot trials, AQx® shoe trials, and land-based trials respectively. Previous related studies have set submaximal VO_2 tests at 60-80 percent of maximal VO_2 or at ventilatory threshold, and the participants used in the present study were triathletes and therefore highly trained. This seemingly supports 70 percent of maximal VO_2 to be an acceptable intensity for the submaximal tests performed during this study (Frangolias et al. 1995, Frangolias et al. 2007, DeMaere & Ruby 1997, and Pohl & McNaughton 2003). Prior to commencing each trial, resting HR, resting BP, and weight were measured. Participants were then allowed a 1 to 5 minute warm up period, followed by 30 minutes of simply running at 70 percent of maximal VO_2 with no change in pace, grade, or jet resistance throughout. HR and physiological data including oxygen consumption and RER were measured continuously, RPE was assessed every 5 minutes, and BP was taken pre and post test. It was not feasible to take BP during the tests, especially in the case of the water trials.

Table 4

Submaximal VO_2 Trial Values

	Avg. VO_2 for Trial	*% of VO_2max*	*Speed Mean (SD)*	*Workload Mean (SD)*
Water Treadmill (barefoot)	36.0ml/kg/min (7.6)	69.5% (8.5)	6.4mph (.43)	46% jets (8.4)
Water Treadmill (with AQx shoes)	38.3ml/kg/min (5.9)	70.8% (7.0)	6.2mph (.44)	43% jets (7.1)
Land Treadmill	40.8ml/kg/min (4.6)	76.6% (25.5)	6.9mph (1.0)	.6% grade (1.0)

Measures

The trials took place at the University of South Florida’s Tampa campus, either in the Athletic Training Facility or in the Exercise Science Teaching Lab. All water-based trials took place in the Athletic Training Facility’s Sports Medicine clinic on a Hydroworx 1000® treadmill consisting of a variable speed treadmill with an integrated underwater treadmill surface, at the bottom of an adjustable pool. The speed range of this treadmill is 0 to 7.5mph, which could be increased by .1mph. The pool it was in was 7’6” wide, 14’ long, and 5’4” deep, with a 2,100 gallon capacity. Water level in the pool could be raised or lowered to a person's xiphoid process for trials by utilizing a control panel which allowed the water to drain into reserve tanks or to be pumped back into the pool. Water jets were inset at the front of the pool to provide water flow resistance which could be increased or decreased from 0 to 100% resistance using the control panel.

The land-based trials took place in the Athletic Training Facility's Strength and Conditioning room when possible, but due to scheduling conflicts and participant availability, 6 land-based trials were completed in the Exercise Science Teaching Lab. The land trials conducted in the Athletic Training Facility were done on a Woodway® treadmill; those done in the Exercise Science Lab were done on a Trackmaster RS-232® treadmill.

HR, BP pre and post, RPE, VO_2, RER, caloric expenditure, and substrate oxidation were the variables of interest to be measured during the study. Caloric expenditure and substrate oxidation were only calculated for submaximal trials. HR was monitored continuously using a Polar Heart Rate Monitor® (Polar, USA) which the participants wore strapped to their chests. BP was measured at the beginning and end of each trial using standard pressure cuffs and sphygmomanometers. RPE was assessed every 2 minutes during maximal tests and every 5 minutes during submaximal tests using the Borg 15 point (6 – 20) scale. This scale was explained to the participants at the start of the study prior to beginning their first trial to ensure they knew how to read and use it accurately. Exertion was indicated by participants using hand signal responses to the numerical chart held in front of them while they ran. Metabolic measurements including VO_2 and RER were assessed via expired gas collection analyzed by a Vacumed® metabolic measurement system which was appropriately calibrated prior to each trial. For maximal tests the highest VO_2 and RER values measured were the values used. For the submaximal tests the average VO_2 and RER values measured from minute 2 through minute 30 of the trials were the values used. (Minute 1 values were not used in the average as the participant had not yet reached 70 percent of their maximal VO_2). VO_2 and RER determined using the metabolic measurement system were used to calculate each participant's caloric expenditure (in kilocalories) as well as their substrate utilization (in percentage of fats and carbohydrates). This method of indirect calorimetry, according to Robergs and Kravitz (1992), is the most suitable and accurate method to evaluate caloric expenditure during exercise. Percent of carbohydrates oxidized and of fat oxidized during each trial was determined by comparing the RER to the "Caloric Equivalents for Oxygen and Foodstuff Contributions to Energy for Various Non-protein Respiratory Exchange Ratios" chart. Caloric expenditure was calculated using the appropriate formula for extrapolating calories utilized from VO_2 according to *ACSM's Metabolic Calculation Handbook*, taking into account RER. Water temperature was monitored using the pool thermometer, and ranged from 20.6 -35.6 degrees Celsius even though the aim was to maintain the temperature within 2 -4 degrees. This temperature range is broad due to factors acting outside of the study which will be discussed later. On average the water temperature was 25.8 degrees Celsius (78.5 degrees Fahrenheit). All measurements were recorded by hand using data collection sheets, with the exception of the metabolic cart's measurements, which were printed out at the end of each trial.

Statistical Analysis

Maximal trials were completed prior to their corresponding submaximal trial in order to establish submaximal workload; however the order by which the trials were completed was mostly random and based on scheduling availability. Each participant served as their own control. Descriptive statistics, repeated measures ANOVA, and paired t-tests were performed using SPSS 17.0 software to analyze the effects of the three modalities being investigated (water treadmill barefoot, water treadmill with AQx® shoes, and land treadmill) for each dependent variable. If statistical significance was found for a variable, follow up pairwise comparisons were conducted between modalities using Bonferroni adjustments. Analyses were performed for the dependent variables including: HR, RPE, VO_2, BP, RER, caloric expenditure, substrate utilization, as well as for other dependent variables that were not of primary interest in this study. Significance level for all tests was set at $p < 0.05$ and effect size was determined using the formula $d = t * (2 * (1-r)/n)^{1/2}$, shown to be effective for repeated measures analysis (Dunlap, W., Cortina, J., Vaslow, J., & Burke, M., 1996). The variables used in this formula *d*, *t*, *r*, and *n* are defined as effect size, t-score, correlation value, and sample size, respectively. Effect size was considered small at d = 0.2, medium at d = 0.5, and large at d = 0.8.

Chapter Four

Results

Descriptive statistics including mean and standard deviation, as well as significance values are presented in Tables 5 and 6 below, for maximal and submaximal trials as groups respectively. For each dependent variable, repeated measures ANOVAs were performed for all trials to see if there was a significant difference. If there was a difference, pairwise comparisons were conducted between the 3 modalities for the variable of interest, using Bonferroni adjustments to determine which modalities the significant difference existed between. Paired samples t-tests were performed to determine t-value and correlation for each variable, across all 3 modalities (3x for each variable). These values were then used to calculate effect size using the equation established to be effected for repeated measures by Dunlap et al. (1996). Effect size for all variables was taken into consideration for effects of this study due to the low subject number (n=10) and weak power. Dependent variables included HR, VO_2, RPE, RER, BP pre and post, caloric expenditure, and substrate utilization (percentage of fats and carbohydrates utilized). Caloric expenditure and substrate utilization were the primary variables of interest, and were determined for submaximal tests only.

Table 5

Maximal Test Results

	Water Treadmill Barefoot	*Water Treadmill with Aqx Shoes*	*Land Treadmill*	
	Mean (SD)	Mean (SD)	Mean (SD)	P value
VO_2 Max (ml/kg/min)	51.79 (8.7)	54.08 (5.7)	53.28 (6.4)	0.848
HR Max (bpm)	174.2 (10.2)	174.0 (14.6)	187.2 (14.7)	.018*
RPE Max	18.6 (.88)	19.5 (.71)	18.8 (1.2)	0.113
RER Max	1.09 (.1)	1.11 (.11)	1.17 (.04)	0.394
Pre SBP	123.3 (9.2)	120.9 (8.3)	114.6 (9.8)	0.091
Pre DBP	74.1 (9.0)	70.8 (6.1)	71.1 (11.0)	0.35
Post SBP	123 (7.5)	122.7 (18.3)	121.3 (11.8)	0.536
Post DBP	73.6 (5.7)	75.6 (10.0)	75.1 (16.4)	0.201

*Indicates significance was found for $p < 0.05$.

Table 6

Submaximal Test Results

	Water Treadmill Barefoot		*Water Treadmill with Aqx Shoes*		*Land Treadmill*		
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	P value
VO_2 avg. (ml/kg/min)	36.4 (7.9)	22.1 – 5.7	39.1 (5.6)	31.0 -48.2	40.8 (4.6)	31.4 -5.9	.014*
HR avg. (bpm)	140.3 (11.0)	127 - 160	148.0 (16.7)	125 - 178	150.0 (9.2)	141 -172	0.137
RPE avg.	13.5 (1.2)	12 – 15	14.0 (2.0)	13 – 19	12.7 (.50)	12 – 13	0.27
RER avg.	.93 (.05)	.86 –.99	.92 (.04)	.85 – .99	.92 (.04)	.87 - .99	0.77
Total Calories	410.6 (66.7)	275 - 486	442.6 (69.4)	257 - 510	487.3 (41.9)	434 -554	.012*
%Fats Utilized	24.1 (16.1)	3.2 - 45.9	26.0 (13.5)	3.2 – 49.3	24.9 (12.4)	3.2 – 2.5	.896
%Carbs Utilized	76.0 (16.1)	54.1 – 6.8	74.0 (13.5)	50.7 -96.8	75.1 (12.4)	57.5–6.8	.896
Pre SBP	114.3 (6.5)	108 - 126	116.4 (6.7)	104 - 128	124.7 (5.9)	118 -132	.004*
Pre DBP	68.9 (5.7)	60 – 80	75.0 (7.8)	60 –90	69.3 (8.2)	60 – 80	0.227
Post SBP	116.2 (7.8)	104 - 130	115.3 (10.4)	98 – 134	124.7 (4.1)	120 -130	0.288
Post DBP	71.2 (8.3)	60 – 80	73.9 (10.8)	52 – 86	67.3 (12.4)	52 –82	0.487

* Indicates Significance was found for $p < 0.05$.

Test of Hypotheses

There were four primary hypotheses tested in this study, two null hypotheses (Ho) tested against two alternative hypotheses (Ha). Ho_1 stated that there is no significant difference in the caloric expenditure during water treadmill running versus land-based treadmill running at submaximal exercise intensities. The results showed that there was a significant difference between water treadmill running and land treadmill running ($p = 0.045$), and therefore we reject the null hypothesis. This does not mean we can accept the alternative (Ha_1), which stated that water treadmill running would elicit a greater caloric expenditure than land treadmill running at submaximal exercise intensities. The results showed a significant difference between the two modalities, but in comparing the means land treadmill running elicited a greater caloric expenditure than water treadmill running. The means for running on the water treadmill barefoot, water treadmill with shoes, and land treadmill were found to be 410.8kcals, 442.6kcals, and 487.3kcals, respectively. See table 7.

Table 7

Caloric Expenditure (descriptive data)

	Mean (SD)	*Range*
Water Treadmill Barefoot	410.8 kcals (66.7)	275.2 - 486.5 kcals
Water Treadmill With Shoes	442.6 kcals (69.4)	257.9 - 509.8 kcals
Land Treadmill	487.3 kcals (41.9)	434.1 - 554.3 kcals

P-value for Caloric Expenditure (main): $p = .012$

Table 8

Caloric Expenditure (pairwise comparisons)

	P value	*ES*	*Correlation r*	*T-score*
Water Barefoot vs. Water With Shoes	0.271	0.46	0.65	1.75
Water With Shoes vs. Land	0.564	0.7	-0.05	1.44
Water Barefoot vs. Land	.027*	1.34	0.32	3.44

*Indicates significance. ($p < 0.05$)

Ho2 stated that there is no significant difference in the substrate utilization (percentage of fats and carbohydrates) during water treadmill running versus land-based treadmill running at submaximal exercise intensities. The results found supported Ho_2, indicating no significant difference exists in substrate utilization during water treadmill running compared to land treadmill running ($p = .896$), therefore we fail to reject the null hypothesis. In failing to reject Ho_2, we accept it, and therefore can not accept the alternative hypothesis (Ha_2) which states that water treadmill running will have a greater utilization of calories from carbohydrates than land-based treadmill running at submaximal exercise intensities. Comparing the mean values of percent carbohydrates and fats utilized supports the null (Ho_2), as shown in table 9.

Table 9

Substrate Utilization (at submaximal levls)

	Fats Utilized Mean (SD)	*Carbs Utilized Mean (SD)*	*Fats Utilized Range*	*Carbs Utilized Range*
Water Treadmill Barefoot	24.1% (16.1)	75.9% (16.1)	3.2 - 45.9%	54.1 - 96.8%
Water Treadmill With Shoes	26.0% (13.5)	74.0 (13.5)	3.2 - 49.3%	50.7 - 96.8%
Land Treadmill	24.9% (12.4)	75.1% (12.4)	3.2 - 42.5%	57.5 - 96.8%

P-value for percent fats utilized: $p = .896$
P-value for percent carbohydrates utilized: $p = .896$

Contributing Variables

Statistical analysis was done for the dependent variables of HR, VO_2, BP pre and post, RPE, and RER which were not of primary concern to the research question. For the maximal tests VO_2 max. ($p = .848$), RPE max. ($p = .113$), RER max. ($p = .394$), BP pre systolic ($p = .091$) BP pre diastolic ($p = .350$), BP post systolic ($p = .536$), and BP post diastolic ($p = .201$) were all found to be non-significant across all 3 modalities. For the submaximal tests average HR ($p = .137$), average 70% of maximal VO_2 ($p = .713$), average RPE ($p = .270$), average RER ($p = .770$), percent fat utilized ($p = .896$), percent carbohydrates utilized ($p = .896$), BP pre diastolic ($p = .227$), BP post systolic ($p = .288$), and BP post diastolic ($p = .487$) were all found to be non-significant. For the maximal tests HR max. was the only variable found to be significant ($p = .018$). For the submaximal tests average VO_2 ($p = .045$), calories expended ($p = .012$), and BP pre systolic ($p = .004$) were found to be significant. For the significant variables, pairwise comparisons were performed. Interestingly, after completing pairwise comparisons, all variables of significance were found to be significantly different between the water treadmill barefoot and land treadmill tests only. See tables 5 and 6 for descriptive statistics and main significance. Table 10 provides data for the pairwise comparisons of the significant variables.

Table 10

Pairwise Comparisons for Variables of Significance

	Water Barefoot and With Shoes		*Water With Shoes and Land*		*Water Barefoot and Land*	
	P value	*ES*	*P value*	*ES*	*P value*	*ES*
HR max (bpm)	1	.02	1.52	0.97	0.048*	.99
VO2 avg. (ml/kg/min)	0.223	0.31	0.604	0.31	0.043*	0.45
Kcals (over 30 min.submax)	0.271	0.46	0.564	0.7	0.027*	1.34
Pre systolic BP (submax)	0.105	0.56	0.174	1.23	0.057*	2.32

*Indicates significance ($p < .05$)

It is also interesting and important to note that a large effect size (ES) was found for a number of variables that were not found to be significant. This could potentially be due to the small sample size used in this study (n=10) which gives it a weak power. For submaximal tests the ES was large for HR compared between water barefoot and land (ES = .90), RPE compared between water barefoot and land, and water with shoes and land (ES = .77 and ES = .84), pre diastolic BP compared between water barefoot and with shoes (ES = .87), and for post systolic BP compared between water barefoot and land, and water with shoes and land (ES = .94 and ES = .86). None of these variables were found to be significant, though. For maximal tests the ES was large for HR compared between water with shoes and land (ES = .97), RPE compared between water barefoot and with shoes (ES = .84), RER compared between water barefoot and land (ES = .84), and compared between water with shoes and land for pre systolic BP (ES = .88). None of these were found to be significant, though. For the four variables that were found to be significant ($p < 0.05$), all but one had a large ES. Those variables include average VO_2 compared between water barefoot and land (ES = .45; not large), calories expended compared between water and land (ES = 1.34), pre systolic BP compared between water and land (ES = 2.32), and maximal HR compared between water and land (ES = .99). This is shown graphically in figures 1, 2, and 3.

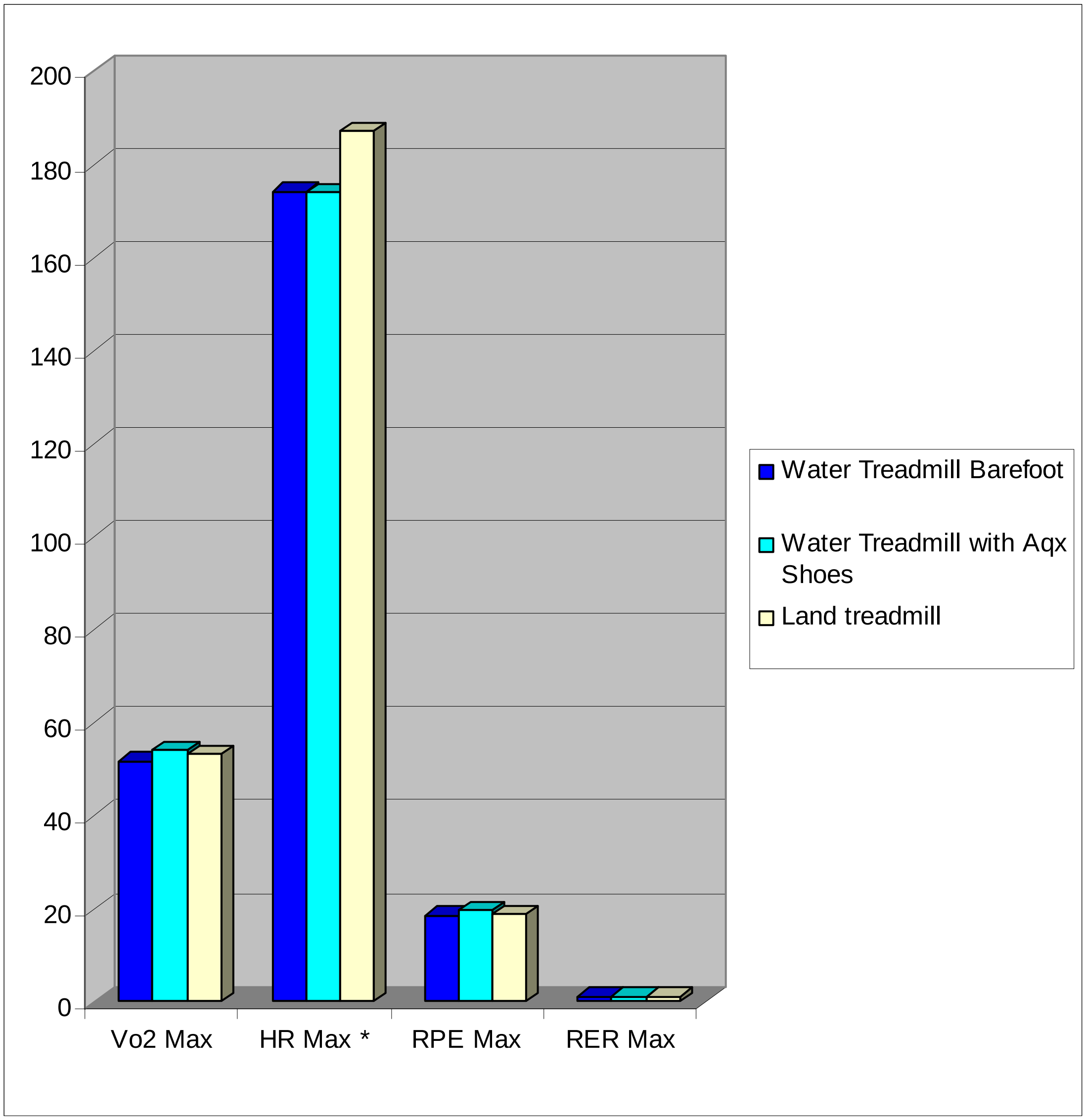

Figure 1. Results of Maximal Oxygen Consumption Trials
* Significant difference between trials, $p < 0.05$.

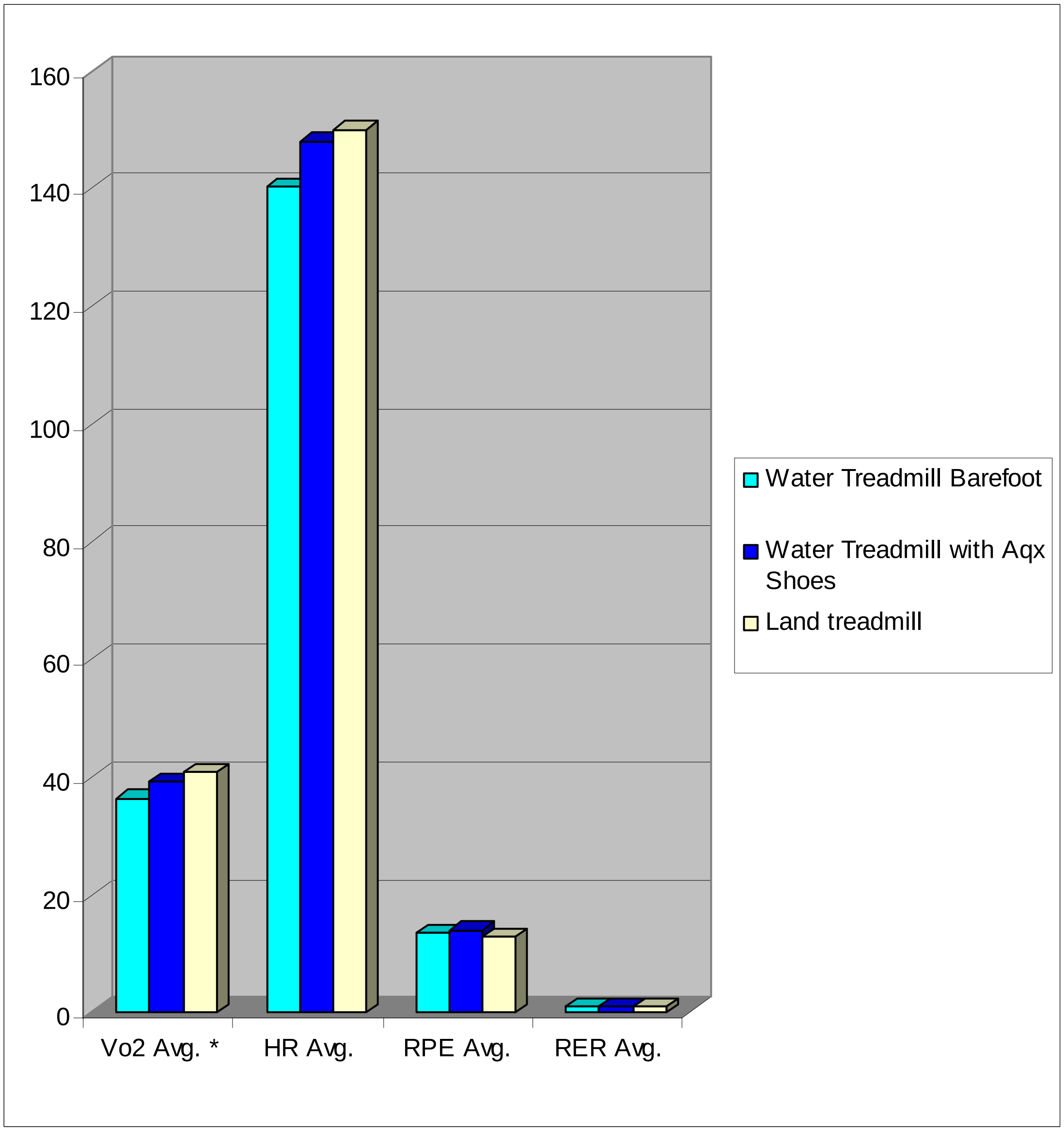

Figure 2. Results of Submaximal Oxygen Consumption Trials
* Significant difference between trials, $p < 0.05$.

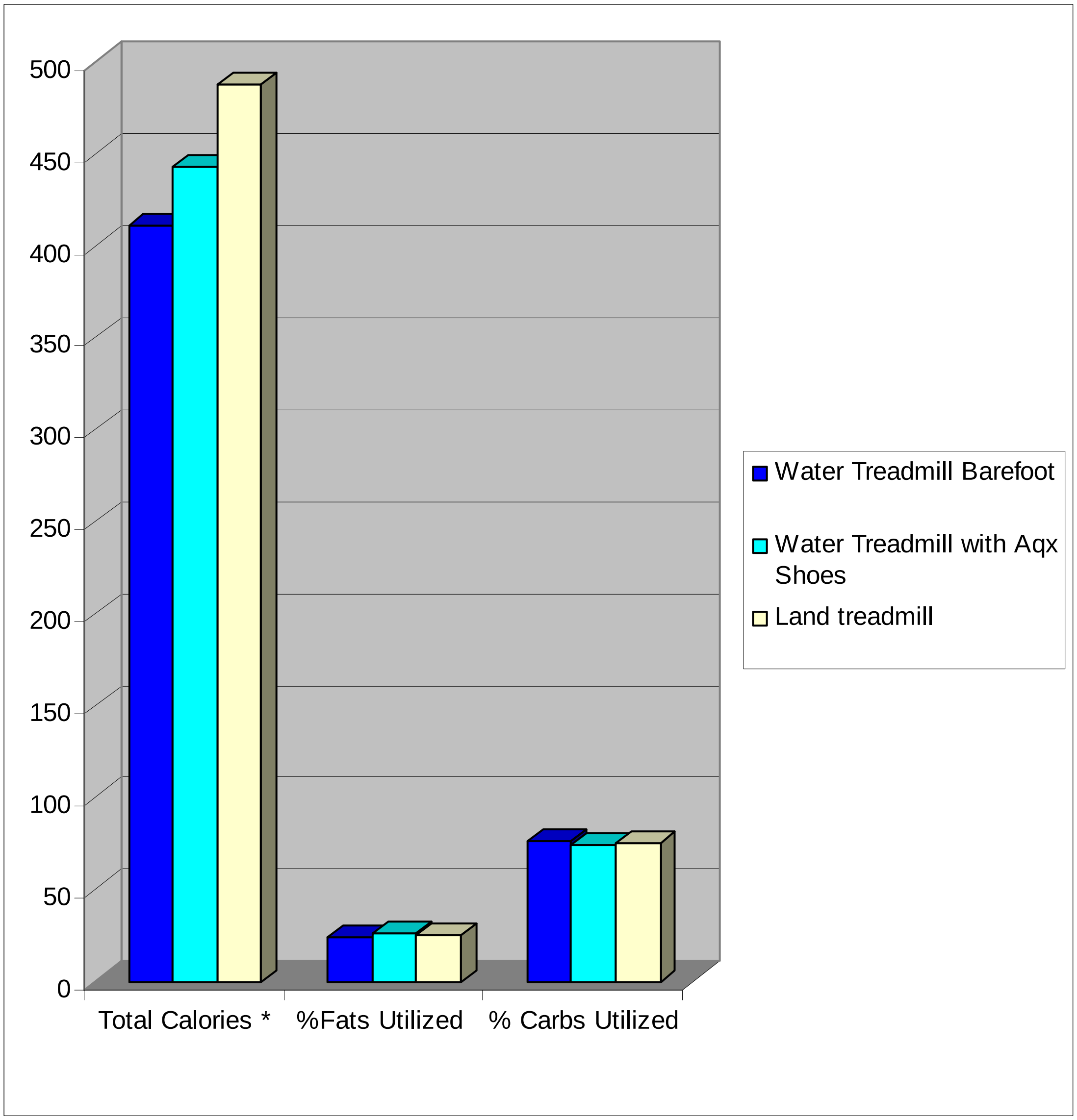

Figure 3. Submaximal Calories and Substrates Utilized
* Significant difference between trials, $p < 0.05$.

Chapter Five

Discussion

Results of the present study indicate that running on a water treadmill both barefoot and with the AQx® brand underwater training shoes may elicit similar cardiorespiratory responses to land-based running during maximal aerobic capacity trials, but elicit results that vary from land-based running during submaximal intensity trials. Silvers et al. (2007) found no significant differences for VO_2, HR, RER, or RPE when comparing water treadmill running to land-based treadmill running at maximal capacities. This supports the findings of the present study which found VO_2, RER, RPE, and BP to have no significant differences at maximal exertion; with the exception of HR which was found to be greater during land-based treadmill running. A number of previous studies utilizing underwater running without an underwater treadmill have noted a greater HR on land than in the water also, which is likely due to the hydrostatic effect caused by water immersion (Butts et al. 1991, Frangolias et al. 1995, Dowzer et al. 1999, Frangolias et al. 2000, and Svedenhag & Seger 1992). The results of the present study may also potentially be due to the water temperature during underwater treadmill trials being cooler than the ambient temperature of the air during land-based trials, as HR is affected by temperature (Gleim & Nicholas, 1989). Interestingly, the difference found for HR was only seen between running on a water treadmill barefoot and running on a land-based treadmill, but there was no difference between running on a water treadmill with the

AQx® brand shoes and running on a land treadmill. This suggests that for maximal exertion performance, the AQx® shoes may elicit HR responses similar to that of land-based treadmill running. Outside of HR, all other variables were found to be similar for all 3 modalities during maximal trials, suggesting that water treadmill running may elicit similar cardiorespiratory responses at maximal exertions.

At submaximal capacities HR, RPE, RER, substrate utilization (percentage of fats vs. carbohydrates utilized), and BP were all found to be similar for water treadmill running in comparison to land-based treadmill running. In contrast, average VO_2, total calories burned during the 30 minute trials, and pre-exercise systolic BPs were all found to be significantly lower during water treadmill running in comparison to land-based treadmill running at submaximal exertions. It was expected that water and land-based treadmill running would have elicited similar results for all variables at submaximal levels, but this was not shown in the results. It is interesting to note that for each variable that differed at the submaximal level (as well as at the maximal level), the significant difference was found between the barefoot water treadmill running in comparison to land-based treadmill running, but not for the water treadmill running with AQx® shoes in comparison to land-based treadmill running. This lends further evidence to the concept that running on under water treadmills with the AQx® brand shoes may elicit results that are more similar to land-based treadmill running than simply running on an underwater treadmill barefoot. While a difference in general was not expected, since average VO_2 was significantly lower underwater than on land, it is not surprising that the calories expended over the 30 minute duration of the submaximal tests were also significantly lower underwater compared to on land. Calories are measured in the amount utilized per liter of oxygen consumed, so if the average number of liters of oxygen consumed per minute is lower, then it is expected that the number of calories expended would also be lower. There was a greater difference found for the calories expended across the 3 modalities than there was for the average VO_2, though. The difference in average VO_2 observed between underwater running and land running was less than the difference seen in caloric expenditure between the two, even though it would be expected that the differences should be similar. This may potentially be due to land running utilizing a greater percentage of carbohydrates in comparison to fats which would elicit a great caloric expenditure at a given VO_2 than if a greater percentage of fats were utilized at the same VO_2. If this is the case then the already existing difference in VO_2 would be even greater when extrapolated into calories expended.

When reviewing the results found in this study, it is important to take into the consideration the average work load of the submaximal trials, which were based on the maximal VO_2 found during the maximal trials. While the goal for all submaximal trials was for their workloads to be set at 70 percent of the maximal VO_2, they were actually performed at 69.5%, 70.8%, and 76.6% of maximal VO_2 for the underwater barefoot, underwater with shoes, and land-based trials, respectively. This indicates that the land-based submaximal trials were performed at a higher percent of maximum, and therefore at a higher intensity than either of the water trials. If the land-based trials were performed at a higher intensity then it would be expected for them to expend a larger number of calories (as the results of this study demonstrated). If all submaximal trials had been able to have been held closer to a consistent 70 percent of the max, there may not have been a difference noted in the average VO_2 or caloric expenditure for the 30 minute submaximal trials (Table 4). The reason it was seemingly more difficult to control for submaximal VO_2 levels at 70 percent on land than it was in the water may be due to the method of adjusting intensity on land versus in the water. Increasing jet resistance in the water by just 1% allowed for finer adjustments in workload, whereas increasing treadmill grade by 1% seemed to elicit greater adjustments in workload making it slightly more difficult to adjust to precisely 70 percent of maximal VO_2.

Earlier studies investigating underwater running without the use of underwater treadmills proposed that a decreased VO_2 seen in the water may be due to the buoyancy effect and decreased limb loading which would reduce cardiorespiratory responses in the water as a result of an overall reduced workload (Silvers et al., 2007). The water jet propulsions exerted out of the front of the underwater treadmill pool at the runner were thought to oppose the effects of buoyancy to elicit a training response similar to that of land. The results of the present study found this to hold true at maximal levels, but not at submaximal levels. This may indicate that at stronger jet resistances (reached during maximal exertions) the effects of buoyancy are opposed, but at the weaker jet resistances (maintained during submaximal exertions) the effects are not enough to counteract buoyancy and so workload is less.

Pre-exercise systolic BP for submaximal tests was also found to be significantly different between water treadmill running and land treadmill running, and was found to have a large ES. While this indicates that a real difference may be present, it does not logically seem to be a factor affected by the different modalities. BP may vary for a number of reasons but in this case it was the BP taken before a participant completed a trial so the difference of whether the trial was done on land or in the water should not have affected the outcome. Diurnal variations in BP would not have been a factor in this study, as all participants with the exception of one completed each of their trials at the same time of day throughout the study.

RER at both maximal and submaximal levels was found to be similar between modalities of running, which is consistent with the majority of the prior literature (Butts et al. 1991, Dowzer and Reilly 1999, and Silvers et al. 2007). Two previous studies (Reilly et al. 2003, and Svedenhag et al. 1997) reported a higher RER, but both of these studies utilized buoyancy devices during water running rather than water running alone or on an underwater treadmill. The findings of the current study showing RER to be similar for underwater treadmill running in comparison to land-based treadmill running can be used to indicate that the substrate utilization was also similar for the two types of running. This can be seen when comparing RER values to the “Caloric Equivelent for Non-protein Foodstuffs Contributions” chart to determine the percentage of fats and carbohydrates utilized during exercise.

The AQx® underwater running shoes utilized in this study are designed to enhance underwater running and elicit responses to simulate land-based running. They have rubber traction bottoms and gills that protrude slightly off of the side of the shoe to increase resistance during locomotion through the water. During maximal intensity trials utilizing greater speeds and jet resistance, the gills on the shoes seemed to pose an added resistance that a number of participants noted to be uncomfortable and a hindrance. The jets seemed to catch the gills initially as they shot of out the front of the pool directly at the participant, then catch the gills a second time coming from the back of the pool as the water that was being propelled hit the back wall and circulated back towards the front of the pool. There were mixed responses from the participants pertaining to the AQx® shoes. Some participants noted that the shoes caused sharp pains in their anterior tibialis when running on the underwater treadmill in comparison to being barefoot; even to the point where one participant chose to terminate his submaximal trial wearing the AQx® shoes 7 minutes early. Other participants; however, noted that they preferred running on the underwater treadmill using the shoes in comparison to being barefoot. This was because without the shoes they felt like they were slipping off of the treadmill and at higher intensities it was difficult to stay on the treadmill. The slipping that occurred on the treadmill also lead to blisters on the feet of 2 participants. The shoes provided traction to avoid slipping, and were found to be favorable for some participants. The participants who noted that they preferred the shoes to being barefoot during underwater treadmill running, also stated that they did not experience any pain in their anterior tibialis. No formal data on preference of shoes vs. no shoes was collected, but verbal questions were asked regarding the participants' preference.

There were some limitations of the study that were seemingly unavoidable. One aspect that was intended to be controlled for was the time separation of the trials. The original intent was to separate trials by no more than a week in order to avoid changes in VO_2, weight, and other variables as a result of changing training status. If the trials were kept close together in time, then a change of training status would be less likely to affect the outcome of the study. Due to unforeseeable events such as participant availability, facility availability, and issues with malfunctioning of the metabolic cart used, there were approximately 5 trials separated by more than a week. Two of these trials occurred over a month after the previous trial, during which time the athletes had altered their training status. In one case the participant had been out for an injury and lessened training, and in the other the participant had started increasing training notably. The other limitation that was intended to be controlled for was the pool temperature during water trials which ranged from 20.6 – 35.6 degrees Celsius, and averaged 25.8 degrees Celsius (78.5 degrees Fahrenheit). It was intended to maintain the temperature within a 4 degree range; however, since the water treadmill and pool used was located in the University's Athletic Training Facility, athletes using the pool when the study was not taking place were free to alter the temperature. There were also approximately 3 trials completed during a time when the thermostat of the pool would increase without manual alterations overnight, so when the pool was utilized the next morning for a trial the temperature would be higher than it would be ideally. This may have effect certain variables such as RPE and HR, but should not have affected the primary variables of VO_2, caloric expenditure, and substrate utilization to a large extent. According to previous literature, VO_2 is not affected by water temperature (Gleim et al. 1989, Mcardle et al, 1992, and Craig & Dvorak, 1996). One other limitation of the study that should be noted for future research was that approximately 5 of the 10 participants reached the underwater treadmill's maximal workload capacity (treadmill speed = 7.5mph and jet resistance = 100%) before they had reached their own maximal VO_2. Only on two occasions did the participants state that they felt they could have kept going after they reached and maintained this point for an entire minute, but it would have been beneficial to have been able to increase treadmill speed and/or jet resistance further to ensure that all participants reached their greatest maximal exertion.

The study utilized only healthy triathletes as participants, so the results found are not generalizable to a normal population. Utilizing triathletes is a good indicator for elite athletes such as runners who may be interested in underwater treadmill running as an alternate or supplementary means of training to avoid the stress placed on their musculoskeletal system on land. Based on the findings of this study, underwater treadmill running at higher levels of exertion (near maximal) elicits cardiorespiratory and metabolic responses similar to those seen during land treadmill running. This does not generalize for water treadmill running at submaximal intensities as VO2 and caloric expenditure will not be as high as they would be during land treadmill running. These concepts are inconclusive though, as the results of this study are consistent with some prior studies, but are not all prior studies done in this area. It is also possible that the level of exertion an individual trains at while using an underwater treadmill may affect the similarity of the cardiorespiratory elicited during running on a water treadmill versus running on a land treadmill. Furthermore, it is acknowledged that little is known regarding the reliability of water exercise testing (Silvers et al, 2007). Further research should be done to determine reliability of underwater exercise testing, and to further investigate the cardiorespiratory responses of underwater treadmill running in comparison to land treadmill running using different levels of exertion and fluid jet resistance. It appears that the goal of underwater running of all types is to provide a form of supplementary training, injury prevention, and injury rehabilitation without the impact and musculoskeletal loading of land-based running, while maintaining the same training stimulus as land-based running. This supports the need for further research into underwater running modalities in order to elicit the same responses as land-based treadmill running.

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