ABSTRACT

TUCKER, M. Physiological response differences between treadmill and pool running in college - aged women. M.S. in Adult Fitness/Cardiac Rehabilitation, 1988. pp. 59 (N.K. Butts).

18 women (19 - 30) were studied to determine if running in a pool elicited similar physiological responses as treadmill running. Each Ss performed 2 VO_2max tests, one in the pool (P) which consisted of simulating running mechanics while wearing a light weight flotation device (Wet Vest), with the second performed on a treadmill (T). A student's dependent t-test showed the T VO_2max ($50.6\ ml \cdot kg^{-1} \cdot min^{-1}$) was sig ($p <.05$) higher than during the P ($42.6\ ml \cdot kg^{-1} \cdot min^{-1}$) as were all other physiological responses (absolute VO_2max, V_Emax, HRmax, and RERmax). It was concluded that, upon immersion, increases in both hydrostatic pressure and intrathoracic blood volume limited ventilatory and cardiovascular mechanics. These findings indicated that physiological adaptations occur upon immersion in a water medium which result in lower maximal responses than those observed on land.

PHYSIOLOGICAL RESPONSE DIFFERENCES BETWEEN TREADMILL AND POOL RUNNING IN COLLEGE - AGED FEMALES

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to
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CHAPTER I

INTRODUCTION

Jogging and running are popular exercise modalities for increasing and maintaining cardiorespiratory endurance. Even though both are still popular exercises, other aerobic activities such as biking, swimming and aerobic dance have emerged as popular aerobic alternatives among recreational runners. Recreational and competitive runners differ not only in their approach to attain cardiovascular fitness but also in their training philosophies. The competitive runner spends less time in other sports and is mainly concerned with specificity of training and, therefore, is becoming more aware of the biomechanical, technological and physiological factors which enhance running performance. The recreational runner may jog between 10-20 miles per week to maintain cardiovascular fitness whereas the competitive runner, in order to compete at a higher level, may run between 30-100 miles per week depending upon specific event or competitive schedule. The general recommendation for developing and maintaining cardiorespiratory fitness is a frequency of 3-5 days per week at an intensity level of 60-90% of maximal heart rate reserve (ACSM, 1986), with the recreational runner generally performing at the lower end of this range. Competitive runners, however, may run from 6-7 days per week at an intensity level of 85-95% of maximal heart rate reserve. They also vary certain components of their training schedule such as interval training, sprints, and short and long distance workouts. A problem with increasing both distance and intensity is that exertional injuries become more prevalent.

Cases of stress fractures and musculo-skeletal problems have become more common than previously observed. In 1987, Matheson, Clement, McKenzie, Taunton, Lloyd-Smith and MacIntyre analyzed 320 athletes with stress fractures. At the time of the injury, running was reported as the most common sporting activity. A major problem with an injury is the length of the recovery period necessary for proper healing. For a less severe injury, the recovery period can be measured in days but for a more severe injury the recovery period may take weeks. In the above study, the authors found that the average time for recovery was 13.4 weeks. Because these injuries may lead to involuntary rest days which hinder training progression, a runner must adopt alternate training philosophies.

Alternate philosophies may range from a complete lay-off from exercise, a reduction in mileage and/or days, or alternate training modalities. The effects of a complete lay-off can cause psychological, as well as physiological, problems for the competitive runner. Two to three months of detraining can reduce cardiovascular fitness to levels similar to that of non-athletes of the same age category (Drinkwater & Horvath, 1972), thereby neutralizing the effect of a conditioning program (Pedersen & Jorgensen, 1978). In order to minimize the detraining effects caused by lay-offs, alternate forms of exercise are used. Swimming and cycling are both popular alternatives because both are non-weight bearing activities which lead to decreased stress to the lower extremities. For individuals who are concerned about maintaining cardiovascular fitness achieved through their running, neither of these activities are training specific. Therefore, an alternate exercise modality which enables the athlete not only to maintain aerobic capacity but also to allow specificity of training would be ideal.

A new exercise modality has recently entered the scene. The Wet Vest (Bioenergetics) offers specificity of training while also being a non-weight bearing activity which minimizes the risk of injury. An added benefit of exercising in a water medium is that the muscles are toned and conditioned as a result of the work being done against the resistance of the water. The Wet Vest does, however, require accessibility to a pool. The major problem of using the Wet Vest is that, to date, there is very little information concerning the physiological effects during maximal exercise performance in the vest, as compared to running.

Purpose of the Study

The purpose of this study was to compare the physiological responses of treadmill running to water running in women between the ages of 19-30 years.

Need for the Study

Running in a water medium has been practiced since the middle of the 1970's, but very little information concerning its effects as a cardiovascular training alternative is known. The Wet Vest produces a number of training possibilities. Water running is an endurance activity which uses large muscle groups, as well as providing a bouyancy that creates a non-weight bearing atmosphere to alleviate any stress on the joints. Theoretically, the vest could also be used during rehabilitation, not only to alleviate the stress on joints, but also to maintain cardiovascular fitness.

Coaches and athletes alike would benefit from an endurance activity that would maintain the cardiovascular fitness developed from a running program. Training responses are normally observed when the specific muscle mass desired for the activity is utilized (McArdle, Magel, Delio, Toner & Chase; 1978; Pechar, McArdle, Katch, Magel & DeLuca; 1973). It would, therefore, be beneficial to compare physiological responses at maximal exercise of running in the water versus running on a treadmill.

Hypothesis

The null hypothesis for this study was: there will be no significant differences in measured physiological responses between maximal treadmill and pool running in women between the ages of 19-30 years.

Assumptions

1. All subjects tested reached their actual maximal oxygen uptake for both the pool and treadmill tests.

2. During the water running test, all subjects demonstrated the same technique as that displayed during the practice session.

3. While performing the water running test, all subjects kept

with the cadence of the metronome.

4. All subjects felt relatively comfortable in the pool.

Delimitations

1. Changes in ventilation, maximal oxygen uptake, respiratory exchange ratio and heart rate were used as indices of physiological response differences during maximal performance.

2. All subjects were women between the ages of 19-30 years.

3. All subjects were within the good cardiorespiratory fitness classification with a VO_2max of at least 45 $ml \cdot kg^{-1} \cdot min^{-1}$ for the treadmill test.

4. All subjects performed the two tests within one week of each other and also with at least one day between tests.

Limitations

The subjects were not randomly selected but were volunteers.

Definition of Terms

Cardiorespiratory Fitness Classification - a table which categorizes cardiorespiratory fitness levels. The range between 38-48 $ml \cdot kg^{-1} \cdot min^{-1}$ is classified as good for women between the ages of 20-29 years old (American Heart Association, 1972).

Maximal Oxygen Uptake (VO_2max) - the maximal amount of oxygen that can be taken in, transported and used per minute. Is commonly used as the single best indicator of cardiovascular fitness. In this study, VO_2max was measured in response to treadmill running and water running.

Wet Vest - light weight floatation vest, used in a water environment, which keeps the head above the water and is used while simulating the running motion (Bioenergetics).

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

This chapter is divided into the following sections: injuries; exercise performance, training - specificity of training and detraining; hemodynamic changes in water - influence of temperature, of face immersion and, of body posture; and, exercise in water which includes water walking/jogging, swimming, and wet vest studies.

Injuries

One of the most frustrating dilemmas encountered by runners is an injury. Injuries can result in loss of training time, a decrease in cardiovascular fitness, as well as psychological problems created by these factors. Some injuries may be minimal and result in decreased intensity or mileage for a short period of time. Many injuries, if severe enough, however, can incapacitate the runner for weeks.

Kowal (1980) analyzed injuries in women which were attributed to an endurance program. Four hundred women, average age 21 years, were exposed to a strenuous Army basic training endurance program. Forty-two percent of the injuries were considered due to "overuse syndrome". The injuries included tibial stress fractures (45%), chondromalacia of the patella (21%), hip stress fracture (20%), and calcaneal/metacarpal stress fractures (8%). A major problem with all the injuries was loss of time from training. The average time lost was 13 days with 41% of the injuries preventing participation from all activities.

In 1987, Matheson et al. studied stress fractures in 320 athletes. Running was the most common sport at the time of injury with 221 athletes reporting stress fractures (69%). The most common site of injury was the tibia (49%) followed by the tarsals (25%) and metatarsals (8.8%). The average time of recovery was shown to be 12.8 weeks with a range from 2 - 96 weeks.

Sixty runners were studied to determine incidence of injuries and injury provoking factors involved with a training regimen (Lysholm & Wiklander, 1987). The most common factor in provoking an injury was determined as training error such as excessive distance or a drastic alteration in the training routine (72%). The most common injuries were backache and hip problems in the middle distance runners while the marathon runners suffered more from foot problems. The involuntary rest period created by the injury averaged from 1.6 - 1.9 days each month.

Walter, Hart, Sutton, McIntosh and Gauld (1988) gave a questionnaire to 436 male and female runners to determine injury prevalence, type, and reason of onset. Fifty-seven percent of the runners reported injuries which required reduction in mileage, medication, or visitation to a health professional. Running was linked to 72% of all the injuries with the majority of the injuries recorded as sudden onset problems. The most frequent site of injury was the knee followed by the foot, hip, heel and ankle. The majority of the runners included in the study were considered recreational runners.

Exercise Performance

Maximal Oxygen Uptake

Maximal oxygen uptake is considered the best indicator of aerobic fitness. It is used in clinical and research facilities to provide information about the cardiorespiratory and neuromuscular systems. Measurement of VO_2max is used to determine the cardiovascular endurance of individuals as well as to measure fitness changes which take place over a training period.

Factors Affecting VO_2max

Many factors determine maximal oxygen uptake values including biological and technological variability, somatic factors, heredity, psychological factors, training, mode, and physiological factors.

Together the biological and technological variability have been estimated to be almost 5.6% (Katch, Sady & Freedson, 1982). Biological variation refers to inherent biological fluctuations, whereas technological variability is due to environmental, instrumental and reading errors. These biological factors were found to be 90% of the total variability with technological being the remaining 10%.

Somatic factors are related to sex, age, composition and health. A review of literature on sex differences in maximal oxygen uptake was reported by Pate and Kriska (1984). Based upon other research, they concluded that the inter-gender differences in VO_2max were attributed to different cardiovascular dimensions, blood constituents, body size and body composition. Cureton, Bishop, Hutchinson, Newland, Vicken and

Zwiren (1986) equated hemoglobin (Hb) concentration in men and women to determine the effect of Hb on VO_2max. They concluded that the sex difference in Hb levels was a significant factor between VO_2max values, however, they suggested that other factors such as oxygen transport and musculature were of greater importance.

Another factor which affects VO_2max performance is age. With increasing age VO_2max has been shown to decrease. For every ten year increase VO_2max decreased by 9-10% after maturity (Pollock & Gushiken, 1985), however, this decline has been shown to be variable based upon training (Hagberg, 1987). According to Astrand and Rodahl (1986), the decrease in VO_2max with aging is due to a decrease in maximal heart rate.

Body composition is another somatic factor which contributes to VO_2max. Because body weight affects oxygen consumption, absolute values are not as relevant as relative values when reporting VO_2max. Increases in weight, either fat or lean, increase oxygen requirements per unit of lean muscle mass. Fat is an inert tissue (Astrand & Rodahl, 1986) and, therefore, excessive body fat will hinder VO_2max.

The contribution of heredity to maximal aerobic power was determined by Klissouras (1971). He suggested that 93.4% of VO_2max was genetically determined. Bouchard et al. (1986) studied aerobic performance in 42 brothers, 66 dizygotic twins and 106 monozygotic twins. Their findings showed less of an influence of heredity on VO_2max than previous literature. They calculated the effects of genetics on VO_2max was approximately 40% when based upon body weight. Hamel, Simoneau, Lorte, Boulay and Bouchard (1986) studied six pairs of monozygotic twins to determine whether muscle adaptation and VO_2max values during endurance training were genotype-dependent. Their results confirmed previous literature, finding a genotype-dependent response for both VO_2max and muscle adaptations during training.

Psychological factors can affect an individual's VO_2max value. Motivation and attitude both play important roles, with individuals performing best when motivation is at a maximum (Astrand & Rodahl, 1986).

Training is a significant factor in increasing VO_2max values of an individual. Astrand and Rodahl (1986) stated that training three times per week for 30 minutes each time at an intensity of 50% VO_2max could increase VO_2max values from 5-10% after six weeks of training. A 10-20% increase was suggested as being possible if the training was more intensive such as 70-80% of VO_2max. Improvement, however, is variable depending upon initial fitness levels. Fox and Mathews (1981) suggested a 5-20% increase in values for college-aged men and women following 8-12 weeks of training. According to ACSM (1978), the following training guidelines are recommended to maintain or develop cardiorespiratory fitness levels in healthy individuals: frequency of 3-5 days per week, intensity at 60-90% heart rate maximum or 50-85% VO_2max, duration of 15-30 minutes, and a mode of activity that utilizes large muscle groups and is aerobic and rhythmical in nature.

The mode of exercise used when determining an individual's VO_2max also affects the results of oxygen consumption. Astrand and Rodahl

(1986) analyzed various exercise modalites to determine VO_2max. Treadmill VO_2max tests generally resulted in the highest VO_2max values Furthermore, running on a treadmill with a grade greater than 3% produces greater VO_2max values than running with no incline.

Another common exercise modality for determining VO_2max is a cycle ergometer. When compared to treadmill tests, individuals tested on cycle ergometers have been shown to have lower VO_2max values ranging from 4-8% in individuals used to cycling and up to 20% lower for non-cyclists. Fox and Mathews (1981) reported 5-15% higher VO_2max values on the treadmill than on the cycle. They also reported that these differences were due to the larger muscle mass being utilized during uphill running. Astrand and Rodahl (1986) refute the claim that the greater VO_2max values achieved during treadmill running is due to the greater muscle mass utilized, by stating that simultaneous arm and leg exercise does not increase maximal aerobic capacity when compared to just leg exercise for the same mode. Another mechanism suggested for the lower value obtained during cycling is local fatigue (Astrand & Rodahl, 1986; Fox & Mathews, 1981). Local fatigue could occur during cycling prior to maximally stressing the oxygen transport system, thus, leading to smaller VO_2max values. Other modes, although less common, are the step test and swimming, both which produce lower values than those achieved on the treadmill (Astrand & Rodahl, 1986).

Numerous physiological factors also influence VO_2max values. The rate at which oxygen is taken in, transported and utilized is affected by minute ventilation, pulmonary diffusion, cardiac output distribution as well as the physiological states of the muscles (Astrand & Rodahl, 1986). Cardiac output appears to be the major factor in determining VO_2max (Ekblom, 1986; Guyton, 1986). Cardiac output is a product of stroke volume and heart rate, with differences being accounted for mainly through stroke volume (Guyton, 1986). Oxidative capacity of the muscles and oxygen carrying capacity are also major factors (Pate & Kriska, 1984).

Training

Specificity of training

In order to obtain the maximal benefit from a training program, it is imperative that the training exercises involve the same muscle groups and simulate the same motor patterns as the activity for which the training is being done. This results in specific physiological adaptations required for that specific mode of exercise. The adaptations brought about by training occur mainly to the skeletal muscle and cardiorespiratory systems. There are two major changes which occur to these systems, biochemical and systemic (Fox & Matthews, 1981). Some of the biochemical changes as a result training include an increase in myoglobin content, increase in oxidative activity of carbohydrates and fats, and an increase capacity of the phosphocreatine and glycolytic systems. The cardiorespiratory changes include an increase in heart size, increase in stroke volume, increase in capillary density and an increase in muscle mass (Astrand & Rodahl, 1986; Fox & Matthews, 1981).

McArdle et al. (1978) studied specificity of run training on VO_2max and heart rate during both running and swimming. Nineteen volunteers underwent a 10 week run training program to evaluate specificity of training. They observed a significant increase in VO_2max for the treadmill test after the training program. Only a small non-significant improvement in VO_2max values was observed between the pre- and post-swimming tests. Based upon this data, they concluded that a relative specificity in metabolic changes occurred with the run training. Running, therefore, was suggested as not being an effective training mode to enhance VO_2max for swimming.

The opposite question, whether swimming could increase running VO_2max, was studied by Magel, Foglio, McArdle, Gutin, Pechar, and Katch (1975). Thirty recreational male swimmers were studied for a 10 week swim training program. A significant increase in swimming VO_2max was observed, whereas, no improvement was noticed for running VO_2max. They suggested that specificity for swim training existed.

Beaudet (1984) reported conflicting results to previous claims that improvement in fitness levels are only observed when the test mode and the training mode are the same (Magel et al., 1975; McArdle et al., 1978). Twenty-two women were involved in a six week training program which involved both swim and run training. Maximal oxygen uptake was determined prior to and after the six weeks on a cycle ergometer. Both groups showed a significant improvement in VO_2max values after training. Beaudet (1984) concluded that even though the results conflicted with the concept of specificity of training, the low initial fitness level of these subjects could have resulted in the discrepancy.

Both bicycle and treadmill training specificity were compared by

Pechar et al. (1974). Sixty college age males were separated into three groups; treadmill training, bike training and no training. Maximal oxygen consumption was determined by both treadmill and cycle tests. The run training produced similar increases in VO_2max for both treadmill and cycle tests. For the cycle training group, a small increase in VO_2max was observed on the treadmill, however, a significant increase was found for VO_2max on the cycle. They concluded that a specificity of VO_2max response existed for cycle training, whereas a general VO_2max improvement was produced by the run training.

Detraining

Physical conditioning programs can produce greater endurance and higher VO_2max values. Detraining can cause a mirror effect and, therefore, eliminate the positive training effects.

Seven females participated in a detraining study which followed their track season (Drinkwater & Horvath, 1972). During the three month period, they were not involved in a formal exercise program. They were, however, involved in a high school physical education class. Prior to the three month training lay-off, the average VO_2max was 47.8 $ml \cdot kg^{-1} \cdot min^{-1}$ which was significantly higher than the post test value of 40.4 $ml \cdot kg^{-1} \cdot min^{-1}$.

Pedersen and Jorgensen (1978) studied VO_2max values following training, detraining and retraining in six female subjects. The subjects trained for seven weeks on Monark cycle ergometers. After the training period, the average VO_2max was 46.7 $ml \cdot kg^{-1} \cdot min^{-1}$ which corresponded to an increase of 13.8%. After seven weeks of inactivity, the VO_2max decreased significantly to 43.8 $ml \cdot kg^{-1} \cdot min^{-1}$. The inactivity was sufficient to neutralize the training programs effects on VO_2max.

Hickson and Rosenkoetter (1981) trained 12 subjects to determine the minimal amount of exercise required to maintain cardiovascular endurance. The subjects went through an extensive six day per week training program prior to the reduced training period. One group reduced their exercise to four days per week while the second group exercised only two days per week. Following these reduced training periods, VO_2max values for both groups remained similar to the values obtained after the 10 week training period. They stated that a greater amount of exercise was required to increase VO_2max during training than was required to maintain those values during the reduction in training. Two to four days per week were, therefore, sufficient to maintain VO_2max.

Seven male subjects stopped training for 85 days following an average of 10 years endurance training. There was a significant decrease in VO_2max from 46.0 to 38.9 $ml \cdot kg^{-1} \cdot min^{-1}$ following the 12 week detraining period (Coyle, Martin, Bloomfield, Lowry, & Holloszy, 1985), with significantly lower values observed after only 22 days.

Twelve subjects exercised six days per week, 40 minutes per day for 10 weeks, prior to a reduction in intensity, to determine the intensity level required for maintenance of VO_2max values (Hickson, Foster, Pollock, Galassi, & Rich, 1985). Following the training, two groups were formed, one with a one-third and the second with a two-thirds reduction in intensity. In the group training at one-third intensity reduction, a significant decrease in VO_2max values occurred after 10 weeks. In the group training at a two-thirds reduction, VO_2max declined by a greater extent than the group with only a one-third reduction in training.

Cullinane, Sady, Vadeboncoeur, Burke, and Thompson (1986) reported on VO_2max values following a short term (10 day) lay-off from exercise in fifteen competitive runners. No significant difference in pre and post values following 10 days of exercise cessation (61.3, and 61.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) were found. A period of greater than 10 days was, therefore, required to decrease values in competitive runners.

Hemodynamic Changes in Water

Influence of Temperature

Water temperature will influence physiological variables due to circulatory adjustments which occur at various water temperatures. Thermoneutrality of skin temperature is approximately 34° C in a water environment (Kawakami, Natelson, & DuBois, 1967). Both metabolic and heat regulatory adjustments occur in the movement from air to a nonthermoneutral, colder water medium.

Craig and Dvorak (1969) compared exercise in air to exercise at three separate water temperatures (25°, 30°, 35° C). Only two subjects were studied, with exercise consisting of pedaling a cycle ergometer. Among the variables analyzed were ventilation, oxygen uptake, and heart rate. Ventilation (V_E) was greater for exercise in 25°C water than under any other condition. When V_E was plotted versus VO_2, however, no significance was found between any of the conditions. Heart rate at any given VO_2 was 10 beats lower at 25°C than under any of the other three conditions. When VO_2 was analyzed, the VO_2 for all workloads (0, 18, 36, 64, 84 watts) were similar in air and water at 30°C and 35°C. At 25°C, VO_2 was greater ($0.14\ l \cdot min^{-1}$) than the other conditions for all workloads. They concluded that the difference in VO_2 for exercise in 25°C could have been due to shivering at the lower temperature. The lower heart rate at the lower temperature was attributed to an increase in venous return, which resulted from the hydrostatic forces imposed upon the body during water immersion.

Cardiorespiratory responses to exercise in water (35-35.5°C) and on land (18-26°C) were studied in four male subjects (Denison, Wagner, Kingaby, & West, 1972). The exercise consisted of cycling in a supine position with a cycle ergometer. Respiratory gas exchange, end-tidal gas tension, alveolar ventilation, respiratory frequency, cardiac output and pulse rate were measured at rest and exercise at eupneic pressures. There was no significant change for alveolar ventilation or end-tidal gas for all levels between a VO_2 of $0.2\text{-}2.0\ l \cdot min^{-1}$ however, there was a 10% increase in pulse rate and cardiac output associated with immersion. They concluded that there were no important differences in cardiorespiratory responses in air and underwater. These findings were similar to data from other researchers when exercise in air was compared to exercise in a thermoneutral environment (Craig & Dvorak, 1969; McArdle, Magel, Lesmes & Pechar, 1976).

In 1976, McArdle et al. studied circulatory changes in six volunteers during immersion. Exercise in three separate water temperatures (18, 25, 33°C) were compared to exercise in air. Cardiac output, oxygen consumption, stroke volume and heart rate were all determined at various work rates using a discontinuous test protocol on an air water cycle ergometer. For oxygen consumption, a linear relationship was found between work load and VO_2 for all testing conditions. The VO_2 for air and 33°C water temperature were nearly identical. A significantly greater VO_2 was found at 25° and 18° when compared to submaximal exercise at 33°C (9%, 25.3%, respectively). At maximal work, the difference in VO_2 between air and water were within 110 ml, with the lowest VO_2max observed at 25°C. A linear relationship was found when heart rate was plotted versus VO_2 for work at 33° and in air. At any given submaximal VO_2 the heart rate for the 25° and 18°C conditions were 5 and 15 beats per minute lower than for 33°C. Maximal heart rate values were also significantly lower for the 18° and 25°C tests. When cardiac output was plotted versus VO_2, a linear relationship existed for all exercise conditions. Since there was no change in cardiac output, the lowered heart rates at 18° and 25°C were opposed by a relative increase in stroke volume for those two conditions.

Maximal aerobic power was determined in 15 men during training in air and in water at 32° and 20°C (Avellini, Shapiro, & Pandolf, 1983). The training consisted of one hour exercise, five days per week on a cycle ergometer. Heart rates and VO_2max values were compared for all three training groups which maintained an exercise intensity of 75% of VO_2max for the first week and increased it by 5% every additional week of training. When comparing air to water exercise, individuals' heart rates while exercising on land averaged 10 beats per minute greater than those during exercise at 32°C water and 20 beats per minute greater than the group in 20°C water. Maximal oxygen consumption increased by 16% for those training on land whereas a 13% and 15% increase was observed for the 32° and 20°C water tests, respectively. They concluded that training in cold water may be more efficient than training in either warm water or air due to the similar responses of VO_2 values for cold water and land, but at a lower heart rate in the water. They also stated that the decrease in heart rate at the lower temperature was compensated by a similar increase in stroke volume.

McMurray, Horvath, and Miles (1983) exercised water polo players and trained runners on a modified cycle ergometer in four different water temperatures. Hemodynamic responses were different between the trained runners and polo players. The water polo players' stroke volumes remained the same after training at both 30° and 35°C temperatures. The swimmers, however, had a decrease in stroke volume by 9.2 and 11.5 percent at water temperatures of 30° and 35°C, respectively. The opposite was found for the 20° trial. The stroke volume of the runners decreased significantly, with no change observed for the water polo players. There was also a difference in heart rates at all water temperatures between the swimmers and polo players, with the swimmers having higher heart rates. McMurray et al. (1983) concluded that the differences between the two groups were based upon specificity of training. They concluded that the runners were able to adapt to the heat (30°, 35° C) whereas swimmers were better adapted to the cold (20°C.).

Influence of Face Immersion

A number of cardiovascular reflexes are known to occur upon application of a cold, wet stimulus to the face or immersion of the face in water. These changes include bradycardia, peripheral vasoconstriction, and redistribution of the blood supply to vital organs such as the brain and heart.

Kawakami et al. (1967) studied the effects of face immersion and factors affecting the diving reflex in 15 subjects. There was a marked decrease in heart rate during face immersion, with or without breathholding, as compared to face out of water. The greatest drop in heart rate was observed during face immersion with breath holding in cold water (10-17°C). They suggested that cold receptors may be present in the face which act as a trigger for this diving reflex. They also stated that the maintenance of the reflex may be due to hypercapnia followed by hypoxia, during breath holding.

Forty subjects were observed during rest and exercise at apneic conditions to determine the effects of the diving reflex (Stromme, Kerem, & Elsner, 1970). There was a significant decrease in heart rate from apnea in air to apnea during face immersion. The greatest decrease in heart rate was found during the combination of apnea in air followed by apneic face immersion. A normal blood pressure was maintained, even during the bradycardia. They indicated that the lower heart rate and lower blood pressure combination occurred with a concommitant vasoconstriction. They also noted that the bradycardia was also present when the sensation of wetness on the face was tested, however, the heart rate increased when the face was removed from the water but was still very wet.

Breath-holding and breathing through a snorkel during immersion in warm and cold water were compared to determine the role of cold stress, perceived stress and apnea on bradycardia (Natelson, Nary, Curtis & Creighton, 1983). The greatest decrease in heart rate occurred during immersion in the cold water environment. Apnea was also found to cause a significant decrease in heart rate when compared to breathing through a snorkel. They stated that perceived stress was less prominent in producing bradycardia than such factors as temperature and apnea. They hypothesized that immersion in cold water stimulated facial receptors which produced a vagal response. The degree of the response was affected by apnea and to a lesser degree, perceived stress.

Influence of Position

When an individual moves from air to a water medium, a number of cardiorespiratory adaptations occur. These changes vary depending upon body posture, horizontal or vertical, as well as depth of immersion. The effects of the horizontal body posture will be discussed in a separate section on swimming. This section deals with a vertical position but at various immersion levels.

Hong, Cerretelli, Cruz and Rahn (1969) studied lung volume changes in four subjects. Comparisons were made between immersion to neck level and immersion to the xiphoid process. They found an 8% decrease in vital capacity when the water level was moved from the xiphoid to the neck. They attributed this decrease to a greater amount of the intrathoracic space being occupied by approximately 200 ml of pooled blood. A reduction in expiratory reserve volume was also found when the water level was increased. This change was attributed to the movement of the diaphragm cranially during immersion. They also found no significant change in the tidal volume.

In 1972, Arborelius, Baldin, Lilja and Lundgren determined cardiac output, right atrial pressure, heart rate and stroke volume for 10 subjects. In three of the subjects central blood volume and pulmonary arterial pressure were also measured. Comparisons were made between air and water immersion to neck level for all cardiovascular changes. In the transition from air to a thermoneutral water environment, cardiac output increased 32% or 1.8 $l \cdot min^{-1}$, while stroke volume increased by 26 ml or 35%. They found no significant change in heart rate, however, they did report a small decrease in heart rate when subjects moved from air to a water environment. The mean increase in the transmural pressure gradient at the right atrium was 13 mmHg, while a decrease in peripheral resistance of almost 30% was observed during immersion. When an individual moved from a standing to a supine position, there was an approximately 500 ml shift of blood into the thorax. This shift was due to the elimination of hydrostatic transmural pressure differences in the blood vessels around the heart. During immersion, the transmural pressure gradient exerted by blood above the diaphragm produced a reversal in the pressure gradient which resulted in a shift of 0.7 L of blood into the thoracic cavity.

Postural changes as well as effects of immersion on heart volume were studied by Lange, Lange, Echt and Gauer (1974). Cardiovascular responses of ten subjects between the ages of 24-32 years old who were immersed in a thermoneutral bath were compared for both standing in air and lying in the supine position. In the water environment, the subjects were immersed to the level of the clavicle. When posture was changed from the standing to the supine position, a shift of 80 ml of blood to the heart was found, with an additional 100 ml shift due to immersion. This total of 180 ml of blood shifted to the heart from standing in air to immersion in water was approximately 25% of the total volume shifted from the periphery into the thoracic cavity.

Begin, Epstein, Sackner, Levinson, Dougherty, and Duncan (1976) found no significant changes in oxygen consumption or heart rate in five subjects when moving from a seated position in air to a seated position in thermoneutral water at neck level. Significant increases in pulmonary blood flow and diffusing capacity of alveolar volume occurred in the water. There was no significant changes between supine immersion and supine nonimmersion for oxygen uptake and heart rate.

Heart volume, heart rate and pressure changes were compared during graded immersion (Risch, Koubenec, Beckmann, Lange & Gauer, 1978) in twenty male volunteers. Subjects were immersed to the diaphragm, or to the neck for both supine and standing. The change in position from standing in air to immersion to the diaphragm showed similar results as the postural change of moving from standing to supine in air. As a result of the positional change, heart volume increased by approximately 130 ml. Raising the water level to the neck caused an additional distension of the heart by 120 ml. The central venous pressure also increased from 2.5-12.8 mmHg. They concluded that the increase in heart volume was due to the additional hydrostatic pressure exerted on the extrathoracic blood vessels. The extra pressure of 25 cm Hg corresponded to the pressure exerted by the water column from the diaphragm to the xiphoid process. They also reported a decrease in vital capacity due to the increased filling of the pulmonary system. With the increased heart volume, they also concluded that the decrease in heart rate by almost 15% was due to cardiovascular reflexes.

Exercise in Water

Swimming

Swimming is a popular recreational activity. It is also utilized by many athletes during rehabilitation from various sporting injuries. Circulatory responses to swimming are different than for other exercise modalities. For example, there is a large heat transfer from skin to water, exercise is performed in the horizontal position and external pressure is increased due to hydrostatic forces.

Trained and recreational swimmers' cardiac outputs during maximal performance were compared during running and tethered swimming (Dixon &

Faulkner, 1971). At maximal exercise, there was no significant differences for cardiac output (CO), ventilation (V_E) or maximal oxygen consumption (VO_2max) between swimming and running for trained swimmers. There was a significant decrease in CO and V_E between running and swimming for recreational swimmers. They concluded that the decrease in CO from 23 to 17 $l \cdot min^{-1}$ resulted in a decrease in VO_2max by 25%.

Conflicting data were reported by Holmer, Lundin and Erickson (1974). Elite male and female swimmers were tested on a treadmill and in a swimming flume to determine VO_2max values. Ventilation, heart rate, ventilation equivalent ($V_E:VO_2$) and RER were significantly lower in swimming than in running for both male and female swimmers. They stated four different factors which could have resulted in the decrease in aeobic capacity between running and swimming. The degree of training, size of muscle mass, body position and heat exchange were considered influential factors.

Similar results were found in five subjects when hemodynamic and respiratory responses were compared for running and swimming (Holmer, Stein, Saltin, Ekblom, & Astrand, 1974). For similar submaximal VO_2 values, cardiac output, heart rate and stroke volume were similar. During maximal swimming, lower values were found for VO_2max (15%), cardiac output (10%), and heart rate. They explained the differences between swimming and running were due to smaller muscle groups involved in swimming. Even though both the arms and legs were used, minimal muscular work was required to support the body.

In 1974, Holmer reviewed and summarized the research literature concerning the physiological adaptions to swimming. He stated that oxygen uptake at submaximal levels was dependent upon degree of training, body dimensions, swimming technique and swimming style. Overall swimming VO_2max values were found to be 6-7% lower than during running for elite swimmers and 20% lower for untrained swimmers. For corresponding submaximal VO_2 levels, V_E and $V_E:VO_2$ were similar. During maximal exercise, V_E and $V_E:VO_2$ were significantly lower in swimming than in running while heart rates were 15 beats per minute lower during maximal swimming than running. He also stated that in a cold environment, shivering increased VO_2 at submaximal levels but decreased VO_2 at maximal exercise.

Walking and Jogging

Metabolic and circulatory responses to walking and jogging in waist deep water were compared to walking and jogging on land (Evans, Cureton, Purvis, 1978). Six male subjects exercised in the water for five 6-minute periods at various walking speeds. Treadmill walking or jogging were also performed but at speeds which would elicit similar energy expenditures as those achieved during the water tests. Heart rate and VO_2 were plotted and were found to be similar for all four testing conditions. The energy cost to walk or run at any speed in the water was greater than for similar speeds on the treadmill. They stated that walking in the water at one-half to one-third the speed of treadmill walking would result in similar metabolic requirements. Based upon the similar heart rate response to water and air exercise at similar energy expenditures, they concluded that these two water exercises can be prescribed based upon data achieved from a treadmill test.

A comparison of heart rate responses during water walking and treadmill walking was studied by Whitley and Schoene (1987). A second purpose of that study was to determine if water walking would elicit an exercise intensity sufficient to achieve cardiovascular fitness. The subjects walked at similar speeds in the water and on the treadmill.

The heart rates during water walking were significantly higher than during treadmill walking. They concluded that the heart rates were of sufficient magnitude to achieve cardiorespiratory fitness. All of the heart rates were above 70% of age predicted maximal heart rate. At the three fastest speeds this represented 75%, 82%, and 86% of age-predicted maximal heart rate.

Wet Vest Research

Two studies have used the "Wet Vest" as a testing device to compare energy expenditure between water-running and treadmill-running. Coad, Storie, Perez and Wygard (1987) studied four different trials: treadmill walking; treadmill running; water walking; and water running. They found significantly higher VO_2 values during water-walking as compared to treadmill walking. They also found a greater V_E for both pool tests as compared to the treadmill tests. Energy expenditure was significantly greater for the water walking test when compared to the treadmill walking. The two energy expenditures for the running tests were found to be similar. There was no significance found among any of the heart rate responses.

Conflicting data were reported by Bishop, Frazier and Smith (1987) when comparing pool and treadmill running. Seven runners were studied during a 45 minute period of "self pacing" for both running tests. They measured V_E, VO_2, RER, HR, and RPE during the test. The variables of HR and RPE were not found to be significantly different between the two tests. When comparing the treadmill run to the wet vest run, a significant decrease in V_E (79.1, 58.1 $l \cdot min^{-1}$), VO_2 (2.69, 1.97 $l \cdot min^{-1}$), and RER value (0.95, 0.91) were found. They concluded that previous claims of significantly increased metabolic costs for running in the Wet Vest were suspect.

Summary

Injuries are becoming more common among runners, which can lead to a loss of valuable training time. They are generally the result of increased distance or a drastic change in training routine. Injuries have been shown to result in loss of training time due to involuntary rest periods. This lay-off period or detraining period can eliminate the positive effects produced by training. In order to combat the detraining period, any mode of exercise which may maintain cardiorespiratory fitness levels would be beneficial. Alternate exercise modes are available during an injury so that detraining is kept to a minimum. Biking and swimming are popular rehabilitation exercises, however, they are not running specific. In order to maintain the cardiovascular and neuromuscular advantages gained by running, an alternate form of exercise which can produce specificity would be ideal.

Maximal oxygen uptake is the greatest predictor of fitness levels, but is affected by many biological, psychological and physiological determinants. The mode of exercise also can affect VO_2max values due to physiological adaptations. Research literature on VO_2max, HR, and V_Emax values is lacking for upright exercise in the water. A number of hemodynamic changes occur when moving from air to a water medium. The magnitude of response is influenced by water temperature and depth of immersion. The VO_2 values are greatest for nonthermoneutral temperatures during submaximal exercise. This is believed to be due to the metabolic cost of shivering at the lower temperatures. As VO_2max is approached, the values for all water temperatures is similar to those results achieved on land, with the lowest VO_2max shown at 25°C. Heart rate values for submaximal and maximal exercise are lower for all water temperatures when compared to land values. When an individual moves to a water medium two major changes result. The first is an increase in intrathoracic volume, and therefore, greater blood volume to the heart, with the second being a greater hydrostatic force exerted on the respiratory muscles. The lower heart rate response is believed to be a result of a greater stroke volume upon immersion due to an increased venous return, therefore, cardiac output is maintained.

Very little research on the wet vest and the benefits obtained from it are known. It does require similar mechanics to running but with the added benefit of working against the water resistance.

CHAPTER III

METHOD AND PROCEDURE

Introduction

The purpose of this study was to determine if any physiological differences exist between treadmill running and water running. This chapter deals with the methods of data collection and the analysis of that data. It is divided into the following sections: subjects; data collection; and, statistical treatment.

Subjects

Initially 20 healthy females between the ages of 19-30 years old volunteered for the study. The subjects participated in both a treadmill running VO_2max test and a water running VO_2max test. An informed consent (see Appendix A) which consisted of a description of the study and risks involved in the study was obtained from each subject prior to the initial testing session. The subjects were also required to participate in practice sessions in the pool as well as on the treadmill. All of the pool VO_2max tests were performed during one weekend. Ten of the subjects finished their treadmill VO_2max tests prior to the pool testing, whereas, eight of the subjects performed the treadmill test in the week following the pool testing. Both VO_2max tests were performed less than one week apart with at least one day in between both tests.

The female subjects were chosen based upon the following criteria: between the ages of 18-35 years; could swim adequately and felt comfortable in the pool; and, were in moderate exercise condition which was set at a treadmill VO_2max of at least 45 $ml \cdot kg^{-1}$.

Data Collection

Treadmill Test

The treadmill tests were conducted in the Human Performance Laboratory on the campus of University of Wisconsin - La Crosse. Each subject practiced on the treadmill prior to the test. The practice consisted of walking and running at various speeds as well as getting on and off the treadmill. The subject was instructed to stretch and was measured for height and weight. Both measurements were recorded to the nearest .25 in centimeters (cm) and kilograms (kg), respectively.

Each subject was prepped for a single lead electrocardiogram. The skin was rubbed with an alcohol gauze pad and abrasive pad to remove any oil and dry skin. A lead II, which consisted of three electrodes at the following sites, right subclavicular fossa, right tenth rib in a direct line below the first electrode, and the left tenth rib in a similar position as the previous electrode, was used. The subject was fitted for a headpiece, mouthpiece, noseclip and practiced breathing with the entire apparatus.

The electrode wires were connected to a Burdick M-200. The plastic hose was connected to the headgear and to the mixing chamber of the Beckman Metabolic Measurement Cart (MMC). While the subject practiced breathing with the apparatus, two final sets of instructions were given. The subject was instructed to continue to run until exhaustion and then to straddle the treadmill. The following instructions were also given concerning the Borg Scale of Perceived Exertion (Borg, 1970) [see Appendix B] :

> At various times throughout the run I will hold up this scale and ask you to select the number that best represents how hard you feel the work is for you at that time. As you can see this scale ranges from a low of 6 to a high of 20. The higher the number the harder you feel the effort is for you. The highest number (20) should represent the maximal effort and fatigue level you have ever felt while running. There is no right or wrong answer. Just try to estimate your total feeling of exertion and effort as honestly and accurately as possible. (Butts, 1982, p.9)

The treadmill test protocol (Butts, 1982) consisted of a 5 minute warm-up period at 5 miles per hour (mph) with a 0% grade. After the warm-up, the speed was increased to 6 mph with a 2.5% grade. The grade was increased by 2.5% every two minutes thereafter, until a grade of 10% was obtained. After reaching the 10% grade, the speed was increased 0.5 mph every 2 minutes until VO_2max was reached.

Heart rate recordings were obtained on a Burdick M-200. The recordings were taken the last 15 seconds of each minute as well as the last 15 seconds of maximal exercise. In order to determine the heart rate per minute, each R wave in the 15 second strip, with the exception of the first, was counted and multiplied by a factor of four. The proportion of the first R wave to the previous wave was determined and multiplied by four. This number was added to the previous number to determine the final heart rate expressed in beats per minute.

Gas analysis was performed using a Beckman Metabolic Measurement Cart (MMC). The Beckman MMC, an open circuit system, consisted of an oxygen analyzer (OM-1) and a carbon dioxide analyzer (LB-2).

Calibration was done prior to and immediately following each test using a known gas sample which was determined prior to testing with the Scholander Technique. Gas measurements were recorded at the end of every minute and at maximal exercise. At the end of the five minute warmup and every two minutes thereafter, the rate of perceived exertion (RPE) was obtained using the Borg Scale.

The test was terminated when the VO_2 remained the same or leveled off with increasing workload, or when the subject could no longer maintain the treadmill speed and stopped due to fatigue. Maximal oxygen uptake (VO_2max) was assumed to be obtained if the oxygen uptake at two successive workloads differed by 2 ml$\cdot$kg$^{-1}\cdot$ or less (Taylor, Buskirk & Henschel, 1955). If the increment was greater than 2.1 ml$\cdot$kg$^{-1}\cdot$ then respiratory exchange ratio (RER) of 1.00 or greater was used as attainment of maximal values. The VO_2max was defined as being the highest oxygen uptake during a minimum of 30 seconds of a one minute period.

Pool Test

The water running test was performed in Mitchell Hall Pool at the University of Wisconsin - La Crosse. Each subject had practiced with the Wet Vest prior to the water VO_2max test. The practice session consisted of proper fitting of the Wet Vest for size as well as demonstration of the proper running technique using the vest.

The subject was given specific instructions in regard to the proper technique of water running, but was also instructed to simulate their own running form as closely as possible. The following instructions were given: the hips should be kept in a direct line with the back, thereby reducing the tendency to arch the back as well as reduce the tendency to lean too far forward; the leg motion should be hip flexion and knee flexion followed by knee extension then hip extension; next, the leg in the kick back phase should be brought back to a position that is in a direct line with the body or slightly posterior to the body; and, the arms and the hands are to be used in a manner similar to the individual's running style.

Upon entering the pool area, the subject was instructed to stretch followed by attainment of height and weight measurements. Next the subject was prepped for a modified Lead II (RA, LL, no ground) telemetered electrocardiogram. This consisted of the following sites: right subclavicular fossa and left tenth rib in a direct line with the left subclavicular fossa. The connection between the electrode and the wire clip-on was sprayed with Firm-Grip and tape was placed over it to insure a secure fit while being immersed in the water. Heart rate was monitered via a telemetry unit using a LifePak 5 for ECG strips for a 15 second time period. The Beckman MMC was used for gas analysis and was calibrated before and after each test as previously described. Similar headgear was used for both the treadmill running test and the water running test.

Each subject was tethered into place, therefore a stationary position was maintained. During immersion, the water level stayed between the superior clavicular border and mid-sternal level of the runner. After being connected to the telemetry unit, headgear, mouthpiece, noseclip and plastic tubing, the subject entered the water to adjust to the breathing apparatus and water prior to the start of the test. At this time a re-explanation of the proper water running mechanics as well as an explanation of the Borg Scale of Perceived Exertion (see Appendix B) was given. Each subject was also given the following instructions:

> If at any time you feel that you cannot stay with the cadence of the metronome then begin an all out sprint. When you can no longer go on then pull yourself to the side of the pool. If at any point we feel that you are not keeping with the cadence of the metronome then we will instruct you to pick up your pace. If you still cannot keep the pace then do an all out sprint for as long as possible. Remember that with each click of the metronome, 1 leg is in the down position.

The pool protocol consisted of a five minute warm-up at a cadence of 100 beats per minute (bpm). Each beat of the metronome coincided with 1 foot in the down position. Every two minutes thereafter, the speed was increased by 20 bpm until a rate of 200 bpm was attained. The subject then continued until VO_2max was reached. If at any point the VO_2 decreased between two consecutive minutes or it was visibly noticeable that the cadence was not being maintained, the runner was instructed to increase speed. If the cadence was still not maintained, the subject was instructed to sprint for as long as possible. The test was discontinued when the VO_2 plateaued, the subject could no longer keep with the cadence, or the subject stopped due to exhaustion. Throughout the entire test, the runner's form was being analyzed and adjusted when necessary. The cadence, recorded from a metronome, was played over a tape recorder.

Ratings of perceived exertion were recorded at the end of the five minute warm-up and after each two minute stage. Gas measurements were recorded at the end of every minute as well as at maximal exercise, with heart rate recordings being taken the last 15 seconds of each minute and also the last 15 seconds of maximal exercise. Heart rates were determined from the ECG strips based upon the same procedures as previously described for the treadmill.

Statistical Analysis

After completion of both the treadmill running and water running tests, the data were analyzed to determine if a significant difference in physiological responses existed between the two tests at maximal exercise performance. A student's dependent t-test was used with the following variables being analyzed: VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$, $l \cdot min^{-1}$), V_E $l \cdot min^{-1}$, respiratory exchange ratio (RER), and heart rate (HR). Means and standard deviations for age, height and weight were also determined. The hypotheses were tested at the .05 level of significance.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to compare the physiological differences between treadmill running and water running in moderately trained females during maximal exercise. Means and standard deviations were determined for the physical characteristics of age, height and weight. A student's dependent t-test was used to analyze values at maximal exercise performance. The physiological responses analyzed were: maximal oxygen uptake ($VO_2\ l \cdot min^{-1}$, $VO_2\ ml \cdot kg^{-1} \cdot min^{-1}$); maximal ventilation ($V_E max$); maximal heart rate (HR) and respiratory exchange ratio (RER).

Physical Characteristics

Twenty women between the ages of 19-30 years initially volunteered as subjects for the exercise testing. Subjects were required to complete two tests and only those completing both were included in the final statistical analysis. Two of the subjects were eliminated due to failure in completing both exercise tests. Eighteen subjects were, therefore, used for final statistical analysis, with all 18 attaining the minimal requirement of 45 $ml \cdot kg^{-1} \cdot min^{-1}$ on the treadmill test.

The means, standard deviations, and ranges for age, height and weight are shown in Table 1. Although both tests were performed less than one week apart with at least one day in between tests, there was a significant (p<.05) difference in weight (kg) between the treadmill and pool test. Upon further data analysis, it appears that this significant difference in weight was due to one subject's weight increasing by more than two kilograms.

Table 1

Means and Standard Deviations of Physical Characteristics (n=18)

Variable	Mean	SD	Range
Age (yrs)	23.6	3.4	19 - 30
Ht (cm)	64.2	1.6	60 - 67
Wt (kgs)			
Pool	57.6*	5.2	49.9-67.4
Treadmill	57.0	5.1	50.6-67.7

* Pool weight significantly (p<.05) greater than treadmill weight

Average weekly physical activity levels for the previous month were recorded for each subject. Five of the individuals ran between 1-9 miles per week with the same number of subjects running between 10-19 miles. Seven of the runners averaged over 20 miles per week, whereas, one subject recorded no running mileage but had participated in a land aerobics program three times per week for one hour each time. Five of the runners also participated in a land aerobics program. Based upon the activity levels of these subjects, they could be considered to be very active for college-aged females.

Table 2
Means and Standard Deviations for Responses to the VO_2max Tests

Variable	Pool	Treadmill
VO_2max	2.425[a]	2.919[a]*
($l \cdot min^{-1}$)	0.304[b]	0.421[b]
($ml \cdot kg^{-1} \cdot min^{-1}$)	42.6	50.6*
	4.2	4.3
V_Emax	92.5	101.7*
($l \cdot min^{-1}$)	8.8	10.4
HRmax	180.2	190.5*
	8.6	10.2
RER	1.04	1.15*
	0.10	0.10

a=mean b=standard deviation $*p<0.05$

Maximal Exercise Data

Maximal oxygen uptake tests are commonly used as the single best indicator of aerobic power. In order to determine whether an individual has reached true maximal performance, a number of requirements are necessary for test termination. The general requirements are: a leveling of VO_2 with increasing workload of no more than 150 $ml \cdot kg^{-1} \cdot min^{-1}$, achieving age predicted maximal heart rate, a respiratory exchange ratio (RER) greater than 1.00, blood lactate 90-100 mg per 100 ml of blood, or volitional exhaustion.
In order to be considered a maximal effort at least one of these requirements had to be met in the present study.

During the treadmill test all subjects reached an RER value of 1.00 or greater, whereas, during the pool test four individuals obtained an

RER of less than 1.00. During exercise in a water medium, lower RER values are generally observed (Holmer et al., 1974; Magel et al., 1974; McArdle et al., 1978), and, therefore, values of less than 1.00 in the water does not necessarily indicate maximal values were not reached. Three of these four individuals displayed a plateauing of VO_2 with increasing workload with the last individual stopping due to volitional exhaustion. Upon termination of the tests, all subjects were considered to have reached true maximal values.

Maximal Ventilation

A significant ($p<0.05$) difference was found between the pool and treadmill maximal ventilatory ($V_E$max) responses. The $V_E$max during the pool test was 8.8% lower than for the treadmill.

Ventilation refers to the amount of air either inspired or expired. For the purpose of this study, expiratory ventilation (V_E) values were used. At rest V_E can range from 4-15 liters per minute which is dependent upon age, sex, and height (Fox & Mathews, 1981). Maximal ventilation volumes during exercise can range as high as 25-30 times greater than resting values. During exercise, increases in V_E are approximately linear to oxygen consumption and carbon dioxide production in the working muscles (Astrand & Rohdahl, 1986; Fox & Mathews, 1981). When maximal values are approached the increase in ventilation becomes steeper than the increase in oxygen uptake, however, carbon dioxide values remain proportional to ventilation. At maximal exercise, minute ventilation is needed more for carbon dioxide removal than for oxygen consumption purposes (Fox & Mathews, 1981). Increased lactic acid levels can also stimulate ventilation increases, therefore, ventilation can serve as a buffering device. Any increase in ventilation during exercise are a result of all three of these factors. At or near maximal values, carbon dioxide production appears to play the major role (Astrand & Rodahl, 1986).

Maximal ventilation during exercise differs not only between the population studied but also exercise mediums. Male and female athletes have greater V_E values than their sedentary counterparts. Elite female runners were shown to have a V_E of 108.9 l·min^{-1} (Wilmore & Bown, 1974) and a group of marathon runners with a V_E of 94.7 l·min^{-1} (Christensen & Ruhling, 1983). In the average population, maximal ventilation is lower. Some of the values recorded for sedentary college-aged women and female army recruits were 77.4 l·min^{-1} and 86.6 l·min^{-1}, respectively (Kearney, Stull, Ewing & Stein, 1976; Vogel,Patton, Mello & Daniels, 1986).

Maximal ventilation values also vary depending upon the exercise mode and whether the exercise occurs on land or in water. Holmer et al. (1974) found significantly lower ventilation values for swimming when compared to running (111.0 l·min^{-1} & 154.2 l·min^{-1}, respectively). Maximal data were collected from college-aged males before and after a running and swimming training program. Lower $V_E$max values were observed for the swimming tests in all groups for both pre and post training tests (Magel et al., 1975). In another study, Holmer and colleagues

(1974) found significantly lower swimming $V_E$max (132.6 $l \cdot min^{-1}$ & 103.1 $l \cdot min^{-1}$) values than treadmill values for elite male and female swimmers . Similar results were found by McArdle et al. (1976) for running and swimming maximal value, with significantly greater V_E values during the treadmill running. Less of a difference was found between the two values when trained swimmers were studied (Dixon & Faulkner, 1971). Trained swimmers' values only differed by approximately 2 $l \cdot min^{-1}$, however, in the same study recreational swimmers had a significantly greater difference.

There are two factors which may account for lower $V_E$max in the pool compared to land values. Upon immersion there is an increase in the intrathoracic blood volume as well as an increase in hydrostatic forces which oppose the respiratory muscles. Hong et al. (1969) found these two factors result in an approximately 60% decrease in vital capacity with the expiratory reserve volume also decreasing and tidal volume remaining relatively unchanged at rest. During exercise, there is an increase in tidal volume which is brought about by an increased utilization of the inspiratory and expiratory reserves (Astrand & Rodahl, 1986). Since vital capacity is reduced by such a large extent, tidal volume must also be affected and, therefore, reduced. Ventilation values are directly proportional to tidal volume, hence, $V_E$max during exercise in a water medium is reduced.

Respiratory Exchange Ratio (RER)

As with the maximal ventilation volume, there was a significant ($p<0.05$) difference between the pool and treadmill RER values with the treadmill yielding higher results. These values are very similar to RER values in the literature for treadmill and swimming tests.

The respiratory exchange ratio (RER) is the ratio of the volume of carbon dioxide expired to the volume of oxygen utilized. A number of factors can affect the magnitude of these values including the oxidation of food, hyperventilation and short term exhaustive exercise which increase lactic acid production (Fox & Mathews, 1981). There is a direct relationship between ventilation and the volume of carbon dioxide produced, therefore the decrease in ventilation observed for the pool values would have a direct effect in decreasing carbon dioxide production thus resulting in a lower RER value for the pool exercise.

Maximal Heart Rate

A statistical ($p<.05$) difference existed between the maximal heart rate values for the treadmill and pool running tests. The treadmill heart rate was 5.4% greater than that achieved during the pool test.

Diving bradycardia, a phenomenon which has been observed in swimmers, is represented by a peripheral vasoconstriction and decreased heart rate. This diving reflex is also seen during face immersion which elicits a pronounced bradycardia (Stromme et al., 1970; Kawakami et al., 1967). During a swimming VO_2max test, diving bradycardia plays a role in limiting maximal heart rate to a level less than that achieved during treadmill running. During water running the face was not immersed at all and, therefore, diving bradycardia should play a minimal, if any part, in decreasing the heart rate.

A number of hemodynamic changes occur during graded immersion in a water medium which may have a slowing effect on heart rate. During immersion a hydrostatic pressure is exerted on the body surface. Due to this pressure, approximately 700 ml of blood is shifted into the thoracic cavity (Lange et al., 1974). This results in an increase in central venous pressure which results in an increase in venous return therefore a greater heart volume (Arborelius et al., 1972). It has been suggested, based upon the increased blood volume to the heart, that a decrease in heart rate by 15% results due to compensatory reflexes (Risch et al., 1978). Accumulation of blood in the heart will produce both a dilitation of the ventricle as well as a lengthening of the myocardial fibers, resulting in a greater active tension. According to Frank-Starling Law of the heart, the increased diastolic fiber length will facilitate a greater ventricular contraction which produces an increase in stroke volume (Berne & Levy, 1983). The decrease in maximal heart rates in a water medium has been suggested as being a response to this increase in stroke volume (Craig & Dvorak, 1969; McArdle et al., 1976; Avellini et al., 1983).

Denison and colleagues (1972) estimated cardiac output from respired air, blood tensions and assumptions concerning gas transporting characteristics. They found an approximately 10% difference between cardiac output in air and in water. They concluded, however, that the

10% disparity could be accounted for as a result of 1°C underestimation of body temperature. McArdle et al. (1976) determined cardiac output by the CO_2 rebreathing method and found similar values for work in air and in a thermoneutral water environment. They suggested that similar cardiac outputs were maintained due to greater stroke volumes, hence, lower heart rates for immersion in water.

Another mechanism which may play a role in decreasing maximal heart rate during immersion is thermoregulation. Bradycardia may be a response to water temperature and not hydrostatic forces (McArdle et al., 1976). These authors found a greater decrease in heart rate in a water temperature less than 25°C. than compared to temperatures greater than 30°C. The water temperature in the present study averaged 29°C., thus should not have been a contributing factor to the bradycardia displayed in the pool test.

VO_2max

The absolute mean value of VO_2max for the treadmill test was 2.919 L. min^{-1}, whereas, the pool test was significantly ($p < .05$) lower by 17% (2.43 $l \cdot min^{-1}$). When VO_2max was expressed relative to body weight, a significant ($p < .05$) difference also existed. The treadmill and pool values were 50.6 $ml \cdot kg^{-1} \cdot min^{-1}$ and 42.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, which represents a 16% difference (see Table 2).

The treadmill values are similar to those reported for high school cross country runners, who were measured at 50.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (Butts, 1982). They are also similar to 13 experienced female marathoners who had a VO_2max of 51.8 $ml \cdot kg^{-1} \cdot min^{-1}$ but higher than the novice marathoners who had a VO_2max of 45.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (Christensen & Ruhling, 1983). These values are also greater than 13 sedentary subjects of similar age (24 years) who recorded a VO_2max of 33 $ml \cdot kg^{-1} \cdot min^{-1}$ (Lortie, Simoneau, Harvel, Boulay, Landry & Bouchard, 1984). On the basis of their treadmill VO_2max values, the subjects in the present study were considered to be above average for their age category.

In the transition from air to water, various cardiovascular adjustments are made. Water temperature and body position affect the extent of these adjustments. Maximal oxygen uptake values have been shown to be higher in the 18-25°C temperature range than in 30-35.5°C (Craig & Dvorak, 1969; McArdle et al., 1976). This increase in oxygen consumption is believed to be due to shivering in the colder water environment, which increases metabolic rate and results in higher VO_2 values. During a range closer to a thermoneutral temperature (30-35.5°C), VO_2max values in air and on land have been shown to be similar (Craig & Dvorak, 1969; Denison et al., 1972).

During the wet vest study, the pool temperature of 29°C was close to the thermoneutral temperature thus should not have played a major role in heat loss. In addition, shivering was not observed during the pool testing which averaged 13.4 minutes. Due to the buoyancy the wet vest adds to the body, minimal muscular work is required to support the body in contrast to running. This decrease in active muscle usage would contribute to a decrease in oxygen requirements. Another compounding factor may be the limitations imposed on the body's ability to work against the water pressure. The resistance of the water during the pool running may prevent the individual from increasing their limb speed which would not occur during treadmill running.

Summary

The purpose of this study was to compare maximal physiological values during running on the treadmill and in the pool. The treadmill values were significantly higher in all variables analyzed during maximal exertion (V_E, VO_2, HR, RER). There was a 9% decrease in V_E, 16% decrease in VO_2max, and a 5% decrease in maximal heart rate when pool values were compared to treadmill values. These differences appear to be due to the hemodynamic responses brought about by immersion into a water medium. The hydrostatic forces oppose the respiratory muscles thus decreasing ventilation. These hydostatic forces, however, enhance blood flow to the heart which results in an increase in venous return and a corresponding decrease in heart rate response. Upon immersion into water, the weight of the body is reduced to a few kilograms in weight. With the addition of the Wet Vest, less work is required to maintain posture. This decrease in work requirement for the anti-gravity muscles to maintain posture results in a possible decrease in active muscle mass from treadmill to pool thus, reducing the oxygen consumption requirements.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to compare the maximal physiological responses between treadmill and pool running. Eighteen women between the ages of 19 - 30 years participated in the study which required two VO_2max tests. The pool test required that the subject wear a light weight flotation device (Wet Vest) while simulating running mechanics in the water, whereas, the second test consisted of a treadmill run.

The physical characteristics of height and weight were recorded prior to each test to determine means, standard deviations and ranges. Throughout both tests V_E, VO_2 ($l \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot min^{-1}$), HR and RER were collected. Maximal values for these variables were used to determine means and standard deviations. A student's dependent t-test was used to determine whether differences at maximal exercise existed between the two tests.

Conclusions

Various conclusions were made based upon the results of this study. A number of physiological adaptations appear to occur when an individual moves from land to a water medium. Significantly lower responses were found for the pool test in all physiological variables analyzed.

One possibility for lower pool values could be biomechanical constraints. In the water, the resistance may have prevented the subject from sufficiently increasing limb speed for maintenance of proper cadence. This could lead to lower maximal values in the pool.

A second possibility for the lower pool values could be due to local fatigue. The resistance to the limbs exerted by the water could result in fatigue to the arms and legs, thus terminating exercise before the oxygen transport system has maximally been stressed.

The final possibility could be the result of physiological changes which occur upon immersion. Increased hydrostatic forces may produce hemodynamic and respiratory alterations. This hydrostatic pressure forces an increase in blood volume to the intrathoracic space resulting in a greater blood volume to the heart. With this increase in venous return, a greater diastolic filling would occur, thereby increasing stroke volume. This greater stroke volume, however, does not apparently increase cardiac output during maximal exercise. There is not much research data which directly measures cardiac output for both air and water. The CO_2 rebreathing technique was used in a few studies, which concluded that cardiac output was similar for work in air and in a thermoneutral environment. Based upon the assumption that cardiac outputs were similar, combined with the increase in stroke volume during immersion, a compensatory decrease in heart rate was expected and occurred in the present study.

The hydrostatic forces will also affect maximal ventilation and ultimately RER values. The opposition of the hydrostatic pressure to the respiratory muscles, as well as the increase in intrathoracic blood volume, result in a decrease in vital capacity and expiratory reserve volume. During exercise, a decrease in tidal volume would result from the reduction in vital capacity. Ventilation volumes are proportional to tidal volume, therefore, $V_E$max would be reduced in the pool. There is also a direct relationship between ventilation and the volume of carbon dioxide produced. Lower $V_E$max reduces the volume of carbon dioxide produced resulting in lower RER values in the pool.

An individual weighs only a few kilograms when immerged in water. This, as well as the added buoyancy from the Wet Vest, will minimize the muscular work to support the body. This decrease in the muscular work involved in supporting the body could contribute to the lower VO_2max values observed in the pool.

Running in the water provides numerous rehabilitation and training possibilities. Water running is a non-weight bearing activity and therefore reduces the stress to the joints. In addition, training at exercise intensities similar to those achieved on land is possible, while neuromuscular specificity is still maintained. Water running provides a training alternative which may combat boredom encountered by running. Due to the water resistance, toning and conditioning of the muscles is also possible. Another possible benefit of water running could be an increase in flexibility. Water running could also provide similar benefits for populations other than athletes. Individuals in many rehabilitation programs, such as orthopedic, neuromuscular or cardiac, could possibly achieve similar benefits. Special care must be taken when higher risks groups exercise in the Wet Vest due to the lack of available research on blood pressure responses during water running.

Recommendations for Future Study

A number of recommendations are possible due to the lack of research with the wet vest. Training studies with both male and female subjects would be beneficial for coaches and their athletes to determine if water running develops or maintains cardiorespiratory fitness. Some athletes may want to use the vest as a training alternative during off days, however, they may not want to risk the possibility of losing any training time or risk the chance of decreasing cardiovascular fitness.

Due to the increased number of individuals running in water at thigh level, a study which compares energy expenditure between water running, treadmill running, and running in water at thigh level may be beneficial. Another recommendation is to underwater weigh each subject in order to determine if any differences in the lower pool VO_2max values are due to body composition.

A number of assumptions have been made based upon limited research. Research similar to this study should be done with simultaneous determination of cardiac output values at maximal performance.

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Appendix A

Subject Informed Consent

INFORMED CONSENT

I,___________________________, volunteer to be a subject in a research study entitled " Physiological Response Differences between Treadmill Running and Pool Running in College-Aged Females".

I understand that I am required to complete two VO_2max tests, one wearing the Wet Vest in the pool and the other on the treadmill. Prior to the pool test, I am required to attend a practice session in the pool which consists of practicing the proper running technique using the Wet Vest. I am also required to practice running on the treadmill prior to the actual test.

Both tests consist of a warm-up period followed by increased workloads. During the test my heart rate will be continuously monitored with an electrocardiogram (EKG). I agree to wear a headpiece and noseclip as well as breath through a mouth piece so that the collection of expired gas may be attained. I understand that because this requires a maximal effort, there are a few risks involved. These risks include dizziness and breathing difficulty.

The testing sessions as well as the practice sessions will be scheduled at my convenience. I understand that I will be continuously monitored throughout the test, and at any point I am free to stop the test.

I am not afraid of the water and have basic swimming skills. To my knowledge I am in good health and do not have any physical condition which could alter my results.

I have read and understand the previous material. All questions I have, have been answered prior to the testing periods. I understand that I am free to withdraw my participation at any time during the study.

I, therefore, voluntarily consent to be a subject in this study.

Signed:_______________________ Date:___________________
Witness:______________________ Date:___________________

Appendix B

Borg Scale of Perceived Exertion

6

7 Very, Very Light

8

9 Very Light

10

11 Light

12

13 Somewhat Hard

14

15 Hard

16

17 Very Hard

18

19 Very, Very Hard

20