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Physiological Differences between Land and Water Treadmill Running

Rachel Kemp Rife
Brigham Young University - Provo

PHYSIOLOGICAL DIFFERENCES BETWEEN LAND AND WATER TREADMILL RUNNING

by

Rachel K. Rife

A thesis submitted to the faculty of

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Department of Exercise Sciences

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Rachel K. Rife

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

Date	J. William Myrer, Chair
Date	Pat R. Vehrs
Date	J. Brent Feland
Date	Iain Hunter

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Rachel K. Rife in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

______________________ ______________________________

Date

J. William Myrer
Chair, Graduate Committee

Accepted for the Department

____

Larry T. Hall
Chair, Department of Exercise Sciences

Accepted for the College

____

Gordon B. Lindsay, Associate Dean
College of Health and Human Performance

ABSTRACT

PHYSIOLOGICAL DIFFERENCES BETWEEN LAND AND

WATER TREADMILL RUNNING

Rachel K. Rife

Department of Exercise Sciences

Master of Science

Objective: To determine if water treadmill running with (WTR-S) or without water shoes (WTR-NS) could produce similar cardiorespiratory responses as land treadmill running (LTR). Design and Setting: A repeated measures design was used to assess the differences between LTR and WTR-S and WTR-NS. All testing was done in either a research laboratory or an athletic training hydro-therapy room. Subjects: Eighteen trained runners (9 men and 9 women) volunteered for this study. All 18 subjects participated in three running conditions. Measurements: Treadmill speed, HR, and SF were assessed at four exercise intensities representing 50%, 60%, 70%, and 80% of land VO_{2max} for all three running conditions. Results: WTR with and without water shoes produces similar cardiorespiratory responses to LTR. The VO_2/HR relationship showed that at a HR of 150 bpm, VO_2 was significantly less ($p < 0.0001$) when running on a land treadmill (34.66 ml/kg/min) compared to a water treadmill with shoes (37.51

ml/kg/min) and without shoes (37.21 ml/kg/min) were nearly identical. At a HR 150 of bpm, the VO_2 in males (40.52 ml/kg/min) was 8.12 ml/kg/min higher than that of their female (32.40 ml/kg/min) counterparts. At a treadmill speed of 6 mph, stride frequency during LTR was 23.6 steps/min greater ($p < 0.0001$) than WTR-S and 21.8 strides/min greater than WTR-NS. VO_2 was on the average 4.12 ml/kg/min higher ($p < 0.0001$) during WTR-S compared to WTR-NS running condition at the same treadmill speed. Conclusion: Statistical analysis indicated that 50%, 60%, 70%, and 80% of land VO_{2max} was achieved in the water. Therefore, WTR can be used during rehabilitation of athletes unable to fully weight bear to prevent deconditioning. Wearing the AQinc water running shoe increases the metabolic demand by 4.12 ml/kg/min at any given water treadmill speed. Gender differences existed in the absolute HR/VO_2 relationship but not in the relative HR/VO_2 relationship among the three running conditions.

ACKNOWLEDGMENTS

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Physiological Differences between Land and Water Treadmill Running

Rachel K. Rife, MS, ATC; J. William Myrer, PhD; Pat R. Vehrs, PhD; and Gilbert W. Fellingham, PhD, Iain Hunter, PhD; J. Brent Feland, PhD

Brigham Young University, Provo, Utah

Abstract

Objective: To determine if water treadmill running with (WTR-S) or without water shoes (WTR-NS) could produce similar cardiorespiratory responses as land treadmill running (LTR). Design and Setting: A repeated measures design was used to assess the differences between LTR and WTR-S and WTR-NS. All testing was done in either a research laboratory or an athletic training hydro-therapy room. Subjects: Eighteen trained runners (9 men and 9 women) volunteered for this study. All 18 subjects participated in three running conditions. Measurements: Treadmill speed, HR, and SF were assessed at four exercise intensities representing 50%, 60%, 70%, and 80% of land VO_{2max} for all three running conditions. Results: WTR with and without water shoes produces similar cardiorespiratory responses to LTR. The VO_2/HR relationship showed that at a HR of 150 bpm, VO_2 was significantly less ($p < 0.0001$) when running on a land treadmill (34.66 ml/kg/min) compared to a water treadmill with shoes (37.51 ml/kg/min) and without shoes (37.21 ml/kg/min) were nearly identical. At a HR 150 of bpm, the VO_2 in males (40.52 ml/kg/min) was 8.12 ml/kg/min higher than that of their female (32.40 ml/kg/min) counterparts. At a treadmill speed of 6 mph, stride frequency during LTR was 23.6 steps/min greater ($p < 0.0001$) than WTR-S and 21.8 strides/min greater than WTR-NS. VO_2 was on the average 4.12 ml/kg/min higher ($p < 0.0001$) during WTR-S compared to WTR-NS running condition at the same treadmill speed. Conclusion: Statistical analysis indicated that 50%, 60%, 70%, and 80% of land VO_{2max} was achieved in the water. Therefore, WTR can be used during rehabilitation of athletes unable to fully weight bear to prevent deconditioning. Wearing the AQinc water running

shoe increases the metabolic demand by 4.12 ml/kg/min at any given water treadmill speed. Gender differences existed in the absolute HR/VO_2 relationship but not in the relative HR/VO_2 relationship among the three running conditions.

Introduction

Many athletes incur lower extremity injuries that necessitate a reduction in training volume. Research has shown that six weeks of cardiovascular detraining may result in a 14% - 16% decrease in VO_{2max}.[1] In an effort to minimize the deleterious effects of detraining following an injury on cardiovascular fitness, water running has been used in the rehabilitation process. Water running can be done in the deep or shallow end of the pool and on a water treadmill. The properties associated with water, such as buoyancy and viscosity, make it an appealing exercise medium for injured populations.[2]

Effective rehabilitation protocols are vital to the injured athlete to allow him/her to safely return to full activity as soon as possible. The early introduction of movement and restoration of normal function is of paramount importance during the rehabilitation process.[3] Therefore, the clinician's objective is to prevent deconditioning of injured athletes, while properly rehabilitating the injury to provide the athlete the best possible outcome. Water training can be used to accomplish this outcome.

Studies show that VO_{2max} and maximal heart rate (HR_{max}) are significantly lower in deep-water running (DWR) and shallow water running (SWR) when compared to land treadmill running (LTR) (subject replicated land-running movement as closely as possible while water running).[4-7] Also, DWR and SWR have stride frequencies (SF) significantly lower than LTR [5, 6]

Researchers show that when looking at maximal effort SWR elicits greater VO_2 than DWR and the VO_2, HR, and SF associated with SWR are more closely related to LTR than DWR.[5] One explanation for this is that during SWR, the subject is able to mimic the normal land-running gait. It is reasonable to expect that for the same reason, water-treadmill running (WTR) would elicit an exercise response similar to that of LTR. The physiological responses to WTR may vary depending on whether or not the subject is wearing a water shoe. A paucity of research has been done on water treadmill running. Additional research addressing water treadmill running (with and without water shoes) would provide beneficial information with respect to the prescription of water training for healthy and injured populations.

The purpose of this study was to determine if water treadmill running could produce similar cardiorespiratory responses as land treadmill running. To this end we analyzed the differences in HR, treadmill speed, SF, and gender between land-based treadmill running vs. water treadmill running when wearing a water shoe and when not wearing a water shoe at four exercise intensities representing 50%, 60%, 70%, and 80% of land VO_{2max}.

Methods

Subjects

Participant characteristics are listed in Table 1. Eighteen trained male (n = 9) and female (n = 9) runners between 18 and 30 years were subjects for this study. To qualify for this study subjects were engaged in a running program for at least two months prior to the commencement of the study consisting of a minimum of three training sessions per week of at least 30 minutes per session. All subjects signed an approved Institutional Review Board consent form before participating in this study. Subjects also completed a pre-exercise testing questionnaire to determine history of injuries, neurological impairments, and risk of untoward cardiovascular, pulmonary, or metabolic events during exercise. All subjects were classified as “low risk” according to the American College of Sports Medicine (ACSM) risk stratification.[8]

Equipment

All subjects completed a maximal graded exercise test (GXT) and a submaximal exercise test on a land-based treadmill (Model TMX425C, Full Vision, Inc., Newton, KS) and two submaximal exercise tests on a motor-driven treadmill in a hydro-therapy pool (HydroWorx model 500, Middletown, PA). Prior to the GXT and each of the submaximal exercise tests, subjects were fitted with a chest-strap heart-rate monitor (Polar Electro OY, Hong Kong) to measure HR during exercise. Metabolic responses to exercise were measured using a Truemax 2400 metabolic cart (Consentious Technologies, Sandy, UT). Prior to testing each subject, the flow meter was calibrated using a 3-L syringe at five different flow rates. The oxygen (O_2) and carbon dioxide (CO_2) analyzers were calibrated using room air and a medical grade calibration gas of known concentrations. The metabolic cart was programmed to display and print metabolic and ventilatory data every 15 sec.

Maximal Graded Exercise Test

All subjects completed the GXT first in order to determine appropriate exercise intensities for the three running conditions. Subjects began the GXT by walking at a self-selected brisk walking pace at level grade for 3 min. This was followed by jogging at a self-selected, submaximal pace between 4.3 and 7.5 mph at level grade for 3 min. The treadmill speed remained constant throughout the remaining stages of the exercise test as the grade was increased 1.5% each additional minute until the subject voluntarily terminated the test due to fatigue, despite verbal encouragement. The subjects' efforts were considered maximal if physical signs suggestive of exhaustion were apparent and at least two of the following three criteria were met: a) maximal respiratory exchange ratio (RER) > 1.10, b) maximal HR (HR_{max}) no less than 15 beats below age predicted maximal HR, and c) leveling off of VO_2 despite an increase in workload.[9-12] VO_{2max} was defined as the highest 30-s average VO_2 value. HR_{max} was defined as the highest single HR value recorded during the GXT.

Running Conditions

At least 48 hours following the GXT, all subjects completed the first of three submaximal exercise tests under the following three running conditions: 1) land-treadmill running (LTR), 2) water treadmill running while wearing water shoes (WTR-S), and 3) water treadmill running when not wearing water shoes (WTR-NS). At least 24 hours lapsed between each of the three running conditions. The LTR condition was completed first in order to determine appropriate water running speeds. The order of the water running conditions was randomized, and all exercise testing was completed within two weeks. Steady state VO_2, HR, and SF were recorded while running at approximately 50%, 60%, 70%, and 80% of VO_{2max} during each of the three running conditions. Each submaximal exercise test began with a 3-min warm-up at a self-selected walking speed. The speed of the treadmill was then gradually increased until the subjects reached a randomly selected intensity of exercise (50%, 60%, 70%, and 80% of VO_{2max}). Subjects jogged at this intensity for at least 5 minutes to obtain steady state VO_2 and HR values. Stride frequency (strides/min) was visually counted and recorded. A stride was considered to be a complete cycle of the running motion (right foot heal strike to right foot heal strike). Following a 5-min rest period, subjects repeated this process until they had run at all four intensities of exercise.

During WTR-S, subjects were fitted with a water-running shoe (AQinc, Corvallis, Oregon) (Figure 1). During the WTR-NS and WTR-S exercise tests, the water level was set at chest height. Water temperature was maintained at 32.2° ± 2°C. Subjects were instructed to jog looking straight ahead with their hands free of the hand rail. In order to prevent sculling motions of the arms, subjects were instructed to keep their arms at their sides with their hands in a loose-fisted position and their elbows flexed at 90°.[3] Subjects were also instructed to jog with a normal gait minimizing hang time following rear foot push off. Excess hang time increases the time between foot contacts and reduces effort. The water treadmill has a rail along its front where subjects were instructed to watch their vertical movement in relation to the rail through videography. The subjects were able to watch a frontal and saggital view of themselves, which helped them minimize hang time.

Statistical Analysis

All data were analyzed with SAS statistical software. The alpha level of significance was maintained at $p = 0.05$. Eighteen subjects participated in this study, each of whom performed a submaximal exercise test under all three running conditions (i.e., LTR, WTR-S, and WTR-NS). Steady-state data from all four intensities of exercise (i.e., 50%, 60%, 70% and 80% of VO_{2max}) were obtained for all three running conditions. Thus, each subject (n = 18) contributed 4 data points to each running condition and each running condition was represented by 72 data points.

Statistical analyses were conducted to determine differences in the HR and VO_2 responses by gender and running condition. Analyses were also conducted to determine differences in stride frequency and VO_2 as a function of treadmill speed between the three running conditions. In the data analysis, it was appropriate to center the data so intercepts were calculated within the range of data rather than when the independent variable was zero. When analyzing the VO_2 response as a function of HR, the HR data was centered at HR of 150 bpm. When analyzing the VO_2 response as a function of $\%HR_{max}$, the HR data was centered at 75% of HR_{max}. When analyzing the differences in stride frequency as a function of treadmill speed, treadmill speed was centered at 6 mph.

Linear mixed models (Proc Mixed in SAS) were used in all analyses so that within subject covariances could be appropriately accounted for. Since there were multiple measures per subject, failure to account for covariances within subjects would lead to underestimated standard errors for the model terms. All data were analyzed as linear growth curves. That is, the VO_2 response was represented as a function of HR,

$\%VO_{2max}$, and % HR_{max}, stride frequency as a function of the treadmill speed, and VO_2 as a function of treadmill speed. In all cases, a linear growth curve was appropriate for the range of values tested (see Figures 2-7). Because we centered the data, tests on intercepts were conducted at the center of the independent variable values, and thus are appropriate even when the slopes are not parallel.

Results

All 18 participants demonstrated maximal efforts during the maximal graded exercise tests as demonstrated by RER values greater than 1.10 and HR_{max} values ranging from 91.8% to 101% of age predicted HR_{max} (mean = 97.6% ± 2.46%).

Figure 2 illustrates the HR/VO_2 relationship in male and female participants averaged over the running conditions for all exercise intensities. The growth curve analysis revealed a significant gender effect ($p < 0.001$) in intercepts of the growth curves. At a HR of 150 bpm, the VO_2 in males (40.52 ml/kg/min) was 8.12 ml/kg/min higher than that of their female (32.40 ml/kg/min) counterparts. The slope of the HR/VO_2 relationship was significantly greater ($p < 0.0001$) in males (0.4453) than in females (0.3477).

The $\%HR_{max}/\%VO_{2max}$ relationship in male and female participants were averaged across the three running conditions (Figure 3). The growth curve analysis revealed that at a HR of 75% of HR_{max}, the $\%VO_{2max}$ in males (63.44%) was not significantly different ($p = 0.2335$) than that of females (60.36%). The slope of the $\%HR_{max}/VO_{2max}$ relationship was not significantly different ($p = 0.2827$) in males (1.4022) compared to females (1.3214).

The HR/VO_2 relationship in each of the three running conditions was averaged across gender (Figure 4). The growth curve analysis revealed that the intercept of the HR/VO_2 relationship at a HR of 150 bpm was significantly less ($p < 0.0001$) when running on a land treadmill (34.66 ml/kg/min) compared to a water treadmill. The intercepts of the HR/VO_2 relationship during WTR-S (37.51 ml/kg/min) and WTR-NS (37.21 ml/kg/min) were nearly identical ($p = 0.4115$). The slopes of the HR/VO_2 relationships during LTR (0.3953), WTR-S (0.4004), and WTR-NS (0.3938) were not significantly different ($p = 0.72$-0.94).

Figure 5 illustrates the $\%HR_{max}/\%VO_{2max}$ relationship in each of the three running conditions averaged across gender. The growth curve analysis revealed that the intercept of the $\%HR/\%VO_2$ relationship at a HR of 75% of HR_{max} was significantly less ($p < 0.0001$) when running on a land treadmill (58.82% of VO_{2max}) compared to a water treadmill. The intercepts of the $\%HR_{max}/\%VO_{2max}$ relationship during WTR-S (63.71 $\%VO_{2max}$) and WTR-NS (63.17 $\%VO_{2max}$) were not significant ($p = 0.3914$). The slope of the $\%HR_{max}/\%VO_{2max}$ relationships during LTR (1.3277), WTR-S (1.3829), WTR-NS (1.3749) were not significant ($p > 0.05$).

There were no gender differences ($p = 0.5287$) in SF at the various treadmill speeds used to elicit the desired intensity of exercise. There were significant differences in SF between running conditions. Figure 6 illustrates the differences in SF at various treadmill speeds during LTR, WTR-S, and WTR-NS. At a treadmill speed of 6 mph, stride frequency during LTR was 23.6 steps/min greater ($p < 0.0001$) than the SF during WTR-S and 21.8 step/min greater than SF during WTR-NS. There were no significant differences ($p > 0.05$) in the slopes of the SF data during LTR, WTR-S and WTR-NS conditions.

The relationship between VO_2 and various water treadmill speeds during WTR-S and WTR-NS conditions are plotted in Figure 7. VO_2 was on the average 4.12 ml/kg/min significantly higher ($p < 0.0001$) during WTR-S compared to WTR-NS condition at the same treadmill speed. There was no differences in the slopes between WTR-S and WTR-NS ($p = 0.8498$).

Discussion

The results of this study reveal 4 significant findings. First, WTR at intensities from 50% to 80% of VO_{2max} produced cardiorespiratory responses similar to that of LTR. WTR can thus be used to produce an overload significant enough to maintain cardiovascular fitness.[1, 5] Second, is that HR values were lower during WTR compared to LTR, even though the metabolic demand (VO_2) was similar (Figure 4). Third, gender differences existed in the absolute HR/VO_2 relationship (Figure 2), but not in the relative HR%/VO_2% relationship (Figure 3) among the three running conditions. Finally, running on al water treadmill while wearing the AQinc[13] water shoe produces a similar cardiorespiratory workout at a slower treadmill speed (approximately 0.6 mph slower) than without a shoe.

In this study, the cardiovascular and metabolic responses of trained runners were recorded at 50%, 60%, 70%, and 80% of their VO_{2max}. All subjects were able to exercise on the water treadmill at intensities equivalent of 80% of their VO_{2max}. Likewise, subjects exercised on the water treadmill at intensities equivalent of 55% to 94% of their HR_{max}.

These intensities fall within the recommendations of the ACSM to improve or maintain cardiorespiratory fitness.[14] Therefore, WTR could be an effective exercise for maintaining cardiovascular fitness during injury recovery.

Eyestone et al. found that VO_{2max} and a 2-mile run time can be maintained for six weeks by DWR at designated intensity, duration, and frequency equal to that of land running.[1] The most clinically applicable way to compare metabolic demands of running on a land treadmill with running on the water treadmill is by monitoring HR. Data presented in Figure 4 shows the HR at any given VO_2 is about 7 bpm lower during WTR compared to LTR. The data in this study concur with that of several previous studies.[4-7] Svedenhag and Seger[4] reported that HR during WTR was 8-11 bpm lower than during LTR. In contrast, Pohl and McNaughton[15] reported that VO_2 and HR were higher while walking on a water treadmill when compared to land walking. One explanation for the discrepancy between our findings and those of Pohl and McNaughton[15] is they had subjects walk on a water treadmill with the water level at mid thigh. A lower water level results in less buoyancy. They also reported that when water levels were increased to waist depth, the VO_2 and HR decreased due to the increase in buoyancy, which supports the findings of this and other research.[4] Buoyancy is thought to reduce the metabolic demands of exercising in water. Buoyancy decreases the weight-bearing component of exercise by increasing the subject's hang time while running, thereby decreasing physical effort and HR. The viscous properties of water also play a role in water running. Water is at least 800 times more viscous than air,[16] creating a greater resistance and longer muscle contraction time. During WTR, subjects took 22 fewer strides/min than running at the same treadmill speed on land. Our data concur with that previously reported.[3,5,6] Subjects in the current study had increased resistance, due to water viscosity, with minimal hang time, thus maintaining a similar metabolic demand (VO_2) as on land. The lower HR at any given VO_2 during WTR compared to LTR may be due to the additional hydrostatic pressure associated with WTR. Increased hydrostatic pressure while running in the water is thought to contribute to a central shift in blood volume which facilitates a greater venous return and a greater stroke volume, thereby decreasing HR while running in the water.[6] Therefore, the water treadmill could be beneficial to injured and healthy individuals who are seeking an exercise alternative that is metabolically comparable to land-based running while minimizing impact forces. Based on the results of this study, individuals can select a treadmill speed during WTR that elicits a HR of about 7 bpm less than their typical run on land to obtain an equivalent cardiorespiratory overload.

The gender differences observed in the absolute HR/VO_2 relationship (Figure 2) among the three running conditions may be due to the fact that male subjects had higher VO_{2max} values than their female counterparts (Table 1). The VO_{2max} in men (59.6 ± 4.6 ml/kg/min) was on the average 8.7 ml/kg/min higher than in females (50.9 ± 2.9 ml/kg/min). Compared to males, at any given VO_2, females had a higher HR. This can be explained by the fact that any given VO_2 represented a higher percentage of the females VO_{2max}. When the HR/VO_2 relationship was compared relative to maximal values (Figure 3), there were no gender differences. Therefore, clinicians should prescribe exercise intensities in relative terms (i.e., %HR_{max} or %VO_{2max}). The absolute HR at any given intensity will be lower in males than in females.

The AQinc shoe[13] has been designed for water running. The shoe creates greater resistance during water running due to small cups placed on the sole of the shoe (Figure 1). On average, at any given VO_2, subjects in this study ran about 0.6 mph slower when wearing the water-running shoe compared to when running without the shoe. Likewise, at any give water treadmill speed, wearing the water-running shoe elicited a higher VO_2 response ($\approx$ 4.12 ml/kg/min) than when not wearing the water running shoe (Figure 7). Wearing a water running shoe during WTR increases the overload at any given treadmill speed. The water running shoe also provides padding between the subjects' foot and the treadmill surface which tends to be more comfortable while training.

In conclusion, the water treadmill provides athletes an alternative method of training to maintain cardiovascular fitness without the weight-bearing demands of land running. By monitoring HR, both males and females can use WTR to induce a similar overload as LTR. Subjects should select water treadmill speeds which elicit a HR response that is 7 bpm less than their typical training HR during land-based running. Wearing the AQinc water-running shoe increases the metabolic demand (i.e., VO_2) at any given water treadmill speed. Further research reporting the usefulness of WTR during rehabilitation of lower extremity injuries would supplement the findings of this research. A biomechanical analysis of WTR compared to LTR could also be useful information for cross trainers.

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Table 1. Participant Characteristics

	Male (n=9)	Female (n=9)	Combined (n=18)
Age (years)	23.0 ± 3.2	21.6 ± 1.1	22.3 ± 2.4
Height (cm)	180.2 ± 5.0	167.9 ± 6.3	174.0 ± 8.4
Weight (kg)	72.7 ± 5.2	61.4 ± 6.6	67.1 ± 8.2
BMI (kg/m^2)	22.4 ± 1.7	21.7 ± 1.4	22.1 ± 1.6
VO_{2max} (ml/kg/min)	59.6 ± 4.6	50.9 ± 2.9	55.3 ± 5.8
HR_{max} (bpm)	191.9 ± 6.5	194.1 ± 5.6	193.0 ± 6.0
RER_{max}	1.16 ± 0.03	1.19 ± 0.04	1.18 ± 0.04

All values are mean ± SD.

Figure 1. The AQinc water running shoe.[13]

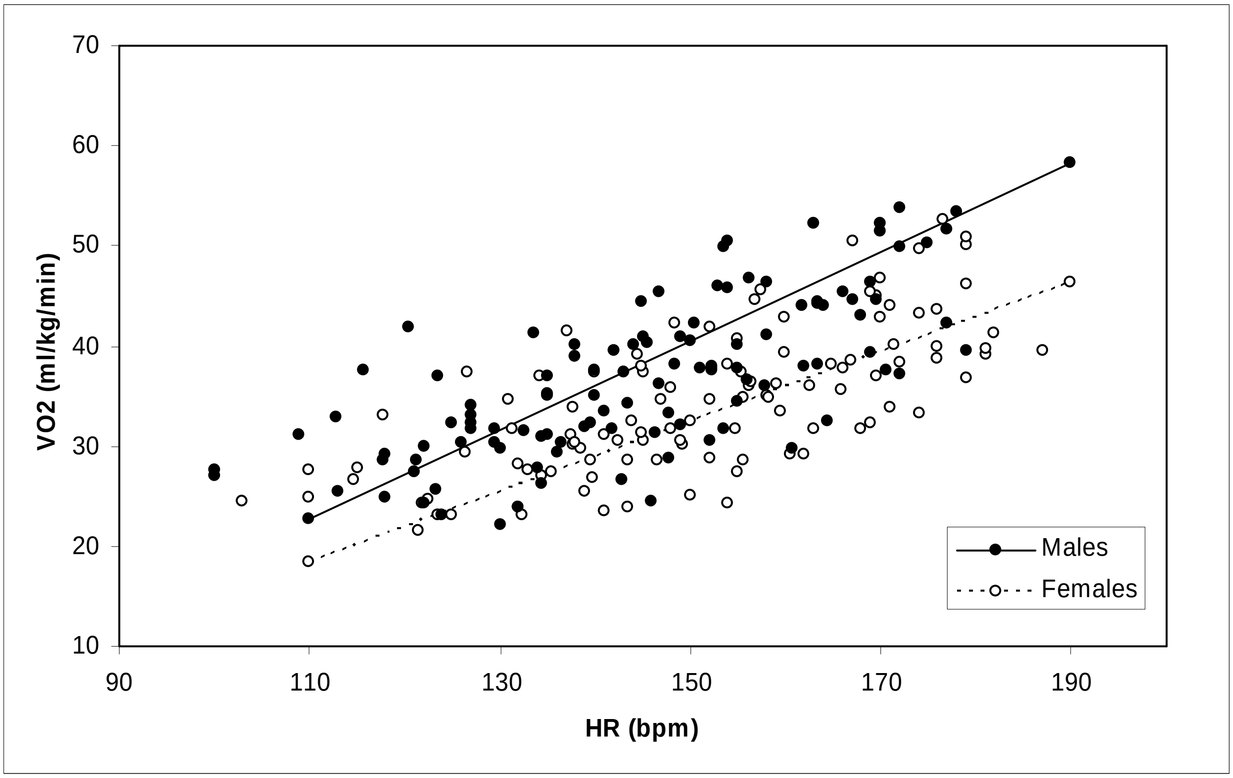

Figure 2. Gender differences in heart rate and VO_2 responses for all three running conditions and at all exercise intensities.

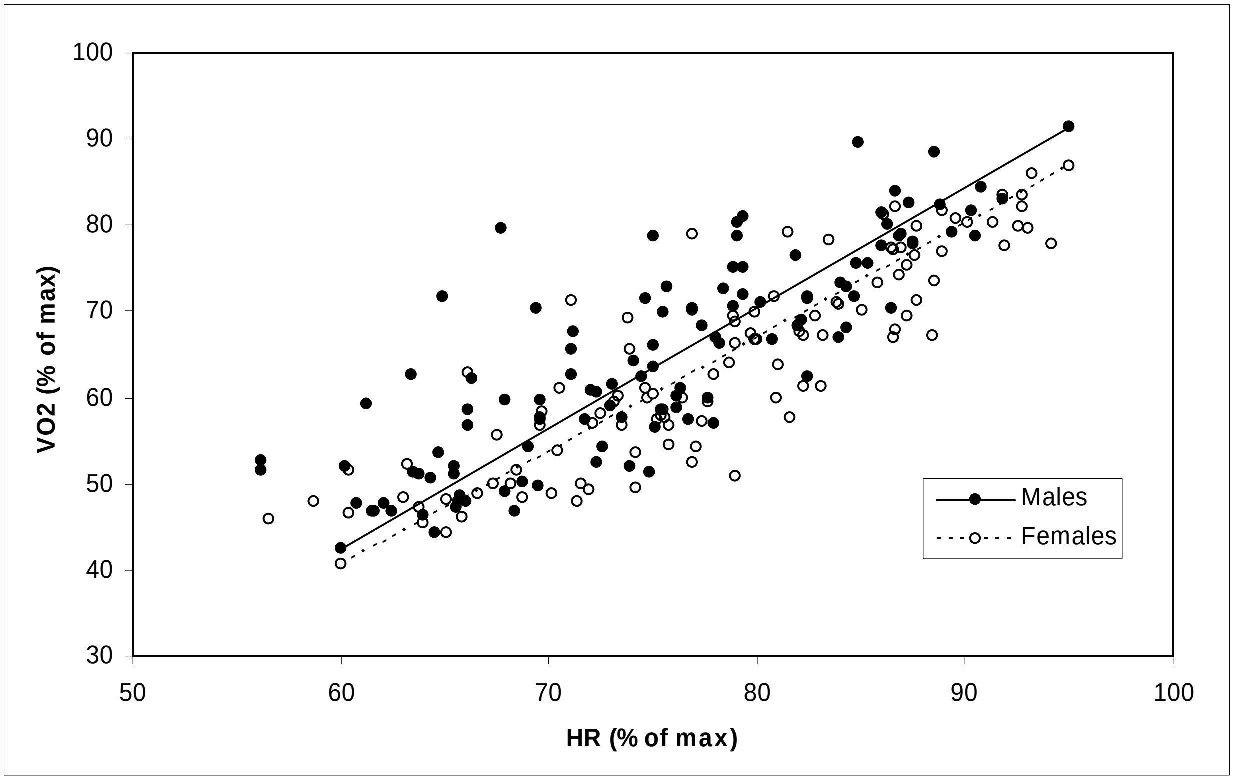

Figure 3. Gender differences in percentage of maximal heart rate and VO_2 responses to treadmill running during all three running conditions.

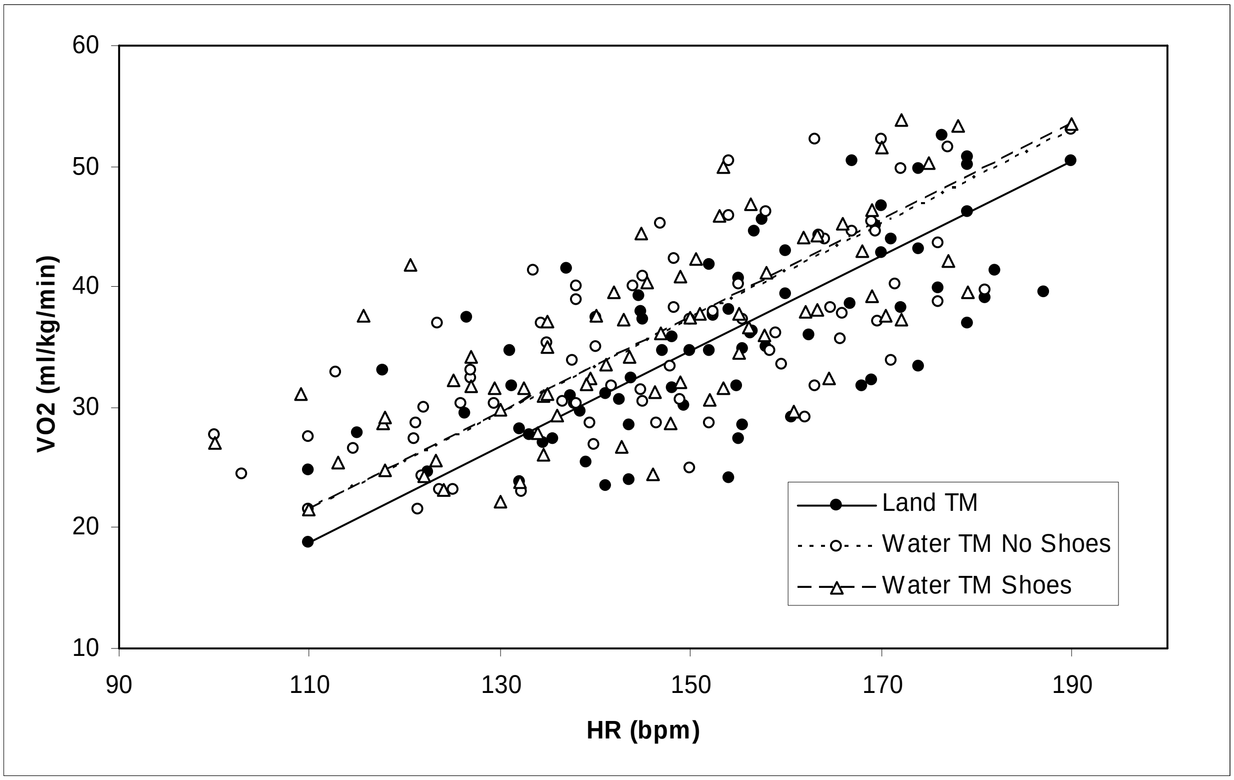

Figure 4. Differences in heart rate and VO_2 responses to treadmill during all three running conditions across genders.

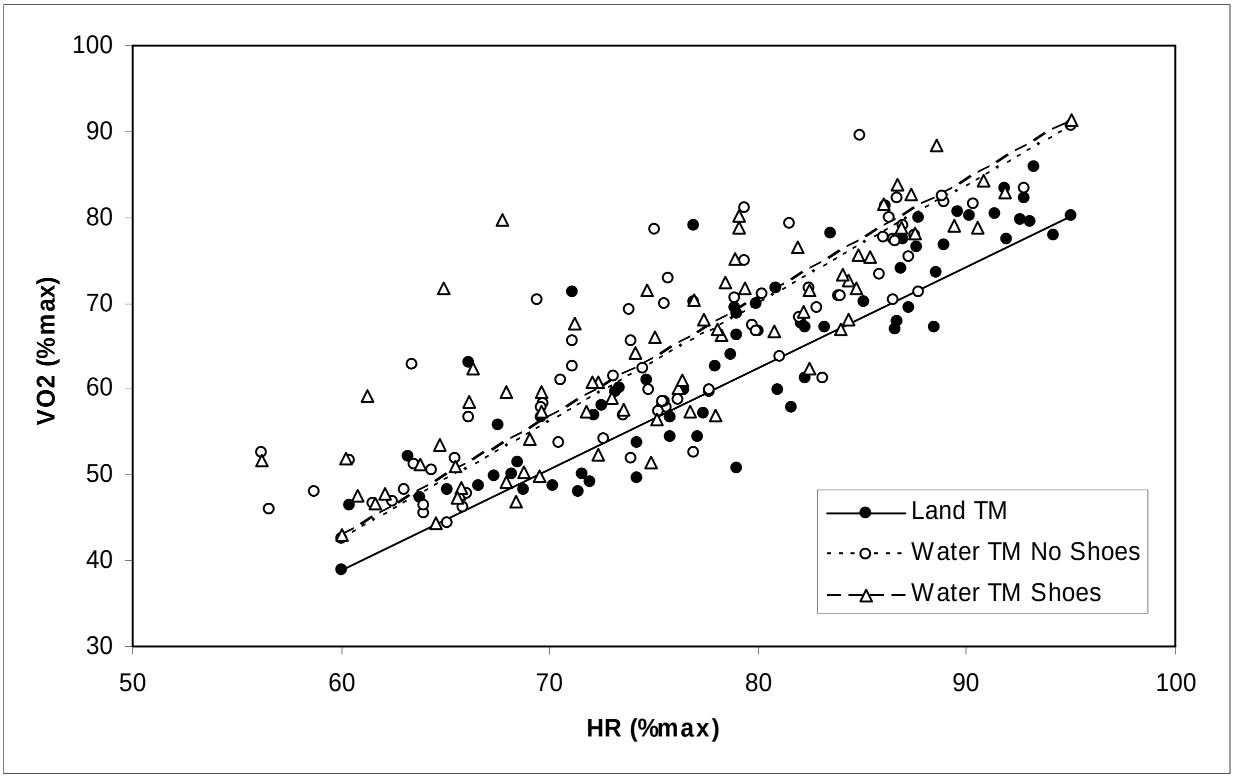

Figure 5. Percentage of maximal heart rate and VO_2 responses to treadmill running during all three running conditions across genders.

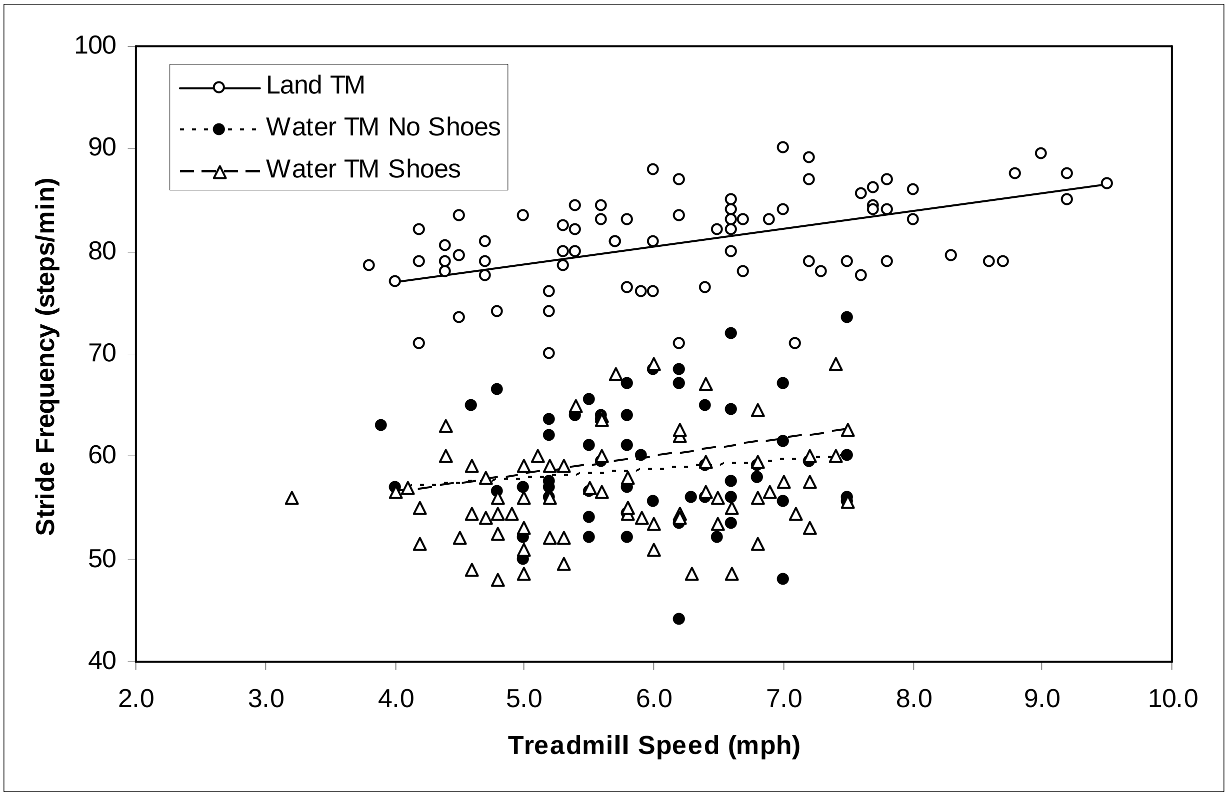

Figure 6. Treadmill speed (mph) and stride frequencies during treadmill running during all three running conditions across genders.

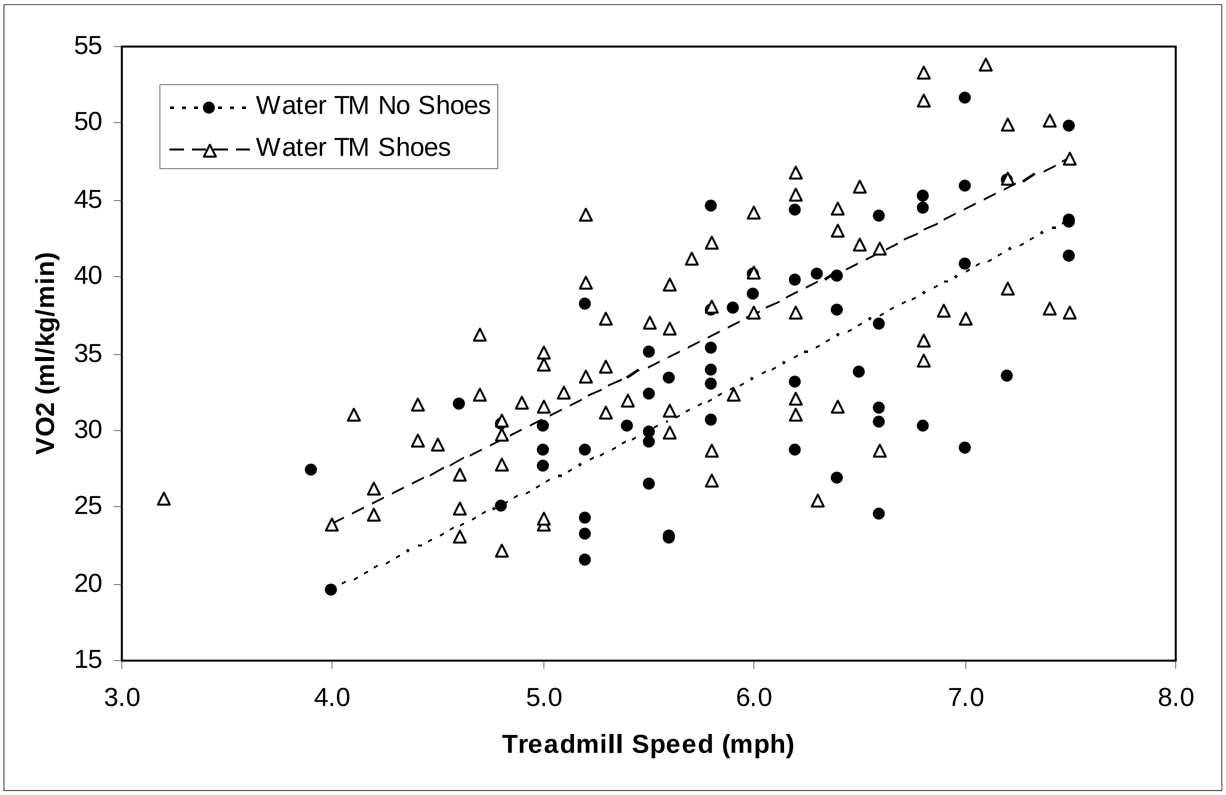

Figure 7. Treadmill speed (mph) and VO_2 (ml/kg/min) during treadmill running in water with and without shoes across genders.

Appendix A

Prospectus

Chapter 1

Introduction

Water running uses the medium of water to provide buoyancy and drag forces that alter loading on the body when compared to land-based running. Water running can be done in the deep-end of a pool (with a flotation device), in the shallow-end of the pool where the bottom of the pool is contacted during the running motion, and on a water treadmill. The properties associated with water such as buoyancy and viscosity make it an appealing exercise medium for healthy as well as injured populations.[1] Buoyancy decreases the resultant vertical force exerted on the body, creating an optimum mode of exercise for injured athletes.[2, 3, 4] In addition, viscosity enables the patient to get a cardiovascular workout due to the increased resistance without the full weight bearing component of land exercise.

Effective rehabilitation protocols are vital to the injured athlete to allow him/her to safely return to play as soon as possible. The early introduction of movement and restoration of normal function are of paramount importance during the rehabilitation process.[5] Therefore, the clinician's objective is to prevent de-conditioning of injured athletes while properly rehabilitating the injury to provide the athlete the best possible outcome. Water training has been used to accomplish this outcome.

Research has shown that deep water running (DWR) exhibits less metabolic stress than land running when working at VO_{2max}. Studies show that VO_{2max} and heart rate (HR) are significantly lower in deep water running and shallow water running (SWR) when compared to land treadmill running (LTR) when running at maximal effort.[6, 7, 8, 9]

Also, DWR and SWR have stride frequencies (SF) significantly lower than LTR[8, 7] On the other hand, Frangolias et al. have found that the ratings of perceived exertion (RPE) were similar for both DWR and LTR (12 vs. 13).[8, 10]

Town and Bradley[7] studied the metabolic responses to SWR and DWR compared to LTR. They reported that SWR elicits greater physiological demands than DWR and the VO_2, HR, and SF associated with SWR are more closely related to LTR than DWR.[7] Similar findings might be seen in water treadmill running (WTR) due to the subject's ability to make contact with the ground, which mimics a more normal running gait like SWR. In addition, running on a water treadmill with a water shoe provides additional resistance and increases the effectiveness of the rear foot push off. Wearing a water shoe would likely provide a sense of stability and control while water treadmill running, possibly enhancing the rehabilitation of the athlete. Wearing a water shoe, while water treadmill running, may also alter the metabolic demands when compared to not wearing a water shoe. However, a paucity of research has been done on water treadmill running; additional research addressing water treadmill running (with and without shoes) would be beneficial to the rehabilitation and prescription of water training for healthy and injured populations.

Statement of the Problem

The purpose of this study is to analyze the differences in speed, HR, RPE, and SF between land-based treadmill running vs. water treadmill running with a water shoe (WTR-S) and without a water shoe (WTR-NS) at four exercise intensities representing 50, 60, 70, 80% of land VO_{2max}.

The Null Hypothesis

1. Heart Rate and VO_2 relationship – There is no difference in the relationship between HR and VO_2 during LTR, WTR-NS, and WTR-S.

2. Stride frequency - There is no difference in SF during LTR, WTR-NS, and WTR-S.

3. Ratings of perceived exertion -There is no difference in PRE during LTR, WTR-NS, and WTR-S.

4. Speed – There is no difference in speed during LTR, WTR-NS, and WTR-S

Operational Definitions

Water Treadmill - A treadmill placed in the bottom of a small pool, where the entire treadmill is immersed in water. The water treadmill acts similarly to a normal land treadmill due to its capability to adjust speeds (mph or m/s). Water depth can also be adjusted.

Buoyancy - Archimedes' Principle states that a submerged object loses weight equal to the weight of the water displaced.[11]

Viscosity - Is the resistance to movement caused by an interaction of water molecules to the surface of the moving object. Resistance increases with movement and creates a resistance proportional to the effort exerted.[12]

Hydrostatic Pressure - The force acting on an object in the water is equal to the weight of the water above the object. The deeper the depth in the water the more pressure will be acting on an object.[12]

VO_2 - The amount of oxygen consumed by a person at any given time.

VO_{2max} - Is the highest rate at which oxygen can be utilized by a person during strenuous exercise.

Stride Frequency - The number of times a person moves through a full gait cycle in one minute (heel contact of the right/left heel to heel contact of that same foot).

Borg's Perceived Exertion Scale - A numerical scale that corresponds to a certain degree of effort. This scale functionally integrates physiological and psychological aspects of work. Borg's scale relates to several physiological variables such as, heart rate, ventilation, respiration rate, oxygen uptake, and blood lactate.[13]

Steady State - When the HR and VO_2 have consecutive readings that are similar during an exercise bout. This shows that the subjects have adjusted to the new demand.

Trained Runner - An individual who is currently running at least four times per week for a minimum of 30 minutes per exercise bout for a minimum of two months.

Assumptions

The land VO_{2max} test can be used to analyze the VO_2 data found in the water.

Delimitations

1. This study will be delimited to 18 trained male and female runners between the age of 18-35 years.

2. Subjects will be selected from the student body at Brigham Young University.

Limitations

The water treadmill does not exceed 7.5 mph; therefore, to reach the desired VO_2 for some subjects the jets could be used.

Significance of this Study

The running motion is a common component of most sports. Water treadmill running is a therapeutic and rehabilitative alternative to land treadmill running. The objective is to rehabilitate injured athletes using exercise modalities which closely mimic the sport specific demands and avoid the deleterious effects of de-conditioning.

The water treadmill could provide a progressive rehabilitative program appropriate for those who desire to return to a normal land gait pattern while maintaining cardiovascular fitness. Prior research has not evaluated the differences in the physiological responses to WTR-NS or WTR-S when compared to LTR. Therefore, the purpose of this study is to compare the physiological responses to WTR (with and without water shoes) to those of LTR. This study could find a compatible metabolic load during WTR, thus enabling clinicians to prescribe a workout in the water comparable to the land. This knowledge would provide the basis for safe, graduated exercise prescription for both the non-injured and rehabilitating athlete.

Chapter 2

Review of Literature

This review synthesizes the literature that focuses on several aspects of this study, including: (1) fluid dynamics, (2) types of water running, (3) the uses of water training (4) the differences in VO_{2max}, VO_2, and heart rate (HR) during shallow water running (SWR), deep water running (DWR) and land treadmill running (LTR), (5) the differences in stride frequency (SF) during SWR, DWR, and LTR, (6) the metabolic comparisons of water treadmill walking, (7) the comparison of water treadmill walking and DWR and SWR, (8) Borg's perceived exertion scale, and (9) the differences in the ratings of perceived exertion (RPE) during SWR, DWR and LTR.

Fluid Dynamics

Water walking and running have been popular methods of rehabilitation and exercise. Three properties of water, buoyancy, viscosity, and hydrostatic pressure make exercising in water appealing for healthy as well as injured populations.[1]

Archimedes' Principle states that a submerged object loses weight equal to the weight of the water displaced. As a person enters the water their body weight will be reduced by the weight of water displaced. Harrison[14] reported that body weight decreased by 85% when submersed to the level of 7th cervical vertebrae, 71% at the xiphisternum, and 57% at the anterior superior iliac spine. Due to buoyancy, water decreases the vertical forces exerted on the body. Therefore, water running can be an optimal mode of exercise for injuries that require movement but do not allow the subject to full weight bear.[3, 4]

Water viscosity plays a critical role in water running. Viscosity is the resistance to movement caused by an interaction of water molecules to the surface of the moving object. Resistance increases with movement and creates a resistance proportional to the effort exerted.[12] The viscosity of water is 800 times that of air. Exercising in the water is an alternative means of applying an overload without the consequences of the total weight bearing component of land exercise.[4]

Hydrostatic pressure is the pressure on an object that is submersed in a fluid. The pressure placed on the object increases the further the object is submersed. Hydrostatic pressure is thought to contribute to the central shift in blood volume while running in water.[8] This facilitates a greater venous return and a greater stroke volume, thus decreasing the HR while running in water.[8] Water running has been shown to produce a lower HR compared to land running.[6, 7, 8, 9]

Types of Water Running

Water running uses the medium of water combined with cardiovascular overloading as a beneficiary alternative to land-based running. Several methods of water running have been developed: DWR, SWR, and water treadmill running (WTR).[1, 15, 16] DWR is done in the deep end of the pool where subjects mimic normal running mechanics.[15] SWR is also done in a pool; however, patients run in the shallow end enabling them to have contact with the pool floor. WTR consists of an underwater treadmill that allows the patient to monitor speed, water resistance via jets and water depth.[15] Deep water, shallow water, and water treadmill running have been designed, tested, and modified to provide both healthy and injured people an alternative to land-based training.[15, 17,18]

Although DWR has been proven to produce a training effect, it results in an altered gait when compared to running on land.[15, 19] To normalize the DWR gait researchers have monitored cadence, used float vests, water current, or have tied the patient to the side of the pool to eliminate forward movement.[1,17, 18] Moening et al.[19] give three explanations for why gait during DWR differs from land running: 1) the absence of contact with the ground, which eliminates a rebounding response, 2) it is an open kinetic chain exercise which permits the tibia to move on the femur rather than the femur on the tibia, as is the case in the closed kinetic chain movement during running on land and, 3) there exists methodological difficulties of obtaining similar effort and cadence in the water when compared to land. Despite these complications to DWR, Wilder et al.[1] have shown a way to predict heart rate and intensity of the workout by monitoring the stride frequency while running in water. Wilder put subjects into the deep end of the pool with an exercise belt that was tethered to the side of the pool. A T-shaped target was made out of PVC pipe that was anchored to the pool floor via a cement block. The target permitted the subjects the opportunity to regulate their stride length. Thus, providing a way to predict DWR exertion compared to land running. This information is helpful; however, Wilder's methods are not clinically applicable due to the complexity of his design.

Differences between DWR and LTR led to the use of SWR, which elicited a more normal land running gait.[15] SWR creates a closed chain activity much like land running;

however, it can produce a distorted posture causing the athlete to lean forward due to the increased frontal resistance.[15]

Underwater treadmills are becoming an alternative to land running due to the possibility of a more normal ambulatory running motion when compared to DWR or SWR. It minimizes the gait abnormalities associated with DWR because contact is made with the ground, thus producing a closed kinetic chain movement. Another benefit to WTR is it enables the clinician to monitor effort and cadence through treadmill speed, water depth and water current. Thus, the underwater treadmill could possibly be a more effective tool for rehabilitation, and especially beneficial for those patients who desire to return to a functional gait pattern while producing a training effect.[15]

The Uses of Water Training

Vital to the injured athlete is a quick, effective rehabilitation program that allows him/her to return to play as soon as clinically possible. For this optimum result, the introduction of early movement and restoration of normal function are of paramount importance.[5] When the body is injured, it loses its normal ability to react and gauge normal stresses that are imposed on it.[Abfall] Therefore, the clinician's objective is to prevent de-conditioning of injured athletes while properly rehabilitating the injury to provide the athlete the best possible outcome. Crucial components of the rehabilitation processes include: strength, proprioception, range of motion, cardiovascular fitness, and functionality.[20]

Maintaining strength and range of motion are often the main goals during rehabilitation for many clinicians, while proprioception, cardiovascular training, and functional movements are under emphasized. Borsa et al.[21] suggest that extremity function is influenced more by input via proprioception than the amount of strength demonstrated during a specific activity. A loss of proprioception could be the predetermining factor in re-injury.[21] To ensure that proprioception is restored, functional activities must be incorporated throughout the rehabilitation process.[20]

Aerobic conditioning must also be included in the rehabilitation of athletes. Research has show that six weeks of cardiovascular detraining, VO_{2max} can decrease 14% to 16%.[18] In the effort to minimize the deleterious effects of injury on cardiovascular fitness, water training has been used in the rehabilitation process. Eyestone et al.[18] reported that VO_{2max} and a 2-mile run time can be maintained for six weeks by water running at designated intensity, duration, and frequency equal to that of land running. The data reported by Eyestone et al.[18] suggests that individuals who want to maintain their cardiovascular fitness while they are recovering from a soft tissue injury can use DWR as an effective alternative mode of exercise.[18] Because the running motion is a common component of most sports, DWR or WTR may be used as an effective mode of rehabilitation.

The Differences in VO_{2max}, VO_2, and Heart Rate between Water and Land Running

Studies show that VO_{2max}, VO_2, and heart rate are significantly lower in DWR and SWR when compared to LTR.[6, 7, 8, 9] Svedenhag and Seger[6] found that VO_2 was 4.03 ± 0.13 vs. 4.60 ± 0.141 L/min and max heart rate was 172 vs. 188 bpm during water and land running, respectively. Frangolias et al.[8] also reported lower VO_{2max} (54.6 vs. 59.7 ml/kg/min) and a lower maximal heart rate (175 vs. 190 bpm). Svedenhag and Seger conclude that for a given VO_2, heart rate was 8-11 bpm lower in water than on land. The decrease in heart rate is attributed to hydrostatic pressure which contributes to the central shift in blood volume that facilitates a central venous return and a greater stroke volume.[8]

In contrast, Pohl and McNaughton[15] found that VO_2 and HR were higher in the water. They compared the physiological demands of walking on a water treadmill with the water level at the thigh and at the waist to land treadmill walking. One explanation for their findings is that the water levels were set so low that buoyancy did not have much of an effect but the viscosity of the water did. They found that as the water level increased to waist deep the VO_2 and HR decreased due to the increase in buoyancy, which supports other research.

Town and Bradley[7] studied metabolic responses to shallow and deep water running compared to LTR. Maximal exercise tests were preformed during LTR, DWR, and SWR (1.3m in depth). They reported that SWR elicited greater physiological demands than DWR and similar responses to LTR. VO_{2max} for DWR was 74% of LTR while SWR was 90%. Treadmill running elicited a maximal heart rate higher than DWR and SWR. SWR elicited a higher maximal heart rate than DWR.[7] Frangolias[10] also found that VO_2, and HR levels were lower in DWR during prolonged exercise (42 min).

The differences in VO_{2max} during water running with the similar peak blood lactate levels and lower SF suggests that the active musculature and muscle recruitment patterns during DWR are different than that of land running due to the high viscosity of water and the non-weight bearing nature of water running.[8] This theory is supported by the results of SWR. SWR had a weight bearing component, and decreased amount of viscosity (water level was at 1.3m), which could have been part of the reason the metabolic values for SWR match more closely to LTR.

The Differences in Stride Frequency

Studies have demonstrated that stride frequency during DWR are significantly lower than LTR. For example, Frangolias et.al[8] reported 108 strides/min for DWR compared to 176 during LTR. Town and Bradley[7] have also found lower SF during DWR (83.9strides/min) when compared with SWR (108.5 strides/min). Videography of water running has shown that there are three possible explanations to the lower SF in water: 1) water runners predominately use their lower body musculature for the activity, 2) there is no eccentric contraction of the lower trunk musculature because there is no push-off phase due to the non-weight bearing component of water running, and 3) the viscosity of the water influences the running style by reducing the need to rely on the postural muscles, reducing stride frequency and increasing the demand on the arms during the forward and backward pumping motion.[8] Hall and Grant[5] hypothesize that the reduced stride frequency could imply a longer contraction time and cause a greater reliance on anaerobic pathways.

Stride frequency may be closer to that of LTR due to similarities in running style and the weight bearing component. No research has been done comparing stride frequency of LTR and WTR.

The Differences in Perceived Exertion

Several studies have reported ratings of perceived exertion during DWR and LTR. Svedenhag and Seger's[6] reported a higher perceived exertion during DWR than LTR.

Frangolias reported similar RPE values for both DWR and LTR (12 vs. 13) and similar findings were seen during prolonged running.[8, 10]

The Metabolic Comparisons of Water Treadmill Walking

Few studies have compared water treadmill walking to land walking. Most studies have compared the kinematics of water treadmill walking to land walking.[2, 3, 4] Hall et al.[5] did a physiological comparison in patients with rheumatoid arthritis. Three speeds were used (2.5, 3.5, and 4.5 km/h) during all walking protocols. Water height was set at the xiphoid process (unloading the lower limbs by about 71%). They reported that VO_2 was lower at 2.5, and 3.5 km/h during water treadmill walking, however at 4.5 km/h VO_2 values were the same as land walking. Heart rate was lower while walking in water at 2.5km/h; however, at 3.5 km/h the HR was equal to land and then at 4.5 km/h the heart rate was significantly higher than on land.[5] In another study done by Hall et al.,[22] similar relationships were seen in VO_2. Hall[22] reported a significant increase in HR when the water temperature was set at 36°C when compared to 28°C. In water below 30°C HR values were always lower on land than in water.[22] Differences in HR and VO_2 may have been due to differences in SF. The SF in the water was consistently 21.9 strides/min lower than land walking.[5] These findings suggest that at a water walking speed of 2.5 km/h, the buoyancy effect overrides the minimal water resistance resulting in a lower metabolic demand than on land.[5] On the contrary, walking in the water at the speed of 4.5 km/h had a similar VO_2 as on land and some studies show a higher HR due to the increase in water resistance.[5]

The Comparison of Water Treadmill Walking to DWR and SWR

Studies that have researched DWR and SWR show different metabolic demands than water treadmill walking. These discrepancies could be due to: 1) DWR and SWR show the metabolic demands of running in water while water treadmill walking shows the demands of walking in water, 2) the difficulty in matching the land treadmill speeds/effort with DWR and SWR efforts when water treadmill walking speeds can be adjusted to equal that of land. Research comparing the metabolic demands of water treadmill running could be a beneficial addition to the current literature.

Borg's Perceived Exertion Scale

Borg's perceived exertion scale is a numerical scale that corresponds to a certain degree of effort. This scale functionally integrates physiological and psychological aspects of work.[13] Borg's scale relates to several physiological variables such as, heart rate, ventilation, respiration rate, oxygen uptake, and blood lactate.[13] The scale is shown to subjects and they are asked to verbally or to physically (point) choose a numerical value that represents their effort (see appendix A-1).[13] High correlations (r = 0.85) have been found between the Borg's ratings of exertion and heart frequencies. [13]

Summary

In summary, little published data is available on the physiological responses to WTR. Water running is an optimum medium for maintaining cardiovascular fitness. "The effects of water resistance and buoyancy make possible high levels of energy expenditure with relatively little movement and strain on lower extremity joints, suggesting that this exercise may be a valuable alternate mode of conditioning for developing and maintaining work capacity and cardiovascular fitness".[16] Due to the benefits of water running, further research is needed to compare the physiological responses to water treadmill running to land treadmill running. In addition, no research is available comparing the physiological responses of water treadmill running with and without a water shoe. Research addressing the physiological responses to WTR could be beneficial in the rehabilitation and exercise prescription of injured as well as healthy individuals.

Chapter 3

Methods

Experimental Design

The experimental design is a 3x4 repeated measures across three treatments and four exercise intensities. The primary dependent variable is HR and the independent variable is VO_2. Secondary dependent variables of interest are speed, RPE, and SF.

Procedures

Heart rate (HR), stride frequency (SF), speed, and ratings of perceived exertion (RPE) will be measured during 50, 60, 70, and 80% of maximal oxygen consumption (VO_{2max}). Eighteen trained male and female runners will be tested in the following submaximal exercise conditions: 1) land treadmill running, 2) water treadmill running with water shoes (AQinc, Corvallis, Oregon), and 3) water treadmill running without water shoes. Following familiarization and maximal land exercise testing, subjects will complete the three submaximal exercise conditions in a randomized balanced block design. Steady state VO_2, HR, RPE, and SF will be recorded while running at approximately 50, 60, 70, and 80% of VO_{2max} during each of the three submaximal exercise conditions. At least 48 hours will lapse between maximal exercise testing and submaximal exercise testing. At least 24 hours will lapse between submaximal exercise tests. All exercise testing will be completed within two weeks.

Subjects

Participants in this study will be trained male and female runners between 18-35 years of age. Subjects will be recruited from the running club at Brigham Young

University and the general student population who meet the following criteria: 1) subjects must currently be engaged in a running program for at least the last two months consisting of a minimum of three training sessions per week of at least 30 min per session, 2) subjects must be free of injury or rehabilitated from injury to the lower extremity within the last two months 3) no surgery to the lower extremities within the last six months, 4) no neurological disorders, and 5) subjects will be excluded from participation if their VO_{2max} is above 70 mL $kg^{-1}min^{-1}$.

Familiarization

All subjects will read and sign an approved Institutional Review Board consent form before participating in this study. Subjects will also complete a pre-exercise testing questionnaire to determine history of injuries, neurological impairments, and risk of untoward cardiovascular, pulmonary, or metabolic events during exercise (see appendix A-2). All subjects will be classified as "low risk" according to the American College of Sports Medicine (ACSM) risk stratification.[23] Any subjects who do not fit this classification will not be aloud to participate in this study.

Subject's height (cm) and weight (kg) will be measured to the nearest 0.5 cm and 0.1 kg, respectively, using a weight and height scale (Scale-tronix Model 5005, Wheaton, IL) while wearing spandex shorts and no shoes.

In preparation for exercise testing subjects will be instructed to (1) wear comfortable, loose-fitting clothing during land exercise and spandex shorts for water exercise; (2) drink plenty of fluids 24-hours preceding all tests to ensure normal hydration prior to testing; (3) avoid tobacco, alcohol, and caffeine for at least 3 hours before testing;[23] (4) avoid consumption of food, other than water, 4 hours prior to testing;[23] (5) avoid exercise and strenuous physical activity the day before and of the day of testing; and (6) get at least 6 to 8 hours of sleep the night before the test.

During the pre-exercise testing day, subjects will be familiarized with treadmill jogging in water and land treadmill jogging if necessary. Subjects will be given the opportunity to jog at varying speeds on the water treadmill to become accustomed with running in water. Subjects will also be familiarized with the use of water shoes while water treadmill jogging. Additionally, subjects will be instructed on the use of the Borg's 15-point perceived exertion scale and they will be asked to periodically report their rating of perceived exertion.

Instrumentation

Metabolic and ventilatory responses to treadmill running on land and in water will be measured using a Truemax 2400 metabolic cart (Consentious Technologies, Sandy, UT). Prior to each exercise test, the flow meter will be calibrated using a 3-L syringe at five different flow rates and the oxygen and carbon dioxide analyzers will be calibrated using room air and a medical grade calibration gas of known concentrations. A nose clip will be worn for measurement of expired gases. A 9 foot (274 cm) breathing tube with a 35 mm ID will be used to connect the two-way non-rebreathing valve (Hans Rudolf Inc., Kansas City, MO) to a water filter trap and mixing chamber for exercise testing on the land and in the water. The metabolic cart will be configured to calculate and print metabolic values every 15 seconds. A heart rate monitor (Polar, Inc.) will be used to gather steady state HR during all testing. Rating of perceived exertion (RPE) will be monitored using the Borg 15-point scale.[13]

Maximal Exercise Testing

Maximal graded exercise tests (GXT) will be performed on land on a calibrated motorized treadmill (Trackmaster TMX425C, Full Vision Inc., Newton KS). Oxygen consumption will be measured during the GXT using the metabolic cart. Heart rate will be continually monitored and interfaced with the metabolic cart using a radiotelemetry heart rate monitor.

Subjects will begin the maximal GXT by walking at a self-selected brisk walking speed at level grade for 3 minutes. This will be followed by jogging at a self-selected, submaximal speed between 4.3 and 7.5 mph at level grade for 3 minutes or until a steady-state HR is achieved. The treadmill speed will remain constant throughout the remaining stages of the exercise test as the grade is increased 1.5% each additional minute until the subject voluntarily terminates the test due to fatigue, despite verbal encouragement. The subject's effort will be considered maximal if physical signs suggestive of exhaustion are apparent and at least two of the following three criteria are met: a) maximal RER > 1.10, b) maximal HR (HR_{max}) no less than 15 beats below age predicted maximal HR, and c) leveling off of VO_2 despite an increase in workload.[24, 25, 26, 27] Maximum VO_2 will be defined as the highest 30-s average value, while HR_{max} will be defined as the highest single HR value recorded during the GXT. The leveling off of VO_2 despite an increase in workload will be defined as a change in VO_2 of less than ± 2 mL $kg^{-1}min^{-1}$ once VO_{2max} is achieved.

Submaximal Exercise Testing

Submaximal exercise testing on land will be performed in the Exercise Physiology Lab of the Human Performance Research Center. Submaximal exercise testing in water will be performed in the Athletic Training Room in the Student Athlete Building at Brigham Young University.

Subjects will complete three 5 minute submaximal exercise tests under three conditions: 1) land treadmill running, 2) water treadmill running with water shoes, and 3) water treadmill running without water shoes at approximately 50, 60, 70, 80% of their land VO_{2max}. The submaximal exercise test on land will be performed on the same treadmill that was used during the GXT. The submaximal exercise tests in the water will be performed on a motor-driven treadmill in a hydro-therapy pool (HydroWorx model 500, Middletown, PA). Oxygen consumption and HR will be measured during land and water treadmill running using the metabolic cart configuration described above. Stride frequency (steps/min) will be visually counted during submaximal exercise testing on land and in the water two times during each of the three testing speeds. One of the three stride frequency measurements will be counted during the final minute of the exercise stage. The other minute will be sampled at random. The two measurements will be averaged.

During each of the three submaximal exercise tests, subjects will jog for at least 5 minutes at all four intensities in a randomized order, separated by a 10-minute rest period. The submaximal exercise test will begin with a 2-minute warm-up at a self-selected walking speed followed by a gradual increase in treadmill speed over the next 3 minutes until the first randomly selected intensity (% VO_{2max}) is achieved. Subsequent stages will begin with walking and a gradual increase in treadmill speed over a 3-5 minute time period until the randomly selected intensity is achieved. Once the jogging speed which elicits the desired VO_2 response is achieved, the subject will continue to jog for an additional 2-3 minutes to assure steady state values.

The water level in the hydro-therapy pool will be maintained at the same level. The water level will be between the subjects' xiphoid process and the axillary region. If the water level is above or below the desired area then the water level will be adjusted for that particular subject. Water temperature will be set at 32.2° (± 2°). Subjects will be instructed to jog looking straight ahead with their hands free of the hand rail. In order to prevent sculling motions of the arms, subjects will be instructed to keep their hands in a loose-fisted position and their elbows flexed at 90°.[5] Subjects will also be instructed to jog with a normal gait minimizing "hang time" following rear foot push off as excess "hang time" increases the time between foot contacts and reduces effort. Through videography, the subjects will have a frontal and saggital view of themselves during the water running session. They will be informed to minimize any vertical movement or "hang time" during their orientation period and throughout their water running sessions.

Statistical Analysis

Descriptive data of the subjects including age (yr), sex, weight (kg), height (cm), body mass index (BMI; kg/m^2), and VO_{2max} will be reported. Mean and standard deviations of steady state VO_2, HR, RPE, speed and SF for each of the four treadmill jogging intensities for all three submaximal exercise conditions will be reported. Each dependent variable will be analyzed with analysis of variance where within and between subject covariant structure have been appropriately estimated. An ANOVA will be used to compare speed, HR, SF and RPE at each of the four VO_2 intensities for all three submaximal exercise conditions. Linear regression will be used to analyze the relationship between VO_2 and HR, and the dependent variables treadmill speed, RPE, and SF for all three submaximal exercise testing conditions. SAS PROC MIXED software will be used to analyze the data. Statistical significance will be maintained at $p<0.05$.

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Appendix A-1

Borg's 15-point Scale of Perceived Exertion

Borg's 15-point scale of perceived exertion.

	Resting	**13**	Somewhat Hard
7	Very, Very Light	**14**	
8		**15**	Hard
9	Very Light	**16**	
10		**17**	Very Hard
11	Fairly Light	**18**	
12		**19**	Very, Very Hard
		20	

Appendix A-2

Pre-participation Screening Questionnaire

Pre-participation Screening Questionnaire

Complete this questionnaire before performing an exercise test, beginning an exercise program, or increasing the effort or intensity in your current exercise program. Answer the following questions by checking the appropriate box (yes or no).

Yes	No	**Physical Activity Readiness Questionnaire (PAR-Q)**
□	□	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
□	□	Do you feel pain in your chest when you do physical activity?
□	□	In the past month, have you had chest pain when you were not doing physical activity?
□	□	Do you lose your balance because of dizziness or do you ever lose consciousness?
□	□	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
□	□	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
□	□	Do you know of any other reason why you should not participate in physical activity or this exercise test? If Yes, explain.

Yes	No	**Personal History Questionnaire**
□	□	Do you have a male family member (father, son, or brother), who before the age of 55 or female family members (mother, daughter, sister) who before the age of 65 suffered from a myocardial infarction, coronary re-vascularization, or sudden death?
□	□	Do you get more than 30 minutes of moderate physical activity most days of the week?
□	□	Do you have a thyroid disorder (or are you taking medications for a thyroid disorder)?
□	□	Are you currently taking any medications to control blood pressure?
□	□	Have you ever been told you are you diabetic (Type 1 or 2)?
□	□	Do you have a pacemaker?
□	□	Do you have asthma?
□	□	Do you take insulin?
□	□	Are your currently taking medications for a renal (kidney) disease, or have you ever been told you have a renal disease?
□	□	Do you have any condition that you should be seeing, have seen, or are currently seeing a doctor about?
□	□	Do you have chronic obstructive pulmonary disease (COPD), interstitial lung disease, or cystic fibrosis?
□	□	Have you had shortness of breath when not doing physical activity?

☐ ☐ Have you had shortness of breath during physical activity?

☐ ☐ Do you (or have you had) have swelling of the ankles?

Yes No

☐ ☐ Do you have a heart murmur?

☐ ☐ Do you experience unusual fatigue or shortness of breath with usual activities?

☐ ☐ Do you have difficulty breathing when reclined, lying down or sleeping?

☐ ☐ Have you had sensations of rapid or irregular heart beats?

☐ ☐ Do you have pain, tension or weakness in you legs during walking which intensifies or produces lameness, and is relieved by rest?

☐ ☐ Are you pregnant?

☐ ☐ Are you anemic?

☐ ☐ Have you been diagnosed with anorexia or bullemia?

☐ ☐ Have you ever had a resting or exercise ECG?

☐ ☐ Have you ever had your blood lipids measured?

☐ ☐ Have your ever had a glucose tolerance test?

☐ ☐ Are you currently under a doctor’s care for any reason?

☐ ☐ Have you ever been told not to participate in any particular kind of physical activity?

☐ ☐ Have you had any recent injuries?

☐ ☐ Have you had any surgeries in the last 6 months?

☐ ☐ Are you currently taking any medications?

I have read, understood, and completed this questionnaire. Any questions which I had were answered to my full satisfaction.

Name: ____________________ Signature: ___________________ Date: ___________
(Participant) (Participant)

Name: ____________________ Signature: ____________________ Date: ___________
(Witness) (Witness)