COMPARISON OF CARDIORESPIRATORY PARAMETERS DURING TREADMILL AND IMMERSION RUNNING

by

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ABSTRACT

The purpose of this study was to compare the relationship between immersion running and treadmill running through the measurement of cardiorespiratory parameters.

Sixteen subjects completed two exercise protocols to exhaustion. The treadmill running protocol was initiated at 3.08 m*s-1 and increased a 0.22 m*s-1 every sixty seconds. The immersion running protocol utilized an immersion running Ergometer (IRE). The IRE is similar to a tethered swim machine. The initial weight was set at 1 kg and increased a 1/2 kg every sixty seconds. Heart rate (HR), oxygen consumption (VO2), ventilatory equivalent (VE/VO2), and minute ventilation (VE) were determined at ventilatory threshold and at maximal effort. HR, VO2, VE/VO2 and VE were analyzed by MANOVA (RM). Tidal volume and frequency of breathing were collected for four subjects at ventilatory threshold and at maximal effort (no statistical analysis). Two subjects who had completed the initial exercise protocols volunteered for a follow up study of blood flow distribution testing (no statistical analysis). These subjects were injected with Tc-99 2-methyloxy isobutyl isonitrile at ventilatory threshold during immersion and treadmill running. Imaging was performed with a Seimans Gamma Camera at the UBC Dept. of Nuclear Medicine.

VO2 and HR at ventilatory threshold and maximal effort were significantly lower ($P < .05$) during immersion running. VE/VO2

was significantly greater at maximal effort during immersion. Minute ventilation was unaffected by immersion, however, there was a trend towards a smaller tidal volume and greater frequency of breathing. The blood flow distribution data varied considerably partially between subjects.

The significant drop in VO2 at maximum effort and at ventilation threshold during immersion running may be accounted for by changes in muscle mass recruitment, muscle fibre type recruitment, recruitment pattern and state of peripheral adaptation (muscular). A lower heart rate during immersion may be due to increases in intrathoracic blood volume. The trend towards a higher breathing frequency and lower tidal volume during immersion running may be due to the increased effort to breath caused by hydrostatic chest compression. The significant increase in VE/VO2 at maximal effort during immersion running was due to the significant drop in VO2.

It may be concluded that immersion running causes significant changes in cardiorespiratory parameters at ventilatory threshold and at maximal effort. Research is needed to investigate the significance of the changes.

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CHAPTER 1

THE PROBLEM

INTRODUCTION

Immersion running (IR) involves the simulation of running motion while immersed to the neck in an aqueous environment. IR has been utilized for two specific functions.
They include:

1. Rehabilitation of runners suffering from lower leg injuries (Johnson et al., 1977; Koszuta, 1986); and
2. Initiating physiological adaptations specific to land based running (Koszuta, 1986).

Koszuta (1986), documented the use of immersion running as a form of rehabilitation for runners with stress related injuries (i.e. stress fractures and achilles tendonitis). Injured runners upon resumption of land training, subjectively felt that they were able to maintain or improve cardiorespiratory fitness as it related to land based running performance because of immersion running. The subjective measures from injured runners has provided the foundation upon which coaches and athletes have utilized immersion running as an alternative form of athletic training. To date, there is a lack of research substantiating the subjective measures.

For immersion running to be utilized as a mode of athletic training for the competitive runner, it should induce adaptations specific to land based running performance. Land based performance is a function of two properties. Those properties are:

1. A highly developed central cardiorespiratory system with the ability to sustain prolonged endurance activities (Astrand, 1977); and
2. A highly developed peripheral musculature with the ability to sustain a running performance for a given period of time (Astrand, 1977).

The areas documented in the previous paragraph (cardiorespiratory and peripheral adaptations) can be measured by a number of varying methods. Although both areas are worthy of investigation, it is the purpose of this study to concentrate on comparing cardiorespiratory parameters between an immersion and treadmill running condition.

Traditionally, the measurement of maximum oxygen consumption (VO2max) has been used to assess the degree of cardiorespiratory fitness (Astrand, 1977). Characteristically, highly trained middle distance runners elicit VO2max values greater than 65 ml*kg-1*min-1. More recently, a number of authors have utilized ventilatory threshold as a measure of cardiorespiratory fitness because of its correlation with endurance performance (Rhodes et al., 1984; Withers et al., 1981). Well trained middle distance runners traditionally acquire a ventilatory threshold greater than 80% of VO2max (Davis et al., 1984; Withers et al., 1981). In order for immersion running to be utilized effectively by athletes, it must be able to elicit oxygen consumption values (at maximal effort and at ventilatory threshold) equivalent or greater to those measured during a treadmill running protocol.

If immersion running can elicit a VO2 at maximum effort and at ventilatory threshold equivalent to treadmill running, an individual may be able to maintain or improve their level of cardiorespiratory adaptation. Ultimately, any change in oxygen consumption that may occur between an immersion running and treadmill condition will be due to:

1. The introduction of a water environment which increases thoracic blood volume and hydrostatic chest compression (Epstein, 1976; Begin et al., 1976); and
2. Changes in task specificity (Astrand, 1977; Secher et al., 1977; Withers et al., 1981). Within the area of task specificity, there are a number of subfactors that may affect VO2 at maximal effort and at ventilatory threshold. It was hoped that some of these factors could be isolated and measured utilizing an experimental radionuclide procedure.

The primary factor in cardiorespiratory fitness is oxygen consumption. However, secondary to this factor, a number of other parameters including heart rate, minute ventilation, tidal volume, breathing frequency and VE/VO2 may help in overall cardiorespiratory function. The measurement of these parameters will be included in this study. Similarly, any changes that may occur in the cited parameters between an immersion and treadmill running condition will be due to either the introduction of the water environment and/or changes in task specificity (Astrand, 1977; Epstein, 1976; Withers et al., 1988).

Ultimately, understanding the nature of immersion running is important to the coach, the athlete, and the physiotherapist. The use of IR may:

1. Decrease the rate of incidence and prevent lower extremity injuries (and therefore increase the effective training time); and
2. Increase the performance level of the athlete due to its potential ability to induce cardiorespiratory and peripheral adaptations specific to land based running.

STATEMENT OF THE PROBLEM

The purpose of this study was to compare the relationships between immersion running and treadmill running through the measurements of cardiorespiratory parameters. It has been hypothesized that oxygen consumption will be similar under both conditions and that the VE/VO2 ratio should be lower during immersion running. It has also been hypothesized that heart rate, ventilation and tidal volume will be greater during treadmill running than immersion running.

HYPOTHESIS

1. Maximal oxygen consumption (VO2max) during an IR protocol (W) will be equal to maximal oxygen consumption during a treadmill running protocol (T). Equality shall be defined as a $P > .50$. VO2maxW = VO2maxT
2. Oxygen consumption at ventilation threshold (VO2vt) will be equal during an IR protocol and during a treadmill protocol. Equality shall be defined as $P > .50$. VO2vtW =VO2vtT
3. Heart rate at VO2max (HRmax) will be greater during a treadmill protocol than an IR protocol. HRmaxT > HRmaxW
4. Heart rate at ventilation threshold (HRvt) will be greater during a treadmill protocol than an IR protocol. HRvtT > HRvtW
5. Ventilation at VO2max (VEmax) will be greater during a treadmill protocol than an IR protocol. VEmaxT > VEmaxW
6. Ventilation at ventilation threshold (VEvt) will be greater during a treadmill protocol than an IR protocol. VEvtT > VEvtW
7. Tidal volume at VO2max (TVmax) will be greater during a treadmill protocol than an IR protocol. TVmaxT > TVmaxW
8. Tidal volume at ventilation threshold (TVvt) will be greater during a treadmill protocol than an IR protocol. TVvtT >TVvtW

9. Ventilatory equivalent at VO2max (VE/VO2max) will be smaller during an IR protocol than a treadmill protocol.
   VE/VO2maxW < VE/VO2maxT
10. Ventilatory equivalent at ventilation threshold (VE/VO2vt) will be smaller during an IR protocol than a treadmill protocol. VE/VO2vtW < VE/VO2vtT
11. Frequency of breathing at VO2max (Fmax) will be greater during an IR protocol than a treadmill protocol.
    FmaxW > FmaxT
12. Frequency of breathing at ventilation threshold (Fvt) will be greater during an IR protocol than a treadmill protocol.
    FvtW > FvtT

RATIONALE

1. It has been hypothesized that there will be a non-significant change in oxygen consumption at maximum effort and at ventilatory threshold during immersion and treadmill running. These hypothesis are based upon two assumptions. Those assumptions are:
   A. That the water environment will not affect normal cardiorespiratory function as it relates to oxygen consumption. Dressendorfer et al., 1976 and Denison et al., 1972 noted that there were non-significant changes in VO2 at maximal and submaximal intensities

comparatively between a land and immersion cycling protocol; and

B. That any changes (or lack of changes) in task specific factors will not cause significant changes in the rate of oxygen consumption.

2. It has been hypothesized that there will be a significantly lower heart rate (at maximal effort and ventilatory threshold) during immersion running. These hypothesis are based upon two assumptions. Those assumptions are:

A. That the increase in intrathoracic blood volume due to the introduction of a water environment will increase stroke volume and lower heart rate at any given cardiac output or exercise intensity. A lower heart rate due to water immersion during exercise has been reported by investigators (Sheldahl et al., 1976; Sheldahl et al., 1984; Dressendorfer et al., 1976);

B. That task specific factors (i.e. the training state of recruited musculature and the type of recruited musculature) which may increase heart rate at ventilatory threshold during immersion running will be insignificant comparatively to the effects of the water environment (Clausen et al., 1973; Withers et al., 1981).

3. It has been hypothesized that ventilation at maximal effort and at ventilatory threshold will be significantly lower

during immersion running. These hypothesis are based upon two assumptions. Those assumptions are:

A. That the increase in hydrostatic chest compression and intrathoracic blood volume (the water environment), will result in an increased effort to breathe. An increased effort to breathe may be characterized by changes in lung mechanics (Dahlback et al., 1975, 1978a and 1978b);

B. That task specific factors (i.e. the involvement of large quantities of upper body musculature) may contribute in lowering minute ventilation during immersion running (Secher et al., 1977; Toner et al., 1984).

4. It has been hypothesized that tidal volume will be significantly higher and breathing frequency significantly lower during immersion running. These hypothesis are based upon two assumptions. Those assumptions are:

A. That the increase in intrathoracic blood volume and hydrostatic chest compression (the water environment) will inhibit normal respiratory mechanics (Dahlback et al., 1975, 1978a and 1978b);

B. That task specific factors (i.e. the utilization of upper body musculature) may contribute to the changes in tidal volume and breathing frequency initiated by the water environment (Secher et al., 1977; Toner et al., 1984).

5. It has been hypothesized that the VE/VO2 ratio will be significantly lower during immersion running at maximum effort and at ventilatory threshold. These hypothesis are based upon two assumptions. Those assumptions are:
   A. Oxygen consumption will be equivalent between the two exercise conditions; and
   B. Minute ventilation will be lower during immersion running comparatively to land running.

DELIMITATIONS

1. The sample type (male middle aged runners trained in both land and immersion running).
2. The sample size (22 male subjects).
3. The initially high level of aerobic fitness of the subjects (a maximal oxygen consumption of 60ml*kg*-1min-1 or greater is needed in order to participate in the study). This criteria has been utilized in order to ensure that the subjects are adequately trained in relation to cardiorespiratory fitness.

LIMITATIONS

1. The ability of the subjects to simulate the immersion running motion correctly.

2. The ability of the researcher to ensure that the subject will be able to perform maximally on both tests during the time required.
3. The ability of the immersion running ergometer (IRE) to apply resistance to the subject allowing expression of ventilation threshold and maximal oxygen consumption.
4. The ability of the investigator to accurately extrapolate ventilation threshold from excess CO_2, ventilation, and VE/VO_2.

DEFINITIONS

1. **Maximal oxygen consumption** - the highest oxygen uptake attained during physical work while breathing at sea level.
2. **Ventilation threshold** - Ventilation threshold is the point at which a nonlinear increase in excess CO_2 is detected. Because of potential variability in excess CO_2, VE and VE/VO_2 were utilized secondarily to increase the accuracy of the excess CO_2 parameter. Ventilatory threshold was determined independently by three separate investigators.

   $$\text{Excess } CO_2 = VCO_2 - \text{Resting RQ} * VO_2$$

CHAPTER 2

METHODS AND PROCEDURES

SUBJECTS

Twenty-two male subjects between the ages of eighteen and thirty-one were utilized in this study. All subjects were trained middle distance runners (members of the UBC middle distance high performance unit) familiar with immersion running. These subjects were utilized because immersion running was a regular part of there training program. Subjects were required to have a VO2max of 60 ml*kg*-1min*-1 (treadmill) or higher to participate in the study. All subjects completed a consent form describing the laboratory procedures. Four of the twenty-two subjects volunteered for a follow-up procedure which involved nuclear imaging techniques to assess changes in blood flow distribution. The four subjects completed additional consent forms describing these procedures.

TESTING PROCEDURES

1. Laboratory Measures
    a) Height and weight determinations
2. IR Measures
    a) Maximal O2 consumption test
    b) ECG monitoring to determine heart rate
    c) Beckman Metabolic Cart to measure VO2, ventilation, tidal volume and frequency of breathing

d) Extrapolation of ventilation threshold from excess CO_2, ventilation and VE/VO_2

3. Treadmill Measures

a) Maximal O_2 consumption test

b) ECG monitoring to determine heart rate

c) Beckman Metabolic Cart to measure VO_2, ventilation, tidal volume and frequency of breathing

d) Extrapolation of ventilation threshold from excess CO_2, ventilation and VE/VO_2

4. Blood Flow Distribution Measures (Nuclear Imaging)

a) Two submaximal exercise protocols (immersion vs land)

b) ECG monitoring to determine heart rate

c) Beckman Metabolic Cart to assess VO_2

d) I.V. catheterization of the cephalic vein

e) Injection of TC-99 2 methyloxy isobutyl isonitrile during the exercise protocol.

The subjects were asked to refrain from training on the day of the testing session.

TESTING PROTOCOLS

Cardiorespiratory Testing

A. IR and maximal O_2 consumption test

An immersion running ergometer (IRE) was developed to test maximal O_2 consumption in an aqueous environment. The IRE is box shaped, measuring 2.5 metres high and one metre long and wide. A metal bar was attached lengthwise across the bottom of the IRE. Attached to the top of the IRE and the metal bar was a pulley system creating a one to one advantage. One-half centimetre nylon rope was used throughout the pulley system. A five centimetre flat webbing waist harness attached the subject to the IRE.

Subjects were immersed to the neck in water. The IRE was placed by the side of a pool and 1.5 metres of rope was passively pulled through the pulley system. The subjects were required by correct running motion to pull out an additional 1.5 metres. This action moved the weight attached to the end of the pulley system 1.5 metres. A marker was used to indicate the three metre point.

Subjects were asked to maintain the three metre position throughout the test. The IR protocol used to test maximal oxygen consumption was a continuous model with a progressive load increase every sixty seconds. The initial weight value was set at one kilogram with a load increase of 500 grams every sixty seconds. The test was performed to exhaustion. Exhaustion was determined when the subject could not maintain a position between the 1.5 and 3.0 metre mark. The test protocol was approximately 12 to 14 minutes in length.

Immersion running posture was measured subjectively. Researchers were looking specifically for hip flexion followed by hip and leg extension. Arm action followed a normal running motion. The subjects were asked not to cup their hands.

B. Treadmill running and maximal oxygen consumption test

The treadmill protocol to test maximal O2 consumption was a continuous model with a progressive load increase every sixty seconds. The treadmill run was initiated at 3.08 m*s-1 and increased 0.22 m*s-1 every sixty seconds until exhaustion. Exhaustion was determined when the subject could no longer maintain treadmill velocity. The test protocol was approximately 12 to 14 minutes in length.

C. Gas analysis and anaerobic threshold

Gas analysis was conducted using a second generation Beckman Metabolic Measurement Cart. Minute ventilation, VCO2, VO2, tidal volume and breathing frequency were measured and tabulated every fifteen seconds during treadmill running and every 30 seconds during water immersion running. Ventilation threshold was determined by the break or non-linear increase in excess CO2. VE and VE/VO2 were used secondarily to confirm the threshold break in excess CO2. Three examiners determined ventilation threshold independently. Discrepancies that may occur in ventilatory threshold determination were reviewed by the examiners collectively. The use of "excess CO2" has been studied and validated against other metabolic gas parameters used in the prediction of ventilation threshold (Rhodes et al., 1984).

D. Heart rate determination

A standard ECG machine and electrodes were used to determine heart rate. Three electrodes were used. One electrode was placed on the sternum, the other two electrodes were placed on the left and right sides on the lateral aspects of the fifth intercostal space. The electrodes during the immersion condition were covered with waterproof tape to prevent interference from the water environment.

The immersion running protocol was performed prior to the treadmill protocol. One to three weeks separated the two exercise protocols. Statistical analysis was performed on heart rate, oxygen consumption, minute ventilation and VE/VO2 utilizing a MANOVA model with a repeated measure on the exercise condition (immersion vs treadmill running). Values at ventilatory threshold and at maximal effort were analyzed in separate MANOVAs.

Blood Flow Distribution Testing

Tc-99 2 methyloxy isobutyl isonitrile was utilized in this part of the study to demonstrate changes in blood flow distribution. Isonitrile is a lipophilic compound that binds to the inner and outer membrane of muscle cells. Isonitrile is most commonly used in heart tissue to image ischemia. Recently, investigators have utilized isonitrile to image skeletal muscle tissue (Dhekne et al., 1988). Scientific evidence seems to show that there is a linear relationship between isonitrile uptake and muscle blood flow (Mousa et al., 1987b; Liu et al., 1987).

A. IR protocol

The subject performed the IR protocol at the University of British Columbia Aquatic Center. An I.V. catheter was inserted into the cephalic vein of the right arm. The catheter was secured to the arm with waterproof tape. The catheter line was washed with a dilute Heparin solution. Heart rate and VO2 were monitored by the procedures described above. The subject was secured to the immersion running ergometer as described previously.

Once immersed to the neck, the subject performed IR as previously described. The subject warmed up at a workload of 1.5 kgs for five minutes. At the end of the warmup period, the load was increased to elicit a heart rate (plus or minus 5 bpm) and a VO2 (plus or minus 3 ml*kg*-1min-1) that corresponded with ventilatory threshold (previously determined). The subject maintained this intensity for five minutes. At the end of the five minute period approximately 740 MBq of TC-99 2-methyloxy isobutyl isonitrile was injected and washed into the I.V. catheter with saline solution. Approximately 90 seconds was required for injection of the radiopharmaceutical and 30 ml of saline. The subject continued to exercise at ventilatory threshold for two minutes to allow optimum uptake. At the end of the exercise protocol, the catheter was removed. The subject was then escorted to the Dept. of Nuclear Medicine for imagery. The immersion running protocol was performed approximately one week prior to the treadmill protocol.

B. Treadmill Protocol

An I.V. catheter was inserted into the cephalic vein of the subject. The catheter was secured with waterproof tape. The line was washed with a dilute Heparin solution. Heart rate and VO2 were monitored as previously described.

The subject warmed up at a treadmill velocity of 3.08 m*s-1 for 5 minutes. At the end of the warmup period, the velocity of the treadmill was increased to elicit a heart rate (plus or minus 5 bpm) and a VO2 (plus or minus 3 ml*kg*-1min-1) that corresponded with ventilatory threshold (previously determined). The subject maintained this intensity for 5 minutes. At the end of the five minute period, 740 MBq of Tc-99 2 methyloxy isobutyl isonitrile was injected into the catheter and washed with a saline solution. The subject continued to exercise at ventilatory threshold for 2 minutes post-injection to allow optimum uptake. At the end of exercise protocol, the catheter was removed and the subject was escorted to the Dept. of Nuclear Medicine for body imagery.

C. Imaging Techniques

Imaging was performed utilizing a Seiman Gamma Camera. A signature I.D. of 500 counts per square cm was used. Fifteen views were obtained. They included:

1. Anterior Right and Left Oblique;
2. Posterior Thorax;
3. Anterior and Posterior Abdominal;
4. Anterior Right and Left Thigh;
5. Posterior Right and Left Thigh;
6. Lateral Right Thigh;
7. Anterior Right and Left Leg;
8. Posterior Right and Left Leg; and
9. Lateral Cranium

From the planar images, regions of interest were drawn and analyzed using existing nuclear medicine software. Data obtained from the regions of interest included area (pixels), radiation count, and radiation count per pixel. In order to "semi" quantify the data, two ratios were generated. The first ratio was radiation count (muscle group) divided by radiation count (central brain area). The central brain case was utilized because of consistently low isonitrile uptake. The second ratio was the radiation count (muscle group) divided by total radiation count (whole body) and multiplied by 100%. An example of the total radiation calculation is supplied in Appendix J.

CHAPTER 3

LITERATURE REVIEW

The literature review will be divided into three areas. Those areas are:

1. The cardiovascular system during body immersion;
2. The respiratory system during body immersion;
3. Task specificity and its relationship to cardiorespiratory parameters during dynamic exercise.

Introduction

Early investigations utilized immersion as a medium to counteract gravitational forces (Howard et al., 1967; Graveline et al. 1962; Graybiel et al., 1961; Torphy et al, 1966). The counteraction was useful in the simulation of spaceflight (Howard et al., 1967; Torphy et al., 1966). These reports provided the foundation for future immersion research.

Cardiovascular and respiratory changes during immersion are due to two basic physiological phenomena (Epstein, 1976; Greenleaf, 1984). They are:

1. The hydrostatic compression of the lower limbs causing a redistribution of blood from the leg vascular beds to the thoracic cavity (Epstein, 1976);
2. The hydrostatic compression of the abdominal and thoracic region causing diaphragm lift and relocation

of blood from the abdominal to the thoracic region (Epstein, 1976).

The Cardiovascular System During Body Immersion

A. Cardiac Output:

During resting immersion, cardiac output (C.O.) increases (Arborelius et al., 1972; Begin et al., 1976; Farhi et al., 1977). Arborelius et al. (1972), using a dilution dye technique, demonstrated that resting C.O. rose from 6.0 l/min to 7.7 l/min during immersion. The 32% rise corresponds well with investigations reporting overall increases ranging from 20 to 60 percent (Begin et al., 1976; Farhi et al., 1977). Farhi et al. (1977) concluded that C.O. increased linearly with the depth of immersion.

Two factors that may suppress C.O. increases at rest during immersion are water temperature and measurement reliability. Arborelius et al. (1972), questioned the reliability of the CO_2 rebreathing technique during resting conditions. Correspondingly, McArdle et al. (1976), reported that water temperature below the body's thermoneutral point (approximately 35C) can depress heart rate, ventilation, and VO_2 at rest (McArdle et al., 1976).

B. Heart Rate

Although controversial, heart rate during resting immersion is lower than erect posture on land (Lange et al., 1974; Farhi et al., 1977). This is an area widely debated because of conflicting results (Arborelius et al., 1972; Begin et al., 1976).

Discrepancies in heart rate may be accounted for by differences in water temperature, methodological procedures and reflex mechanisms (Arborelius et al., 1972; Begin et al., 1976; Farhi et al., 1977). As reported earlier, a drop in water temperature may lower heart rate during immersion while invasive physiological techniques may increase heart rate under both an immersion and land condition (Arborelius et al., 1972; Begin et al., 1976).

The influence of reflex mechanisms on heart rate has been discussed by Lin (1988). During immersion, there is an increase in central blood volume and pressure. An increase in these parameters may induce a general tachycardia (Lin, 1988). The induced tachycardia may be countered by a bradycardia response elicited by an increase in stroke volume (Lin, 1988). Changes in the magnitude of either response could also influence heart rate during rest (Lin, 1988).

C. Stroke Volume

A rise in cardiac output during resting immersion may be explained through increases in stroke volume (Arborelius et al., 1972; Lollgen et al., 1981). Recent literature has concentrated on the extent of the rise in stroke volume (S.V.) and how it is affected by a dynamic exercise condition (Greenleaf, 1984; Lin, 1988).

The general increase in S.V. and reduction in heart rate during immersion is initiated by hydrostatic limb compression (Epstein, 1976; Greenleaf, 1984). Hydrostatic limb compression during immersion counteracts the effect of gravity within the columns (arteries and veins) of blood. As the depth of immersion increases, the extent of the hydrostatic compression rises (Lollgen et al. 1981). Arborelius et al. (1972), concluded that during neck immersion the increase in central blood volume was approximately 0.7 l. Lange et al. (1974) estimated the rise in heart volume to be approximately 180ml or 26% of the increase in intrathoracic blood volume. A rise in heart volume should increase end diastolic volume and, therefore, cause an increase in stroke volume (Echt et al., 1974; Poliner et al., 1980).

Stroke volume is a function of four major determinants. Those determinants are:

1. Preload;
2. Afterload;
3. Heart Rate;
4. Inotropic State.

The measurement of these determinates and how they may affect stroke volume during immersion will be discussed in the following paragraphs.

1. **Preload**

Preload can be described as the tension in the ventricular wall at the end of diastole (West, 1984). The tension within the wall will determine the resting fiber length (West, 1984). Preload is most commonly determined through ventricular end diastolic volume, ventricular end diastolic pressure and other hemodynamic parameters.

Measurement of preload can be categorized into three areas. These are:

1. Indirect hemodynamic measurements;
2. Echocardiographic studies; and
3. Radiopharmaceutical studies.

Hemodynamic measurements have been utilized to make indirect inferences on changes in preload and stroke volume during immersion (Farhi et al., 1977; Lollgen et al., 1981; Risch et al., 1978a; Risch et al., 1978b). The most commonly measured hemodynamic parameters are central venous pressure, pulmonary artery pressure, pulmonary wedge pressure, effective compliance, atrial transmural pressure and right atrial pressure (Arborelius et al., 1972; Lollgen et al., 1981; Lange et al., 1974). During immersion, there are increases in central venous pressure (12-17mm Hg) and central blood volume (Arborelius et al., 1972; Echt et al., 1974; Koubenec, 1978; Risch et al., 1978a). Investigators have also reported greater pulmonary artery pressure, pulmonary wedge pressure, and right atrial pressure

(Arborelius et al., 1972; Koubenec, 1978; Lollgen et al., 1981). The measurement of hemodynamic parameters suggests that preload (and potentially stroke volume) is enhanced during immersion (Lollgen et al., 1981).

Sheldahl et al. (1984), using echocardiographic measurements noted increases in end diastolic dimension at rest and at two submaximal exercise conditions during immersion. During upright rest, the average left ventricle dimension was 4.54 cm on land vs. 4.92 cm during neck immersion. At the highest of the two exercise conditions, the upright left ventricle dimension on land was 4.76 cm vs. 5.27 cm during neck immersion (Sheldahl et al., 1984). The rise in left ventricular dimension along with increases in hemodynamic parameters supports the hypothesis of augmented preload and stroke volume during resting immersion (Lollgen et al., 1981; Epstein et al., 1975).

Further studies have been conducted using technetium labelled red blood cells to monitor changes in left ventricular function during varied postural positions and exercise levels. Left ventricular end diastolic pressure (LVedp) and volume (LVedv) rises above normal during supine rest and exercise compared to erect posture (Crawford et al., 1978; Poliner et al., 1980; Thadani et al., 1978). Results from Poliner et al. (1980), suggest that the difference between LVedv at rest (supine vs. upright) to be approximately 22 ml (107 ml vs. 85 ml). Poliner et al. (1980), also reported that LVedv rose progressively during progressive exercise intensities, however, the difference between the supine and upright exercise remained relatively constant (22 ml). Left ventricular end systolic volume (supine) remained constant at 32 ml during low and moderate workloads. Left ventricular end systolic volume (upright) was lower during low and moderate exercise (Crawford et al., 1979; Poliner et al., 1980).

The utilization of radiographic techniques allows direct measurement of S.V. and left ventricular ejection fraction (LVef). Under specific resting and exercise conditions, S.V. in the supine position is greater relative to S.V. in the upright position (Bevegard et al., 1960; Crawford et al. 1979; Weiss et al. 1979). This is in agreement with the measurement of LVedv and LVesv cited above (Poliner et al. 1980). Thadani et al. (1978) and Crawford et al. (1979) concluded that the increase in measured stroke volume at rest and exercise (supine vs. upright) was due to the rise in LVedv. Poliner et al. (1980), reported smaller changes in LVef from rest to higher exercise intensities during a supine position. Poliner et al. (1980), concluded that left ventricular response to exercise, irrespective of the position, includes a combination of a Frank-Starling mechanism and an increase in contractile state, however, changes in contractile state are of greater relative importance in the upright rather than in the supine position.

2. Afterload

Afterload can be described as the tension developed by the fibres of the ventricular wall (West, 1984). Two measures of afterload are systolic aortic pressure and systolic left ventricular pressure (West, 1984). Under experimental conditions, if preload is constant and aortic pressure is gradually increased, a steady decrease in stroke volume and peak ejection velocity should occur (West, 1984).

There is a lack of investigation evaluating systolic aortic pressure and systolic left ventricular pressure during immersion. However, some indirect evidence may warrant attention. Sheldahl et al. (1984), reported increases in end diastolic and systolic dimension during immersion under resting and exercise conditions. From these results Sheldahl et al. (1984), calculated ventricular shortening. It was concluded that during immersion, ventricular shortening was lower at rest and during exercise and that changes may be accounted for by an increase in afterload or a decrease in myocardial contractility (Sheldahl et al., 1984). Investigations reporting decreases in the systolic blood pressure to end systolic dimension ratio, systolic pressure, and systemic vascular resistance suggests that afterload is not increased during immersion (Epstein et al., 1975; Greenleaf, 1984). Further investigations are needed.

3. Inotrophic State

The inotrophic state refers to the contractility of the heart (West, 1984). Under experimental conditions, a positive inotrophic state will induce a rise in stroke volume and peak ejection velocity (West, 1984). The relationship between neck immersion and the inotrophic state remains unclear. More investigations are needed.

4. Heart Rate

Although controversial, it may be stated that during immersion, exercise and resting heart rate remains depressed (Dressendorfer et al., 1976; Sheldahl et al., 1984) This depression influences stroke volume in a two folded manner (particularly during exercise). At high exercise intensities a depressed heart rate may enhance stroke volume by allowing a greater ventricular filling time. However, the heart rate depression may also inhibit the increase in stroke volume through a force frequency relationship (West, 1984). Hemodynamic, echocardiographic, and radiopharmaceutical studies suggest that the latter plays a minor role in stroke volume regulation (Arborelius et al., 1972; Poliner et al., 1980).

The Respiratory System During Immersion

Evaluating the effects of static and dynamic immersion on the respiratory system can be divided into two categories:

A. Lung volumes and the factors influencing those volumes; and

B. Pulmonary gas exchange in respect to ventilation, diffusion and perfusion.

A. Lung Volumes

1. Vital Capacity

Vital Capacity (VC) decreases between 1.9% and 8% during neck immersion (Hong et al., 1969; Agonstoni et al., 1966; Dahlback et al., 1975; Dahlback et al., 1979a). The decrease in VC is due to increased central thoracic blood volume (Dahlback et al., 1978a; Dahlback et al., 1978b). Using radiographic techniques, Risch et al. (1978a & 1978b) correlated the rise in lung blood volume with decreases in VC.

2. Total Lung Capacity and Residual Volume

During thorax immersion (which entails the immersion of the chest and abdominal region without the upper and lower limbs), total lung volume (TLC) significantly decreases (Bondi et al 1976; Dahlback et al., 1975; Dahlback et al., 1978a). The decrease in TLC correlates with a lower residual volume (decrease in TLC = .31 L, decrease in RV = .25 L). Dahlback et al. (1978a), concluded that thorax immersion inhibited inspiration as much as it enhanced expiration (Dahlback et al., 1978a and 1978b). Changes in TLC and RV during thorax immersion are due to hydrostatic chest compression.

During neck immersion (immersion including the upper and lower limbs), TLC dropped .44 L (Dahlback et al., 1978a and 1978b). The decrease was not countered by a corresponding decrease in RV (RV rose .06 L). Investigators concluded that the decrease in TLC was due to the space competition between alveolar gas and redistributed blood (Dahlback et al., 1978a; and 1978b).

3. Functional Residual Capacity

Dahlback et al. (1978b), reported decreases in functional residual capacity (FRC) during thorax immersion. The investigators were, however, unable to demonstrate decreases in FRC during neck immersion. Increases in thoracic blood volume may enlarge pulmonary capillaries contributing to lung stiffening. Decreases in lung compliance and lung recoil during immersion confirm the hypothesis of lung stiffening (Agonstoni et al., 1966; Blomquist et al., 1983; Hong et al., 1969).

4. Lung Recoil

Lung recoil pressure at TLC decreases from -42 cm of H2O during nonimmersion to -25 cm of H2O during neck immersion (Dahlback et al., 1978a and 1978b). High lung recoil pressures correlate positively with high inspiratory and total lung capacities (West, 1984).

5. Lung Compliance

Lung compliance expresses the relationship between lung volume and lung pressure (West, 1984). During immersion, the pressure volume relationship will change (Agonstoni et al., 1966; Hong et al., 1969). Lung compliance during immersion decreases from .39 cm of H2O (land) to .27 cm of H2O (Dahlback et al., 1978b). Lung compliance is reduced because of hydrostatic thoracic compression and blood redistribution (Dahlback et al., 1978b).

5. Trapped Air and Closing Lung Volume

Under experimental conditions (controlling end expiratory and tidal volume), the volume of trapped air (Vtr) during immersion increased 2.5 L (Dahlback et al., 1975). Dahlback et al. (1975) concluded that decreases in Vtr were due to a rise in hydrostatic chest compression and intrathoracic blood volume (Dahlback et al. 1975). The increase in Vtr could be the result of either premature airway closure or lung stiffening. A further investigation has demonstrated that premature airway closure does occur during immersion (Bondi et al., 1976).

B. Pulmonary Gas Exchange: Ventilation, Perfusion and Diffusion

Pulmonary gas exchange is a coordinated relationship between lung ventilation, lung perfusion, and pulmonary diffusion. Risch et al. (1978a & 1978b) documented increases in thoracic blood volume during immersion. Risch et al. (1978a & 1978b) concluded that the change in thoracic blood volume resulted in an increase in height, width and area of blood perfusion. Similar changes have been documented by other researchers (Prefaut et al., 1978). Changes in blood perfusion led to a greater lung perfusion homogeneity (Risch et al., 1978a; Risch et al., 1978b; Prefaut et al., 1978). Risch et al (1978b), hypothesized that it was the opening of apical channels that lead to the perfusion homogeneity during immersion. The opening of apical lung channels also occurs during exercise (Risch et al., 1978a and 1978b). Rises in perfusion homogeneity was accompanied by an increase in right atrial pressure, pulmonary arterial pressure, pulmonary wedge pressure and cardiac output (Risch et al., 1978a and 1978b).

Prefaut et al., (1980) reported an inversion of blood perfusion in some subjects during immersion. Prefaut et al. (1980) hypothesized that an inversion of blood perfusion may occur if there was an increase in pulmonary vascular resistance at the base of the lung. It was suggested that an increase in pulmonary vascular resistance was feasible because of the interaction of three mechanisms. Those mechanisms were:

1. A decrease in lung volumes;
2. Hypoxic vasoconstriction; and
3. Increases in alveolar pressure.

Changes in PaO2 and PaCO2 occur during immersion (Lollgen et al., 1976; Cohen et al., 1971). A drop in the PaO2 (9mm Hg), an increase in (A-a)DO2 difference (16mm Hg) and in PaCO2 (2 mm Hg) were reported during resting immersion (Cohen et al., 1971; Lollgen et al., 1976). These changes may occur because of alterations in ventilation and diffusion. More specifically, these changes were attributed to:

1. A decrease in the pulmonary diffusion constant. Guyatt et al. (1965) and Hyde et al. (1971), demonstrated decreases in carbon monoxide diffusion capacity during immersion;
2. A smaller diffusion area. Lollgen et al. (1976) hypothesized that during immersion, diffusion area may decrease due to a rise in intrathoracic blood volume and hydrostatic compression of the chest. Lower lung volumes during immersion substantiate this argument (Dahlback et al.,1978a; Dahlback et al., 1978b); and
3. Changes in lung ventilation. Cohen et al. (1971) suggested that changes in lung ventilation during resting immersion were minimal and that this factor plays a minor role in blood gas changes.

Task Specificity and its Relationship to Cardiorespiratory Parameters

A. Oxygen Consumption

1. Task Specificity

Oxygen consumption and its relationship to exercise specificity has been studied intensely (Gergley et al., 1984; Matsui et al., 1978; McArdle et al., 1972; Secher et al., 1977; Withers et al., 1981). Early studies compared the relationship between treadmill and bicycle oxygen consumption (McArdle et al., 1972; Roberts et al., 1972; Withers et al., 1981). It was concluded that:

1. The physiological responses to exercise are significantly influenced by the quantity of active musculature (Gergley et al., 1984);
2. The training state of a muscle group has a relatively high degree of specificity in relation to oxygen consumption (Gergley et al., 1984). Subjects elicit higher oxygen consumption rates on work modalities that utilized trained musculature (Withers et al., 1981);
3. Muscle recruitment patterns. Trained subjects will register higher VO2max values on work modalities that generated familiar recruitment patterns (Withers et al., 1981; McArdle et al., 1971); and
4. Differences in the type of muscle contractions between the two activities may significantly affect overall blood flow and oxygen consumption (Davies et al., 1972; Eiken et al., 1987; Gergley et al., 1984; Matsui et al., 1978). Running is a ballistic movement with short contraction phases involving concentric and eccentric motions (Gergley et al., 1984; Matsui et al., 1978).

Cycling is a slower movement comprised on concentric motions (Gergley et al., 1984; Matsui et al., 1978). A number of investigators have suggested that at equivalent workloads concentric work require a larger recruitment of muscle fibres comparatively to eccentric work (Abbott et al., 1952; Davies et al., 1972). As the amount of recruited muscle fibres is increased, rises in systolic arterial and tissue pressure will occur resulting in lower blood flow to active musculature (Eiken et al., 1987). Therefore, maximal oxygen consumption during cycling activity (concentric work) may be lower comparatively to treadmill running (concentric and eccentric work) because of a decrease in muscle blood flow elicited by changes in the type of muscle contraction (Gergley et al., 1984; Matsui et al., 1978).

The central and peripheral responses to combined exercise have been investigated (Secher et al., 1977; Secher et al., 1974; Toner et al., 1983). VO2max (arm and leg exercise) can vary considerably, relative to normal leg exercise (Secher et al., 1977; Secher et al., 1974; Toner et al., 1983). Secher et al. (1977) concluded that the fluctuations may be accounted for by the percentage of work performed by the upper body. Secher et al. (1977), noticed that a decrease in VO2max (compared to leg exercise alone) was most pronounced when the upper body performed more than 40% of the total exercise load (as measured by VO2). Secher et al. (1977), Toner et al. (1983), and Clausen et al. (1976) have attributed the decrease in VO2max to:

1. A decrease in blood flow to slow twitch (ST) musculature;
2. An increase in blood flow to fast twitch (FT) musculature; and
3. Changes in vascular resistance;

A number of investigations have compared oxygen consumption during upper and lower body exercise (Dixon et al., 1971;Gergley et al., 1984; McArdle et al., 1978; McArdle et al., 1971; Secher et al., 1974). It has been concluded that VO2max was significantly lower during upper body exercise (Dixon et al., 1971; Gergley et al., 1984; McArdle et al., 1971). This reduction was due to the following:

1. A significant decrease in the quantity of active musculature (Gergley et al., 1984); and
2. Inadequate blood flow to upper body musculature (Clausen et al., 1976; McArdle et al., 1971). The combination of inadequate blood flow and a smaller atrio-ventricular (a-v) O2 difference leads to lower VO2max and an increase in anaerobic metabolism (Clausen et al., 1976; Klausen et al., 1974).

2. **Immersion Exercise**

There have been a number of studies investigating cardiovascular changes during immersion exercise (Avellini et al., 1983; Dressendorfer et al., 1976; Denison et al., 1972; Sheldahl et al., 1984; Sheldahl et al., 1986). It may be concluded from these studies that:

1. VO2max was not compromised by a water environment (Denison et al., 1972; Dressendorfer et al. 1976; Moore et al., 1970; Sheldahl et al., 1983). Similar VO2max values were obtained during immersion despite a drop in maximal heart rate (approximately 10 bpm) (Denison et al., 1972; Dressendorfer et al., 1976);
2. At a given submaximal VO2, heart rate was significantly less during immersion (Denison et al., 1972; Sheldahl et al., 1983). A lower heart rate is accompanied by a rise in stroke volume (Sheldahl et al., 1983)
3. The cephalad shift in blood volume with water immersion does not alter normal cardiovascular adaptation to exercise training (Avellini et al., 1983; Sheldahl et al., 1986);
4. Water temperature below the thermoneutral point (33 degrees celsius) may cause increases in submaximal VO2 (McArdle et al., 1976). McArdle et al. (1976), recorded a 9.0% increase in submaximal VO2 when water temperature was dropped from 33 to 27 degrees celsius.

B. Ventilation, Breathing Frequency and Tidal Volume

1. Ventilation

Changes in ventilation, frequency and tidal volume may be attributed to a number of factors. They include:

1. Changes in the surrounding environment (Dressendorfer et al., 1976). Hydrostatic chest compression, thoracic blood volume and water temperature may contribute to a decrease in ventilation. A number of investigators, however, have reported no significant changes in ventilation at submaximal and maximal immersion exercise (Denison et al., 1972; Moore et al., 1970; McArdle et al., 1976);
2. The training state of a specific muscle (Gergley et al., 1984; Withers et al., 1981). Reductions in ventilation are greatest when a task uses previously trained muscles. Withers et al., (1981), consistently found that trained runners and cyclists ventilated higher on the modalities that they were unfamiliar with; and
3. The involvement of upper body musculature in exercise. Dixon et al. (1971) noted significant decreases in ventilation during swimming. The decrease in ventilation was attributed to arm and intercostal activity. McArdle et al. (1978) drew similar conclusions. A decrease in minute ventilation has also

been reported during maximal arm cranking (Secher et al., 1977; Secher et al., 1974; Toner et al., 1984).

2. Tidal Volume and Breathing Frequency

Changes in tidal volume and breathing frequency have been reported by a number of investigators (Denison et al., 1972; Holmer et al.,1974; Hermansen et al., 1969; McArdle et al., 1970; McArdle et al., 1971). These changes have been attributed to:

1. The surrounding environment (Dressendorfer et al., 1976; Holmer et al., 1974; McArdle et al., 1971). During immersion, tidal volume may decrease and breathing frequency increase because of hydrostatic chest compression and an increase in intrathoracic blood volume; and
2. The exercise modality (McArdle et al., 1971; Secher et al., 1977; Toner et al., 1984). Exercise modalities which require considerable recruitment of upper body musculature may inhibit normal respiration mechanics (Secher et al., 1977; Toner et al., 1984).

C. Heart Rate

1. Immersion Exercise

Heart rate at submaximal and maximal exercise remains significantly lower during immersion (Krasney et al., 1984; Moore et al., 1970; Sheldahl et al., 1983). The reduction in submaximal heart rate has been attributed to:

1. The rise in intrathoracic blood volume which, as explained earlier in the cardiovascular section, causes an increase in preload and myocardial contractility. This in turn increases stroke volume (Arborelius et al., 1972).

2. Task Specificity

Submaximal heart rate is significantly affected by a number of task specific factors (Clausen et al., 1973; Homer et al., 1974; McArdle et al., 1976; McArdle et al., 1977; Toner et al., 1974). They include:

1. The training state of the muscle group (Clausen et al., 1973; Withers et al., 1981). Clausen et al. (1973) reported that submaximal heart rate dropped significantly after training a specific muscle group; and
2. The quantity and type of musculature recruited (Gergley et al., 1984). Submaximal heart rate was significantly higher (at a given VO2) during arm exercise as compared to leg exercise (Clausen et al. 1973; Gergley et al., 1984).

Maximal heart rate seems to be robust to changes in exercise modality and task specificity (Clausen et al., 1973; Toner et al., 1984).

CHAPTER 4

RESULTS

Twenty-two male middle distance runners completed the two testing protocols. Four subjects did not meet the minimum criteria of 60 ml*kg*-1min-1 (treadmill) and were subsequently removed from the study. Two additional subjects were removed because of poor immersion running technique. The mean age, height and weight of the remaining 16 subjects was 22.5 yrs ± 4.2, 180.1 cms ± 6.0, and 69.8 kgs ± 5.5 respectively.

	Height (cm)	Weight (kg)	Age (yrs)
mean	180.1	69.8	22.5
St. Dev.	6.0	5.5	4.2

Table 1: Descriptive data for 16 male middle distance runners.

The cardiorespiratory parameters measured at ventilatory threshold are outlined in Table 2. The multivariate P recorded for all factors within the exercise condition was less than 0.01. Consequently, this was significant at the preset P level of less than .05. Univariate significance was demonstrated ($P < .05$) between exercise conditions (immersion vs. treadmill) for heart rate and oxygen consumption. Heart rates (HR) during immersion and land conditions were 165.9 and 177.5 bpm. Oxygen consumption (VO2) was 51.8 and 56.8 ml*kg*-1min-1 for the immersion and land protocols.

	Mean	St.Dev.	P
HRvt (immersion)	165.9 bpm	10.1	< 0.01
HRvt (treadmill)	177.5 bpm	7.4	
VEvt (immersion)	83.9 l*min-1	8.5	< 0.07
VEvt (treadmill)	88.7 l*min-1	9.4	
VE/VO2vt (immersion)	1.61	0.18	< 0.07
VE/VO2vt (treadmill)	1.55	0.15	
VO2vt (immersion)	51.8 ml*kg*-1min-1	4.5	< 0.01
VO2vt (treadmill)	56.8 ml*kg*-1min-1	3.6	

Table 2: Cardiorespiratory parameters collected at ventilatory threshold(vt) during immersion running and treadmill running. Values are normalized at STPD. N=16

The cardiorespiratory parameters measured at maximal effort are outlined in Table 3. The multivariate P recorded for all factors within the exercise condition was less than .01. Correspondingly, the multivariate P was significant at a preset level of .05. Univariate significance (P < .05) was demonstrated for heart rate, oxygen consumption and VE/VO2. Heart rates (HR) during immersion and land conditions were 182.4 and 194.1 bpm respectively. Oxygen consumption (VO2) was 62.6 and 66.3 ml*kg*-1min-1 for the immersion and land protocols.

	Mean	St.Dev.	P
HRmax(immersion)	182.4 bpm	8.2	< 0.01
HRmax(treadmill)	194.1 bpm	11.0	
VEmax(immersion)	124.1 l*min-1	11.3	< 0.42
VEmax(treadmill)	122.0 l*min-1	8.8	
VE/VO2max(immersion)	2.01	0.19	< 0.01
VE/VO2max(treadmill)	1.88	0.15	
VO2max(immersion)	62.6 ml*kg*-1min-1	3.9	< 0.01
VO2max(treadmill)	66.3 ml*kg*-1min-1	4.0	

Table 3: Cardiorespiratory parameters collected at maximal effort(max) during immersion running and treadmill running. Values were normalized to STPD. N=16

Ventilation and frequency of breathing measurements were measured for four subjects under both an immersion and land conditions. The cardiorespiratory parameters measured for the four subjects were also used as part of the data in Tables Two and Three. Methodological problems (i.e. the computer integration with the data acquisition system) prevented the collection of frequency measurements for the remaining 12 subjects. Tidal volume was calculated, dividing ventilation by breathing frequency. Table 4 contains these parameters as measured at ventilatory threshold. Table 5 contains similar parameters measured at maximal effort.

The mean ventilation at ventilatory threshold during immersion and land conditions was 81.8 and 84.5 l*min-1 respectively. The breathing frequency at ventilatory threshold was 37.9 and 37.1 br*min-1 during immersion and land running respectively. The calculated tidal volumes were 2.17 litres and 2.28 litres were for immersion and land running at ventilatory threshold.

	Ventilation(vt)		Frequency(vt)		Tidal Volume(vt)	
	IR	Treadmill	IR	Treadmill	IR	Treadmill
	(l*min-1)		(br*min-1)		(l)	
Mean	81.8	87.4	37.9	37.1	2.17	2.28
S.D.	7.4	11.2	5.3	5.6	0.17	0.23

Table 4: Mean values for four subjects at ventilation threshold(vt) during immersion running(IR) and treadmill running. Values were normalized to STPD.

The mean ventilation at maximal effort during immersion and land conditions were 126.6 and 123.5 l*min-1 respectively. The frequency of breathing at maximal effort was 54.6 and 48.7 br*min-1 during immersion and land running respectively. The calculated tidal volumes for immersion and treadmill running at maximal effort were 2.32 litres and 2.56 litres.

	Ventilation(max) (l*min-1)		Frequency(max) (br*min-1)		Tidal Volume(max) (l)	
	IR	Treadmill	IR	Treadmill	IR	Treadmill
Mean	126.6	123.5	54.6	48.7	2.32	2.56
St.Dev.	6.0	5.0	3.1	1.3	0.08	0.15

Table 5: Mean values for four subjects at maximal effort(max) during immersion running and treadmill running. Values were normalized to STPD.

An experimental technique utilizing Tc-99 2-methyloxy isobutyl isonitrile was incorporated to attempt to monitor changes in blood flow distribution during immersion and treadmill running at ventilation threshold. Appendices E, F, G, H, and I contain data referring to the regional uptake of isonitrile. Because of problems with the methodological procedures data could only be collected for two subjects. In subject one there was a lower uptake of isonitrile in the anterior thigh, posterior thigh, anterior calf and posterior calf during immersion running at ventilatory threshold. In subject two, an increased uptake of isonitrile was measured in the anterior and posterior thigh during immersion running. A lower uptake of isonitrile was measured in the posterior gluteal region, anterior calf and posterior calf. It can be postulated from the data, that uptake (and potentially blood flow) changed from region to region depending on the exercise condition. Because this was an experimental procedure with a small number of subjects, direct inferences from the isonitrile data to explain changes in cardiorespiratory parameters will not be possible.

Hypothesis Verification

	Hypothesis	Accept or Reject
1.	VO2maxW = VO2maxT	Reject
2.	VO2vtW = VO2vtT	Reject
3.	HRmaxW < HRmaxT	Accept
4.	HRvtW < HRvtT	Accept
5.	VEmaxW < VEmaxT	Reject
6.	VEvtW < VEvtT	Reject
7.	VE/VO2maxW < VE/VO2maxT	Reject
8.	VE/VO2vtW < VE/VO2vtT	Reject

DISCUSSION

A. Oxygen Consumption:

VO2max and VO2vt were significantly lower during immersion running comparatively to treadmill running. This study appears to be the first to attempt to measure oxygen consumption during immersion running and, therefore, comparative data from other investigations is not available.

It was initially hypothesized that oxygen consumption at maximal effort and at ventilatory threshold would be equivalent under an immersion and treadmill running condition. The results of this study are contrary to the initial hypothesis.

The lower oxygen consumption values recorded during IR may be explained by the influence of a water environment and/or changes in task specificity. Because the initial purpose of this study was to record basic physiological data comparing the two exercise conditions, the scientific measurement of water environmental and task specific factors was not pursued. The VO2 values measured in this study did, however, allow researchers to develop a theoretical model whereby water environmental and task specific factors may be discussed in relationship to oxygen consumption. The section to follow will express this theoretical model. At the conclusion of the model, the effects of water temperature on oxygen consumption will be discussed.

1. The Water Environment

It could be theoretically hypothesized that the significantly lower oxygen consumption values recorded during immersion running may be the result of a water environment impairing the normal relationship between alveolar ventilation and perfusion. Such a hypothesis can be based on research suggesting altered respiratory and perfusion parameters at rest (Cohen et al., 1971; Risch et al., 1978a + 1978b). In response to this hypothesis, however, investigations studying the specific relationship between oxygen consumption and a water environment during cycling have concluded that oxygen consumption was not significantly affected even though there were changes in static respiratory parameters (Dressendorfer et al., 1976; Denison et al., 1972; Sheldahl et al., 1984). Because the immersion condition in this study was identical to those reported in the cycling studies, it seems unlikely that the theoretical model proposed initially is responsible for the reduction in oxygen consumption during immersion running.

2. Task Specificity

Hypothetically, if the reduction in oxygen consumption can not be attributed to the water environment, it should be attributed to changes in task specificity. Task specificity is a function of five factors. Those factors are:

a. Total muscle mass recruitment (Gergley et al., 1984);

b. Type of muscle mass recruited (Secher et al., 1974);

c. The familiarity with recruitment pattern (Secher et al., 1974);

d. The type of muscular contractions (Gergley et al., 1984); and

d. The state of the muscular adaptation (Withers et al., 1981).

Theoretically, any one or a combination of these factors may have contributed in lowering oxygen consumption during immersion running.

a) Muscle Mass Recruitment

Maximal oxygen consumption is a function of muscle mass (Astrand, 1977; Gergley et al. 1984.; McArdle et al., 1971). As the amount of recruited muscle mass is elevated, an increase in VO2max will usually occur (Astrand, 1977; McArdle et al., 1971). Correspondingly, any decrease in oxygen consumption may be the result of a smaller recruited muscle mass (Astrand, 1977; McArdle et al., 1971).

It may be hypothesized that the reduction in oxygen consumption during immersion running may be due to a decrease in the recruited muscle mass. It was hoped that the isonitrile data collected in this study would help to measure the amount of recruited muscle mass. Unfortunately, because of the small number of subjects and the conflicting results, it is not possible to make accurate inferences in relation to the quantity of recruited muscle mass.

b) Muscle Fibre Type

Muscle fibre type can affect VO2 at submaximal and maximal exercise (Dixon et al., 1971; McArdle et al., 1971; Secher et al., 1974). This was illustrated by Secher et al. (1977), who utilized an exercise protocol that varied the contribution of upper and lower body musculature to overall VO2max. Secher et al. (1977), concluded that VO2max was significantly lower when an exercise protocol required 40% of the total power output to be generated by the upper body. It was suggested that the lower VO2max was due to blood shunting from slow to fast twitch fibres (Secher et al., 1977).

It may be theorized from the information cited in the previous paragraph, that a decrease in VO2max during immersion running may be due to the shunting of blood from the O2 efficient lower extremities to the O2 inefficient upper extremities. It was hoped that the data from subjects injected with isonitrile would clarify this factor in relation to oxygen consumption.

c) The Familiarity With Motor Recruitment Pattern

Exercise recruitment patterns may significantly affect oxygen consumption at submaximal and maximal intensities (Gergley et al., 1984; Dixon et al., 1971; Avellini et al., 1983). McArdle et al. (1978) reported that VO2max in trained swimmers was comparable between a treadmill run and a tethered swim. It was suggested that although less muscle mass was recruited during swimming (which should promote a decrease in VO2max as previously cited), that local muscular adaptation and the familiarity with motor recruitment patterns (of the swimmers) may counteract any decrease resulting in a non-significant change.

It may be theorized from the cited literature, that a decrease in VO2max and VO2vt during immersion running may be due to unfamiliar motor recruitment patterns. Although the subjects were acquainted with immersion running in this study, it may be hypothesized that their degree of familiarity was lower comparatively to treadmill running.

d) The Type of Muscular Contraction

As stated in the literature review, activities such as cycling may elicit a lower oxygen consumption (comparatively to treadmill running) at maximal effort because of arterial occlusion (Gergley et al., 1984; Matsui et al., 1978). Matsui et al. (1978), suggested that arterial occlusion was more likely to occur during cycling (comparatively to treadmill running) because it was predominately concentric in nature. It may be suggested that immersion running is similar to cycling in that it is predominately concentric. Correspondingly, it may be hypothesized that a decrease in oxygen consumption at maximal effort and at ventilatory threshold during immersion running may be due to blood flow restriction elicited by strong concentric contractions. Concentric contractions are more likely to restrict blood flow because a greater recruitment of muscle fibres (i.e. force generation) are required for a given work output comparatively to eccentric contractions (Abbott et al., 1952; Eiken et al., 1987).

e) The State of Muscular Adaptation

Trained musculature may elicit higher oxygen consumption values than untrained musculature (Klausen et al., 1974; Withers et al., 1981; Davis et al., 1984). Withers et al. (1981), demonstrated a positive relationship between oxygen consumption and muscular adaptation. They concluded that cyclists and runners elicited a greater oxygen consumption value on exercise modalities which utilized trained musculature (Withers et al., 1981). It may be theorized from the cited literature that a decrease in VO2max and VO2vt during immersion running may be due to differences in muscular adaptation (i.e. lower adaptation within immersion running musculature).

3. Water Temperature

A drop in water temperature below the thermoneutral point can increase oxygen consumption at a given exercise intensity.

McArdle et al. (1976), observed a 9.0% increase in submaximal VO2 when water temperature was dropped from 33 degree to 27 degrees celsius. The average water temperature during this study was between 29 and 30 degrees. This is below the thermoneutral point and theoretically may result in a slight elevation of oxygen consumption at maximal effort and at ventilatory threshold. If such a mechanism did occur during this study, it may be hypothesized that the effects of the water temperature were minimal in comparison to the changes in task specificity

B. Ventilation, Breathing Frequency, Tidal Volume, and VE/VO2.

Ventilation

Minute ventilation at maximal effort and at the ventilatory threshold did not significantly change between the two exercise conditions. As stated earlier, this study seems to be the first to attempt to measure cardiorespiratory parameters during immersion running and, therefore, comparative data is unavailable.

The non-significant changes in VEmax and VEvt during immersion running suggests that neither the water environment nor changes in task specificity significantly affected minute ventilation. The results reported in this study are contrary to the initial hypothesis.

1. **Water Environment**

It was initially hypothesized that minute ventilation would be lower during immersion running. This hypothesis was based partially upon the assumption that the water environment would increase intrathoracic blood volume and hydrostatic chest compression, resulting in restricted respiratory mechanics. A number of investigations have reported inhibited respiratory mechanics during resting immersion (Dahlback et al., 1975; 1978a and 1978b).

Contrary to resting immersion studies, exercise studies have concluded that although resting respiratory mechanics were affected by water immersion, minute ventilation did not significantly change. (Dressendorfer et al., 1976; Denison et al., 1972; Sheldahl et al., 1976). Therefore, it may be theorized (after the fact) that the non-significant change in minute ventilation during immersion running (at maximal effort and at ventilatory threshold) is in agreement with exercise immersion studies (Dressendorfer et al., 1976; Denison et al., 1972).

2. **Task Specificity**

It was initially hypothesized that task specific factors (i.e. utilization of upper body musculature) during immersion running would contribute to a lower minute ventilation. This hypothesis is contrary to the reported results in this study.

Minute ventilation is a function of two task specific factors. Those factors are:

a. The involvement of large quantities of upper body musculature; and

b. The training state of recruited musculature.

a) The Involvement of Large Quantities of Upper Body Musculature

The involvement of large quantities of upper body musculature during exercise may significantly lower submaximal and maximal ventilation. These decreases are most noticeable in activities including swimming and arm cranking (Dixon et al., 1971; Toner et al., 1984; Secher et al., 1977). Toner et al. (1984) suggested lower ventilation during exercise was due to the inhibition of normal respiratory mechanics. It may be theorized from the cited literature that the non-significant change in minute ventilation during treadmill and immersion running reflects the minor role of upper body muscle recruitment (immersion running) on this parameter.

b) The Training State of Recruited Musculature

Investigators have concluded that significant changes in minute ventilation may occur on exercise modalities that utilize musculature with varying degrees of peripheral adaptation. This was illustrated by Withers et al. (1981) who consistently found that trained runners and cyclists ventilated higher on modalities not specific to their muscular adaptation. It was theorized earlier in the discussion (in relation to oxygen consumption), that the level of adaptation within recruited immersion running musculature was lower comparatively to treadmill musculature. Taking into consideration this statement, it may be hypothesized that discrepancies in muscular adaptation could promote a rise in minute ventilation during immersion running. These increases are contrary to the recorded results of this study and, therefore, it may be hypothetically concluded within this section that either:

1. The water environment, the recruitment of upper body musculature (specific to immersion running) and the training state of recruited musculature had no effect on minute ventilation; or
2. The potential decrease in minute ventilation attributed to the water environment and to upper body muscle recruitment are counteracted by the potential increases in minute ventilation due to the training state of recruited musculature.

Tidal Volume and Breathing Frequency

Ventilation is a function of tidal volume and breathing frequency. There was a trend towards a smaller tidal volume and higher breathing frequency at VO2vt and VO2max during IR. This is in agreement with the initial hypothesis that stated that changes in tidal volume and breathing frequency would be due to a water environment and to task specific factors. The section to follow will develop a theoretical model to explain the lower tidal volumes and higher breathing frequencies reported during immersion running.

1. The Water Environment

It may be suggested that the lower tidal volumes and higher breathing frequencies during immersion running were due to water immersion. It could be hypothesized that the increase in intrathoracic blood volume and hydrostatic chest compression may increase a subject's effort to breathe at normal lung volumes (Dahlback et al., 1978a and 1978b). This hypothesis is supported by Dressendorfer et al. (1976), who reported greater breathing frequencies and lower tidal volumes during submaximal and maximal immersion cycling.

2. Task Specificity

Exercise activities which involve a large proportion of upper body musculature may limit tidal volume (McArdle et al., 1971; Toner et al., 1984; Secher et al., 1977). Toner et al. (1984), concluded that arm cranking at submaximal workloads reduced tidal volume because upper body recruitment interfered with normal respiratory mechanics. It may be hypothesized that a higher breathing frequency and a lower tidal volume during immersion running may be partially due to an increased utilization of upper body musculature. When considering this hypothetical model, it should be noted that minute ventilation like tidal volume can be altered by utilization of upper body musculature. However, as reported earlier, the non-significant change in minute ventilation may suggest that the recruitment of upper body musculature may be a minor factor in the determination of ventilation levels. Therefore, a similar relationship may exist for tidal volume regulation.

VE/VO2

A significant increase in the VE/VO2 ratio was reported at maximal effort during immersion running. A small increase in the VE/VO2 ratio was reported at ventilation threshold, however, this increase was non-significant. The increase in VE/VO2 at maximal effort was primarily the result of a lower VO2 at maximal effort. This seems to be the first exercise immersion study reporting the VE/VO2 ratio.

C. Heart Rate

A significantly lower heart rate at ventilation threshold and at maximal effort occurred during immersion running. This is in agreement with the initial hypothesis stating that the water environment would increases intrathoracic blood volume. The discussion to follow will be used to develop a theoretical model around which a lower immersion heart rate can be fully explained. At the conclusion of this section, the effects of water temperature on heart rate will be considered.

1. The Water Environment

A number of investigators have reported lower submaximal and maximal heart rates during exercise immersion (Krasney et al., 1984; Dressendorfer et al., 1976; Sheldahl et al., 1983). Krasney et al. (1984) attributed the changes to a greater intrathoracic blood volume, which may in turn enhance preload and stroke volume. It may be theorized that the reduction in heart rate during immersion running at maximal effort and at ventilatory threshold is due to a greater intrathoracic blood volume.

2. Task Specificity

Theoretically, two task specific factors can affect submaximal heart rate. They included:

a. The training state of the recruited musculature; and

b. The quantity and type of musculature recruited.

a) The Training State of the Recruited Musculature

Heart rate at submaximal intensities are significantly lower when exercise modalities utilize trained musculature (Clausen et al., 1973; Withers et al., 1981). This is best illustrated by Withers et al. (1981), who concluded that heart rate at the ventilatory threshold was lower on modalities which utilized previously trained musculature. Theoretically, if such a model did exist during immersion running, one may expect a slight increase in submaximal heart rate. This model is based on the assumption that the training state of recruited immersion musculature is lower comparatively to treadmill musculature. Such a mechanism would be contrary to results obtained in this study.

b) The Quantity and Type of Musculature Recruited

The utilization of large quantities of upper body musculature at submaximal workloads (i.e. swimming and arm ergometer) can elicit a higher heart rate than lower body musculature (Clausen et al., 1973; McArdle et al., 1971). Secher et al. (1977), concluded that in untrained males, increases in submaximal heart were significant when 40% or more of the total power output was generated by the upper body (comparatively to 100% leg exercise). It may be hypothesized from the cited literature that this factor may increase submaximal heart rate (at ventilatory threshold) during immersion running. This hypothesis is based upon the assumption that the quantity of upper body musculature recruited during immersion running is large enough to elicit the described response. Such a model is contrary to the results recorded in this study.

It should be noted that maximal heart rate is robust to task specific factors (Clausen et al., 1973; Toner et al., 1984). It may be suggested, therefore, that any decrease in maximal heart rate during immersion running is the result of an increase in intrathoracic blood volume.

3. Water Temperature

Water temperature below the thermoneutral point may cause reductions in heart rate during immersion exercise (McArdle et al., 1976). McArdle et al., (1976), reported that a drop in water temperature from 33 degrees to 27 degrees celsius was responsible for a significant reduction in submaximal exercise heart rate. The average water temperature during this study was between 29 and 30 degrees celsius. It may be theoretically hypothesized that water temperature during this study may have contributed slightly to the reduction in heart rate at ventilatory threshold.

D. Isonitrile Data

Technetium-99 labeled isonitrile was utilized to measure blood flow distribution during immersion and land running. This was an experimental technique used on a limited number of subjects. Because of methodological problems (i.e. catheter problems), only two subjects completed the full procedure.

Conflicting results in relation to the isonitrile data were obtained. It was hoped that data from this section would help to further explain changes in cardiorespiratory parameters (in relation to the task specific factors).

Subject one demonstrated a general reduction in leg isonitrile uptake during immersion. This suggests that a decrease in leg blood flow may have occurred during immersion running. However, contrary to subject one, leg uptake of isonitrile in subject two was increased above treadmill values. With the exception of the anterior and posterior calf regions, blood flow to the leg during immersion running may have increased (subject two). Although more investigation is needed, one may speculate that the intersubject differences in blood flow distribution were due to immersion running styles. Although conclusive information cannot be drawn from the data, it may be suggested that isonitrile could be useful in human exercise blood flow studies in the future.

CHAPTER 5

SUMMARY

Five cardiorespiratory parameters (at maximal effort and at ventilatory threshold) were compared between an immersion and treadmill running condition. Those cardiorespiratory parameters were oxygen consumption, minute ventilation, tidal volume, breathing frequency and heart rate. Secondarily, an experimental technique utilizing Tc-99 2-methyloxy isobutyl isonitrile was utilized to measured changes in blood flow distribution. From the data collected in this study, it may be concluded that:

1. VO2 at maximal effort and at ventilatory threshold was significantly reduced during an immersion running condition. It was theorized that the reduction in oxygen consumption was due to changes in task specificity.
2. There was no significant change in minute ventilation comparatively between and an immersion and treadmill running protocol. It was further hypothesized that either task specific and water environmental factors had little effect on minute ventilation or that any increases in ventilation were effectively countered by factors that lowered minute ventilation.
3. There was a trend towards a higher breathing frequency and lower tidal volume during immersion running (at maximal effort and at ventilatory threshold). It was further hypothesized that the changes in tidal volume

and breathing frequency may be due to the introduction of the water environment.

4. There was a significantly lower heart rate at maximal effort and at ventilatory threshold during immersion running. It was hypothesized that the lower heart rate at ventilatory threshold may be due to an increase in intrathoracic blood volume and partially to the low water temperature. It was further hypothesized that the lower maximal heart rate was due solely to the increase in intrathoracic blood volume.
5. That isonitrile may be utilized to measure changes in blood flow distribution between exercise conditions.

It was the purpose of this study to compare the relationship of specific cardiorespiratory parameters during immersion and treadmill running. It was also the objective of this study to hypothetically discuss reasons for changes in these parameters. The hypothetical discussions may help future research in this area. It may be recommended that future research be guided into six main areas. These areas are:

1. To study the long term cardiovascular adaptations of untrained subjects to immersion and treadmill running.
2. To study the long term peripheral adaptations of untrained subjects to immersion and treadmill running.
3. To examine factors leading to decreased oxygen consumption rates during immersion running.

4. To examine the relationship between blood gas parameters during immersion exercise.
5. To study the correlation between isonitrile uptake and blood flow rate in skeletal muscle during exercise.
6. To study the methodological feasibility of utilizing isonitrile in humans for the measurement of muscle blood flow.

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Appendix A

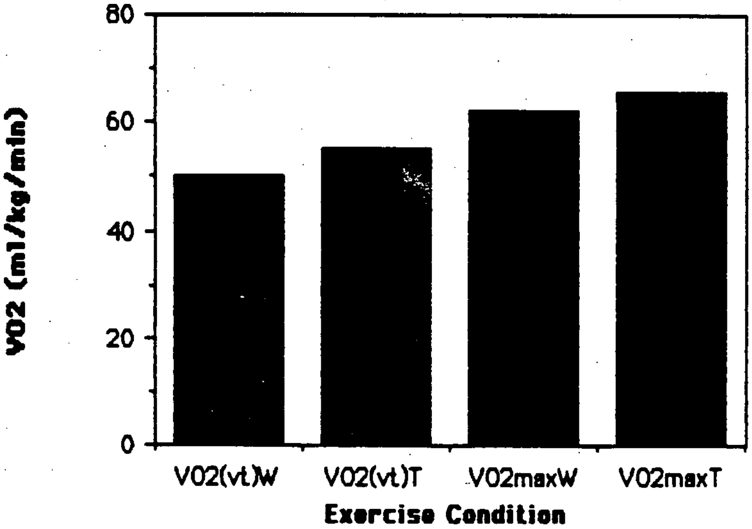

Figure 1: VO2 at ventilation threshold (vt) and maximal effort during immersion (W) and treadmill (T) running.

Appendix B

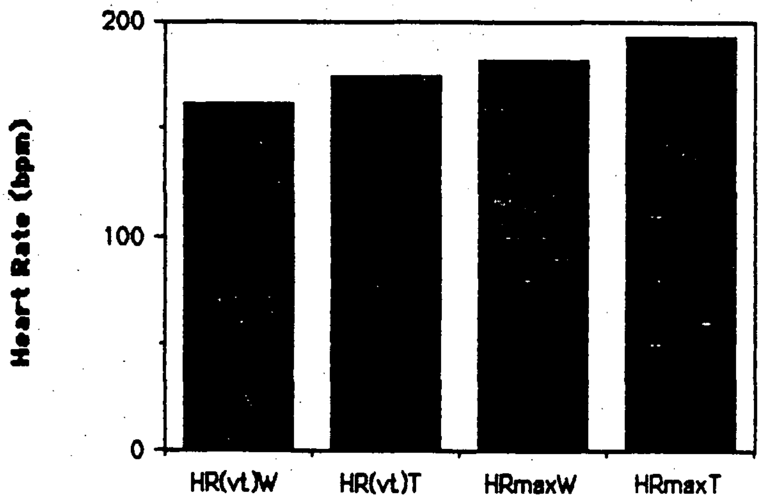

Figure 2: Heart rate at ventilation (vt) threshold and maximal effort (max) during immersion (W) and treadmill (T) running.

Appendix C

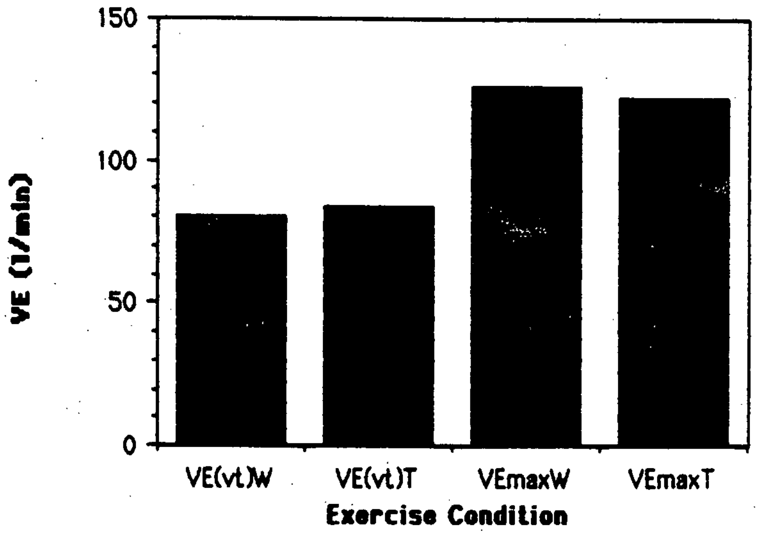

Figure 3: Ventilation at ventilation (vt) threshold and maximal effort (max) during immersion (W) and treadmill (T) running. Values are normalized to STPD.

Appendix D:

Raw Data: Cardiorespiratory Parameters

Subject	HR (vt)	HR max	VE(STPD) (vt)	VE(STPD) max	VO2 (vt)	VO2 max	VE/VO2 (vt)	VE/VO2 max
Treadmill								
1	174	185	94.6	107.9	54.6	61.2	1.74	1.78
2	168	182	83.4	129.0	56.3	67.9	1.48	1.90
3	179	194	102.2	131.4	62.1	74.7	1.65	1.77
4	164	187	86.5	129.5	56.2	66.3	1.42	1.72
5	188	204	95.9	126.0	58.5	69.0	1.64	2.23
6	179	193	95.5	120.8	61.3	68.5	1.55	1.74
7	180	191	99.7	132.7	53.8	63.0	1.85	2.09
8	179	195	99.5	134.4	57.9	66.7	1.72	2.02
9	177	194	79.6	128.3	54.3	70.3	1.47	1.83
10	177	194	82.0	109.2	55.7	64.8	1.47	1.73
11	190	205	94.5	126.7	56.8	62.9	1.61	2.04
12	174	187	81.9	110.0	54.7	62.3	1.50	1.83
13	204	228	86.4	116.6	52.7	60.8	1.63	1.99
14	170	191	67.9	113.9	50.1	63.9	1.36	1.82
15	165	185	78.7	117.6	62.9	71.9	1.25	1.72
16	172	191	90.5	118.4	60.8	66.7	1.49	1.86
mean	177.5	194.1	88.6	122.0	56.7	66.3	1.55	1.88
Immersion								
17	154	176	93.0	121.4	46.8	57.9	2.00	2.16
18	162	168	89.2	129.9	52.3	61.1	1.71	2.12
19	163	187	89.7	135.8	54.1	70.3	1.66	1.93
20	167	183	89.9	123.1	56.7	63.4	1.59	1.99
21	175	189	94.8	137.9	50.9	63.1	1.87	2.19
22	166	175	96.0	124.0	54.6	59.6	1.76	2.10
23	167	187	84.2	135.6	47.3	62.3	1.78	2.23
24	174	189	85.6	119.2	50.8	60.1	1.69	2.05
25	164	179	81.9	112.7	54.8	64.9	1.49	1.75
26	177	194	87.3	112.6	57.2	64.8	1.47	1.74
27	158	186	81.9	142.8	52.3	64.9	1.54	2.29
28	162	177	79.4	101.9	47.6	55.7	1.49	1.85
29	181	204	64.5	125.4	41.8	57.6	1.55	2.22
30	164	175	79.3	114.9	54.3	61.6	1.46	1.88
31	160	180	74.7	114.7	58.6	69.1	1.27	1.67
32	160	180	72.3	133.7	49.3	65.6	1.45	2.04
mean	165.9	182.4	83.9	124.1	51.8	62.6	1.61	2.01

Appendix E

Subject 1: Isonitrile Uptake Data (T=treadmill, W=immersion)

View	Condition	Count/pixel(muscle) / Count/pixel(Brain)	Difference (T-W)
Ventricles	T	11.6	1.7
	W	9.9	
Ventricles	T	12.7	2.1
(horseshoe)	W	10.6	
Deltoid Region	T	5.5	2.6
	W	2.9	
Anterior Thigh	T	7.1	1.6
(Full)	W	5.5	
Anterior Medial	T	7.4	1.4
Thigh	W	6.0	
Anterior Lateral	T	7.2	2.3
Thigh	W	4.9	
Posterior Gluteal	T	7.2	1.1
	W	6.1	
Posterior Thigh	T	6.3	0.9
(full)	W	5.6	
Posterior Medial	T	7.1	1.0
Thigh	W	6.1	
Posterior Lateral	T	6.1	0.9
Thigh	W	5.2	
Posterior Calf	T	4.7	3.3
(full)	W	1.4	
Posterior Medial	T	4.8	3.8
Calf	W	1.0	
Posterior Lateral	T	5.2	3.3
Calf	W	1.9	
Anterior Calf	T	4.0	0.4
(full)	W	3.6	
Anterior Medial	T	3.8	3.1
Calf	W	0.7	
Anterior Lateral	T	5.2	2.5
	W	2.7	
Lateral Thigh	T		
(full)	W		
Lateral Superior	T		
Thigh	W		
Lateral Inferior	T		
Thigh	W		

Appendix F.

Subject 1: Isonitrile Uptake Data (T=treadmill, W=immersion)

View	Condition	Counts(muscle) * 100% / Counts (whole body)	Difference (T-W)
Ventricles	T	1.2	0.4
	W	0.8	
Ventricles (horseshoe)	T	0.8	0.2
	W	0.6	
Deltoid Region	T	0.3	0.0
	W	0.3	
Anterior Thigh (Full)	T	5.9	1.7
	W	4.2	
Anterior Medial Thigh	T	3.3	0.7
	W	2.6	
Anterior Lateral Thigh	T	1.9	0.6
	W	1.3	
Posterior Gluteal	T	2.4	0.0
	W	2.4	
Posterior Thigh (full)	T	5.4	0.7
	W	3.7	
Posterior Medial Thigh	T	2.6	0.4
	W	2.2	
Posterior Lateral Thigh	T	2.0	0.7
	W	1.3	
Posterior Calf (full)	T	2.7	1.9
	W	0.8	
Posterior Medial Calf	T	1.3	1.0
	W	0.3	
Posterior Lateral Calf	T	1.3	0.8
	W	0.5	
Anterior Calf (full)	T	2.3	1.6
	W	0.7	
Anterior Medial Calf	T	1.2	1.0
	W	0.2	
Anterior Lateral	T	0.9	0.4
	W	0.5	
Lateral Thigh (full)	T		
	W		
Lateral Superior Thigh	T		
	W		
Lateral Inferior Thigh	T		
	W		

Appendix G

Subject 2: Isonitrile Uptake Data (T=treadmill, W=immersion)

View	Condition	Counts/pixel(muscle) / Counts/pixel(brain)	Difference (T-W)
Ventricles	T	15.3	0.5
	W	14.8	
Ventricles (horseshoe)	T	17.0	1.2
	W	15.8	
Deltoid Region	T	6.0	1.4
	W	4.8	
Anterior Thigh (Full)	T	8.0	-0.2
	W	8.2	
Anterior Medial Thigh	T	7.9	-0.7
	W	8.6	
Anterior Lateral Thigh	T	8.6	-0.1
	W	8.7	
Posterior Gluteal	T	9.1	3.5
	W	6.6	
Posterior Thigh (full)	T	7.9	-1.8
	W	8.7	
Posterior Medial Thigh	T	8.4	-0.3
	W	8.7	
Posterior Lateral Thigh	T	7.9	-0.1
	W	8.0	
Posterior Calf (full)	T	6.3	3.9
	W	2.4	
Posterior Medial Calf	T		
	W	2.3	
Posterior Lateral Calf	T		
	W	2.8	
Anterior Calf (full)	T	5.1	2.7
	W	2.4	
Anterior Medial Calf	T	5.1	1.0
	W	4.1	
Anterior Lateral	T	5.7	1.2
	W	4.5	
Lateral Thigh (full)	T	7.6	-1.7
	W	9.3	
Lateral Superior Thigh	T	8.2	-1.9
	W	10.1	
Lateral Inferior Thigh	T	7.8	-1.1
	W	9.9	

Appendix H

Subject 2: Isonitrile Uptake Data (T=treadmill, W=immersion)

View	Condition	Counts(muscle) * 100% / Counts (whole body)	Difference (T-W)
Ventricles	T	1.2	0.2
	W	1.0	
Ventricles (horseshoe)	T	0.9	0.2
	W	0.7	
Deltoid Region	T	0.3	0.0
	W	0.3	
Anterior Thigh (Full)	T	4.5	-1.2
	W	5.7	
Anterior Medial Thigh	T	2.5	-1.0
	W	3.5	
Anterior Lateral Thigh	T	1.6	0.0
	W	1.6	
Posterior Gluteal	T	2.3	0.6
	W	1.6	
Posterior Thigh (full)	T	3.3	-1.5
	W	4.8	
Posterior Medial Thigh	T	1.7	-1.1
	W	2.8	
Posterior Lateral Thigh	T	1.1	-0.6
	W	1.7	
Posterior Calf (full)	T	1.9	0.9
	W	1.0	
Posterior Medial Calf	T		
	W		
Posterior Lateral Calf	T		
	W		
Anterior Calf (full)	T	1.8	0.7
	W	1.1	
Anterior Medial Calf	T	0.8	0.3
	W	0.5	
Anterior Lateral	T	0.7	0.1
	W	0.6	
Lateral Thigh (full)	T	4.6	-3.0
	W	7.6	
Lateral Superior Thigh	T	1.9	-0.7
	W	2.6	
Lateral Inferior Thigh	T	1.6	-0.9
	W	2.5	

Appendix I

Isonitrile Data for Central Brain Area

Subject	Condition	View	Counts/pixel
1	Treadmill	Brain	9.1
1	Immersion	Brain	8.0
2	Treadmill	Brain	6.7
2	Immersion	Brain	5.4

Appendix J

Whole Body Photon Calculation

This is an example calculation of whole body photon count. The whole body photon count represents the number of photons released during the specified camera picture time.

95348 photon counts in syringe
193551 photon counts in total (includes syringe and all other material in contact with isonitrile)
(The counts are collected by the Seiman's Gamma Camera. This represents the residual counts and must be subtracted from the original dose.)

15.2 MBq dose in syringe after injection
(This is read through a dosemeter)

Therefore:

$$\frac{15.2\ \text{MBq}}{x} = \frac{95348\ \text{counts}}{98203\ \text{counts (total- syringe)}}$$

x = 15.8 MBq (dose in the contact materials)

Ideal Dose:

769.7 MBq in syringe (preinjection)
\- 19.1 MBq in syringe (post injection)
(15.2 divided by .794 (decay factor))
\- 19.9 MBq in contact materials (post injection)
(15.8 divided divided .794 (decay factor))
= 730.7 MBq injected into subject at time zero

Dose at time of data collection:

730.7 MBq * .865 (decay factor) = 632.1 MBq

Whole Body Photon Count:

$$\frac{95348}{x} = \frac{632.1}{15.2}$$

x = 3965096 photons counts (This number represents the number of photons released during a specific time interval (signature I.D. = 500 counts)).

You will go directly to the Dept. of Nuclear Medicine where you shall undergo scanning procedures. The scanning procedures will take approximately one hour.

The exercise testing procedures will take approximately 20 minutes. Twenty minutes will be required for arm catheterization. One hour will be required for tissue imaging at the Dept. of Nuclear Medicine (University of British Columbia Hospital). The total time required by you to perform the full testing protocol will be a minimum of 1.5 hours to a maximum of two hours.

Consent: At any time before or during the testing you may withdraw from this study within jepordizing your standing within the university structure. Every effort will be made to ensure that you do not experience any unnecessary discomfort. If you wish to ask any questions of the researcher and of this study feel free to do so.

In signing this consent form you will have stated that you have read and understood the description of the test and the potential complications. You enter this test willingly and may withdraw at any time. I have read the above comments and understand the explanation, and I wish to proceed with the tests.

Date:__________________________

Subject (signature):_________________________

Witness:________________________

You will go directly to the Dept. of Nuclear Medicine where you shall undergo scanning procedures. The scanning procedures will take approximately one hour.

The exercise testing procedures will take approximately 20 minutes. Twenty minutes will be required for arm catheterization. One hour will be required for tissue imaging at the Dept. of Nuclear Medicine (University of British Columbia Hospital). The total time required by you to perform the full testing protocol will be a minimum of 1.5 hours to a maximum of two hours.

Consent: At any time before or during the testing you may withdraw from this study within jepordizing your standing within the university structure. Every effort will be made to ensure that you do not experience any unnecessary discomfort. If you wish to ask any questions of the researcher and of this study feel free to do so.

In signing this consent form you will have stated that you have read and understood the description of the test and the potential complications. You enter this test willingly and may withdraw at any time. I have read the above comments and understand the explanation, and I wish to proceed with the tests.

Date:__________________________

Subject (signature):__________________________

Witness:__________________________