RELIABILITY OF A GRADED EXERCISE TEST DURING DEEP WATER RUNNING AND COMPARISON OF PEAK METABOLIC RESPONSES TO TREADMILL RUNNING

THESIS

Presented to the Graduate Council of the University of North Texas in Partial Fulfillment of the Requirements For the Degree of

MASTER OF SCIENCE

by

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Populations that utilize deep water running (DWR) are described in Chapter I. A review of the literature concerning maximal and submaximal responses during DWR, shallow water running and swimming is presented in Chapter II. The protocols to elicit maximal responses during DWR and treadmill running (TMR), subject characteristics, and statistical methods employed are described in Chapter III. The results, presented in Chapter IV, indicate that the DWR protocol is a reliable test for eliciting peak oxygen consumption and heart rate. Furthermore, the metabolic responses during DWR are lower than TMR. Chapter V discusses factors which might limit maximal responses during DWR. Chapter VI contains suggestions for further research. Raw data are presented in Appendix A.
ACKNOWLEDGMENT

Excel Sport Science (Eugene Oregon) provided fifteen Aqua Jogger Belts to be used during the investigation of deep water running.
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CHAPTER I

INTRODUCTION

Exercise programs which utilize the unique properties of water have increased in number over the past several years (Dieffenbach, 1991; Koszuta, 1989). Several special populations are being urged to partake in some form of exercise in the water. These populations include the obese, pregnant women, runners, dancers, cancer patients and burn victims (Dieffenbach, 1991; Eyestone, Fellingham, George, & Fisher, 1993; Koszuta, 1989). Furthermore, people who have sustained spinal cord, neurologic, brain, and orthopedic injuries have also utilized water exercise (Dieffenbach, 1991; Fernhall, Manfredi, & Congdon, 1992; Koszuta, 1989). These populations as well as others have incorporated some form of exercise in the water to provide both a therapeutic and conditioning means.

Certain exercises performed on land are easily adapted to the pool. Water aerobics, running, and swimming are activities which dominate the modes of exercise prescribed in the water. Water immersed cycling has also been utilized, but is more of a clinical method used to investigate responses to water exercise rather than an exercise mode. Water aerobics is usually performed in waist deep water, while running is performed in both shallow and deep water. Deep water running consists of a person submerged up to the neck in water without being able to touch the bottom of the pool. A flotation device, such as an Aqua-Jogger Belt (Excel Sports, Eugene,
Oregon) or Wet Vest (Bioenergetics, Inc., Pelham, Alabama), can be worn to minimize the effort exerted to keep the head above the water level. Both water aerobics and deep water running differ from swimming in that the face is always above the water level.

Due to the diverse populations that are utilizing water exercise, the problem arises as to how to set the intensity level of such exercise. The water environment presents several properties which make it a curious mode in which to train. It is imperative to establish a method to properly set training intensity for water exercise to provide an optimal training response while preventing an overtraining effect. Certain special populations, such as cardiac patients and the elderly, must take extreme care in setting intensity level of exercise in order to prevent any serious complications resulting from any possible metabolic changes during water exercise compared to changes associated with land based exercise. If the field measurement of heart rate is to be used, an understanding of the physiological responses to water immersion is required. Furthermore, it is not known if conventional exercise testing, such as treadmill graded exercise testing, can be used to accurately prescribe the appropriate intensity level for water based exercise.

Purpose

The purpose of this investigation was threefold: 1) to establish the reliability of responses during a deep water running (DWR) graded exercise test; 2) to compare maximal physiological responses during DWR and treadmill running (TMR); 3) to
establish a prediction equation to predict maximal heart rate during DWR for the purpose of prescribing exercise intensity for DWR.

Null Hypothesis

The null hypothesis of this study is that the maximal responses to graded exercise testing during DWR and TMR will not be different.
CHAPTER II

REVIEW OF LITERATURE

Introduction

A discussion is presented in this chapter pertaining to the relevant investigations which have examined both maximal and submaximal responses during deep water running (DWR) and shallow water running (SWR) as well as responses during swimming. Also included in this chapter is a discussion of the difficulty of prescribing intensity for DWR.

Presentation of Literature

There are a limited number of studies in which running in the water has been investigated. The focus of several of these studies has included examination of responses during shallow water running (Evans, Cureton, & Purvis, 1978; Gleim, & Nicholas, 1989; Town, & Bradley, 1991; Whitley, & Schoene, 1987), while others have examined submaximal (Bishop, Wilson, Yarkony, & Belcastro, 1980; Gehring, Keller, & Brehm, 1993; Green, Cable, & Elms, 1990; Ritchie, & Hopkins, 1991; Yamaji, Greenley, Northey, & Hughson, 1990) and maximal effort (Brennan, Michaud, Wilder, & Sherman, 1993; Butts, Tucker, & Smith, 1991a; Butts, Tucker, & Greening, 1991b; Svedenhag, & Seger, 1992; Town, & Bradley, 1991; Wilder, Brennan, & Schotte, 1993) during DWR. The difficulty with integrating the results of the
investigations of both submaximal and maximal DWR is due to the different protocols used to elicit a certain level of intensity. For instance, the maximal protocols used have included increasing cadence (Brennan, Michaud, et al., 1993; Butts, et al., 1991a; Butts, et al., 1991b; Michaud, et al., 1993), subjective effort (Town, & Bradley, 1991), and heart rate (Svedenhag, & Seger, 1992) to increase intensity of exercise.

Maximal Responses to Deep Water Running

Even with the use of various protocols, there are several points of agreement between the investigations which have compared DWR to TMR. The maximal oxygen consumption and heart rate have been reported to be significantly lower during DWR compared to TMR (Butts et al. 1991a; Svedenhag, & Seger, 1992; Town, & Bradley, 1991). Butts and colleagues (1991a) reported that maximal DWR yielded heart rates that were 17.6 bpm lower and oxygen consumption of 17% lower than during TMR. Heart rates of 9 bpm lower and an oxygen consumption of 12.2% lower during DWR compared to TMR were reported by Svedenhag and Seger (1992). Town and Bradley (1991) also reported lower heart rates during DWR (10% less than TMR), and maximum oxygen consumption during DWR (26% less than TMR). There is some disagreement concerning the mechanisms involved which result in the lower metabolic responses of maximal DWR. Explanations offered have implicated adjustments of cardiac output (Yamaji et al., 1990), reduced active muscle mass (Butts et al., 1991a), and biomechanical limitations due to the hydrostatic forces of water (Town, & Bradley, 1992) as the main limiting factors of metabolic responses during DWR.

Although the data pertaining to heart rate and oxygen consumption are in
agreement, there are several discrepancies among these few studies in relation to other variables. There were no differences in respiratory equivalent ratios (RER) in three of the studies (Butts, et al., 1991a; Butts, et al., 1991b; Town, & Bradley, 1991) during DWR and TMR, while a lower RER during DWR was reported in another study (Svedenhag, & Seger, 1992). The concentration of blood lactate was similar during DWR and TMR in one study (Town, & Bradley, 1991), and higher during DWR in another (Svedenhag, & Seger, 1992). Significantly lower minute ventilation during DWR than TMR were reported for a given oxygen consumption (Butts et al., 1991a; Svedenhag, & Seger, 1992) as well as no difference between maximal DWR and TMR (Butts, et al., 1991b). Finally, it has been reported that there was no difference in the rating of perceived exertion (RPE) at maximal effort (Butts et al, 1991b).

Submaximal Responses to Deep Water Running

The studies which have compared submaximal responses during DWR and TMR have also reported conflicting results. This is probably due primarily to the methods employed in matching submaximal effort for DWR and TMR. Several studies used subjective levels of intensity such as "easy", "moderate", "hard", and "normal" running for both DWR and TMR (Green et al., 1990; Ritchie, & Hopkins, 1991; Yamaji et al., 1990). Two studies compared "self selected paces" for 45 minute (Bishop et al., 1989) and 20 minute (Gehring, et al., 1993) runs for both DWR and TMR. Another study required subjects to perform DWR at 60%, 70%, and 80% of the treadmill maximum heart rate (Fernhall, et al., 1992).

Svedenhag and Seger (1992) compared submaximal as well as maximal responses
during DWR and TMR. They reported that heart rate was lower and RPE higher
during DWR at a given oxygen consumption. In agreement, Bishop and colleagues
(1989) reported that during two separate 45 minute runs at self selected paces. One
test was completed on the treadmill, the other in deep water. Oxygen consumption,
ventilation, and RER were greater during TMR compared to DWR. However, heart
rate and RPE were not different. According to the data of these studies, for a given
RPE, oxygen consumption was greater during TMR; and, likewise, for a given oxygen
consumption, RPE was greater during DWR (see Figure 1). RPE has been reported to
increase linearly during increasing work loads (Borg, 1973). DWR appears to shift the
RPE linear relationship with oxygen consumption to the left.

In agreement with the observation represented in Figure 1, Ritchie and Hopkins
(1991) reported that during a "hard" deep water run, oxygen consumption and RPE
were greater than and heart rate similar to a "normal" treadmill run. In two of three
"hard" deep water runs, oxygen consumption was lower than during a "hard" treadmill
run. During the third hard deep water run, oxygen consumption was similar during
the same hard treadmill run. The authors did not discuss the possibility of a learning
factor, but it was reported that the subjects complained of fatigue and could not
continue past 20 minutes during the first deep water run as opposed to 30 minutes for
the other two deep water runs. Additionally, heart rate for all three
exercise conditions were significantly lower compared to heart rates during a hard
treadmill run, but similar to a normal treadmill run.
Figure 1: Ratings of perceived exertion vs. maximal oxygen consumption during treadmill running.

Note: RPE = Rating of Perceived Exertion

DWR = Deep water running

TMR = Treadmill running

Gehring and colleagues (1993) also observed a lower heart rate during a 20 minute DWR compared to TMR, each at a self selected pace. Furthermore, Green and colleagues (1990) determined that 50% of their subjects (n=10) had a higher predicted
maximum oxygen consumption during DWR than TMR determined by lines of best fit for heart rate from three submaximal efforts of "slow", "moderate", and "quite fast". Four of the five subjects who had attained the higher predicted maximal oxygen consumption also had the highest reported values. This seems to implicate an involvement of training level or skill during DWR.

There has not been a study which has investigated the heart rate - RPE relationship. However, the results reported by Green and colleagues (1990) seem to also indicate that for a subjective intensity, oxygen consumption is greater or heart rate is lower during DWR than TMR. A lower heart rate for a given subjective level of intensity during DWR compared to TMR would result in a higher predicted maximum oxygen consumption (see Figure 2). This hypothesis is supported by other studies (Butts, et al., 1991a; Butts, et al., 1991b; Gehring, et al., 1993; Svedenhag, & Seger, 1991; Town, & Bradley, 1991) which have reported lower heart rates for a given subjective intensity level.

One study of submaximal water running does not seem to be in agreement with the other studies cited thus far. In this study, the authors reported that when subjects exercised at 70% and 80% of treadmill maximum heart rate in water and on land, oxygen consumption for both conditions was greater during TMR than DWR (Fernhall et al., 1992). In the other studies cited, for a given heart rate, oxygen consumption for TMR was less than DWR (Green et al., 1990; Svedenahag, & Seger, 1992). The difference might be due to the type of water exercise performed. The subjects from this particular study used the upper body in a type of "swimming action" and were
submerged only to nipple level. In addition, to further complicate matters, half of the subjects were taking beta-blockers, which have the effect of lowering heart rate. Nevertheless, the type of water running used in the study by Fernhall and colleagues (1992) compares better with shallow water running (SWR) studies.

Figure 2: Prediction of maximal oxygen consumption during deep water running and treadmill running

Note. DWR = Deep water running

TMR = Treadmill running
Shallow Water Running

DWR and shallow water running (SWR) appear to elicit different metabolic responses during graded exercise. SWR is performed with the water at or below waist level and with the feet striking the bottom of the pool. The numerous studies which have investigated SWR have reported that the metabolic costs are greater during SWR than TMR at a given speed (Evans et al., 1978; Gleim, & Nicholas, 1989; Town, & Bradley, 1991; Whitley, & Schoene, 1987). In each of these studies, the resistance property of water was identified as the factor which increased the metabolic cost of SWR. Furthermore, heart rate was not lower during maximal exercise during SWR when compared to TMR. The lack of lower heart rate has also been reported during water aerobics compared to land exercise (Eckerson, & Anderson, 1992; Vickery, Cureton, & Langstaff, 1983).

Comparison of Swimming and Deep Water Running

There are no studies which have compared DWR and swimming. However, there are a number of studies which have compared swimming and TMR.

During swimming, the maximum heart rate has been reported to be between 12 bpm (Magel, Foglia, McArdle, Gutin, Pechar, & Katch, 1975) to 21 bpm (Dixon, & Faulkner, 1971) lower during TMR than DWR (represented 81% to 94% of TMR maximum heart rate). Furthermore, maximum oxygen consumption during DWR has been reported to be 75% (Dixon, & Faulkner, 1971) to 94% (Holmer, Lundin, & Eriksson, 1974) of TMR maximum oxygen consumption. Minute ventilation has also
been reported to be lower during maximal swimming compared to TMR (Gergley, McArdle, DeJesus, Toner, Jacobowitz, & Spina, 1984; Holmer, Lundin, et al., 1974; Holmer, Stein, Saltin, Ekblom, & Astrand, 1974; Magel, et al., 1975), and RER as no different (Gergley, 1984; Holmer, Stein, et al., 1974; Magel, et al., 1975). Although the body position and active muscle groups are different during DWR and swimming, similar lower maximal physiological responses have been reported when compared to responses during TMR.

Summary

The most common field measurements for monitoring intensity are heart rate and RPE. During DWR, it has been reported that heart rate is lower for a given oxygen consumption compared to TMR (Butts, et al., 1991a; Butts, et al., 1991b; Svedenhag, & Seger, 1992; Town, & Bradley, 1991). The cause for the bradycardia is not known. Similarly, the relationship of RPE and oxygen consumption has been reported to be shifted to the left for a given work load during DWR compared to TMR (Ritchie, & Hopkins, 1991; Svedenhag, & Seger, 1992).

From this review of literature, it is apparent that there is a need to establish the reliability of a DWR maximal exercise test. Also, further examination of the relationship between maximal physiologic responses during DWR and TMR is required to determine if the level of intensity for DWR can be prescribed based on treadmill data.
CHAPTER III

METHODS AND MATERIALS

Introduction

The procedures employed to elicit maximal responses during deep water running (DWR) and treadmill running (TMR) are explained in this chapter. The subject characteristics, the process of recording the metabolic responses during exercise testing, and the statistical methods employed for analysis of data are other topics of discussion in this section.

Subject characteristics

Twelve females and fifteen males (22.59 ±4.03 years) took part in this study. All but one subject (male) were inexperienced in deep water running. Written informed consent was obtained in accordance with the policy statements of the American College of Sports Medicine (ACSM) for the protection of human subjects (ACSM, 1991). The study was approved by the Institutional Review Board of the University of North Texas. Descriptive data is presented in Table 1.

Table 1: Subject Data

<table>
<thead>
<tr>
<th>n</th>
<th>27</th>
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<tbody>
<tr>
<td>Stature (cm)</td>
<td>174 ±10.84</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.3 ±13.97</td>
</tr>
<tr>
<td>Age</td>
<td>22 ±4.03</td>
</tr>
</tbody>
</table>
Deep Water Running and Treadmill Running Protocols for Graded Exercise

All subjects underwent three graded exercise tests to volitional fatigue. Two of the tests were conducted in deep water (DW1, DW2), and one on a treadmill (TM). The order of the tests were randomly assigned to prevent the test order from affecting the results.

The water tests were performed in a tank 1.8m x 1.8m x 1.8m. The water temperature averaged $26.5 \pm 0.73 \, ^\circ C$. During the test, the subject wore an Aqua Jogger Belt around the waist to aid in flotation. A tether was attached to the Aqua Jogger and run through a series of pulleys with the other end attached to a bucket suspended 0.75 m above the deck (see Figure 2). The bucket was suspended in the air as long as the subject maintained position at the front of the tank.

The protocol for the water test was continuous and consisted of 1 minute stages. To provide for a graded response, a 1.25 lb (0.57 kg) weight was added to the bucket at the beginning of each stage. The added weight had the effect of pulling the subject backwards if the intensity of exercise was not increased. Additional weight was added until the subject could not keep the bucket from touching the ground.

The protocol for the treadmill test was also continuous, and consisted of 1 minute stages. The first stage consisted of the subject running at 80.4 m min$^{-1}$ at a 3% grade. Elevation was increased to 7.5% grade for the second stage and remained constant for all subsequent stages. The next three stages required speeds of 93.8 m min$^{-1}$, 107.2 m min$^{-1}$, and 134 m min$^{-1}$. The speed of all subsequent stages increased by 13.4 m min$^{-1}$. Air temperature averaged $22.7 \pm 1.5 \, ^\circ C$. 

Expired gases were collected continuously during both tests, and recorded every 15 seconds. Oxygen consumption and other ventilatory volumes were determined through the use of a metabolic cart (Medical Graphics CPX, St. Paul, MN) and recorded at 15 second intervals. Ventilatory calibration was performed using a calibrated 3 liter syringe. Prior to each test, O₂ and CO₂ analyzers were calibrated using known gases. Heart rate was monitored through radiotelemetry (Polar, CIC Accurex, Hempstead, NY). Heart rate was recorded 10 seconds prior to the end of
each stage. The criteria for peak values was the highest value achieved for each variable.

Blood lactate levels were determined before and 5 minutes after every maximal test. Blood was obtained by fingertip puncture and collected in a 40 microliter capillary tube and then placed in a microcentrifuge tube containing an 80 microliter premixed cocktail of sodium fluoride and Triton X-100 to lyse cells and halt glycolysis (Van Handel, Bradley, & Troup, personal communication). Duplicate blood lactate levels were determined using a YSI 2300 lactate analyzer, previously calibrated with known standards. Blood lactate measurements were not made on the first nine subjects.

Statistical Procedures

The statistical analysis were performed using the Statistical Procedures for the Social Sciences (SPSS/PC+ Version 4.0.1) program. Statistical significance was established at the .05 alpha level. Reliability of the DWR test was determined by intraclass correlation. To predict maximal heart rate during DWR, equations were built through the use of multiple regression models. Paired t-tests were used to compare the means of the responses to the maximal exercise tests during the two deep water run tests. The average values of responses during the two deep water tests were compared to responses during TMR through paired t-tests.
CHAPTER IV

RESULTS

Introduction

A presentation of the data collected during maximal deep water running (DWR) and treadmill running (TMR) is made in this chapter. The data were also utilized to build regression models to predict the maximal heart rate during DWR.

Results

Reliability of the DWR test was established by intraclass correlation for VO\textsubscript{2peak} (r=0.95) and HR\textsubscript{peak} (r=0.86). Through the use of paired t-tests, it was determined that the means between any of the measured variables (VO\textsubscript{2peak}, HR\textsubscript{peak}, post-lactate, time to exhaustion, VE, RPE, or RER) were no different during the first deep water test (DW1) and the second deep water test (DW2) (p<.01). For statistical purposes, the values achieved for each variable during DW1 and DW2 were averaged and represented herein as DWA. The comparison between DWA and TMR, also through the use of paired t-tests, revealed significantly lower values for VO\textsubscript{2peak}, HR\textsubscript{peak}, blood lactate concentration, and VE for DWA (p<.01). In contrast, there were no significant differences between RPE and RER for DWA and TMR (p<.01). The results are summarized in Table 2.
Table 2: Comparisons of Maximal Responses during Deep Water Running and Treadmill Running

<table>
<thead>
<tr>
<th></th>
<th>DW1</th>
<th>DW2</th>
<th>DWA</th>
<th>TMR</th>
<th>% OF TMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_{peak}$ (ml/kg/min)</td>
<td>44.2+10.72</td>
<td>44.5+12.17</td>
<td>44.4+11.19</td>
<td>55.1+13.36</td>
<td>81</td>
</tr>
<tr>
<td>(L/min$^{-1}$)</td>
<td>3.223+1.19</td>
<td>3.190+1.20</td>
<td>3.206+1.18</td>
<td>3.940+1.42</td>
<td></td>
</tr>
<tr>
<td>HR$_{peak}$ (bpm)</td>
<td>177.1+9.12</td>
<td>178.1+9.90</td>
<td>177.6+8.92</td>
<td>189.4+8.22</td>
<td>94</td>
</tr>
<tr>
<td>Lactate (mM)</td>
<td>8.6+2.01</td>
<td>8.8+2.53</td>
<td>8.7+2.15</td>
<td>11.7+2.65</td>
<td></td>
</tr>
<tr>
<td>time to exhaustion (s)</td>
<td>399.4+118.20</td>
<td>406.8+138.37</td>
<td>403.1+123.14</td>
<td>482.5+151.94</td>
<td></td>
</tr>
<tr>
<td>VE (l/min$^{-1}$)</td>
<td>123.1+39.60</td>
<td>124.7+44.00</td>
<td>123.9+40.48</td>
<td>153.5+48.43</td>
<td>80</td>
</tr>
<tr>
<td>RPE</td>
<td>17.4+1.42</td>
<td>17.3+1.66</td>
<td>17.4+1.32</td>
<td>17.8+1.73</td>
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</tr>
<tr>
<td>RER</td>
<td>1.32+0.11</td>
<td>1.32+0.12</td>
<td>1.32+0.10</td>
<td>1.31+0.09</td>
<td></td>
</tr>
</tbody>
</table>

Note.

DW1: First deep water run maximal test.

DW2: Second deep water run maximal test.

DWA: The average of DW1 and DW2.

TMR: Treadmill maximal test.

* Significantly different from DWA (p<.01).
Prediction Equations

A significant single step multiple regression model was built to predict peak heart rate during DWR using the variables of subject mass (in kg), stature (in cm), and age (R=0.62 SEE=7.46 bpm). The variable of age was used because it is commonly used to predict maximal heart rate. Stature and mass were used because they are anthropometric measurements that are easily measured.

\[
\text{DWR HR}_{\text{peak}} = 207.358 - 0.133(\text{stature}) + 0.085(\text{age}) - 0.338(\text{mass}) \quad (1)
\]

A second prediction equation was built using data collected during the maximal TMR test to predict the peak heart rate during DWR (R=0.76, SEE=6.59 bpm). The variables used in the equation were maximal oxygen consumption expressed in absolute terms (L.min\(^{-1}\)) and heart rate during TMR.

\[
\text{DWR HR}_{\text{peak}} = 111.328 - 3.0(\text{TMR VO}_{2\text{peak}}) + 0.414(\text{TMR HR}_{\text{peak}}) \quad (2)
\]

Post hoc testing established that the average predicted maximal heart rate using equation 1 was 177.52 ±5.50 bpm and using equation 2 was 177.47 ±6.83 bpm. Values derived using equation 2 correlated well with peak heart rate from DWA (r=0.76). Values derived using equation 1 did not correlate as well as the second equation, but the correlation with DWA (r=0.62) indicated a good relationship between
the variables. Further analysis through paired t-tests revealed no significant
differences between either of the predicted heart rates and actual heart rates (p>.01).
The predicted heart rates and actual heart rates are presented in Table 3.

Table 3: Comparison of predicted maximal heart rates

<table>
<thead>
<tr>
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<th>Mean (bpm)</th>
<th>Standard Dev (+ bpm)</th>
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<tbody>
<tr>
<td>Equation 1</td>
<td>177.47</td>
<td>6.83</td>
</tr>
<tr>
<td>Equation 2</td>
<td>177.61</td>
<td>8.92</td>
</tr>
<tr>
<td>HR DW1</td>
<td>177.11</td>
<td>9.12</td>
</tr>
<tr>
<td>HR DW2</td>
<td>178.11</td>
<td>9.90</td>
</tr>
<tr>
<td>HR DWA</td>
<td>177.61</td>
<td>8.92</td>
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Equation 1: $\text{DW HR}_{\text{peak}} = 207.358 - 0.133(\text{st}) + 0.085(\text{age}) - 0.338(\text{mass})$

Equation 2: $\text{DW HR}_{\text{peak}} = 111.328 - 3.0(\text{TM VO}_{\text{peak}}) + 0.414(\text{TM HR}_{\text{peak}})$

HR DW1: Peak heart rate during the first maximal water test

HR DW2: Peak heart rate during the second maximal water test

HR DWA: The average of DW1 and DW2

st: Stature (cm)

mass in kilograms
CHAPTER V

DISCUSSION

Introduction

The reliability of the graded exercise test during deep water running (DWR) is examined in this chapter. Also, the possible mechanisms involved in limiting maximal responses during deep water running compared to treadmill running (TMR) will be discussed. The factors considered in the ensuing discussion are protocol design, cardiac output, water temperature, hydrostatic forces of water, active muscle mass, and running skill. The transferability of effects from a deep water training program to land based running will also be explored.

Reliability of Deep Water Running Graded Exercise Test

One of the goals of this study was to establish the reliability of a DWR graded exercise test. The results of this study indicate that the protocol devised to elicit a maximal graded exercise test is reliable. The 95% confidence intervals of the reliability coefficients for maximal oxygen consumption (r=0.95) and heart rate (r=0.85) are 0.98 and 0.89, and 0.93 and 0.76, respectively (Morrow, & Jackson, 1993). There have been no other studies which have examined the reliability of a DWR protocol.

Maximal Responses During Deep Water Running

Another goal of this investigation was to compare the maximal responses during
DWR and TMR. Because there were no significant differences between the first and second deep water tests (DW1 and DW2, respectively), the results were combined and represented herein as the average of the two deep water tests (DWA). It was observed that the maximum heart rate and oxygen consumption achieved during DW1 and DW2 were less than during TMR. Furthermore, the mean peak heart rates during DW1 and DW2 were 12 and 11 bpm lower than during TMR. The achieved heart rates during DW1 and DW2 represented 93% (+4%) and 94% (+4%), respectively, of the maximum heart rate achieved during TMR. Also, the peak oxygen consumption during both DW1 and DW2 was 81% (+10%) of TMR values. These values concur with other studies which have compared physiological responses during maximal DWR and TMR (Butts, et al., 1991a; Butts, et al., 1991b; Svedenhag, & Seger, 1992; Town, & Bradley, 1992) as well as swimming and TMR (Dixon, & Faulkner, 1971; Gergley, et al., 1984; Holmer, Lundin, et al., 1974; Holmer, Stein, et al., 1974; Magel, et al., 1975).

Maximal blood lactate, minute ventilation, RER, and time to exhaustion were all lower during DW1 and DW2 compared to TMR. The similar maximal response of RPE (Butts, et al., 1991a; Svedenhag, & Seger, 1992) and RER (Butts, et al., 1991a; Town, & Bradley, 1991) during DWR and TMR is in agreement with other studies.

Blood Lactate Concentration

The observation of lower blood lactate concentration during DWR compared to TMR differs with the similar lactate levels during DWR and TMR reported by Town and Bradley (1991). However, my observation is in contrast to the observation
reported by Svendhag and Seger (1992) of a larger accumulation of blood lactate during maximal DWR compared to during maximal TMR. The different observations appears to be due to the methods employed to elicit maximal effort during DWR and TMR. Lactate accumulation can be affected by the intensity of the increments during a graded exercise test (Jacobs, 1986). Both Svedenhag and Seger (1992), and Town and Bradley (1991) utilized similar DWR protocols which consisted of intensity increased subjectively within a 1 to 2 minute period to maximal effort for a total test duration of about 4 minutes. Likewise, similar TMR protocols were employed in both investigations, with Town and Bradley (1991) reporting a time to exhaustion of 6.6 minutes. Svedenhag and Seger (1992) did not report time to exhaustion, but did report a lower RER during DWR compared to TMR. A higher RER (greater than 1.0) would seem to indicate a greater involvement of glycolysis, and therefore a subsequent increase in lactate production. However, the opposite was reported by Svedenhag and Seger (1992): blood lactate was greater during DWR compared to TMR even though RER was lower during DWR.

The time to exhaustion during DWR and TMR for the subjects used in the current study was 6.6 ±2.5 minutes and 8.0 ±2.5 minutes, respectively. Both of these test durations were longer than the test durations reported by Town and Bradley (1991). The contrived graded response in the DWR protocol I used might have allowed the subjects to approach maximal effort with a lower blood lactate accumulation due to the longer duration and subsequent facilitation of removal of lactate during the early stages of the test.
Heart Rate Response During Deep Water Running

Diving Bradycardia Reflex

The cause for the decreased heart rate during DWR compared to TMR seems to be related to the diving bradycardia reflex. A decreased heart rate was also observed in a study which investigated bradycardia during immersion of the face only at rest when compared to rest on land (Natelson, Nary, Curtis, & Creighton, 1983). The authors concluded that the observed decreased heart rate was due in part to the stress of face immersion, even when the subjects wore a snorkel. The subjects utilized in my study did not submerge their faces, but as maximal effort was reached, waves were created due to vigorous exercise in the small testing area. Often the mouth piece (which is similar in function to a snorkel) would be submerged by such waves. However, none of the subjects complained of any stress related to the temporary submersion of the mouth piece, or to any general discomfort of being in the water.

Adjustments in Cardiac Output

Several studies have compared responses to water immersed and land based cycling (Arborelius, Balldin, Lilja, & Lundgren, 1972; Christie, et al., 1990; Costill, 1971; McArdle, Magel, Lesmes, & Pecar, 1976). At rest, Arborelius and colleagues (1972) reported that being submerged in water up to the neck during rest had no effect on heart rate, but cardiac output increased by 32%. This was due mainly to a stroke volume increase of 35%. During a graded exercise test during cycling in the water, cardiac output has been reported to be elevated at all exercise levels of intensity when compared to cycling on land (Christie, et al., 1990). Furthermore, similar maximum
oxygen consumptions have been attained during maximal cycling in the water and on land (Christie, et al., 1990; Costill, 1971) with a lower heart rate (Christie, et al., 1990). It was concluded by Christie and colleagues (1990) that heart rate was similar during rest on land and immersed in water, but during exercise immersed in water heart rate was significantly lower. Thus, the slope of cardiac output as a function of increasing work was similar during land and water cycling, but the y-intercept (cardiac output at rest) was greater during water cycling.

Cardiac output during swimming and running has also been examined. In two studies, the use of recreational swimmers (Dixon, & Faulkner, 1971) and swimming breaststroke (Holmer, Stein, et al., 1974) yielded a lower maximum oxygen consumption, heart rate and cardiac output during swimming compared to TMR. However, it was reported that both maximum oxygen consumption and cardiac output were no different, while heart rate was decreased 12 bpm during swimming compared to TMR for trained swimmers (Dixon, & Faulkner, 1971).

The decreased heart rate during water immersed exercise compared to land based exercise is related to a greater stroke volume, measured invasively, and subsequent increase in cardiac output via the Frank-Starling mechanism (Christie, et al., 1990; Sheldahl, et al., 1986). The increased pressure from the hydrostatic forces of water seems to cause an enhanced venous return from the limbs. Stroke volume is increased due to the greater central blood volume and/or decreased cutaneous blood flow due to the decreased need for cooling the body while immersed in water (Arborelius, et al., 1972; Christie, et al., 1990, 1971; Holmer, Stein, et al., 1974). The greater central
blood volume also increases total peripheral resistance (TPR) (Arborelius, et al., 1972; Christie, et al., 1990; Holmer, Stein, et al., 1974; McArdle, et al., 1976). The baroceptors, located in the atria of the heart, vena cava, aortic, and carotid sinus, are sensitive to pressure changes. The increased TPR could provide a stimulus for the baroceptors which would cause a decreased heart rate (McArdle, et al., 1976).

**Autonomic Nervous System**

The autonomic nervous system has also been implicated as a possible cause of bradycardia during water based exercise (Arborelius, et al., 1972; Christie, et al., 1990; Natelson, et al., 1983). Christie and colleagues (1990) theorized that sympathetic neural outflow is decreased during immersion in water. Sympathetic activation increases with intensity of exercise, a lower outflow would result in a lower heart rate. Although the cardiac output is not entirely understood, there is overwhelming evidence that heart rate is reduced during exercise while immersed in water and cardiac output is maintained by a greater stroke volume due to the increased venous return.

**The Effect of Temperature**

The temperature of the water during my study averaged 26.2 C for DW1 and 26.7 C for DW2. McArdle and colleagues (1976) reported that heart rate was lower for cycling in 18 C and 25 C water compared to cycling in 33 C water and on land. It was also reported that maximal oxygen consumption was increased for both 18 C and 25 C conditions compared to 33 C water and air. The water temperature during the deep water tests during my investigation was slightly cooler than other studies (range: 25 C (Svedehad, & Seger, 1992) to 29 C (Butts, et al., 1991a and b)). However,
contrary to McArdle and colleagues (1976), the maximal oxygen uptake in my study was not greater during water immersed exercise than TMR, and, our subjects did not complain about the water temperature after a short warm up period. Therefore, it is unlikely that water temperature affected the heart rates in this study.

Maximal Oxygen Consumption Response During Deep Water Running

Ventilation Response

The lower ventilation during DWR compared to TMR observed during my investigation is in agreement with Svedenhag and Seger (1992) and Butts and colleagues (1991a). However, Butts and colleagues (1991b) reported no significant differences in ventilation values during DWR and TMR. The maximal ventilation achieved during DWR in my study represented about 80% of that achieved during TMR. The relative differences during DWR and TMR between ventilation (20%) and maximal oxygen consumption (19%) were almost identical. Svedenhag and Seger (1992) reported that ventilation was not different during DWR or TMR at a given oxygen consumption.

The added restrictive load to the chest wall during DWR might be one explanation for the lower maximal oxygen consumption and ventilation. During DWR, the chest cavity was submerged about 30 centimeters below the surface. This corresponds with an increased pressure of 23 mmHg. An observed decrease of 10% and 16% of maximal oxygen consumption and ventilation, respectively, was reported by Cline, Coast, Gonzales, and Denny (1994) when a restrictive force of 60 mmHg was applied.
to the chest wall during land cycling. Cline and colleagues (1994) also reported significant decreases for added restrictive forces of 20 and 40 mmHg (actual values were not reported). It appears that based on Cline and colleagues results, the increased thoracic pressure does affect the maximal achievable oxygen consumption and ventilation. However, the decreases reported by Cline and colleagues (1994) was less than my findings. Therefore, the hydrostatic pressure of water is not likely to be the only factor involved in the altered oxygen consumption and ventilation.

**Active Muscle Mass**

The peak oxygen consumption during DWR represented about 81% of the peak oxygen consumption during TMR. The cause for the lower oxygen consumption could be the amount of active muscle mass. There are no studies which have examined the active muscle mass during DWR. Nevertheless, the antigravity muscles during DWR are not utilized to the degree that they are during TMR. In separate studies, Butts and colleagues (1991a) and Thompson, Boone, and Miller (1982) theorized that reduced active muscle mass resulted in lower achievable maximum oxygen consumption during DWR (Butts et al., 1991a) and swimming (Thompson et al., 1982) than during to TMR.

**Skill**

When elite swimmers were used as subjects to compare swimming and TMR, the maximal oxygen consumption of TMR was only 6% greater (Holmer, Lundin, et al., 1974). The authors theorized that the similar responses were probably due to the use of flume swimming instead of tethered swimming. However, Bonen, Wilson,
Yarkony, and Belcastro (1980) reported that there were no significant difference between maximal values achieved during flume, tethered, or free swimming. Dixon and Faulkner (1971) concluded that the "heart can only pump out the amount of blood that it receives in venous return". Therefore, more efficient swimmers should be able to achieve a higher cardiac output (due to better venous return caused by efficient active muscle contraction) and a corresponding greater maximum oxygen consumption than recreational swimmers during swimming. It appears from the data of these studies that skill level seems to be a factor in the achieveable maximal oxygen consumption during swimming. The question arises as to whether or not skill is a limiting factor during maximal DWR.

Yamaji and colleagues (1990) reported that heart rate for a given oxygen consumption during DWR was dependent on the skill level of the subject. However, Town and Bradley (1991) reported that the subjects they studied were experienced in DWR exercise and achieved only 74% of the TMR maximal oxygen consumption during maximal DWR. In contrast, 87.8% of TMR maximal oxygen consumption was achieved during DWR by elite runners familiar with DWR in another study (Svedenhag, & Seger, 1992). An explanation for the discrepancy between these two studies is that one study used a flotation device (Svedenhag, & Seger, 1992) and the other did not (Town, & Bradley, 1991). Gehring and colleagues (1993) reported that oxygen uptake during a 20 minute submaximal DWR at a self selected pace was lower when no flotation device was worn compared to when a flotation device was worn. The subjects in this particular study were untrained. It is evident that more research is
needed to further examine the effect of wearing a flotation device during DWR.

An Aqua Jogger Belt was utilized in my study and all subjects except one were inexperienced in DWR. Furthermore, the subject pool was diverse in terms of physical activity and fitness. It is quite possible that skill level was an important factor which determined the achieved oxygen consumption during DWR. The extent that skill level determines maximal oxygen consumption is difficult to assess. Nevertheless, the role appears to have been minimal because subjects achieved 81% of the TMR maximal oxygen consumption during DWR. This was less than that reported by Svedenhag and Seger (1992) (87.8%), but more than Town and Bradley (1991) (74%), and comparable with two studies conducted by Butts and colleagues (1991a, 1991b) (83% for both studies).

**Hydrostatic Force of Water**

The main limiting factor of maximal oxygen consumption during DWR seems to involve the hydrostatic forces of water. Stride frequency has been reported to be 83.9 strides/min for a "hard" DWR (Town, & Bradley, 1991). A minimum cadence of 48 strides/min and a maximum cadence of 104 strides/min have been utilized during a graded exercise test for DWR (Wilder, et al., 1993). In contrast, stride rates of 160-210 strides/min have been reported for TMR (Town, & Bradley, 1991). Wilder and colleagues (1993) reported that oxygen consumption increased as cadence increased during a DWR maximal effort test. Although stride frequency was not measured in my study, the stride rate limiting property of water seems to play a major role in explaining a lower peak oxygen consumption during DWR. It appears that during
DWR the legs are not capable of achieving the stride rate needed to reach the maximal oxygen consumption achieved during TMR.

In several studies, the maximal oxygen consumption did not differ during water or land cycling (with similar or lower maximal heart rates) (Avellini, Shapiro, & Pandolf, 1983; Christie, et al., 1990; Costill, 1971; McArdle, et al., 1976). However, for a given work load, cycling in water required an increased oxygen consumption compared to cycling on land (Costill, 1971). During water cycling, the biomechanical actions of the legs are limited to the length of the crank arm. Because cadence is held constant during land and water cycling, the resistance of water is uniform during a graded exercise test for water cycling due to the specific range of motion of the legs. The greater oxygen demand for a given load was due to this resistive force, and the increased caloric cost was consistent regardless of load (Costill, 1971).

In my study, proper DWR form was taught prior to testing and helpful pointers were given during the actual tests. The range of motion of the legs was not controlled. Subjects could increase stride length and/or stride frequency as a greater load was applied to the tether. It appears that the lower oxygen consumption achieved during DWR compared to TMR is due partly to the stride rate limitations caused by the hydrostatic forces of water.

Training Response to Deep Water Running

DWR has become increasingly popular in recent years for runners. Both injured and non-injured runners are utilizing DWR in hopes of maintaining or improving land based performance (Evans, et al., 1978; Michaud, Brennan, Wilder, & Sherman, 1993;
Wilder, et al., 1993). Due to the basic biomechanical differences between DWR and land based running (herein also referred to as TMR), the question of training specificity arises. Can the benefits derived from DWR training be transferred to improve TMR?

Swim Training Compared to Treadmill Running

Gergley and colleagues (1984) conducted a training study which compared the benefits of swimming and swim bench training evaluated by TMR, tethered swimming and swim bench graded exercise tests. It was reported that both the swim and swim bench trained groups improved equally when evaluated by the tethered swimming and swim bench tests. There were no improvements by either group when evaluated by the TMR test. The authors concluded that the improvements in both groups were due to localized adaptations of the upper body and, therefore, TMR did not improve.

The muscle groups utilized during swimming and DWR are different. Swimming employs muscles of the upper body, while DWR and TMR incorporate muscle groups from the legs. Due to the similarity between DWR and TMR, the results from the study conducted by Gergley and colleagues (1984) seem to support the notion that localized improvements from a DWR training program could transfer favorably to TMR.

Deep Water Running Training Responses

There have been a number of studies which have compared training responses of DWR to TMR. These investigations have reported an increase (Brennan, et al., 1993; Michaud, et al., 1993) or no change (Eyestone, et al., 1993; Hertler, Provost-Craig,
Sestili, Hove, & Fees, 1993) in treadmill maximal oxygen consumption and no change in 2 mile (3218 m) run performance (Eyestone, et al., 1993) after DWR training programs. The main weakness of each of these studies is that intensity for DWR has been prescribed based on TMR data. From the results of my study, the training zone based on maximal responses during TMR would be greater than if intensity were prescribed from a maximal DWR exercise test.

The American College of Sports Medicine guidelines for exercise prescription for aerobic training recommend that intensity of exercise should be set at 40-85% of maximal oxygen consumption or 55% to 90% of maximal heart rate (ACSM, 1991). If these guidelines for exercise prescription for DWR are based on TMR data, the relative intensity during DWR could approach and even exceed 100% of the maximal oxygen consumption attained during a DWR graded exercise test. The high intensity could result in overtraining responses. Furthermore, because there is some question as to whether or not angina is suppressed or masked in cardiac patients during water immersed exercise (Fernhall, et al., 1992; Thompson, et al., 1982), overestimation of intensity could result in more serious complications.

If DWR is the mode of exercise prescribed, the intensity should be based on a DWR graded exercise test. If this is not possible, the training zone should be adjusted through the use of a prediction equation. The prediction equations (see Table 4) derived from the results of my study result in a lower training heart rate range for DWR compared to a training heart rate range derived from data during TMR. This is due to a lower maximal heart rate during DWR compared to TMR. The main
weakness of the second prediction equation is that it is based on maximal responses. Additional research must further examine the responses during submaximal DWR to determine if the relationship between heart rate and oxygen consumption is altered during DWR compared during TMR.

Table 4: Equations to predict deep water peak heart rate

Equation 1: \( \text{DW HR}_{\text{peak}} = 207.358 - 0.133(st) + 0.085(\text{age}) - 0.338(\text{mass}) \)

\[ R = 0.62 \]
\[ \text{SEE} = 7.46 \text{ bpm} \]

Equation 2: \( \text{DW HR}_{\text{peak}} = 111.328 - 3.0(\text{TM VO}_{2\text{peak}}) + 0.414(\text{TM HR}_{\text{peak}}) \)

\[ R = 0.76 \]
\[ \text{SEE} = 6.83 \]

Note:

DW HR = deep water heart rate
TM VO_{2peak} = treadmill peak oxygen consumption
st = stature (cm)

Even though the training zone derived from a DWR graded exercise test would result in a lower heart rate compared to a training zone derived from TMR data, similar aerobic improvements have been reported for water cycling compared to land
cycling even though a lower training heart rate was observed during water cycling (Avellini, et al., 1983; Sheldahl, et al., 1986). In two studies in which training responses of water cycling and land cycling were compared, the maximum oxygen consumption determined by land cycling was increased in both groups after a training program (Avellini et al., 1983; Sheldahl et al., 1986). The training intensity for each subject was derived from data collected during a graded exercise test for the mode each subject was to train (water or land cycling). In both studies, the maximum heart rate during water cycling was lower than land cycling.

Conclusion

The first stated purpose of this investigation was to establish the reliability of a graded exercise test for deep water running. The results indicate that the protocol utilized in this investigation was reliable.

The second purpose of this investigation was to compare maximal responses during DWR and TMR. Maximal oxygen consumption, heart rate, blood lactate concentration, and minute ventilation were lower during DWR than during TMR. In contrast, there were no differences in RPE and RER during DWR and TMR. The cause for a lower heart rate may be a greater venous return and subsequent greater stroke volume via the Frank-Starling mechanism with no change in cardiac output. The lower maximum oxygen consumption during DWR may be decreased maximal stride frequency, smaller active muscle mass, and/or the restrictive forces of water to the chest wall.

The third stated purpose of this investigation was to establish a prediction equation
for maximal heart rate during DWR. Two such equations were built. The first equation utilizes the variables of age, mass, and stature. The second equation utilizes maximal oxygen consumption and heart rate data obtained from a maximal TMR test.

This investigation has contributed to the understanding of maximal responses during DWR. However, there is a need for more research comparing maximal responses during these two modes of exercise to further understand the metabolic adjustments observed in this study.
CHAPTER VI

RECOMMENDATIONS FOR FURTHER RESEARCH

1) Investigation of the metabolic responses during deep water running with and without the use of flotation devices.

2) Examination of the biomechanical changes during deep water running.

3) Further analysis of submaximal relative to maximal responses during deep water running.

4) Assessment of the effect of skill level on deep water running performance.

5) Quantification of cardiac output adjustments during deep water running.

6) Comparison of deep water running and treadmill running training responses in order to determine the degree of transferability of deep water running to land based running.

7) Quantification of the active muscle mass during deep water running.

8) Further analysis of the effect of the hydrostatic pressure of water on ventilation.
APPENDIX A

RAW DATA
Note:

DW1 = First deep water test
DW2 = Second deep water test
TMR = Treadmill running test
VO2 = Peak oxygen consumption (mlkg⁻¹min⁻¹)
HR = Peak heart rate (bpm)
VE = Ventilation (Lmin⁻¹)
G = Gender
A = Age
ID = Subject identification number
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APPENDIX B

SUBJECT CONSENT FORM
University of North Texas
Department of Kinesiology

Written Consent Form

Water Based Running vs. Land Based Running: a Training Study

Subject Name: __________

1. I hereby volunteer to participate as a subject in laboratory testing. I understand that this testing is part of a study entitled: "Deep Water Running vs. Land Based Running". The purpose of this study is to investigate the reliability of a maximal exercise protocol for the mode of Deep Water Running (DWR); and, to compare maximal exercise responses for DWR and Treadmill Running.

I hereby authorize John Mercer, Chris Fromme and/or assistants as may be selected by themselves to perform the following procedures:

a. To have me exercise twice in the water and once on a treadmill, with the work rate increasing every minute until I can no longer continue.

b. To have blood samples taken from finger pricks after each maximal test. The blood samples will be taken before and after the water and treadmill tests, and each sample will be less than 5 drops.

c. To have me perform a maximal strength test (30 contractions) of my arms and of my legs.
I understand that during the maximal exercise tests (a and c) I will be breathing through a mouthpiece, which will be attached to a metabolic cart which will analyse the air which I exhale, and that my nose will be pinched shut.

2. The procedures outlined above have been explained to me by John Mercer and/or Chris Fromme.

3. I understand that the procedure described in paragraph 1 (a) involve the following risks and discomforts: temporary muscle pain and soreness is expected. There is a possibility of abnormal changes in my heart beat or blood pressure or even a heart attack during the tests. However, I understand that my heart rate will be monitored during all laboratory testing procedures and that I can terminate any test at any time at my discretion. I also understand that there will be a slight pain due to the fingerprick (b), and there is a small risk of infection. This risk will be minimized through the use of sterile procedures.

4. I have been advised that aside from the educational benefit of learning about aerobic testing there will be no benefits from my participation in this study.

5. I understand that John Mercer, Chris Fromme and/or appropriate assistants as may be selected by them will answer any inquiries that I may have at any time concerning
these procedures and/or investigations.

6. I understand that all data concerning myself will be kept confidential and available only upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.

7. I understand that there is no monetary compensation for my participation in this study.

8. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided. I understand that there will not be a medically certified physician or defibrillator present during the tests. However, medical treatment will be available at the University Health Center and the laboratory has an outside telephone line to the city of Denton emergency services (911). All investigators are certified in Cardio Pulmonary Resuscitation (CPR).

9. I understand that I may terminate participation in this study at any time without prejudice to future care or any possible reimbursement of expenses, compensation, or employment status.

10. I understand that I may contact the chairperson of the Kinesiology Department's Committee on the Use of Human Subjects in Research, Dr. Allen Jackson on any
matters concerning my participation in this study or if I feel that there is infringement on my rights.

Subject’s Signature: __________________________

Witness: _______________________ Date: _____
REFERENCES


