CARDIORESPIRATORY AND METABOLIC RESPONSES TO TREADMILL VERSUS WATER IMMERSION TO THE NECK EXERCISE IN ELITE DISTANCE RUNNERS

by

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ABSTRACT

The purpose of this study was to compare the following: a) the cardiorespiratory responses, in elite endurance runners familiar with water immersion to the neck non-weight bearing (WI) running, at ventilatory threshold (Tvent) and at maximal effort (ie. VO_{2max}) for treadmill and WI running performance to exhaustion and b) the cardiorespiratory and metabolic responses to prolonged performance (42 min.) at exercise intensities reflecting the treadmill and WI Tvent. Thirteen endurance trained runners familiar with water running completed comparable treadmill and WI VO_{2max} tests. Oxygen consumption (VO_2), ventilation (Ve), heart-rate (HR), respiratory exchange ratio (RER), ratings of perceived exertion (RPE) and stride frequency (SF) were measured at Tvent and VO_{2max}. Blood lactate [BLa] samples were obtained 30 seconds and 5 minutes post-test. Correlated t-tests revealed significantly ($p<0.05$) higher VO_{2max} (59.7 vs 54.6 $ml \cdot kg^{-1} min^{-1}$), HRmax (190 vs 175 bpm), RERmax (1.20 vs 1.10), VO_2 at Tvent (46.3 vs 42.8 $ml \cdot kg^{-1} min^{-1}$), HR at Tvent (165 vs 152 bpm) for the treadmill vs WI, respectively. Similar values were recorded for Vemax (109.0 vs 105.8 $l \cdot min^{-1}$), Ve at Tvent (66.4 vs 65.7 $l \cdot min^{-1}$), RER at Tvent (0.99 vs 0.89) and post-test [BLa] at 30 sec (10.4 vs 9.8 $mmol \cdot l^{-1}$) and 5 min post-test (9.7 vs 9.2 $mmol \cdot l^{-1}$) for the two conditions. Wilcoxon's matched pairs signed-ranks test revealed no differences in RPE at Tvent and VO_{2max} level for the two conditions. Significantly higher SF values over time were recorded (88 vs 54 $strides \cdot min^{-1}$, averaged over time) on

the treadmill. The lower WI VO_{2max} with similar peak [BLa] and lower SF suggests that the active musculature and muscle recruitment patterns differ in WI running due to the high viscocity friction of water, and the non-weight bearing nature of WI running.

During steady state exercise at treadmill and WI Tvent no differences in Ve response to exercise were noted in the treadmill and WI conditions. [BLa] response exhibited a decreasing trend over time in the WI condition both during the treadmill and WI Tvent intensity tests. Similar HR values were exhibited for exercise at WI Tvent in both conditions, confirming that the lower HR exhibited at Tvent from the WI VO_{2max} test was related to the lower VO_2 at WI Tvent and not the WI condition. Significantly lower HR values were exhibited for exercise at treadmill Tvent in the WI versus the treadmill condition suggesting that HR is lower only at workloads corresponding to and above 84.8 % of WI VO_{2max}. Results suggest that exercise in the water immersion to the neck condition affects (reduces) HR and [BLa] response over time, with the intensity of exercise being a factor. The WI condition, however does not affect Ve and RPE responses.

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Acknowledgements

To Mr. and Mrs. Steve Frangolias:

Dear Mom and Dad,

For the person you created,

For the person 1 have become,

I dedicate this to you.

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CHAPTER 1

1.0 INTRODUCTION

Water immersion to the neck (WI) has been used as a method of simulating various aspects of the aerospace environment. The application of knowledge attained from this area of research has expanded beyond the aeronautical sciences (Epstein, 1976). The non-weight bearing nature of water immersion exercise has made this form of exercise popular among populations of low fitness levels and those experiencing muscle and joint problems (Vickery et al, 1983; Evans et al, 1978). It has also become popular among special needs populations, such as during pregnancy among women (McMurray et al, 1988) and with individuals affected by chronic soft tissue degeneration and neurological disease (eg. rheumatoid arthritis, multiple sclerosis) (Danneskiolt-SamSoe et al, 1987; Compton et al, 1989).

WI running has gained popularity among runners. WI running has been used by runners and has been prescribed by athletes' doctors and coaches as an alternative to land based running. It is currently being used both as a rehabilitative treatment for lower trunk injury (Koszulta, 1986), and as a supplement to the runners' land based training regimen (Town and Bradley, 1991; Richie and Hopkins, 1991; Yamaji et al, 1990; Bishop et al, 1989). The non-weight bearing nature of WI running makes this form of exercise popular among runners experiencing muscle and joint problems, or trying to avoid such injuries by proportioning their weekly 'mileage' between land and WI running.

The non-weight bearing nature of WI running and the viscosity friction experienced in WI, however, also raises the question of how similar these two activities are. Johnson et al (1977) noted a higher oxygen consumption for similar leg exercise in WI versus land. They noted that, whereas, more energy is required on land to lift a greater mass, a similar effect is present in the WI condition related to the frictional resistance and turbulence of the water. The longer the lever, the larger the girth of the legs and the greater the speed of the movement, the greater will be the frictional resistance and turbulence experienced during WI exercise.

The goal with WI running is to simulate land-based running motion while immersed to the neck in water and non-weight bearing. The assumption is made that the same muscle groups and recruitment patterns are involved in WI running as are with land-based running. Studies comparing land and WI cycling have found no differences in VO_{2max} (Christie et al, 1990; Connelly et al, 1990; Shedahl et al, 1987; Dressendorfer et al, 1976), however, studies which have compared treadmill and WI running have reported lower VO_{2max} responses in WI compared to treadmill running (Svedenhag and Seger, 1992; Town and Bradley, 1991; Butts et al, 1991; Welsh, 1988). WI running style and familiarity with WI running may be factors responsible for the lower WI VO_{2max} reported by WI running studies.

Responses during submaximal exercise on the treadmill and WI running have also been investigated recently (Svedenhag and Seger, 1992; Richie and Hopkins, 1991; Yamaji et al, 1990; Bishop et al, 1989). The authors comment that although their subjects were familiarized with WI running, they were 'less conditioned' in the WI compared to the land (treadmill) condition. These studies have compared the physiological responses of WI and treadmill running among runners with limited WI running familiarity and at absolute workloads, which most likely represent in the WI condition a higher metabolic requirement. This has been demonstrated by the WI running studies comparing treadmill and WI VO_{2max}, which have found lower WI responses.

Static lung volumes have been reported to be reduced in WI (Withers and Hamdorf, 1989; Hong et al, 1969; Agostoni et al, 1966). Exercise minute ventilation (Ve) (in relation to VO_2) has been reported to remain unaffected (Svedenhag and Seger, 1992; Sheldahl et al, 1987; and Welsh, 1988), or reduced (Butts et al, 1991; Dressendorfer et al, 1976) in the WI condition.

Lower maximal HR has been reported for WI running and ergometer cycling (Svedenhag and Seger, 1992; Butts et al, 1991; Town and Bradely, 1991; Connelly et al, 1990; Christie et al, 1990; Welsh, 1988; Sheldahl et al, 1987; Dressendorfer et al, 1977). However, there is no clear consensus on resting and submaximal HR responses. Resting HR in upright WI compared to land has been reported to remain unchanged (Connelly et al, 1990; Christie et al, 1990; Arborelius et al, 1972) or to decrease (Risch et al, 1978; Fahri and Linnarsson, 1977; Lollgen et al, 1976). Similarly, submaximal exercise HR response (matched for VO_2) has been reported to remain unchanged (Christie et al, 1990; Sheldahl et al, 1987; Evans et al, 1978; McArdle et al, 1976) or to decrease (Connelly et al, 1990; Christie et al, 1990; Welsh, 1988; Johnson et al, 1977; Rennie et al, 1971) in WI compared to land exercise.

Cardiorespiratory mechanics are altered by WI at rest and possibly in exercise. It is therefore important to distinguish the physiological differences which can be attributed to the WI condition versus differences which are attributed to limitations of these studies. Studies comparing treadmill and WI running have predominately used runners untrained in WI running (who are not incorporating WI running in their training regimen) and have compared physiological responses to exercise at dissimilar workloads in the two conditions. Ventilatory threshold (Tvent) is representative of one's aerobic capacity (Anderson and Rhodes, 1991; Loat and Rhodes, 1991; Anderson and Rhodes, 1989; Wiley and Rhodes, 1986; Caiozzo et al, 1982; Rusko et al, 1980; Volkov et al, 1975) and is highly correlated with long distance performance (Coen at al, 1991; Maffulli et al, 1991; Rhodes and McKenzie, 1984). The purpose of this study was twofold: a) to compare the physiological and metabolic responses to treadmill and WI running at ventilatory threshold (Tvent) and at maximal effort among a group of elite distance runners familiar with WI running, and b) to compare the physiological and metabolic responses to treadmill and WI running during prolonged exercise at Tvent (WI and treadmill Tvent). It was postulated that studies to date had not controlled adequately for WI running style and the extent of the runners' familiarity with WI running.

1.1 DEFINITION OF TERMS

Excess CO_2. The non-metabolic CO_2 has been calculated by Issekutz and Rodahl (1961) by the following formula: Excess $CO_2 = V_{CO2} - (RQ_{rest} * VO_2)$, with $RQ_{rest} = 0.70-0.80$). It is the non-metabolic CO_2 (and water) generated by the bicarbonate buffering system of the hydrogen ions produced within exercising muscle from the dissociation of lactic acid. The chemical reactions are as follows: $HLa + NaHCO_3 = NaLa + H_2CO_3 = CO_2 + H_2O$ (Wasserman et al, 1973).

Lactate. Also referred to as lactic acid or blood lactate. It is the metabolic by-product of anaerobic energy production (Brooks and Fahey, 1985).

Respiratory Exchange Ratio (RER). Different amounts of oxygen (VO_2) are required for the catabolism (oxidation) of carbohydrate, fat and protein to carbon dioxide (CO_2), water and energy. The ratio of CO_2 produced/VO_2 consumed is defined as the RER and varies depending upon the substrate metabolized (Brooks and Fahey, 1985).

Runner Trained in WI Running. A runner trained in WI running is defined by this study as the runner who utilizes WI running on a regular basis in their training regimen. It is the runner who performs a minumum 6 sessions of WI running per month, of at least 45 minute duration per session, for the previous 6 months prior to participation in the present study.

Steady State Exercise. The intensity of exercise that can be performed for a prolonged period of time without appreciable elevations in VO_2, HR, Ve, RER, [BLa] etc.

Ventilatory Threshold (Tvent). Characterized by the non-linear increase in excess CO_2. It is the intensity of exercise just below the point of the abrupt increase in excess CO_2. The abrupt increase in excess CO_2 is related to increased reliance on anaerobic processes for energy because aerobic energy sources are unable to meet tissue requirements (Loat, 1991; Anderson and Rhodes, 1991; Anderson and Rhodes, 1989).

Maximal Oxygen consumption (VO_{2max}). Defined as the point where VO_2 plateaus and exhibits no further increase (or increases only slightly) with additional worklads (Brooks and Fahey, 1985).

Water Immersion to the Neck Running (WI Running). The simulation of land-based running motion in deep (non-weight bearing) water. The WI runner is immersed in water to the neck and propels herself in the water by simulating land-based running motion. There is no weight bearing, consequently no push-off phase on a stable immoveable surface. The individual propels herself through the water working against the resistance of the water. A flotation devise may be worn to provide minimum boyancy and facilitate the simulation of land-based running motion.

1.2 STATEMENT OF PROBLEM

The purpose of this study was to investigate the cardiorespiratory and metabolic responses during maximal effort and during prolonged performance at the ventilatory threshold (Tvent) during treadmill and water immersion to the neck (WI) running in a group of elite endurance runners familiar with WI running.

1.2.1 Subproblems

The subproblems were:

1) To utilize elite endurance runners who regularly include WI running in their training regimen.

2) To compare the cardiorespiratory and metabolic responses to treadmill and WI running at Tvent and maximal effort (ie. VO_{2max}) among a group of elite endurance runners familiar with WI running.

3) To compare the cardiorespiratory and metabolic responses to treadmill and WI running during prolonged exercise at Tvent (WI and treadmill Tvent) among a group of elite endurance runners familiar with WI running. That is the subjects would be asked to performed four Tvent prolonged performance (42 minute) tests and they were the following:

$Tr_{TrTvent}$ (treadmill Tvent intensity performed on the treadmill).

$Tr_{WITvent}$ (WI Tvent intensity performed on the treadmill).

$WI_{TrTvent}$ (treadmill Tvent performed in the WI condition).

$WI_{WITvent}$ (WI Tvent performed in the WI condition).

1.3 HYPOTHESES

1. The VO_{2max} values determined during the treadmill versus the WI running VO_{2max} test for WI running trained endurance runners would be similar at the 0.05 level of significance.

Specific hypothesis was: $Tr_{VO2max} = WI_{VO2max}$ at $p>0.05$.

RATIONALE: The runners would be simulating land-based running mechanics in an aqueous environment and since VO_{2max} is unaffected by this medium, performance in both environmental conditions should be similar as exhibited with land versus WI ergometer cycling studies (Connelly et al, 1990, Christie et al, 1990, Sheldahl et al, 1986, Avellini et al, 1983, Dressendorfer et al, 1976). Welsh (1988) reported lower treadmill versus WI VO_{2max} values. He attributed these findings to increased blood flow to the upper body musculature, a greater proportion of work performed by the upper body and a reduced ability of the upper body musculature to extract oxygen as possible factors. Lower VO_{2max} values for WI versus treadmill running have been reported by Svedenhag and Seger (1992), Butts et al (1991) and Town and Bradley (1991). These WI running studies utilized runners unexperienced to WI running. The runners were given one to two sessions of instruction and then classified as runners trained in WI running. The authors suggest in their discussions that less familiarity with WI running may have been a factor for the lower WI VO_{2max} values (Svedenhag and Seger, 1992; Butts et al, 1991; Town and Bradley, 1991). If the upper torso is utilized to a greater extent in WI versus treadmill running, in an attempt to remain afloat, then WI VO_{2max} values will be lower than treadmill values. It is postulated that the control measures set in this study, regarding WI running experience and acceptable WI running style will prevent this trend.

2. The treadmill Tvent will be significantly higher than the WI Tvent, at the 0.05 level of significance.

Specific hypothesis is: $Tr_{Tvent} > WI_{Tvent}$ at $p \leq 0.05$.

RATIONALE: The assumption was made here that there would be no significant differences in treadmill and WI VO_{2max} values. It was hypothesized that the absolute and relative treadmill and WI Tvent values would be different. The upper body musculature would be performing a proportionately greater quantity of work in WI versus treadmill running. Arm crank versus cycle exercise elicits a lower anaerobic threshold due to the smaller muscle mass available for recruitment (Sawka, 1986) and a proportionately higher ratio of glycolytic to oxidative muscle fibers, and so increasing lactate production and facilitating exhaustion. It was postulated that WI running motion would simulate treadmill (or land-based) running motion, however, the resistance of the water would result in increased work performed by the back and shoulder muscles as the arms swing back during the running cycle. This would result in a lower WI versus treadmill Tvent value.

3. Cardiorespiratory and metabolic (HR, VO_2, Ve, and [BLa]) responses during prolonged exercise at Tvent (determined from the WI and treadmill VO_{2max} protocols, ie. WI_{Tvent} and Tr_{Tvent} respectively) would differ significantly for the (WI running trained) runners during treadmill versus WI running tests at treadmill and WI Tvent at the 0.05 level of significance.

i) Heart-rate (HR) response during prolonged performance at treadmill and WI Tvent would differ significantly during treadmill versus WI running. The specific hypotheses were:

$TrHR_{WITvent} > WIHR_{WITvent}$ and

$TrHR_{TrTvent} > WIHR_{TrTvent}$ or

$TrHR_{Tvent} > WIHR_{Tvent}$ (if $WI_{Tvent}=Tr_{Tvent}$) at $p \leq 0.05$.

RATIONALE : Lower WI HR values have been reported at maximal effort (Svedenhag and Seger, 1992; Christie et al, 1991; Connelly et al, 1991; Welsh, 1988; Sheldahl et al, 1987; Dressendorfer et al, 1977; Arborelius et al, 1972), and at Tvent (Welsh, 1988). Lower WI running HR values have been reported during 5 minute exercise intervals at 65 % VO_{2max} and above (Svedenhag and Seger, 1992). Lower submaximal WI HR values have also been noted by studies comparing WI versus land ergometer cycling exercise (5 minute intervals) at 60%, 80% and 75% VO_{2max} and above, respectively (Connelly et al, 1991; Christie et al, 1991; Sheldahl et al, 1987). Similar WI HR values were reported during exercise, by these four studies below these exercise levels (Svedenhag and Seger, 1992;

Connelly et al, 1991; Christie et al, 1991; Sheldahl et al, 1987). Middle distance runners commonly reach Tvent at approximately 80% VO_{2max} (Davis et al, 1984), thus lower WI HR values would be expected for the WI tests at Tr_{Tvent} and WI_{Tvent}. The hydrostatic pressure gradient and consequent cephalad redistribution of blood volume are suggested to be responsible for the lower WI HR values (Svedenhag and Seger, 1992; Christie et al, 1991; Connelly et al, 1991; Sheldahl et al, 1987; Lin, 1984).

ii) Oxygen consumption (VO_2) during the Tvent prolonged performance tests would be significantly greater in WI versus treadmill running. The specific hypotheses were:

$WIVO2_{WITvent} > TrVO2_{WITvent}$ and

$WIVO2_{TrTvent} > TrVO2_{TrTvent}$ or

$WIVO2_{Tvent} > TrVO2_{Tvent}$ (if $WI_{Tvent}=Tr_{Tvent}$) at $p \leq 0.05$.

RATIONALE: WI running would utilize a larger muscle mass than treadmill running and therefore would require a higher VO_2 for the activity over time. WI work would result in a greater energy expenditure, and therefore, VO_2 compared to the same work performed on land. This would be related to the viscocity friction and turbulance of the aqueous environment (Evans et al, 1978, Johnson et al, 1977, Costill, 1971). If Tvent was not affected by the condition (ie. treadmill vs WI), the VO_2 would still be expected to be higher during the WI versus treadmill prolonged performance tests, due to these properties of the aqueous environment.

iii) Ve during the Tvent prolonged performance tests would be significantly greater in WI versus treadmill running. Specific hypotheses were:

$WIVe_{ITvent} > TrVe_{WITvent}$ and

$WIVe_{TrTvent} > TrVe_{TrTvent}$ or

$WIVe_{Tvent} < TrVe_{Tvent}$ (if $WI_{Tvent}=Tr_{Tvent}$) at $p \leq 0.05$.

RATIONALE: Similar maximal Ve values have been reported by WI running studies (Svedenhag and Seger, 1992; Town and Bradley, 1991, Butts et al, 1991; Welsh, 1988) and by Sheldahl et al (1987) for WI cycling. Dressendorfer et al (1977) noted lower maximal Ve reponse in WI cycling. Similar Ve and ventilatory equivalent for VO_2 has been reported at Tvent for WI versus treadmill running (Welsh, 1988). Svedenhag and Seger (1992) reported similar Ve responses during 5 minutes of WI versus treadmill running at submaximal exercise intensities. Similar submaximal Ve have also been reported for five minute exercise intervals in WI versus land cycling (Sheldahl et al, 1987; Sheldahl et al, 1984). This study hypothesized that Ve during the Tvent prolonged performance tests would be higher in the WI condition. This would be related to the higher relative intensity of the exercise in the WI versus the treadmill condition. This hypothesis was based on the assumption that $WI_{Tvent} < Tr_{Tvent}$. If WI and treadmill Tvent are similar, then no differences in Ve would be expected for the prolonged performance tests at Tvent in the 2 conditions.

iv) Blood lactate concentration [BLa] during the Tvent prolonged performance tests would be significantly higher in the WI versus treadmill running. Specific hypotheses were:

$$WI[\mathbf{BLa}]_{WITvent} > Tr[\mathbf{BLa}]_{WITvent} \text{ and}$$

$$WI[\mathbf{BLa}]_{TrTvent} > Tr[\mathbf{BLa}]_{TrTvent} \text{ or}$$

$$WI[\mathbf{BLa}]_{Tvent} = Tr[\mathbf{BLa}]_{Tvent} \text{ (if } WI_{Tvent}=Tr_{Tvent}\text{) at } p\leq 0.05.$$

RATIONALE: The greater metabolic demands of WI running, due to the higher relative intensity of the WI prolonged performance tests compared to the same absolute intensity performed on the treadmill would result in higher blood lactate accumulation in the WI (ie. $WI_{TrTvent}$ and $WI_{WITvent}$) versus the treadmill (ie. $Tr_{TrTvent}$ and $Tr_{WITvent}$) prolonged performance tests. If the Tvent did not differ in the two conditions (ie. $WI_{Tvent}=Tr_{Tvent}$), then no differences in blood lactate concentration would have been expected.

See figure 1 for a summary hypotheses diagram.

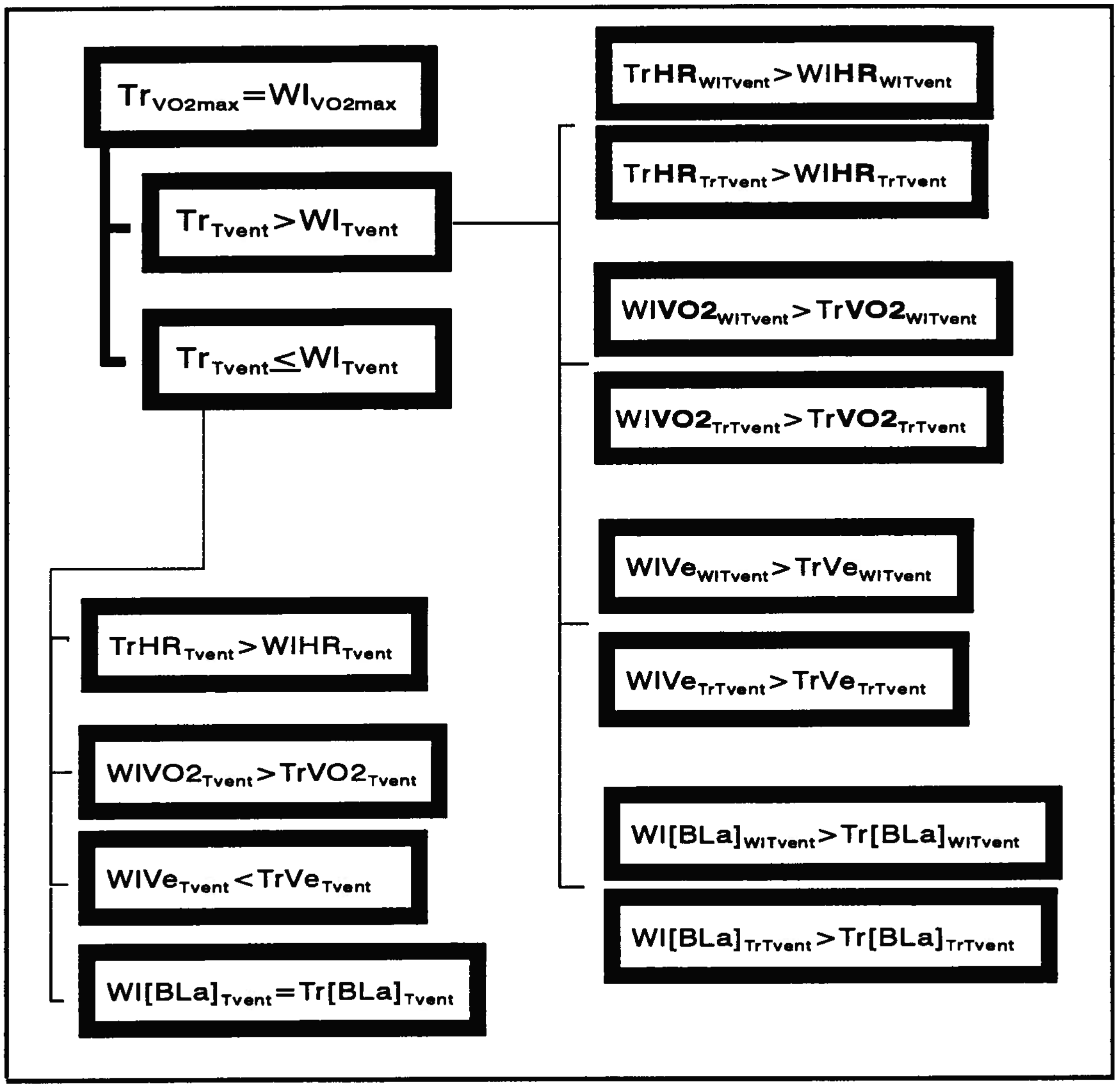


Figure 1. Hypotheses Summary Chart.

1.4 DELIMITATIONS

1) The study was delimited to male and female distance runners, 20-35 years-old, who were trained on land, treadmill and WI running, and who could demonstrate WI running style during high intensity exercise as set by this study (see sampling section).

2) The sample size was restricted to 13 elite runners trained in WI running.

3) The study was delimited to subjects with a minimum treadmill VO_{2max} of 50 and 60 $ml \cdot kg^{\cdot -1} min^{-1}$, for female and male runners respectively. This was to ensure that the subjects had enhanced cardiorespiratory and metabolic abilities comparable in level to top-level varsity and national caliber distance runners.

4) The study was delimited to examine only one intensity of exercise (Tvent intensity), with WI and treadmill Tvent performed and compared on the treadmill and WI condition.

1.5 ASSUMPTIONS

1) The subjects' measured VO_{2max} values were a true reflection of their aerobic capacity.

2) The subjects would be able to run on the treadmill and simulate land running motion with WI running.

3) The trial sessions for familiarization to the equipment and environmental test conditions would be adequate.

4) Running in the water immersed to the neck requires activation of predominantly similar skeletal muscle groups which are activated during land-based running. Land-based running motion is simulated during WI running motion.

5) Subjects would perform maximally to exhaustion in both conditions (ie treadmill and WI running). Use of the Borg scale for ratings of perceived exertion during the VO_{2max} tests and post-test [BLa] measures would provide additional evidence that VO_{2max} was achieved.

6) Hydration and cooling provided for the laboratory treadmill tests would be adequate for the subjects.

1.6 LIMITATIONS

1) The investigation was limited by the WI running ergometer and WI running VO_{2max} protocol used to assess VO_{2max} and Tvent in WI running.

2) The investigation was limited by the WI running ergometer which with increasing load facilitated a foward lean due to the harness pulling the subjects' trunk in a backward direction.

3) The investigation was limited by the functioning of the Beckman metabolic cart and the accuracy of its readings.

4) The study was limited by the laboratory environmental conditions and the inability to control laboratory temperature and humidity for the comfort of the subjects during testing. Attempts were made to maintain a comfortable environment for the subjects by providing them with water to maintain adequate hydration and some cooling by use of an electric fan.

5) The investigation was limited by the subjects' ability and motivation to perform maximally to exhaustion on the WI and treadmill VO_{2max} tests.

6) The study was limited by the water turbulence in the pool caused by activities ongoing during WI test times. This increased turbulence of the water, would work to reduce or increase the subject's workload.

7) The investigation was limited by the subjects' ability to correctly and consistantly simulate WI running motion. Subjects were to remain almost vertical in the pool immersed to the neck with the arms following normal running motion; the hands would not 'cup' the water. Normal running motion of the lower trunk would include flexion of the hip followed by hip and leg extension.

8) The study was limited by the ability of the investigator to objectively evaluate the subjects' running style during testing from

videotape of the sagital view of the subjects' performance against the scaling grid.

9) The investigation was limited by the minimum requirements set for a runner to be trained in WI running, which were neccesary for inclusion in this study. That is the regular WI running training sessions and the quality of the work-outs completed by the subjects during the six months prior to participation in the present study.

10) The investigation was limited by the ability of the unbiased reseachers to extrapolate the Tvent levels from the $ExCO_2$ over time curve (and Ve/VO_2 over time curve and RER around 1.00).

1.7 SIGNIFICANCE

Numerous studies have examined the cardiorespiratory responses of exercise in WI compared to exercise on land. These studies, however, have been limited to the investigation of maximal responses and short duration submaximal exercise at similar absolute intensities. More recently WI running at submaximal intensities of a prolonged nature have been examined and compared with treadmill responses, however, the exercise intensity has not been objectively controlled. Studies comparing treadmill and WI running have utilized predominately runners untrained in WI running, as their subjects. Could differences in physiological responses reported for WI and treadmill running be related to the subjects' unfamiliarity with WI running? Since WI VO_{2max} values have been reported to be lower than treadmill values, could the responses then, exhibited during submaximal exercise be related to the higher relative intensity of the exercise in the WI condition.

HR response during submaximal exercise has been reported to be similar, or lower in the WI versus land (treadmill) condition. WI HR response seems to be exercise intensity dependent, but there is no agreement as to what intensity of exercise (% of VO_{2max}) results in lower WI HR values. Determination of Tvent and comparison of exercise at similar relative exercise intensities (at and above WI Tvent) would provide new information on HR response in WI.

WI running is often used by runners. The incorporation of WI running in the training regimens of elite runners is justified as either a preventative measure to avoid the occurrence of sports-related injuries, or as a form of maintenance training following injury. The training regimens of runners incorporate the principle of specificity of training, which requires that one's training regimen overload the metabolic system and muscles which support his activity (Brooks and Fahey, 1985). If WI running requires a very similar muscle recruitment pattern, then one should expect the runner to be able to sustain the activity at a specific intensity (ie. Tvent) eliciting similar cardiovascular and metabolic responses as during running on land. If this is the case then WI running can also provide training benefits which can be transfered to land-based running and can serve to enhance a runner's training regimen.

CHAPTER 2

2.0 REVIEW OF THE LITERATURE

During the last 30-35 years water immersion to the neck (WI) has been used to simulate weightlessness. Recently, exercise in WI has gained popularity due to its non-weight bearing nature. Running is becoming a common activity in the WI condition. It is being used extensively by competitive runners and other athletes not only during rehabilitation but also to complement their regular training. This literature review will present research pertaining to cardiovascular and respiratory responses to the WI condition, WI exercise studies and the ventilatory threshold concept with respect to steady state exercise.

2.1.0 CARDIOVASCULAR RESPONSES TO WATER IMMERSION TO THE NECK

The four major determinants of cardiac performance are heart-rate (HR), preload, contractility and afterload. Preload is defined as the extent of ventricular filling before contraction. Preload is determined by the venous return of blood to the heart, and venous return is directly affected by cardiac output (CO) (Brooks and Fahey, 1985). Afterload is defined as the resistance to ventricular emptying, that is the force against which the heart muscle must contract during the ejection phase of systole. Increased afterload increases the workload for the heart. Increased afterload is characterized by reduced ventricular-ejection fraction, shortening velocity and increased ventricular end-diastolic and end-systolic volumes (Brooks and Fahey, 1985). Contractility is described as the quality of ventricular performance. Enhanced contractility enables the heart to increase stroke volume (Brooks and Fahey, 1985). HR is described as the major determinant of CO, especially during moderate to maximal exercise (Brooks and Fahey, 1985).

During upright water immersion to the neck (WI) a mean hydrostatic pressure of 20 cm water is exerted on the thoracic cavity and abdominal area. Atmospheric air pressure of 1 atm is exerted on the unimmersed head and neck and is transmitted through the airways into the alveoli. An imbalance is created between the air pressure in the alveaolar spaces and the greater pressure exerted on the thoracic cavity (Epstein, 1976). A redistribution of blood volume to the central circulation by 700 ml is induced. The heart accepts approximately 200 ml of this blood volume (Arborelius et al, 1972).

2.1.1 Heart-rate

Resting and submaximal HR responses have been reported to remain unchanged or to decrease in WI. Although there is agreement that maximal HR is lower in WI (Svedenhag and Seger, 1992; Town and Bradley, 1991; Butts et al, 1991; Connelly et al, 1991; Christie et al, 1991; Welsh, 1988; Sheldahl et al, 1987; Sheldahl et al, 1984; Dressendorfer et al, 1976), there is no clear consensus on the mechanisms responsible for the lower HR responses in WI at higher exercise intensities. The cephalad shift in blood volume which causes the redistribution of 700 ml of blood from the lower extremities and abdomen to the central circulation is implicated (Lin, 1984; Fahri and Linnarsson, 1977; Arborelius et al, 1972). The heart accepts 200 ml of this blood (Fahri and Linnarsson, 1977; Arborelius et al, 1972). It is suggested that the increase in atrial blood volume with WI could result in a reflex increase in HR at rest and up to moderate exercise, offsetting a cardiac decelerating reflex (Christie et al, 1991; Sheldahl et al, 1987; Sheldahl et al, 1984). This is suggested to occur through the Bainbridge reflex (Sheldahl et al, 1987; Lin, 1984).

Bainbridge reported HR to increase with infusions of blood or saline. This was observed when central venous pressure increased to the extent to distend the right side of the heart. In this case cardiac filling rose resulting in increases in HR (Berne and Levy, 1988).

It has also been postulated that CO may be regulated at a higher level in WI in order to maintain an 'appropriate' arterial blood pressure response (Christie et al, 1991; Sheldahl et al, 1987; Lin, 1984). Sheldahl et al (1987) proposes that since similar systolic blood pressure responses are exhibited during WI and land exercise (Sheldahl et al, 1987; Arborelius et al, 1972) and if systemic vascular resistance remains lower during exercise in WI, a greater CO would be neccessary to maintain the same blood pressure response as exhibited on land. Arborelius et al (1972) has noted lower (by 30%) systemic vascular resistance in resting WI.

Lower sympathetic neural outflow in WI has also been suggested to explain the lower HR response to heavy exercise (Christie et al, 1991; Connelly et al 1991; Sheldahl et al, 1987). Lower plasma norepineprine and epineprine concentrations have been noted during heavy and maximal exercise in WI compared to land responses (Connelly et al, 1991). An exercise intensity dependent response of plasma catecholamine levels in WI is suggested (Connelly et al, 1991; Christie et al, 1991).

HR response in WI is also affected by temperature. Similar HR values have been reported during rest and submaximal exercise in thermoneutral WI (29^{o}-35^{o} C) compared to land values (Sheldahl et al, 1987; Fahri and Linnarsson, 1977; McArdle et al, 1976; Arborelius et al, 1972; Craig and Dvorak, 1966). Lower HR values have been reported during rest and exercise in WI at 25^{o} C compared to thermoneutral water (Craig and Dvorak, 1966). McArdle et al (1972) noted lower HR values for exercise at oxygen consumption (VO_2) values of 1.5 and 2.8 $l \cdot min^{-1}$ in WI at 18-25^{o} C. Consequently VO_2 was higher (by 250-700 $ml \cdot min^{-1}$) in WI at 18-25^{o} C compared to VO_2 values on land and WI at 33^{o} C (McArdle et al, 1972). Lower maximal HR (HR_{max}) values, however, were reported for similar VO_{2max} values for WI exercise at 18-25^{o} C compared to thermoneutral WI exercise (Dressendorfer et al, 1976; McArdle et al, 1972).

Rennie et al (1971) reported lower resting HR values, (a-vO_2) difference (15%) and CO in WI at 28-32^{o} C. During exercise, however, no differences in CO-VO_2 relationship were noted, although HR and stroke volume (SV) were lower and higher respectively from land values. The authors concluded that the decline in skin blood flow, CO, HR at rest in WI were related to water temperature. Any differences, however, in CO during WI exercise were minimized by the higher perfusion of muscle in exercise. They postulated that the reduced HR and increased SV during exercise were the result of negative feedback control from baroreceptors.

Resting heart-rate (HR) has been reported to remain unchanged (Connelly et al, 1990; Christie et al, 1990; Arborelius et al, 1972) or to decrease in water immersion to the neck (WI) in water temperatures ranging from 27-31^{o} C compared to resting HR values reported on land (Risch et al, 1978; Farhi and Linnarsson, 1977; Lollgen et al, 1976). Similarily submaximal exercise HR responses (matched for oxygen consumption) have been reported to remain unchanged (Christie et al, 1990; Sheldahl et al, 1987; Evans et al, 1978; McArdle et al, 1976) or to decrease (Connelly et al, 1990; Christie et al, 1990; Johnson et al, 1977; Rennie et al, 1971) with upright exercise in WI compared to on land.

Connelly et al (1990) and Christie et al (1990) reported significantly lower WI HR responses at exercise intensities (on cycle ergometer) corresponding to 60 % VO_{2max} or above and 80 % VO_{2max} respectively. Svedenhag and Seger (1992) reported significantly lower HR responses elicited in WI running at intensities over 80 % VO_{2max} compared to treadmill running. Welsh (1988) reported significantly lower WI HR responses at ventilatory threshold (Tvent) compared to Tvent HR determined from the treadmill VO_{2max} protocol, among endurance trained runners. The HR responses at Tvent in the WI and treadmill condition corresponded to 83 and 86 percent of their respective VO_{2max}. Sheldahl et al (1987) compared WI and land stationary ergometer cycling and reported lower exercise HR responses at 80 % VO_{2max} in WI. In another study Sheldahl et al (1984) noted lower HR values during WI exercise at 76 % VO_{2max} and above.

Although differences in WI and land-based HR's at rest and at submaximal exercise intensities are still being debated, there is agreement that HR response to maximal exercise is lower in WI compared to maximal exercise on land. Lower HR_{max} values have been reported by studies comparing WI and land stationary ergometer cycling (Connelly et, 1990; Christie et al, 1990; Sheldahl et al, 1987; Sheldahl et al, 1984; Dressendorfer et al, 1977) and by studies comparing WI and treadmill running (Svedenhag et al, 1992; Butts et al, 1991; Town and Bradley, 1991; Welsh, 1988).

2.1.2 Preload, Contractility and Afterload

Sheldahl et al (1984) noted increases in ventricular end-diastolic volume and end-systolic diameter during exercise at 37% and 47% VO_{2max} in WI versus land cycle exercise. The authors concluded that preload may be enhanced in WI and suggest that preload may be under-utilized during exercise on land. The decline in the ratio of systolic blood pressure and end-systolic diameter during WI exercise may indicate lower myocardial contractility in the WI condition. The greater left ventricular end-diastolic volume during WI exercise suggests that the left ventricular wall tension is greater at a given left ventricular pressure. This is suggested to result in increased afterload (Sheldahl et al, 1984). Christie et al (1991) also noted higher left ventricular end-diastolic volume during WI exercise, coupled with similar systolic blood pressure and concluded that afterload is increased in WI, but that contractility, most likely, is reduced.

2.2.3 Cardiac Output and Stroke Volume

Cardiac output (CO) has been reported to increase during resting WI (Christie et al, 1991; Farhi and Linnarsson, 1977; Begin et al, 1976; Arborelius et al, 1972;). Decline in CO has also been reported (McArdle et al, 1976; Rennie et al, 1971; Hood et al, 1968), but this decline has been attributed to water temperature (below thermoneutrality) (Farhi and Linnarsson, 1977; Rennie et al, 1971).

Farhi and Linnarsson (1977) noted a progressive increase in CO from land (5.1 $l \cdot min^{-1}$) to water immersion to the hip (5.7 $l \cdot min^{-1}$), xiphoid (7.4 $l \cdot min^{-1}$) and neck level (8.3 $l \cdot min^{-1}$). HR decreased during hip and xiphoid level water immersion, but increased during immersion to the neck (WI). Stroke volume (SV), on the other hand, increased at each water immersion stage. The authors concluded that in the first two water immersion stages atrial baroreceptors played the dominant role and noted that as CO increases and blood pressure rises, HR is reflexly lowered. During neck immersion atrial stretch receptors are responsible for the increase in HR (Farhi and Linnarsson, 1977). Increase in resting SV during the WI compared to land condition have been noted by Christie et al (1991) and Sheldahl et al (1987).

The 30-35% increase in CO during resting WI has been attributed to the increase in SV (up to 77% increase) (Lin, 1984; Farhi and Linnarsson, 1977) related to enhanced diastolic filling (enhanced preload) (Farhi and Linnarsson, 1977; Begin et al, 1976; Arborelius et al, 1972).

Higher SV has been reported during graded intensities of exercise in the WI versus land condition (Christie et al, 1991; Sheldahl et al, 1987; Arborelius et al, 1972; Rennie et al, 1971). Higher CO at a given VO_2 has been noted during submaximal exercise (Christie et al, 1991; Sheldahl et al, 1987; Bonde-Peterson et al, 1980), although the pattern of increase was similar in the WI and land condition (Christie et al, 1991).

Submaximal (above 40% VO_{2max}) to maximal exercise does not result in further increases in SV, although SV has been reported to be higher at any given submaximal and maximal exercise intensity when compared to land values (Christie et al, 1991). Possible explanations for the lack of further increase in SV with WI exercise is attributed to: a) the cephalad shift of blood volume during resting WI has reduced the amount of blood available to be centrally shifted with exercise, or b) the left-ventricular diastolic volume during resting WI is near maximal, consequently there is limited ability to increase SV further with exercise (Christie et al, 1991; Farhi and Linnarsson, 1977).

Cold stress in WI also affects CO and SV. McArdle et al (1976) reported SV values to increase in cold WI, with SV greater at 18^{o} C versus 25^{o} C and versus thermoneutral water. When SV and HR were plotted over VO_2, the increase in SV observed parallelled the decreases in HR in cold stress.

In summary CO and SV increase with WI. The majority of the increase in CO and SV occurs with initial WI in rest. SV does not exhibit further increases with exercise beyond the increase exhibited with resting WI, but compared to land exercise values WI SV values are still higher. CO increases by 30-35% with resting WI and during graded exercise a similar in magnitude increase occurs as during similar land exercise (similar CO-VO_2 slope). HR response during resting WI remains most likely similar to land-based values, as a consequence of atrial stretch receptor activity which increases HR to land resting values. There is no clear consensus on HR response during submaximal exercise, although there is agreement that maximal HR is lower in the WI versus land condition.

2.2.0 RESPIRATORY RESPONSES TO WATER IMMERSION TO THE NECK

2.2.1 Static Lung Volumes

Vital capacity is reduced (3-9%) with WI (Withers and Hamdorf, 1989; Hong et al, 1969, Agostoni et al, 1966). The reduction in vital capacity is attributed to the rise of the diaphragm and the increase in intrapulmonary blood volume (Risch et al, 1978; Hong et al, 1969). Dalback (1975) attributes the reduction in VC solely due to intrathoracic blood accumulation.

Tidal volume during resting WI is unaltered (Withers and Hamdorf, 1989; Sheldahl et al, 1987; Hong et al, 1969). Breathing frequency also remains unaltered during resting WI (Withers and Hamdorf, 1989; Sheldahl et al, 1987; Dressendorfer et al, 1976; Hood et al, 1968). Reduction in maximal voluntary ventilation (MVV) (12%) with no change in breathing frequency during WI compared to air was reported by Dressendorfer et al (1976).

Decreases have also been reported during WI for expiratory reserve volume (ERV) (62-70%) (Withers and Hamdorf, 1989; Hong et al, 1969;, Agostoni et al, 1966), functional residual capacity (FRC) (30-54%) (Withers and Hamdorf, 1989; Fahri and Linnarson, 1977; Hong et al, 1969; Agostoni et al, 1966), residual volume (RV) (16%) (Withers and Hamdorf, 1989; Hong et al, 1969;, Agostoni et al, 1966). The preceeding lung function reductions are attributed to the hydrostatic pressure of the water counteracting the forces of the inspiratory muscles, thereby compressing the abdomen and raising the diaphragm to a position approaching full expiration (when the respiratory muscles are relaxed) (Agostoni et al, 1966). This results in a restriction of the force required for inspiration by reducing total lung capacity (TLC) and VC (Withers and Hamdorf, 1989; Dahlback et al, 1978a; Dahlback et al, 1978b).

The hydrostatic pressure of the water also causes a redistribution of blood volume from the lower extremities to the thoracic cavity (Hong et al, 1969;, Agostoni et al, 1966). This increase in thoracic blood volume results in a reduction in lung compliance, and to space competition between thoracic air and redistributed thoracic blood (Dahlback et al, 1978a; Dahlback et al, 1978b; Arborelius et al, 1972; Agostoni et al, 1966). These events are also responsible for the reduction in lung compliance (Dahlback et al, 1978b). The reduction in lung compliance results in an increase in RV, however the net effect of the hydrostatic chest compression and centrally redistributed blood volume produces a net reduction in RV (Withers and Hamdorf, 1989).

Hong et al (1969) calculated the work of breathing at resting WI and reported an increase with WI by 39 %, of which 29 % was ascribed to an increase in elastic work and 10 % to an increase in dynamic work. The increase in dynamic work was attributed to increased flow resistance of the airways functioning at reduced lung volumes (reduced ERV).

2.2.2 Exercise Respiratory Responses.

Exercise Ve is not affected by the WI condition. Similar Ve (matched for VO_2) responses have been noted by Sheldahl et al (1987) at rest and during exercise at 44%, 60% and 80% VO_{2max}. Greater increases in Bf and lower TV values were noted during WI versus land exercise (Sheldahl et al, 1987). This is in agreement with the findings of Welsh (1988) for Ve at Tvent and VO_{2max} for treadmill and WI running. Welsh

(1988) also noted higher Bf and lower TV at Tvent and VO_{2max} during WI versus treadmill running.

In summary respiratory mechanics are altered by the external application of hydrostatic pressure. The cephalad shift in blood volume (700 ml) is partly accomodated by the heart (which accepts 200 ml) and the remainder is accomodated by the pulmonary circulation. WI results in changes in static lung volumes, but does not seem to affect Ve.

2.3.0 WATER IMMERSION EXERCISE STUDIES

This section will review literature from an exercise science perspective.

2.3.1 VO_{2max} and Short Duration Submaximal Effort.

Svedenhag and Seger (1992) compared treadmill and WI running VO_{2max} and short duration (5 minute bout) submaximal exercise responses in a group of middle and long distance runners (N=9). Seven of the subjects had previous WI running experience and the two remaining were familiarized with WI running once before testing. A wet vest was worn during WI running testing. Four minute submaximal exercise bouts (with one minute pause) of progressive intensity were performed at exercise intensities eliciting HR's of 115, 130, 145 and 155-160 bpm. The subjects WI ran lengths alongside the pool deck and expired air was collected in Douglas bags during the last 1-1.5 minutes of each exercise bout. At the end of each exercise bout blood lactate sample (from the earlobe) and RPE were obtained.

Following completion of the fourth exercise bout, the subjects were asked to increase their exercise intensity to maximal effort within 1-2 minutes and to maintain this intensity for as long as possible (2 minutes). HR and expired air were collected during the last minute of exercise (3-4th minute) at maximal effort and blood lactate obtained 30 seconds post-test. The treadmill protocols for the submaximal exercise tests were matched to the VO_2's determined from the WI tests. The treadmill protocol for determination of VO_{2max} did not match the WI VO_{2max} protocol. A treadmill VO_{2max} protocol of set velocity and increasing grade over time was utilized.

Lower VO_{2max} values were reported for WI compared to treadmill running (4.03 vs 4.60 $l \cdot min^{-1}$). Significantly lower HR's were reported at a VO_2 of 3.5 $l \cdot min^{-1}$ (155 vs 165 bpm) and maximal effort (172 vs 188 bpm) for the WI compared to the treadmill condition. Submaximal and maximal Ve responses were similar for the two conditions. [BLa] values were higher in the WI condition at a VO_2 of 3.5 $l \cdot min^{-1}$ (5.01 vs 1.33 $mmol \cdot l^{-1}$) and 70 % VO_{2max} (4.6 vs 1.5 $mmol \cdot l^{-1}$). Peak [BLa] values (12.4 vs 10.0 $mmol \cdot l^{-1}$) were also higher in the WI condition compared to treadmill values. Higher RER values were noted for WI versus treadmill running at a VO_2 3.5 $l \cdot min^{-1}$ (0.98 vs 0.95). RER_{max} was lower for WI versus treadmill running (1.10 vs 1.20). Similar RPE values were reported for breathing and legs separately for treadmill and WI running. Higher RPE values were reported during exercise at a VO_2 of 3.5 $l \cdot min^{-1}$

(14.6 vs 12.6) and for a HR of 150 bpm (14.2 vs 10.4) in the WI versus the treadmill condition.

The authors concluded that the higher anaerobic metabolism associated with WI running is likely related to the reduced perfusion pressure in the legs with a consequent reduction or maldistribution in total muscle blood flow. The authors also noted that although the subjects were familiarized with WI running, they were less conditioned to WI running (Svedenhag and Seger, 1992). Consequently the lower WI running conditioning may be directly responsible for the RPE, [BLa] and RER behaviour exhibited during submaximal and maximal exercise and not the WI condition.

Butts et al (1991) compared treadmill and WI running responses (N=24). A wet vest was worn for WI running. For WI testing the subjects were tethered to the side of the pool. Stride frequency was used to produce a progressive incremental test to exhaustion for WI running. The subjects WI ran initially at 100 strides per minute and were told to increase their stride frequency every two minutes by 20 strides per minute. The subjects were encouraged to 'go all out' when they were unable to maintain the specific stride frequency for an additional minute. Lower WI values for VO_{2max}, Ve, HR and RER were noted. The lower WI VO_{2max} values were attributed to the hydrostatic pressure and mechanical constraints imposed on WI running related to the water resistance. Restrictions to maximal limb movement and a decrease in active muscle mass in WI running were also suggested as possible explainations. The authors note that antigravity muscles active during land-based running are not neccessary in WI running, consequently the metabolic cost of WI running may be reduced.

Town and Bradley (1991) compared VO_{2max} values from distance runners (N=9) familiarized with water running in WI running, shallow water (SW) running (1.3 meters in depth and arms above the water level) and treadmill running. VO_{2max} tests for water running (SW and WI) were 4 minute duration tests and the subjects were asked to increase their effort each minute resulting in exhaustion by the fourth minute. The treadmill test produced higher VO_{2max} values compared to SW running (representing 90 % of the mean treadmill VO_{2max} value). Both modes produced higher VO_{2max} values than WI running (representing 73.5 % of the treadmill VO_{2max}). HR was lower in the WI running test. Similar oxygen pulse (HR/VO_2) values were noted for treadmill (2.66 $beats \cdot ml^{-1}$) and SW (2.63 $beats \cdot ml^{-1}$) running. Lower HR/VO_2 was reported for WI running (3.40 $beats \cdot ml^{-1}$) and the authors attribute this relationship to greater left ventricular end-diastolic and end-systolic dimensions observed during WI. RER and [BLa] were similar in all three protocols, but treadmill running showed a trend toward higher (ie. 19 %) [BLa] levels than the WI and SW running tests.

Welsh (1988) compared treadmill and WI running Tvent and VO_{2max} responses in middle distance runners (N=16) who regularly performed WI running workouts. Lower VO_2, and HR values were exhibited at Tvent and VO_{2max} in WI compared to treadmill running. Similar Ve values were noted at Tvent and VO_{2max} in the two conditions, but higher ventilatory equivalent for VO_2 (Ve/VO_2) values were noted in WI versus treadmill running. Tidal volume (TV) and breathing frequency (Bf) were measured at Tvent and maximal effort on a subsample (N=4). Bf at Tvent values (37.9 vs 37.1 breaths per minute (brpm)) were similar and slightly higher at maximal effort (54.6 vs 48.7 brpm) in WI versus treadmill running. TV values were lower at Tvent (2.17 vs 2.28 liters) and maximal effort (2.32 vs 2.56 liters) in WI versus treadmill running. TC-99 2-methyloxy isobutyl isonitrile was injected in two subjects to monitor blood flow distribution in the lower trunk during WI and treadmill running at Tvent. Although leg blood flow decreased in one subject, it increased in the other subject during WI running. The intersubject differences in blood flow distributions were suggested to be related to WI running styles.

Dressendorfer et al (1976) reported similar VO_{2max} values for WI and land (3.18 vs 3.92 $l \cdot min^{-1}$) ergometer cycling (N=7). Similar RER (1.08 vs 1.12) and lower HR (169 vs 130 bpm) and Ve (130.2 vs 145.9 $l \cdot min^{-1}$) values were also reported for WI compared to land cycling at maximal effort.

Sheldahl et al (1987) compared WI and land ergometer cycling HR, VO_2, CO, SV, Ve, TV and Bf responses (N=19). Similar VO_{2max} values were noted in both conditions. Exercise responses were compared during 5 minute exercise bouts at 40, 60, 80 % VO_{2max}. In both conditions workloads were matched for VO_2. Lower HR values were noted only during exercise at 80 % VO_{2max}. SV values were greater in WI at rest and exercise at 40 % VO_{2max}. A linear increase in CO values with VO_2 were reported for both conditions, however CO was higher at rest and during exercise at 40 and 60 % VO_{2max} in the WI condition. The authors observed, however, some variability (lower) in CO with WI exercise. Ve, TV and Bf were not altered at rest by the WI condition. Ve responses were similar during exercise in both the WI and land conditions. Higher Bf values were reported during WI exercise at 40 and 80 % VO_{2max}. Decline in TV response were noted in the WI condition during exercise at 80 % VO_{2max}.

Connelly et al (1991) compared VO_2, HR, RER, blood lactate and plasma catecholamine responses to upright graded WI and land cycle ergometer exercise (N=9). Similar VO_{2max} values were reported for WI and land cycling. Five minute exercise bouts were performed at 43, 61, 78-82, and 100 % VO_{2max}. Similar RER and blood glucose values were noted at each exercise intensity and at maximal effort. VO_2 values at each exercise intensity were similar. HR values were lower during exercise at and above 61 % VO_{2max}. [BLa] values were lower in the WI condition only at maximal effort. Plasma norepinephrine values were lower at and above 78-82 % VO_{2max}, whereas plasma epinephrine values were lower only at maximal effort in the WI condition.

Connelly et al (1991) concluded that plasma catecholamine responses are altered by WI. It was, however, unclear whether the decrease in norepinephrine was the result of reduced sympathoadrenal activity, or due to an increase in the clearance of epinephrine, or to an alteration in metabolic response to exercise. The lower plasma epinephrine exhibited during maximal effort was suggested that it may have served to reduce muscle glycogenolysis and thus [BLa]. It was also suggested that there may be an increase in muscle blood flow in WI, which may increase aerobic metabolism and reduce [BLa] resulting in a lower increase in plasma epinephrine. It was also suggested that plasma epinephrine and lactate clearance may be increased during maximal exercise.

The effect of the redistribution of blood volume in WI was investigated by Christie et al (1991). Land and WI VO_{2max} tests were completed on cycle ergometers (N=10). Five minute exercise bouts (matched for VO_2) were completed in the two conditions at 40, 60, 80 and 100 % VO_{2max}. No differences in resting HR, systolic blood pressure, VO_2 and VO_{2max} (43.5 vs 42.5 $ml \cdot kg^{\cdot -1} min^{-1}$) were noted on land and WI. Similar VO_2 values were reported for each exercise bout in both conditions. Lower HR values were noted for exercise at 80 and 100 % VO_{2max}.

Christie et al (1991) reported cardiac index to be higher in WI and to increase in a linear fashion with increasing VO_2. Central hypervolemia was suggested to alter the cardiac output-VO_2 relationship with upright WI exercise. The authors believe that the additional oxygen delivered by the heart may not be utilized by the exercising muscles. Stroke index increased during resting WI, with no further increases noted with WI exercise. The increase in stroke index was attributed to enhanced preload. The lower WI HR's at higher intensity workloads were suggested to be the result of reduced sympathetic neural outflow. It was suggested that reduced sympathetic neural outflow could be the result of altered baroreceptor activity caused by increased central blood volume, or increased muscle blood flow. Similar resting and submaximal HR's were suggested to be indicative of cardiopulmonary mediated vascular dilation.

In summary it appears that differences in WI and treadmill VO_{2max} and Tvent may be attributed to less familiarity of the runners to WI running and possibly not to the WI condition. HR is lower at maximal effort in WI, however, there is no clear consensus regarding submaximal HR response in WI versus land exercise. Ve is not affected by the WI condition, however Bf is higher and TV reduced during WI exercise. There is no consensus on [BLa] and RER response to WI versus land exercise, however, could familiarity to the activity soley have dictated the patterns exhibited.

2.3.2 Submaximal Prolonged Duration Exercise in Water Immersion.

Responses during submaximal exercise on the treadmill and WI running have also been investigated recently. Bishop et al (1989) compared VO_2, HR, Ve, RER, and RPE during a 45 minute subject selected pace on the treadmill and WI running (utilizing a bouyancy vest). The runners were asked to select a running pace which they could comfortably sustain for 45 minutes. The authors state that the runners were 'familiarized' with WI running and they concurrently determined their 45 minute WI running pace following only two practice trials. VO_2 in the WI run was 36 percent lower than treadmill values (ie. WI_{VO2}=29 $ml \cdot kg^{\cdot -1} min^{-1}$ vs Tr_{VO2}=40.6 $ml \cdot kg^{\cdot -1} min^{-1}$) for similar RPE responses (WI_{RPE}=12.4 vs Tr_{RPE}=11.7). Lower Ve and RER were also noted for WI versus treadmill running (ie. WI_{Ve}=58.1 $l \cdot min^{-1}$ and WI_{RER}=0.92 vs Tr_{Ve}=79 $l \cdot min^{-1}$ and Tr_{RER}=0.95). It was concluded that the metabolic cost for WI running at a preferred intensity was less than for treadmill running at a preferred intensity (Bishop et al, 1989).

Richie and Hopkins (1991) suggest that the bouyancy vest Bishop et al (1989) utilized may itself have been a limitation to simulating land running style in the WI condition, but may also have reduced the need for the runners to exercise maximally to remain afloat. However, the main contributing factors for the differences may be related to the unfamiliarity of the runners to WI running and the bouyancy vest.

Richie and Hopkins (1991) compared WI running to treadmill and road running at a hard and normal training pace in distance runners who were 'trained' in WI running technique. WI running training consisted of two sessions with instruction in WI running technique. The subjects were then asked to complete a 30 minute WI running session with VO_2, RER, HR and RPE measured and compared to 30 minutes of subject determined normal training pace and 30 minutes at a hard training pace on the treadmill and to 30 minutes of road running at their normal training pace. Higher VO_2, RER, and RPE were reported for WI running compared to normal training pace running on the treadmill. Similar HR responses were reported by the authors for WI running and normal training pace treadmill and road running. However examination of the VO_2 during these sessions reveals a higher VO_2 and RER for the WI compared to the normal training pace treadmill run, therefore HR was lower in WI relative to VO_2.

Yamaji et al (1990) compared the HR-VO_2 relationship for WI and treadmill running in a group of runners (N=10) with varying WI running abilities. Although they found no differences between the two conditions, they suggest that the (low) WI running skill level of the runners may have produced the higher HR for similar VO_2 in the WI compared to the treadmill condition. They noted that runners who had utilized WI running extensively did demonstrate lower HR values than those runners less familiar with the activity. It was noted that runners less familiar with WI running tended to utilize their upper torso to a greater degree to remain afloat.

Commonality in all three of these studies (ie. Richie and Hopkins, 1991; Yamaji et al 1990; Bishop et al. 1989), is the use of runners who were untrained in WI running. Comparisons of the physiological responses to WI and treadmill running were made at dissimilar intensities of exercise in the two activities. Consequently it is unclear from these studies whether the responses exhibited were related to the WI condition or to the samples utilized.

In summary it appears that WI running studies have compared the physiological responses of WI and treadmill running among runners with limited WI running familiarity and at absolute workloads, which most likely represent in the WI condition a higher metabolic requirement, as has been demonstrated by the WI running studies comparing treadmill and WI VO_{2max}.

2.3.3 Comparison of the specificity of training: WI versus land-based training.

Avellini et al (1983) and Sheldahl et al (1986) investigated the cardiorespiratory adaptations in males to ergometer cycling while immersed in water at shoulder and neck level respectively versus land cycling. Subjects were assigned to either the WI cycling or the land-based cycling training group. In Avellini et al (1983) the subjects trained for one hour per day, 3 times per week for 12 weeks. In Sheldahl et al (1986) the subjects trained for one hour per day, 5 days per week for 4 weeks. The intensity of training in both studies was set between 60-80% VO_{2max} and controlled for the dampened HR responses with WI (trained at a 10 bpm lower HR in WI). Training resulted in increased VO_{2max} of the same magnitude in both the WI and land training groups in both studies. Pre and post testing VO_{2max} tests were completed on the treadmill. Submaximal HR, systolic and diastolic BP were lower and submaximal SV higher at the same exercise VO_2 following training, in both the WI and land training groups.

The authors concluded that differences in physiological responses to WI versus land exercise do not alter cardiovascular adaption to exercise (Sheldahl et al, 1986; Avellini et al, 1983). The ability to stabilize the body on a cycle ergometer therefore permits central and possibly peripheral adaptations which may facilitate land-based cycling performance.

In summary it appears that the WI condition used as the training environment for cycling training does not hinder cardiovascular adaptations. Target training HR for WI exercise of 10 bpm lower than land training HR appears to have produced equivalent WI and land training programs. Consequently, it appears that submaximal HR response is lower in the WI versus land condition.

2.4 VENTILATORY THRESHOLD (Tvent) PERFORMANCE

Tvent during incremental exercise to exhaustion provides an indication of lactate steady-state (Yamamoto et al, 1991). Tvent has been identified as the point where there is a non-linear increase in excess CO_2 (Anderson and Rhodes, 1991; Loat, 1991; Rhodes and McKenzie, 1984). Ve (Davis et al, 1976), RER (Wasserman et al, 1973) and Ve/VO_2 (Ciaozzo et al, 1982; Davis et al, 1979) have also been used to identify Tvent. The use of excess CO_2 to identify Tvent has been suggested as a better indicator of metabolic acidosis in the exercising muscles, because excess CO_2 is the direct result of metabolic buffering (Loat, 1991; Anderson and Rhodes, 1991; Rhodes and McKenzie, 1984).

Tvent intensity level has been used to predict distance running performances. Rhodes and McKenzie (1984) reported a high correlation ($r=0.94$, $p<0.01$) between predicted and actual marathon times. They used the excess CO_2 curves from progressive incremental VO_{2max} tests to identify the velocity at Tvent. The runners then completed an international marathon and their completion times were compared to the predicted time from Tvent velocity. It was concluded that the velocity at Tvent represented the optimal pace to complete a marathon for trained marathoners.

Other studies have also used Tvent velocity to predict running performance for 3.2 km to 42.2 km runs (Hearst, 1982; LaFontane et al, 1981; Farrell et al, 1979). Tvent has also been used to predict steady-state cycling velocity (Loat, 1991) and Ironman triathlon performance by predicting swim, cycle and run time from Tvent pace (Langill and Rhodes, 1993).

Loat (1991) determined individual Tvent workload levels from excess CO_2 curves and then had the cyclists cycle at their determined Tvent workload for 60 minutes in the laboratory. The cyclists completed the test without significant elevations in Ve, VO_2, HR and [BLa]. Hearst (1982) noted low [BLa] maintained over time during exercise at Tvent, but elevated [BLa] (and HR, VO_2, Ve, excess CO_2) levels noted when exercising one kilometer (and 2 km) above Tvent.

In summary Tvent determined from the excess CO_2 curve represents the maximal steady state exercise intensity. Exercising at Tvent intensity appears to allow prolonged exercise without elevations in [BLa], VO_2, Ve and HR.

CHAPTER 3

3.0 METHODS AND PROCEDURES

This study examined and compared maximal oxygen consumption (VO_{2max}) and ventilatory threshold (Tvent) responses on treadmill and water immersion to the neck (WI) running in a group of elite distance runners, trained in deep water running. Forty two minute performance tests at each runner's treadmill and WI Tvent values were thereafter completed and minute ventilation (Ve), oxygen consumption (VO_2), heart-rate (HR) and blood lactate concentration ([BLa]) values were measured. Subjects completed all testing within a 2.5-4 week period with VO_{2max} tests separated by at least 5 days. Tvent performance tests were completed with a minimum one day rest period.

3.1.0 SAMPLE

Thirteen elite distance runners 'trained in WI running' with a minimum VO_{2max} of 50 $ml \cdot kg^{\cdot -1} min^{-1}$ and 60 $ml \cdot kg^{\cdot -1} min^{-1}$ for the female (5) and male (8) runners, respectively participated in the study. Ten of thirteen elite distance runners 20 to 35 years of age who volunteered completed all testing required for the study. This sample consisted of 4 female and 6 male runners. Complete results for only the treadmill and WI VO_{2max} tests are available on the three remaining subjects (N=3) and they have been included for the VO_{2max} section of the study analysis. The subjects ranged in age from 21 to 35 years of age. They competed in distance events which ranged from 800 meters to marathon and ultramarathon distances and were trained in WI running. The goal of this study was to utilize runners who regularly incorporated WI running in their training regimens and simulated in their WI running style certain key land-based running motions.

This study defined an elite distance runner trained in WI running as one who incorporates in their training regimen a minimum of 6 sessions (approximately 45-60 minutes per session) per month of WI running for the former 6 months prior to their participation in this study. Only runners who practiced non-weight bearing WI running were accepted in the study. WI running style was assessed during a WI running session with the investigator and during the WI VO_{2max} test. An underwater video camera was used to videotape each subject's WI running style, initially unattached to the pulley system and then during the WI VO_{2max} test. The videotaped WI running performances were assessed for comparability to land-based running motion. Subjects who met WI running style and training criteria were kept in the study. It was not the intention of this study to do a biomechanical analysis, but only to maintain similar basic running styles in WI as on the treadmill.

Three criteria were set to evaluate WI running style which had to be met by each subject to participate in the study. If the criteria were not met the runner was excluded. The 3 criteria were the following:

i) The trunk remained upright with respect to the scaling grid. A foward lean of up to 45 degrees was deemed acceptable.

ii) Unilateral foward motion of the arms and legs was followed, specifically:

a) The lower right knee was brought foward and upward, in the recovery phase of the right leg cycle. When the thigh reached a horizontal or near horizontal position the lower leg swung forward. The right leg began to descend and the left leg began to move forward.

b) The arms were flexed at approximately right angles with the elbows. The left arm was swung foward as the right knee swung foward and backward and the right leg descended.

iii) The hands were not used to significantly propel the runner. To prevent cupping of the water and thus excessive use of the upper body musculature and excessive foward lean, the subjects were instructed to hold small sponges in either hand during the water tests.

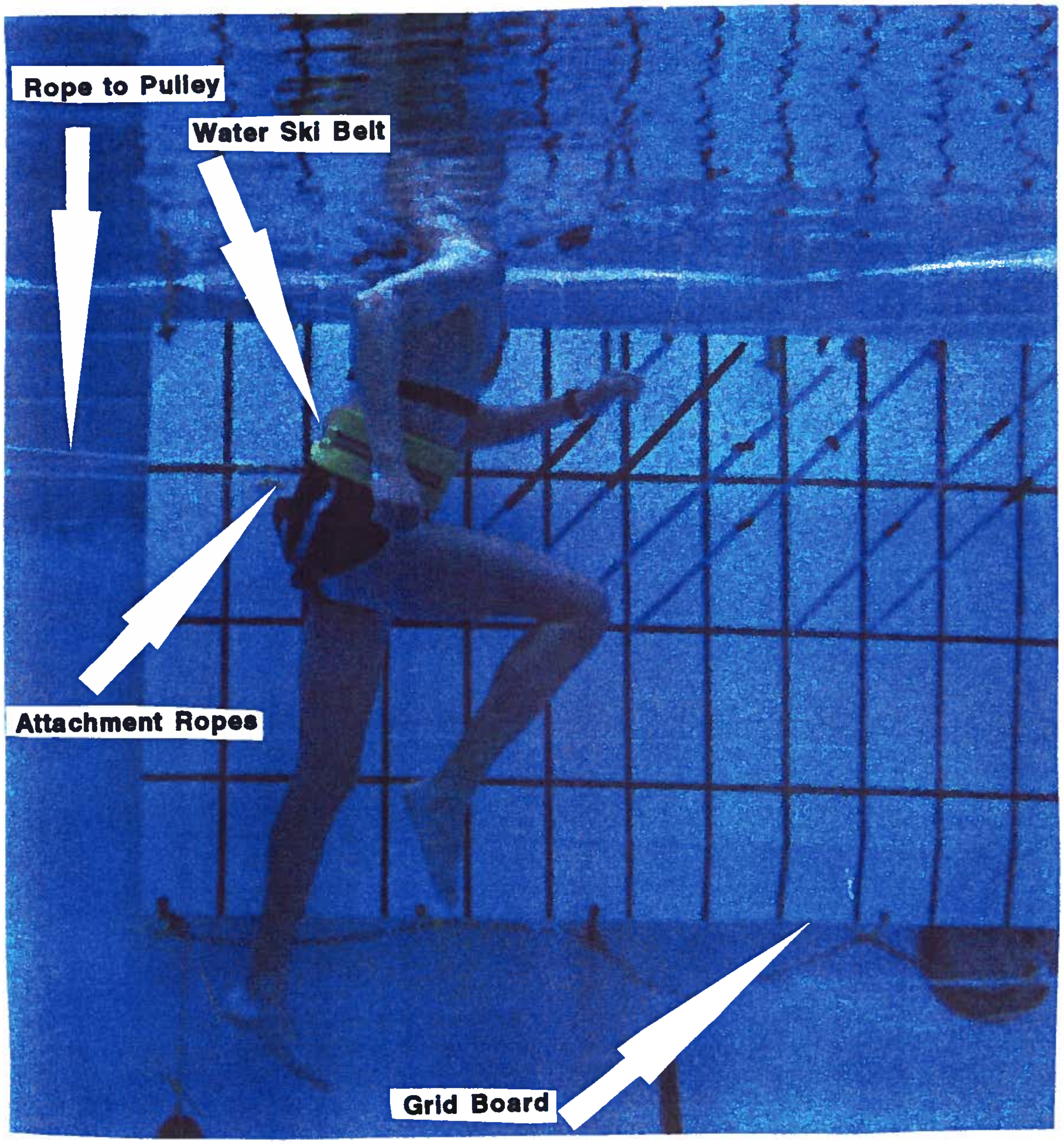


Figure 2. Underwater photograph of a subject WI running. The subject runs in deep water and there is no weight bearing involved. The subject is instructed to simulate land-based running motion and remain in an upright posture, while WI running. The grid board, situated behind the runner serves to assess his forward lean. A maximum lean of 45 degrees is deemed acceptable and is depicted by the diagonal lines on the board. The water ski belt can be seen worn by the subject around his waist. Worn underneath the water ski belt is the waist harness. The attachment ropes connect to the waist harness and lead to the pulley system of the WI ergometer.

3.2.0 PHYSIOLOGICAL TEST EQUIPMENT

The following equipment were used for physiological testing:

1) Beckman Metabolic Cart was utilized to measure expiratory gases and volumes (VO_2, VCO_2, Ve, tidal volume (TV), breathing frequency (Bf)). The Hewlett Packard 3052 A Data Aquisition system was used to process the metabolic data collected and obtain Ve (in STPD), $ExCO_2$ and Ve/VO_2 calculations. Expired gases were sampled at 30 second intervals by the metabolic cart.

2) Two HR monitor models were utilized for HR sampling. The POLAR ACCUREX and the POLAR FAVOR HR monitors were utilized. The POLAR ACCUREX was utilized for all treadmill tests. The POLAR ACCUREX was used in conjuction with the POLAR FAVOR for WI tests, when possible (the 2 HR monitors transmitted at different frequencies). The POLAR ACCUREX HR monitor was worn at the level of the sternoxiphoid junction (for treadmill and WI testing) and the POLAR FAVOR was worn at the level of the third rib (for WI testing) (see Figure 3 for HR monitor placement for WI testing.

A nylon spandex sports top was worn by the male subjects during WI testing. These latter two steps were taken primarily to avoid loosing HR values during WI testing. This occurred often with the male subjects and was due to water moving freely between the subjects' sternum and the HR monitor belts. This inhibited continuous contact of the HR monitor belt with the subjects' chest and therefore the HR signal would be lost.

3) Water ski belt was worn by the subjects around the waist for the WI running tests. This was a limited buoyancy devise providing enough buoyancy to limit upper body musculature involvement during WI running for the purpose of remaining afloat. The buoyancy section was worn in the front (on the abdominal region) versus the back, which caused the subjects to lean foward excessively due to the belt rising up their back (see Figure 2 and 3).

3) Kontron Medical LA640 Blood Lactate Analyzer was used to analyze [BLa] samples. Twenty microliter blood samples were drawn from the fingertip and immediately haemolyzed. The blood samples were then placed in the refrigerator and later analyzed for lactate content (in mmol/l blood) with the lactate analyzer.

4) Quinton 24-72 treadmill was used for treadmill tests.

5) A modified tethered swimming apparatus (ie. WI ergometer) was used for the WI tests (see section 3.4.3 for description and Figure 4 for picture).

6) Underwater film assessment recorder was used for underwater videotaping of WI running.

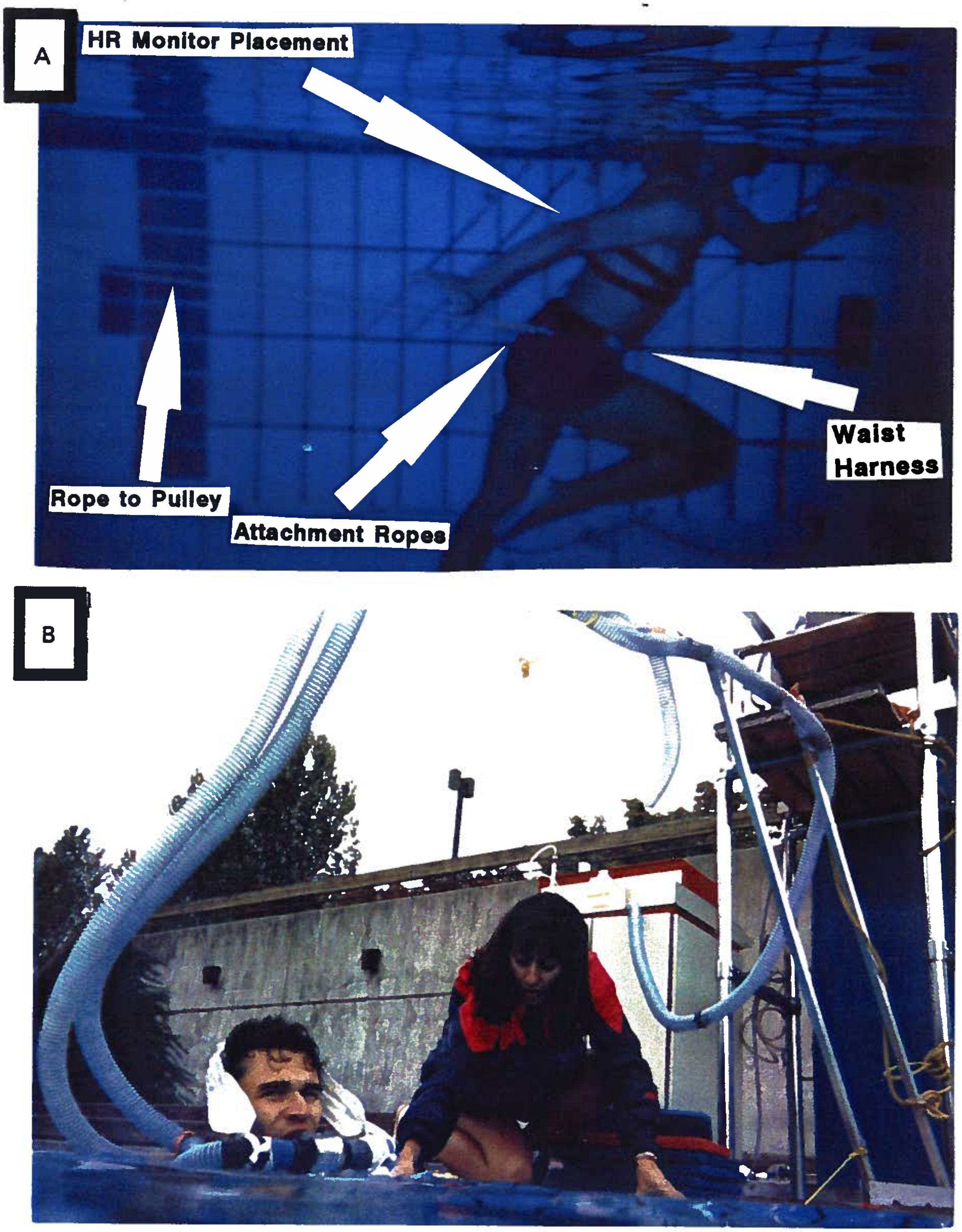


Figure 3. WI running; an above and below surface picture. A. Underwater picture of a subject WI running. The waist harness is shown in this picture. During testing the water ski belt would be worn on top of this harness (see Figure 2). Also shown are the positions of the 2 HR monitors worn for WI running testing. B. Mouthpiece apparatus assembly for WI running testing is shown. The mouthpiece is secured on the subject with head support for VO_{2max} testing.

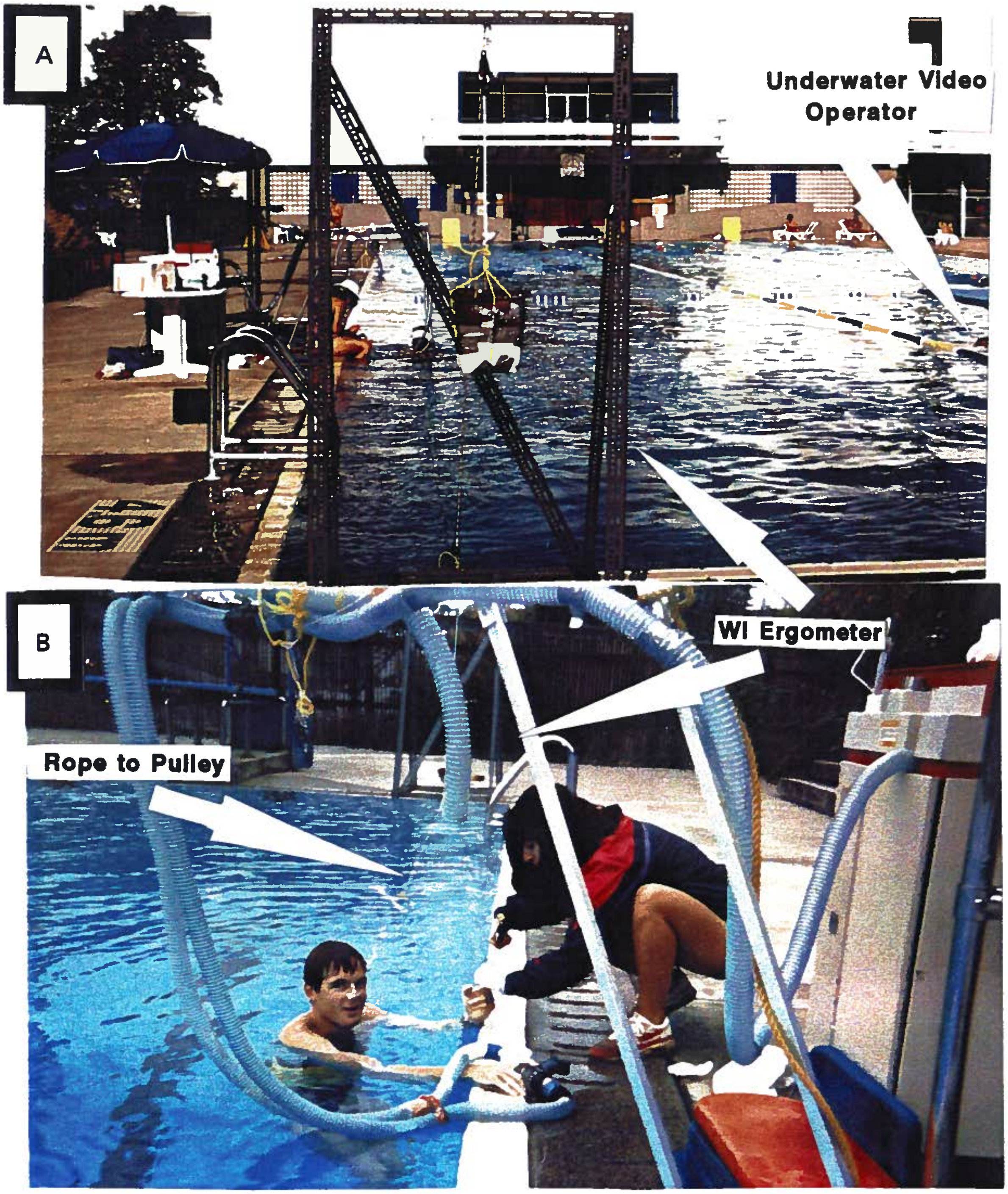


Figure 4. WI running set-up. A. Picture of the WI running set-up from behind the WI ergometer. The WI ergometer is a simple frame equipped with 2 pulley systems and is positioned at the edge of the pool. The rope which attaches to the waist harness runs through the lower and upper pulley systems of the WI ergometer and finally attaches to the loading bucket. The position of the subject and metabolic equipment are visible in the far distance. The position of the video operator relative to the subject is also shown in this picture. B. This picture provides a forward view of the WI set-up. In this picture the investigator can be seen obtaining the final blood lactate sample from a subject following a steady state test. The mouthpiece apparatus and metabolic measurement equipment are visible. The WI ergometer position is also visible in the background. Note the different orientation of the mouthpiece for the steady state Tvent tests versus the VO_{2max} tests (see Figure 2 B). This was to allow for ease of insertion and removal during these tests.

3.3.0 UNDERWATER FILM ASSESSMENT APPARATUS AND PROCEDURES

A grid board and an underwater video recorder were utilized to monitor WI running motion. The grid board measured 1.2 X 2.4 meters and was immersed, longest side across, along the pool wall. Vertical and horizontal lines (2.5 cm in width, vertical lines were spaced 15 cm apart, and horizontal lines were spaced 30 cm apart) were painted on the board. A 2.5 cm tape in bold colours was placed along the grid board at 45 degree angles with their point of initiation 0.76 meters from the top of the grid board. This level was determined to approximate on average the location of the pelvis area. Hooks attached the grid board to the pool deck and weights attached to the lower end of the board prevented excessive movement of the immersed grid board due to water turbulence (see Figure 2 and 3 for a schematic presentation).

The underwater video camera was used to tape the WI VO_{2max} tests. The subject was positioned at the center of the grid board and there was relatively little motion of the subject in relation to the grid board during the WI VO_{2max} test. The video operator videotaped from a stationary position 6 feet in front of the grid board (ie. the sagital view was videotaped) (see Figure 4). The video operator was instructed to videotape the whole grid board and the limbs of the subject. The video operator was thus filming a 2.4 X 1.7 meter area. Filming began 30 seconds prior to test initiation. Test initiation was signalled on the videotape by the investigator waving her arm or a small board across the grid board under the water.

3.4.0 TREADMILL AND WI VO_{2max} AND Tvent PERFORMANCE TEST PROTOCOLS AND PROCEDURES

3.4.1 Treadmill and WI VO_{2max} Common Procedures

Subjects were asked to refrain from eating 2 hours prior to test time and from heavy training on test day. Subjects reported to the laboratory and following the subjects' self selected warm-up (with respect to pace and duration), height and weight measurements were taken. Expired gases were sampled by a Beckman Metabolic Cart during the VO_{2max} tests every 30 seconds. Heart-rates were recorded during the last 5 seconds of each minute utilizing the HR monitors. Subjects were instructed to point to their percieved exertion rating (Borg scale from Borg, 1970) every 2 minutes 45 seconds into the workload.

At test termination a blood lactate sample was obtained within the first minute post-test (within 30 seconds post-test). At 5 minutes post-test an additional blood lactate sample was obtained. The same procedures were followed for the treadmill and WI tests. In the case of the WI VO_{2max} test the subject was instructed to come out of the pool after the first lactate sample was obtained and the second [BLa] sample was obtained on the pool deck (see Figure 6 for a schematic diagram of VO_{2max} test procedures).

3.4.2 Treadmill VO_{2max} Test Protocol and Procedures

The treadmill VO_{2max} protocol followed a continuous progressive regimen. The treadmill speed commenced at 5 mph and was increased every 60 seconds by 0.5 mph. If the treadmill speed reached 12 mph at minute 15 of the test, the speed was no longer increased instead the treadmill grade was increased every following minute by 2 percent until physiological or volitional fatique (see Figure 5). The increase in percent grade was introduced to ensure that a true maximum was achieved and to prevent the treadmill speed exceeding the runner's running skill or capabilities before achieving a true VO_{2max}. The duration of the protocol ranged from 12 to 19 minutes (mean test duration was 14.5 minutes, Table 2).

A 5-25 minute warm-up preceeded the test and the intensity of the warm-up was subject selected. Height and weight were then assessed and the HR monitor, nose clip and mouthpiece secured on the subject. The subject was then instructed to run on the treadmill (treadmill speed=5 mph) and the test commenced within 2 to 3 minutes following final adjustments to mouthpiece position (see Figure 6 for VO_{2max} procedures).

Termination of the test was defined by exhaustion characterized by the point when the subject experienced at least two of the following criteria: 1) volitional fatigue, 2) a plateau in VO_2, 3) an RER $\geq$ 1.10.

3.4.3 WI VO_{2max} Test Protocol, Procedures and Equipment

The WI VO_{2max} protocol followed a continuous progressive model and was designed to resemble the treadmill protocol in loading progression and duration. The goal was to produce a linear progression of Ve, VO_2 with a distinct 'breakaway' point in order to establish the Tvent, but also to ensure that the duration of the test was similar to the treadmill protocol (that is 12 to 19 minutes). Thoden et al (1987) suggest that measurement of cardiorespiratory parameters begin from power outputs which represent 20 % of a subject's VO_{2max}. The protocol which was originally proposed to be utilized for the WI VO_{2max} test was by Welsh (1988). This protocol, however, produced initial power outputs which would represent 45 to 52 % of the present study's subjects' VO_{2max} values. The protocol was revised to meet this study's goals and to account for sex differences in size, muscle mass and possibly the lower fitness level of this study's population of runners from which the sample was drawn.

The water immersion running ergometer (IRE) utilized by Welsh (1988) was used in this study with slight modifications. The IRE was a modified tethered swimming apparatus. It was a rectangular shaped 2.5 meter high frame which sat at the edge of the pool. At the top extension rod a pulley system of low resistance was attached and marine rope of 1.5 cm diameter passed through. Another pulley system (this one was a double pulley system) was secured on the bottom rod, which was 1 m in front of the top rod, and the marine rope was passed through this system. The rope finally attached to a 6 cm flat waist harness which was worn by the subject (see figure 2 to 4) and reached the center of the grid board. The rope at the other end of the pulley system was attached to a bucket, which was loaded with weights for the WI tests.

For all WI tests the subjects were immersed to the neck and wore a water ski belt around their waist (with the flotation segment situated around the abdominal area, see Figure 2 and 3). This belt was worn above the waist harness. The IRE was placed by the end of the pool with the lower pulley rod extending over and into the pool surface. Four meters of rope was passed through the pulley system, in order to position the subject in the middle of the grid board. The subjects were required by correct running motion to maintain the bucket 6 cm from the top pulley system for the duration of the test. A $\pm$ 4 cm variation in the position of the bucket was allowed.

The WI VO_{2max} test required the subject to maintain his/her position in the water (and thus the bucket position stationary) with progressive increased loading. A point of reference was placed 1 m in front of the subject as a point of reference for the subject. With increasing load per minute the subject would be forced to run faster and faster (ie. increase their cadence, length and power) to displace more water in order to maintain his/her position. The protocol and subject would thus be simulating treadmill performance which forces the subject to run faster and faster with increasing velocity until fatigue.

The bucket on the IRE was initially loaded with 500 gram (g) and 750 g weights, respectively, for the females and males. After minute 1 the load was increased by 400 g/min for both females and males until minute 15. On minute 15 and until exhaustion the load was increased by 500 and 750 g/min respectively for the females and males, with the goal being to simulate the change to increasing grade on the treadmill protocol (see figure 5 for comparison of the treadmill and WI VO_{2max} protocols).

Termination of the test was defined as the point of exhaustion characterized by the following: 1) the subject was no longer capable of maintaining his position, and thus the position of the bucket relative to the top pulley system was greater than 11 cm, 2) volitional fatigue, 3) a plateau in VO_2 for more than 1.5 minutes, 4) RER $\geq$ 1.10. Meeting the first criterion and at least two of the other criteria were neccessary to establish VO_{2max}. Post-test evaluation of maximal effort included the comparison of post-test peak [BLa] values to treadmill values. The test protocol was approximately 12 to 19 minutes in duration (mean test duration was 15.0 minutes, see Table 2).

WI running motion was also subjectively monitored during the test by the investigator to ensure acceptable running motion (discussed in section 3.1) in addition to underwater videotaping. A foward lean greater than 45 degrees relative to the grid board and excessive use of the upper body musculature also resulted in early termination of the test. Underwater videotaping was used to assess WI running motion post-test and if the subject's running motion deviated from the study's set criteria, the test and subject were not used in the study's results.

Deviation of WI running motion from the set criteria during the last 2 to 3 minutes of the test with an RER between 1.10-1.20, resulted in consideration that VO_{2max} was reached prior to deviation in acceptable WI running style. The VO_2 prior to running style deviation was accepted as the subject's VO_{2max}. The rationale for this exception was based on the premise that when on the treadmill and the subject reaches exhaustion he/she can no longer maintain the treadmill pace and must either step off or risk falling on the treadmill. The subject, however, does not

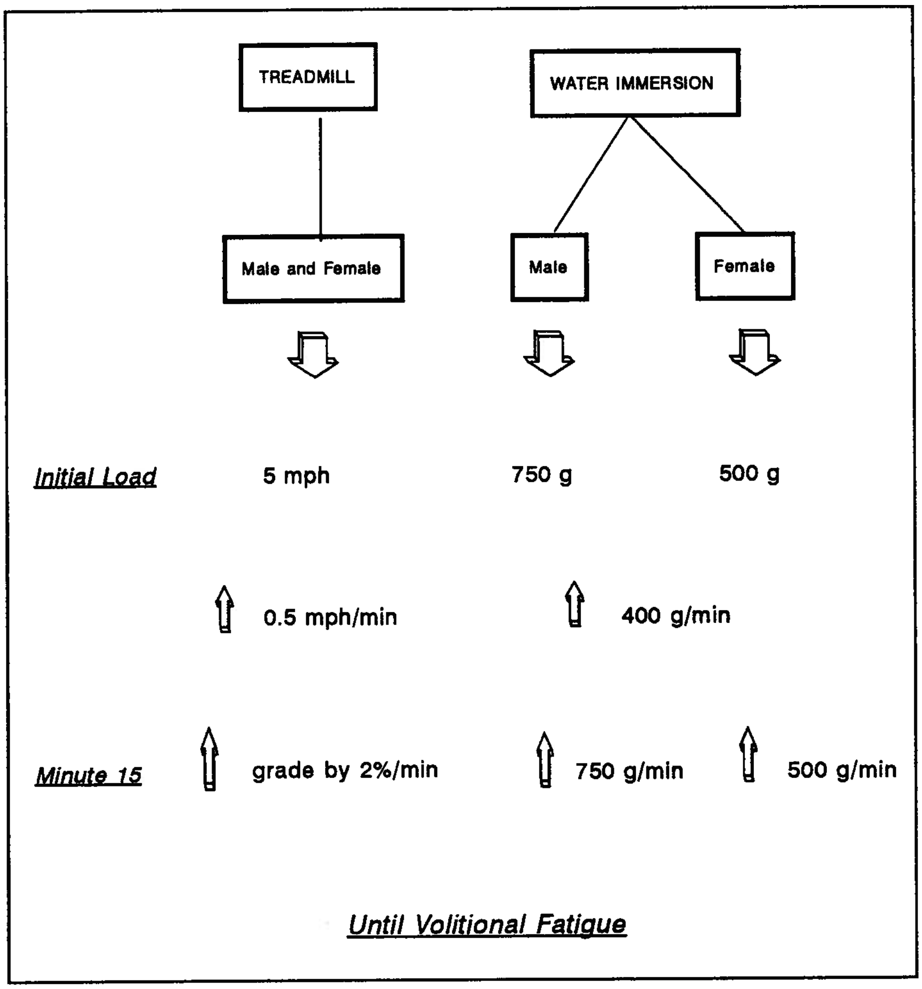


Figure 5. Treadmill and WI VO_{2max} Protocol description. WI VO_{2max} test loading differed by gender. The loadings were higher for male runners.

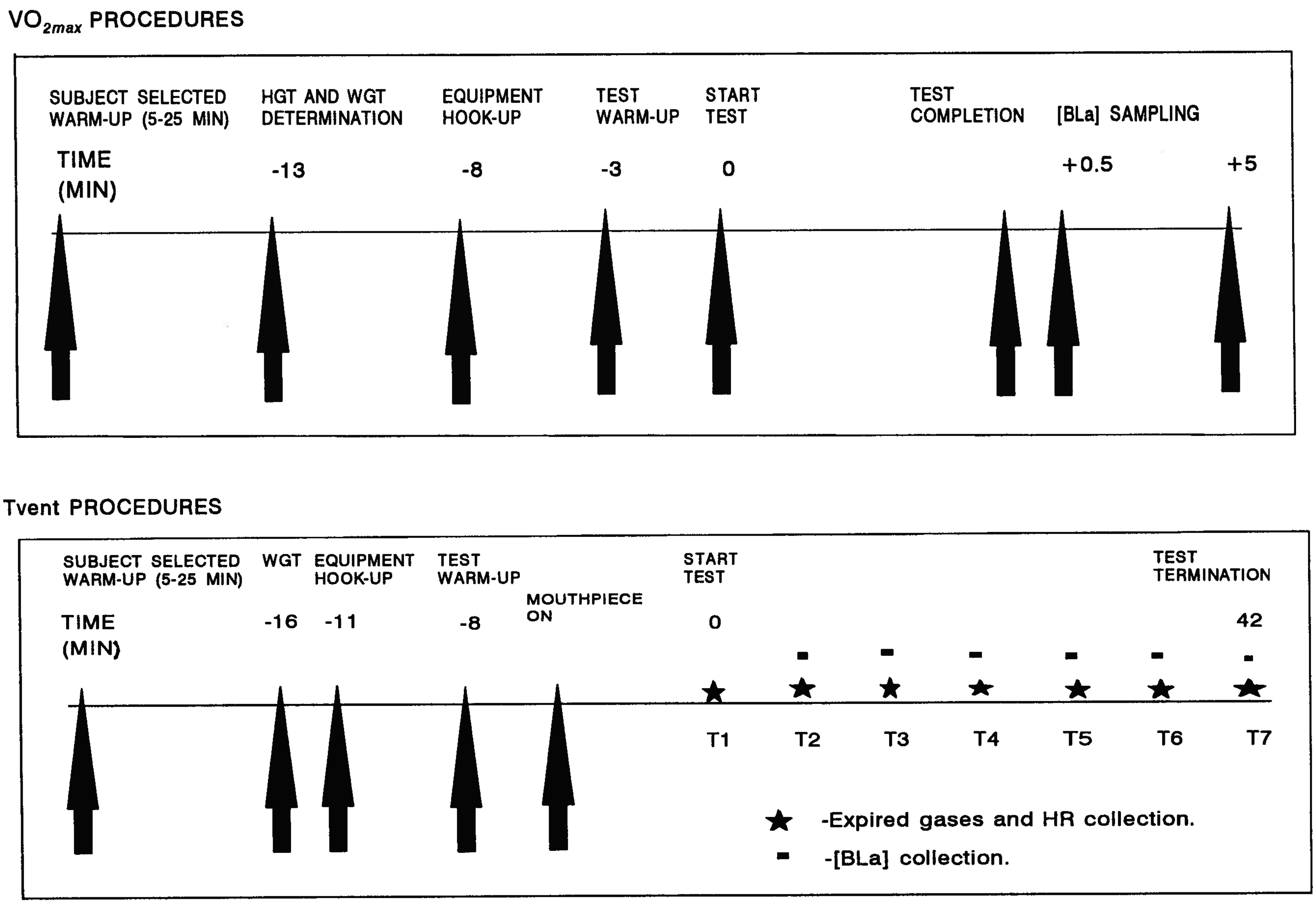


Figure 6. VO_{2max} and Tvent tests schematic representation of procedures.

experience the same fear with WI running. When the subject can no longer maintain his/her position in the water, the subject is either pulled back as the bucket goes down or begins utilizing non-fatigued musculature to remain afloat and maintain their position. In the latter case the subject increases arm and shoulder contribution. The elbows are pushed out to the sides, in line with the shoulders and the hands used to cup the water. This action also results in increasing foward lean of the subject beyond 45 degrees.

3.4.4 Ventilatory Threshold Determination

Excess CO_2 ($ExCO_2$) was plotted against time for the treadmill and WI VO_{2max} test for each subject. Tvent was determined as the point where the slope of $ExCO_2$ increased disproportionately (Anderson and Rhodes, 1991; Loat and Rhodes, 1991; Anderson and Rhodes, 1989; Rhodes and McKenzie, 1984; Volkov et al, 1975) and was established independently by two to three reseachers. The corresponding minute VO_2 values were calculated at Tvent. The treadmill velocity and WI loading at the Tvent levels were used to approximate the woakloads for the Tvent performance tests. The Ve/VO_2 plotted over time (to locate the 'break-away' point) and an RER near 1.00 were also used to substantiate Tvent (see Appendix G).

3.4.5 Tvent Performance Tests

Four Tvent performance tests were completed by each subject and these were:

$Tr_{TrTvent}$ (treadmill Tvent performed on the treadmill)

$Tr_{WITvent}$ (WI Tvent performed on the treadmill)

$WI_{WITvent}$ (WI Tvent performed in WI)

$WI_{TrTvent}$ (treadmill Tvent performed in WI)

The minute VO_2 (in $ml \cdot kg^{\cdot -1} min^{-1}$) values from the treadmill and WI Tvent extrapolations were used to determine the test workloads for all test conditions. Similarily to the VO_{2max} tests, the subjects completed their self selected warm-up (5-25 minute duration) and then had their body weight measured and equipment fitted, except for the mouthpiece. During the Tvent test warm-up the subjects were progressively loaded, or the treadmill velocity increased with HR monitored. Once a HR was achieved just below the anticipated HR at Tvent the subject was asked to put the mouthpiece on (with assistance). While continuing to run, expired VO_2 was monitored and treadmill velocity (or WI loading) manipulated until the desired minute VO_2 at Tvent was obtained. Once the workload at the respective Tvent was obtained expired gases were monitored for 2-3 more minutes to ensure that the minute VO_2 was maintained within the acceptable range. Minute VO_2 values $\pm$ 0.5 ml/kg/min of the VO_2 at Tvent were deemed acceptable and data collected during this period signaled commencement the of the Tvent test and was identified as collection interval T1. The total process for reaching Tvent workload was established within 4-5 minutes.

HR, VO_2, Ve were monitored and collected for 1.5 minutes at test initiation (T1) and at 6.5-8.0 min (T2), 13.5-15.0 min (T3), 20.5-22.0 min (T4), 27.5-29.0 min (T5), 34.5-36.0 min (T6) and 40.5-42.0 min (T7).

Blood lactate samples were drawn during collection periods T2 through T7. Blood lactate samples were obtained following the last expired gas collection for the interval by the metabolic cart. Expired gases (and HR) were continously sampled every 30 seconds during the stated time intervals for the treadmill and WI Tvent performance tests (see figure 6 for schematic diagram of Tvent steady state prolonged performance test procedures).

3.5.0 EXPERIMENTAL DESIGN

The independent variables in this study were Condition (environmental) (factor 1) and Tvent (factor 2), with 2 levels each. The two levels of factor 1 were the treadmill and WI (to the neck) conditions. The two levels of factor 2 were treadmill Tvent (Tr_{Tvent}) and WI Tvent (WI_{Tvent}), determined from the treadmill and WI VO_{2max} tests, respectively.

The experimental design for the VO_{2max} test data for hypotheses 1 and 2 can be treated as a one way within subject comparison (of VO_{2max} and Tvent) under two different conditions (treadmill versus WI). VO_{2max} and Tvent were treated as the main dependent variables.

The dependent variables for the Tvent steady state prolonged performance tests were exercise HR, VO_2, Ve and [BLa]. The experimental design for the Tvent test data, for hypotheses 3, 4 and 5 (ie. HR, VO_2 and Ve), were treated as a 2 X 2 X 7 within subject design with repeated measures on all 3 factors (ie. Condition, Tvent, and Time).

The experimental design for the Tvent test data for hypothesis 6 (ie. [BLa]), were treated as a 2 X 2 X 6 within subject design with repeated measures on all 3 factors (see Figure 7).

A counterbalanced single factor design with 4 treatments was employed. The treatments were the 4 Tvent intensity steady state prolonged performance tests, that is $Tr_{TrTvent}$, $Tr_{WITvent}$, $WI_{TrTvent}$ and $WI_{WITvent}$.

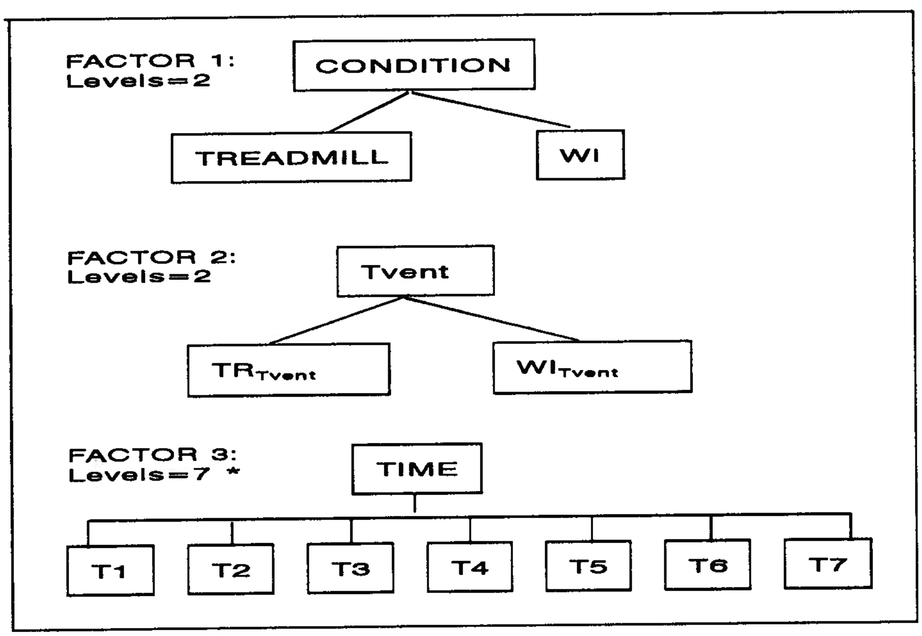


Figure 7. Diagram of the factors and levels of the experimental design. The study examined whether the Condition (WI vs treadmill), Tvent (WI vs treadmill) and Time (over the 42 minute tests) factors, were responsible for the differences in physiological and metabolic function. The contribution of each factor separately and in combination with the other two factors were explored with repeated measures analysis of variance and trend analysis (see section 3.6.0).
*- 6 levels for [BLa], starting at T2.

3.6.0 STATISTICAL ANALYSIS

The data collected was analyzed as follows:

1) Correlated T-Tests were conducted to test Hypotheses 1 and 2 regarding the comparison of treadmill versus WI VO_{2max} and treadmill versus WI Tvent (VO_2 at Tr and WI Tvent). Differences in HR, Ve, RER, RPE, test duration at VO_{2max} and Tvent and post-test [BLa] at 30 seconds and 5 minutes from the VO_{2max} tests were also analyzed in the two conditions using correlated T-Tests.

2) 2 X 2 X 7 within subject repeated measures analysis of variance with trend analyses were utilized to test hypotheses 3 to 5 regarding differences in VO_2, HR, and Ve over Condition, Tvent and Time. Two 2 X 7 within subject repeated measures analysis of variance with trend analysis were used to specifically compare $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$.

3) 2 X 2 X 6 within subject repeated measures analysis of variance and trend analysis was used to test hypothesis 6 regarding differences in [BLa] over Condition, Tvent and Time. Two 2 X 6 within subject repeated measures analysis of variance with trend analysis were used to specifically compare $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$.

CHAPTER 4

4.0 RESULTS

4.1.0 Physical Characteristics of the Sample

The sample consisting of five (5) female and eight (8) male endurance runners trained in water immersion running to the neck (WI) (ie. simulating land-based running style and with minimum WI running experience of 6 months) were selected for this study. Three subjects (one female and two males) have complete data on only the two maximal oxygen consumption tests (VO_{2max}) (ie the treadmill and the WI VO_{2max} tests) due to technical difficulties in completing the remaining steady state performance tests and have only been used for the VO_{2max} results analysis. The female and male subjects had to demonstrate a minimum treadmill VO_{2max} of 50 and 60 $ml \cdot kg^{-1} min^{-1}$ respectively for induction into the study. Table 1 contains the mean physical characteristics of the subjects and mean treadmill VO_{2max} by gender.

Table 1.0. Physical Characteristics and Treadmill Maximal Oxygen Consumption of the Sample.

VARIABLE	FEMALE (N=5)		MALE (N=8)	
	Mean (std)	Range	Mean (std)	Range
Age (yrs)	24.2 (6.7)	18.0 - 35.0	27.3 (4.1)	22.0 - 34.0
Height (cm)	165.6 (4.3)	159.7 - 170.9	182.5 (5.0)	174.7 - 191.0
Weight (kg)	54.2 (4.9)	49.2 - 61.1	71.5 (4.6)	67.7 - 79.4
VO2max (l/min)	2.91 (0.29)	2.60 - 3.17	4.56 (0.36)	4.18 - 5.03
VO2max (ml/kg/min)	53.7 (4.2)	50.5 - 61.0	63.4 (4.2)	60.0 - 72.7

4.2.0 Maximal Oxygen Consumption (VO_{2max}) Test Results

The purpose of the first part of this study was to compare maximal and Tvent responses from the progressive incremental loading to exhaustion (ie. VO_{2max}) tests on the treadmill and WI. The 3 main criteria set to control subject selection a priori were a) WI running style, b) familiarity with WI running and c) minimum treadmill VO_{2max} (of 50 and 60 $ml \cdot kg^{-1} \cdot min^{-1}$ for female and male runners respectively) for classification as an 'elite distance runner familiar with WI running' (see Methods and Procedures chapter). The thirteen subjects included in the present study met the above set a priori criteria.

4.2.1 Maximal Responses

The treadmill running (Tr) VO_{2max} was significantly higher, both expressed in $l \cdot min^{-1}$ ($p<0.05$) and in $ml \cdot kg^{-1} \cdot min^{-1}$ ($p<0.05$), when compared to the water immersion running (WI) VO_{2max} (Figure 8.0 A and B, respectively). The lower WI_{VO2max} was accompanied by significantly lower maximal heart-rate ($p<0.05$) (Figure 8.1 A) and RER ($p<0.05$) (Figure 8.2 A) responses. However there were similar minute ventilation (Ve) responses ($p>0.05$) (Figure 8.1 B), ratings of perceived exertion (RPE) ($p>0.05$) (Figure 8.2 B) and post-test blood lactate concentrations ([BLa]) (both for 30 sec. ($p>0.05$) and 5 min. post-test ($p>0.05$) values) (Figure 8.3 A) for both protocols. The duration of the WI_{VO2max} and Tr_{VO2max} tests were similar ($p>0.05$) (Figure 8.3 B). See Table 2 mean values ($\pm$std) for maximal responses of VO_2, HR, Ve, RER, RPE, [BLa], and test duration.

Table 2.0. VO_{2max} Results : Maximal Responses.

CONDITION	TREADMILL	WI	(T-TEST)
VARIABLE	Mean (std)	Mean (std)	p-value
VO2 (l/min)	3.92 (0.89)	3.60 (0.78)	0.001
VO2 (ml/kg/min)	59.7 (6.4)	54.6 (5.2)	0.001
HR (bpm)	190 (11)	175 (12)	0.001
Ve (l/min)	109.0 (22.7)	105.8 (19.1)	0.73
RER	1.20 (0.08)	1.10 (0.06)	0.003
[BLa]-30 sec.-post	10.4 (1.9)	9.8 (2.3)	0.24
[BLa]-5 min.-post	9.7 (2.0)	9.2 (2.5)	0.57
Test Duration (min)	14:30 (2:00)	15:00 (2:40)	0.37
RPE	20 (0)	20 (0)	1.00

4.2.2 Ventilatory Threshold (Tvent) Responses

The treadmill ventilatory threshold (Tr_{Tvent}) (ie. VO_2 at Tvent) was significantly higher, expressed in $l \cdot min^{-1}$ ($p<0.05$) and in $ml \cdot kg^{-1} \cdot min^{-1}$ ($p=0.03$), when compared to the water immersion ventilatory threshold (WI_{Tvent}) (Figure 8.0 A and B). When Tvent was expressed as a percentage of the respective VO_{2max} results the Tr_{Tvent} and the WI_{Tvent} occurred at approximately 78 percent ($p>0.05$) (Figure 8.4). A significantly lower WI_{Tvent} versus Tr_{Tvent} heart-rate response was exhibited ($p<0.05$) (Figure 8.1 A) and the WI_{Tvent} occurred approximately 2 minutes earlier in the Tr_{Tvent} ($p<0.05$) (Figure 8.3 B). There were no significant differences in Ve ($p>0.05$) (Figure 8.1 B), RER ($p>0.05$) (Figure 8.2 A) and RPE ($p>0.05$) (Figure 8.2 B) responses at Tr_{Tvent} and WI_{Tvent}. See Table 3 for mean values ($\pm$std) for Tvent responses of VO_2, HR, Ve, RER, RPE, [BLa], test duration, and % VO_{2max}.

Table 3.0. VO_{2max} Results : Results at Tvent.

CONDITION	TREADMILL	WI	(T-TEST)
VARIABLE	Mean (std)	Mean (std)	p-value
VO2 (l/min)	3.03 (0.74)	2.81 (0.69)	0.04
VO2 (ml/kg/min)	46.3 (6.4)	42.8 (5.1)	0.03
HR (bpm)	165 (10.8)	152 (12)	0.002
Ve (l/min)	66.4 (16.4)	65.7 (16.0)	0.73
RER	0.99 (0.04)	0.98 (0.04)	0.45
% VO2max	77.7 (6.8)	78.3 (4.7)	0.76
Tvent Time (min)	8:10 (2:00)	6:20 (2:00)	0.004
RPE	13 (2)	12 (2)	0.13

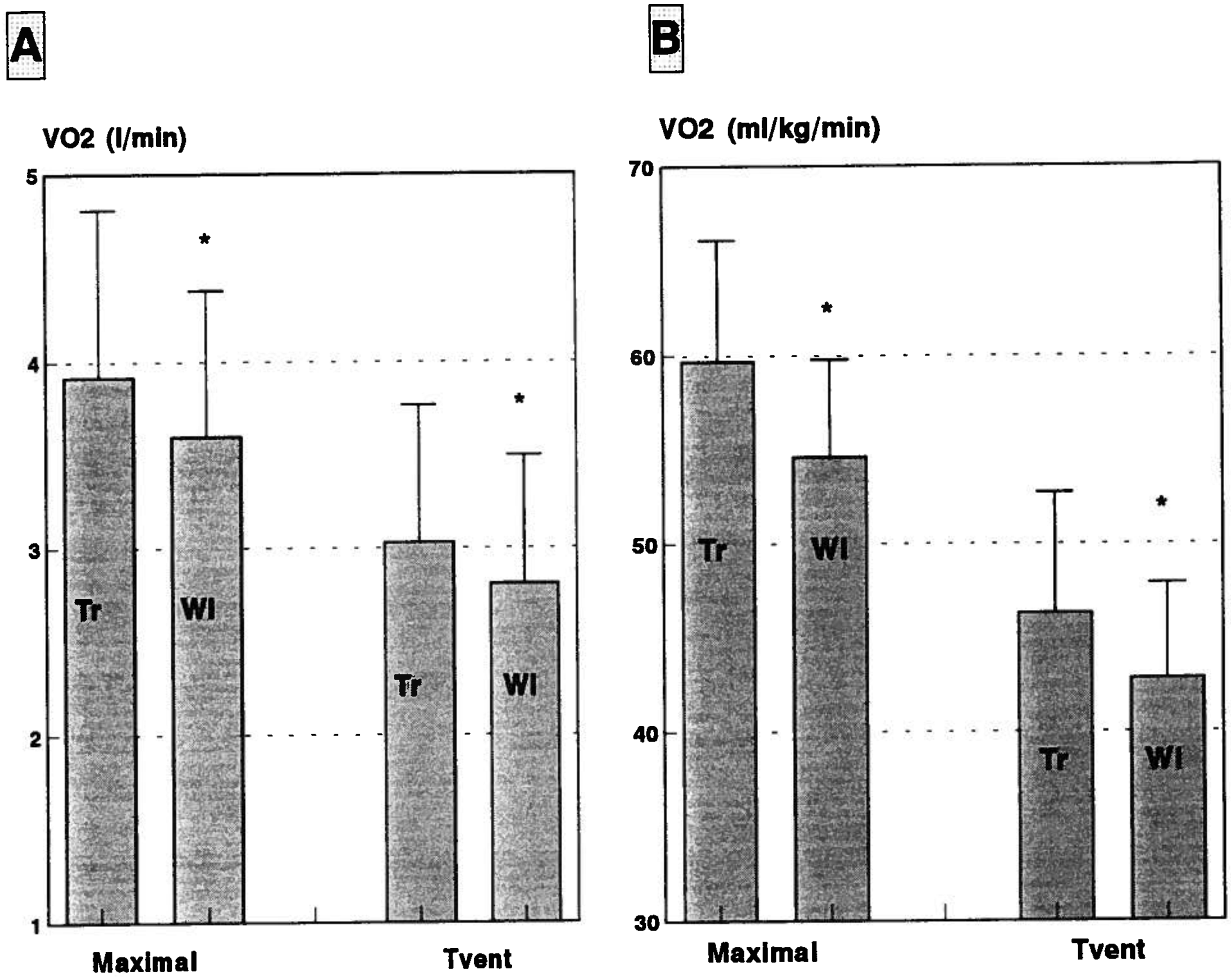


Figure 8.0. Mean oxygen consumption (+1 std) at maximal effort and Tvent level from the treadmill (Tr) and water immersion (WI) VO_{2max} tests. A. Absolute oxygen consumption ($l \cdot min^{-1}$) at VO_{2max} and Tvent. B. Relative oxygen consumption ($ml \cdot kg^{-1} min^{-1}$) at VO_{2max} and Tvent. * Significant differences at a=0.05.

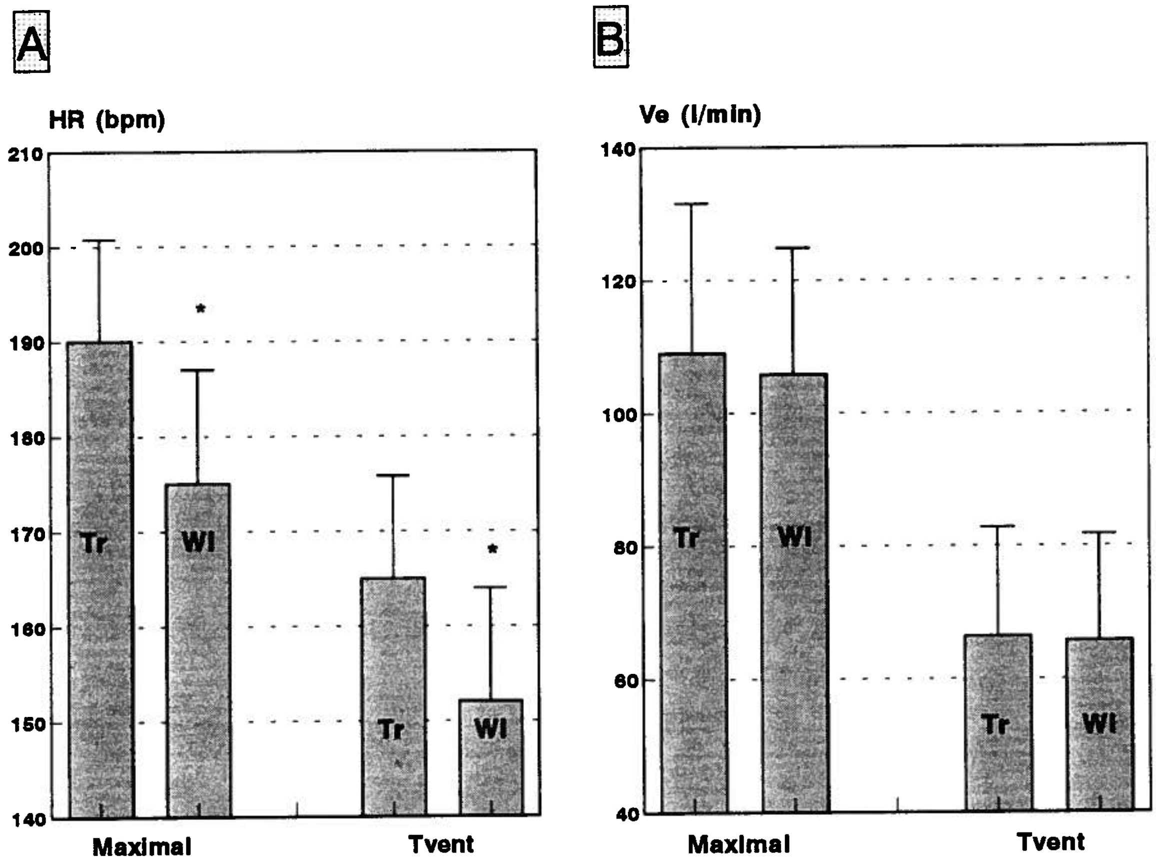


Figure 8.1. Mean heart-rate (HR) and minute ventilation (Ve) (+1 std) at maximal effort and Tvent level from the treadmill (Tr) and the water immersion (WI) VO_{2max} tests. A. Mean HR (bpm) response at VO_{2max} and Tvent, significant differences found at a=0.05 (*). B. Mean Ve ($l{\cdot}min^{-1}$) response at maximal and Tvent, no differences found for Ve on the Tr and WI conditions at a=0.05.

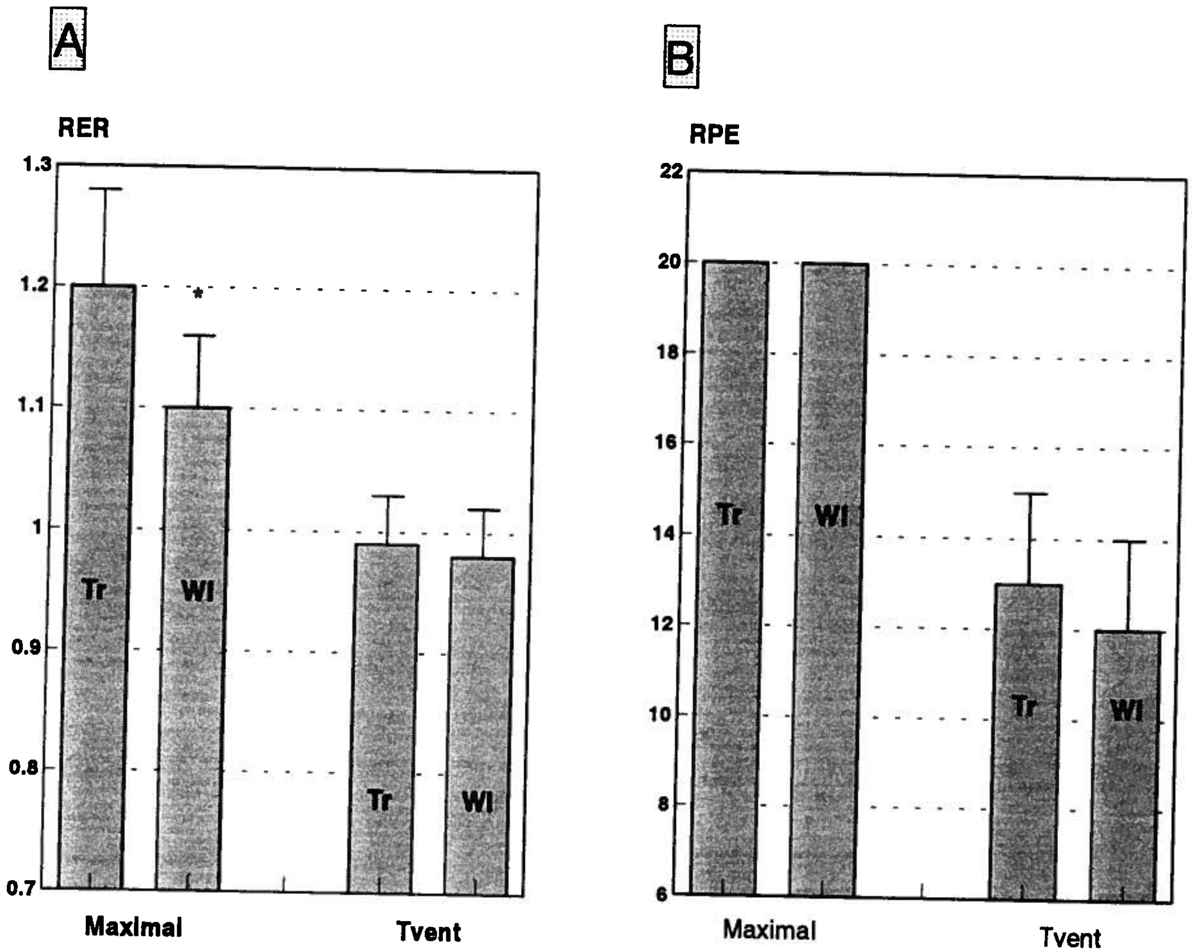


Figure 8.2. Mean RER and ratings of perceived exertion (RPE) (+1 std) at maximal and Tvent level from the treadmill (Tr) and the water immersion (WI) VO_{2max} tests. A. Mean RER responses at VO_{2max} and Tvent, significant differences (*) were found at VO_{2max} level only (a=0.05). B. Mean RPE responses at VO_{2max} and Tvent, no differences were found for RPE on the Tr and WI at VO_{2max} and Tvent at a=0.05.

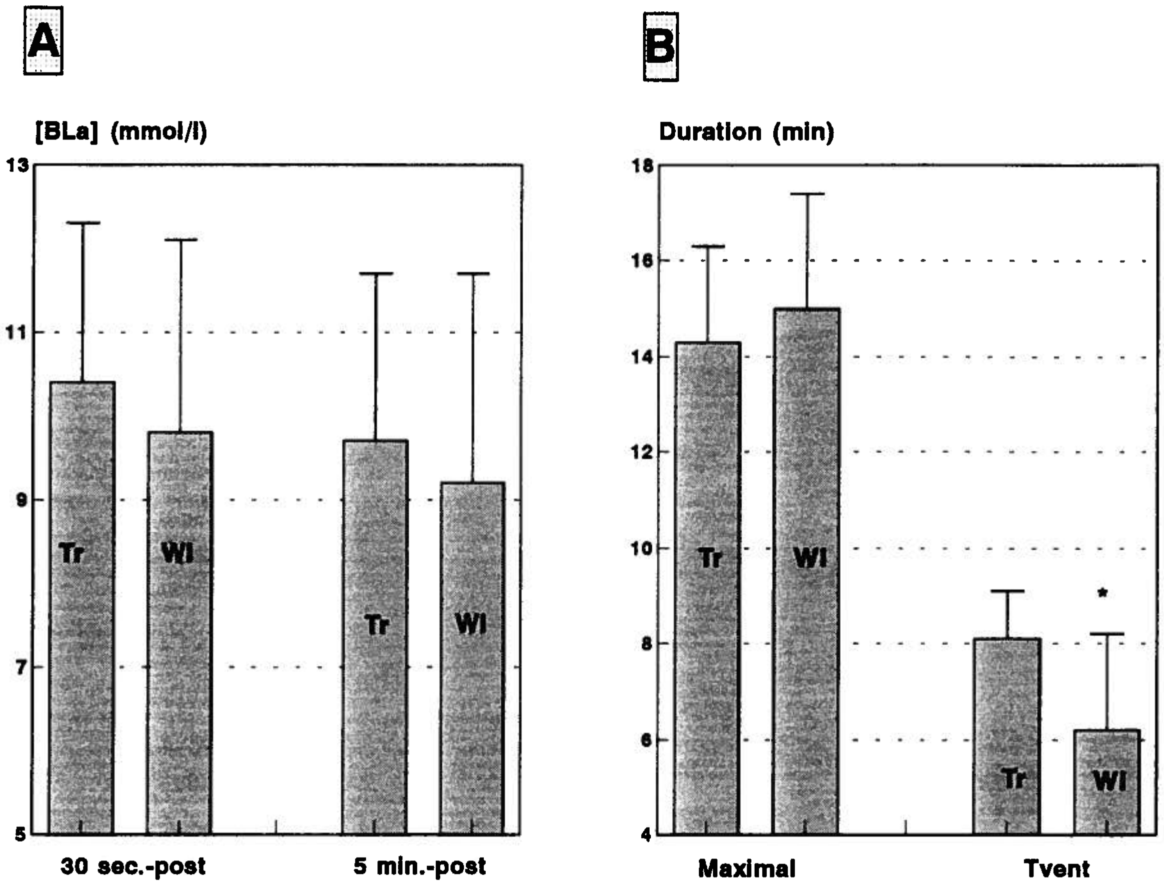


Figure 8.3. Mean post-test blood lactate concentrations ([BLa]} and VO_{2max} test duration at maximal effort and at Tvent level from the treadmill (Tr) and the water immersion (WI) VO_{2max} tests. A. Mean [BLa] at 30 sec. and 5 min. post-test on the Tr and WI following maximal effort, no significant differences were found on the Tr and in the WI conditions at a=0.05. B. Mean VO_{2max} test duration time and mean time at which Tvent occurred in the Tr and WI VO_{2max} tests, significant (*) differences found only for Tvent time occurance (a=0.05).

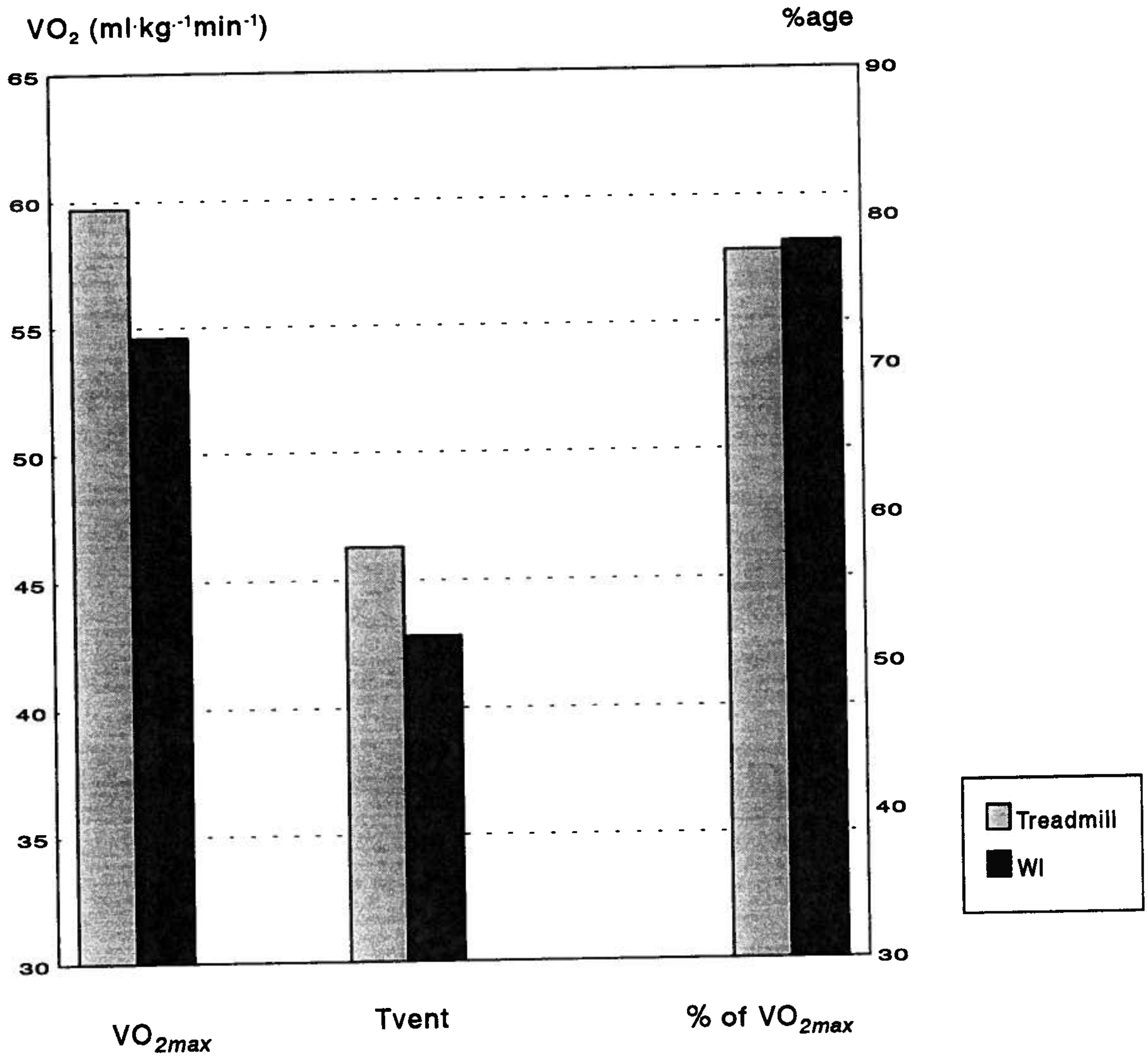


Figure 8.4. Comparison of the treadmill and WI VO_{2max} and Tvent responses and the %age of respective VO_{2max} that each Tvent represents, compared to their respective VO_{2max} responses. Significantly lower VO_{2max} and Tvent responses were exhibited with WI running. No differences were found when WI and Tr Tvent were expressed as a percentage of the respective VO_{2max}.

3.3.0 Tvent Steady State Performance Tests Results

4.3.1 Heart-rate

Heart-rate responses during the steady state performance tests were examined in relation to HR response during the performance tests in the 2 Conditions (treadmill versus WI) and to Tvent (the Tr_{Tvent} versus the WI_{Tvent} intensity) over Time and averaged over the Time factor.

There was a significant Condition main effect exhibited for HR averaged over the Tvent and the Time factors ($F_{1,9}$=19.35, $p<0.05$). When HR responses were averaged across all the time intervals and over the two Tvent's (Tr_{Tvent} and WI_{Tvent}) mean HR was significantly different in the two conditions. Mean HR averaged over condition and across time was 9 bpm higher on the treadmill vs WI (Tr_{HR}=162 bpm vs WI_{HR}=158 bpm), and the lower mean WI_{HR} is directly attributable to the WI environment (Figure 9.0 B).

There was a significant Tvent main effect for HR, when HR was averaged over Condition and across the Time factor ($F_{1,9}$=6.48, $p<0.05$). Averaged over the 2 conditions and across the time intervals mean HR response was significantly lower with the WI_{Tvent} ($HR_{WITvent}$=153 bpm) versus the Tr_{Tvent} ($HR_{TrTvent}$=162 bpm) tests (Figure 9.0 A and B).

There was a significant Condition by Tvent interaction ($F_{1,9}$=6.88, $p<0.05$). Averaged across all time intervals mean HR response was 12 and 7 bpm respectively higher when the performance test was performed on the treadmill ($HR_{TrTvent}$=168 bpm and $HR_{WITvent}$=156 bpm) versus WI ($HR_{TrTvent}$=156 bpm and $HR_{WITvent}$=149 bpm) (repeated measures (RM's) analysis of mean HR averaged over time for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and for $Tr_{WITvent}$ vs $WI_{WITvent}$ identified that mean HR's were significantly lower when Tr_{Tvent} and WI_{Tvent} was completed in the WI condition). Averaged across all time intervals mean HR response was 12 and 7 bpm higher when Tr_{Tvent} ($TrHR_{TrTvent}$=168 bpm vs $WIHR_{TrTvent}$=156 bpm, $p<0.0002$) versus WI_{Tvent} ($TrHR_{WITvent}$=156 bpm vs $WIHR_{WITvent}$=149 bpm, $p<0.05$) intensity was performed in the same condition (Figure 9.0 A and C). See Table 5.0 for HR RM's results and Tables 5.1 and 5.2 for HR RM's results for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ respectively.

There was a significant Time main effect, and conclude that there was a significant difference in mean HR response over Time ($F_{6,54}$=40.34, $p<0.05$). Ninety nine percent of the variability in Time was accounted for by a significant linear trend ($F_{1,9}$=62.82, $p<0.05$) as evidenced by the steady linear increase in mean HR from 153 bpm at T1 to 162 bpm at T7 (see Figure 9.1 A and B for mean HR responses over Time for individual tests).

There was a significant Condition by Time interaction ($F_{6,54}$=10.96, $p<0.05$) and conclude that the nature of the overall change in mean HR responses over the 7 collection times was different between the two conditions. Mean HR responses over Time were consistantly lower in the WI versus the treadmill condition. Ninety five percent of the variability is accounted for by a significant linear trend ($F_{1,9}$=14.23,

$p<0.05$), as evidenced by the steady linear increase in mean HR in both conditions (with WI_{HR} at T1=151 bpm to T7=155 bpm and Tr_{HR} at T1=155 bpm to T7=168 bpm) (Figure 9.2 A and B).

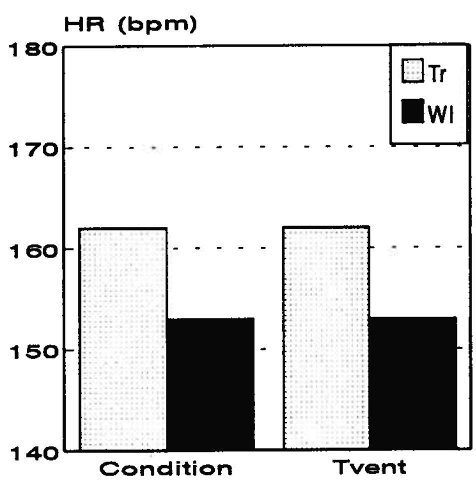
RM's analysis of mean HR over time for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ found significant Time main effects and Condition by Time interactions, in both comparisons. Lower mean HR responses over time were exhibited in the WI compared to the treadmill condition at both Tr_{Tvent} and WI_{Tvent} ($p<0.05$ in both analyses) with significant increasing linear trend exhibited over time (Figure 9.2 A and B).

There was no significant Tvent by Time interaction ($F_{6,54}=2.60$, $p>0.05$) (Figure 9.2 A and C) and Condition by Tvent by Time interaction ($F_{6,54}=0.26$, $p>0.05$).

A

Tvent		Tr	WI	Totals
CONDITION	Tr	168	156	162
	WI	156	149	153
	Totals	162	153	

B



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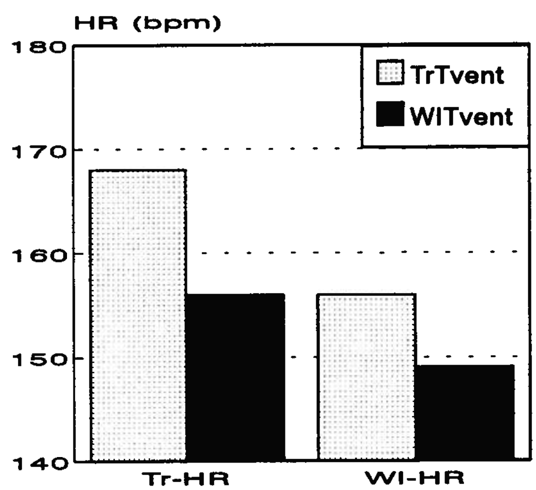


Figure 9.0. Mean HR response for Condition and Tvent main effects, and Condition X Tvent interaction. A. Table of the mean HR response by Condition and by Tvent. B. Comparison of mean HR response over Condition (Tr vs WI) and over Tvent (TrTvent vs WITvent) averaged over Time (Condition and Tvent main effects). C. Comparison of mean HR response averaged over the steady state tests performed on the treadmill (ie. at Tr and WI Tvent) versus the steady state tests performed in WI (ie. at Tr and WI Tvent) (Condition X Tvent interaction).

A

Time		T1	T2	T3	T4	T5	T6	T7
TR	TrTvent	160	164	166	168	172	174	175
	WITvent	149	152	154	156	159	160	161
WI	TrTvent	154	155	155	156	157	158	159
	WITvent	148	149	148	148	148	150	151
Mean	Test	153	155	156	157	159	161	162

B

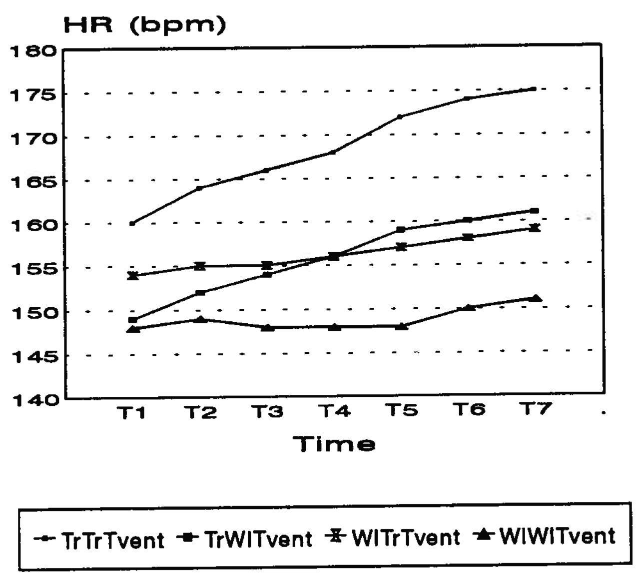
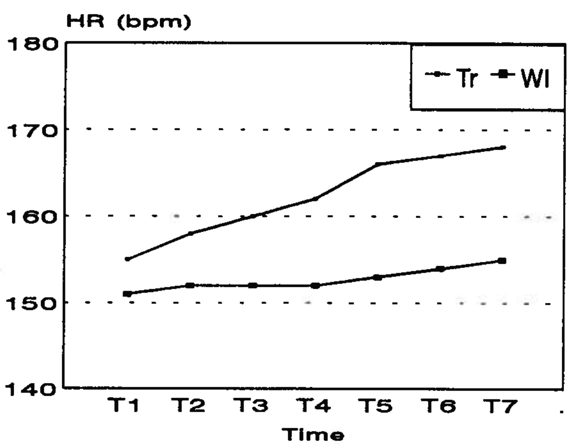


Figure 9.1. Mean HR response over the steady state performance tests over time. A. Table of mean HR response over time for the 4 steady state tests and mean Tvent test. B. Comparison of mean HR response over time for each test condition and Tvent.

A

TIME		T1	T2	T3	T4	T5	T6	T7
CONDITION	Tr	155	158	160	162	166	167	168
	WI	151	152	152	152	153	154	155
Tvent	Tr	157	160	161	162	165	166	167
	WI	149	151	151	152	154	155	156

B



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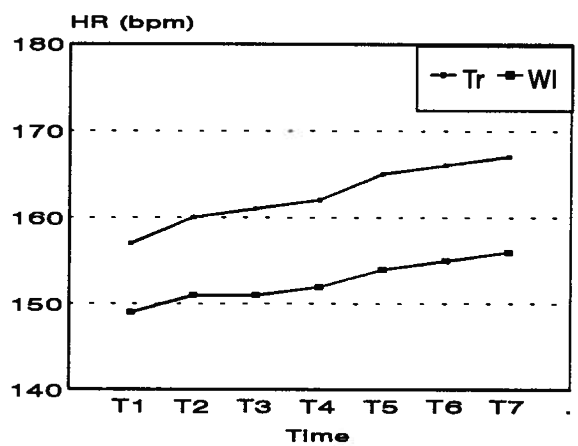


Figure 9.2. Mean HR response for Condition X Time and Tvent X Time interactions. A. Table of mean HR responses for Condition X Time and Tvent X Time interactions. B. Comparison of mean HR response over time for the mean steady state tests completed on the treadmill vs in WI (ie. mean HR at each time interval for Tr and WI Tvent combined) (Condition X Time). C. Comparison of mean HR response over time for mean steady state tests completed at Tr vs WI Tvent (ie. mean HR at each time interval for Tr and WI conditions combined) (Tvent X Time).

4.3.2 Oxygen Consumption

Oxygen consumption (VO_2) was the variable used to set the Tvent intensity of each 42 minute performance test. After the workload producing the specific VO_2 was established and a steady VO_2 at the specific Tvent (either the Tr_{Tvent} or the WI_{Tvent}) intensity was obtained, VO_2 was no longer controlled. VO_2 responses during the steady state tests were examined in relation to VO_2 response during the duration of the performance tests in the 2 Conditions (treadmill and WI) and to the 2 T_{vent} (the Tr_{Tvent} and the WI_{Tvent}) intensities over the performance tests's time intervals and averaged over the Time factor.

There was no significant Condition main effect averaged over the Tvent and Time factors ($F_{1,9}=1.14$, $p>0.05$) (Figure 10.0 A and B).

There was a significant Tvent main effect when averaged over Condition and across the Time factor ($F_{1,9}=7.27$, $p<0.05$). Averaged across all time intervals the mean VO_2 on Tr_{Tvent} ($47.1\ ml \cdot kg^{\cdot -1} min^{-1}$) was significantly greater than the mean VO_2 on WI_{Tvent} ($42.9\ ml \cdot kg^{\cdot -1} min^{-1}$) averaged over the two conditions, as hypothesized (Figure 10.0 A and B).

There was no significant Condition by Tvent interaction ($F_{1,9}=0.68$, $p>0.05$) (see Table 5.0 for oxygen consumption RM's results). RM's analysis of mean VO_2 for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and for $Tr_{WITvent}$ vs $WI_{WITvent}$ found no significant differences in mean VO_2 averaged over time for Tr_{Tvent} (and no difference for WI_{Tvent}) intensity test completed in WI versus completed on the treadmill (see Table 9.1 and 9.2 for RM's analysis results for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$).

There was a significant Time main effect ($F_{6,54}=4.70$, $p<0.05$), with seventy two percent of the variability accounted for by a significant linear trend in mean VO_2 over time from T1=44.4 $ml \cdot kg^{-1} min^{-1}$ to T7=45.3 $ml \cdot kg^{-1} min^{-1}$ (see Figure 10.1 A and B for mean VO_2 responses over time and individual test VO_2 responses over Time).

There was no significant Condition by Time interaction ($F_{6,54}=0.25$, $p>0.05$) (Figure 10.2 A and B). RM's analysis of mean VO_2 over time for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ found no significant Time main effects and Condition by Time interactions, in both comparisons ($p>0.05$). There was a small increase in mean VO_2 over time exhibited in the $WI_{TrTvent}$ and $Tr_{TrTvent}$ (see Table 6.0 for RM's analysis results and Tables 6.1 and 6.2 for RM's analysis of $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ respectively and Figure 10.2 A and B).

There was no significant Tvent by Time interaction ($F_{6,54}=0.47$, $p>0.05$) (Figure 10.2 A and C), and Condition by Tvent by Time interaction ($F_{6,54}=0.82$, $p>0.05$).

A

Tvent		Tr	WI	Totals
CONDITION	Tr	47.1	43.2	45.2
	WI	47.0	42.5	44.8
	Totals	47.1	42.9	

B

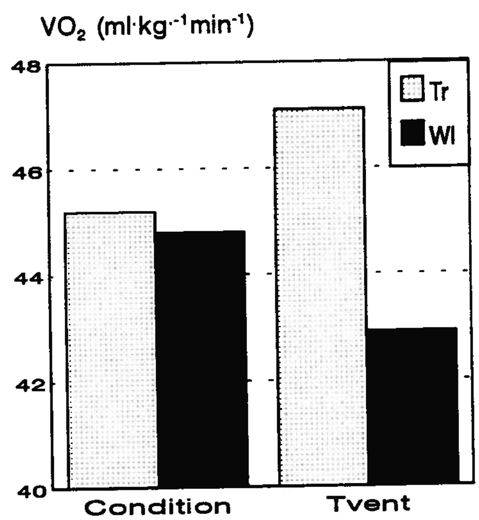


Figure 10.0. Mean VO_2 (in ml·kg^{-1}min^{-1}) response for Condition and Tvent main effects , and Condition X Tvent interaction. A. Table of mean VO_2 response by condition and by Tvent. B. Comparison of mean VO_2 response over condition (Tr vs WI) and over Tvent (TrTvent vs WITvent) averaged over Time (Condition and Tvent main effects).

A

Time		T1	T2	T3	T4	T5	T6	T7
TR	TrTvent	46.5	47.0	47.0	46.7	47.0	47.4	47.8
	WITvent	42.5	43.0	43.0	43.1	43.3	43.8	43.6
WI	TrTvent	46.1	47.2	47.2	47.0	46.9	47.7	47.2
	WITvent	42.5	42.5	42.5	42.2	42.4	42.8	42.7
Mean	Test	44.4	44.9	44.9	44.8	44.9	45.4	45.3

B

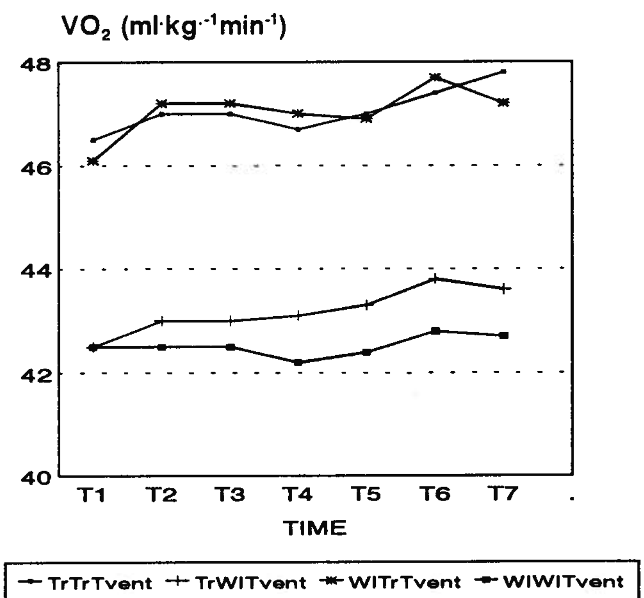
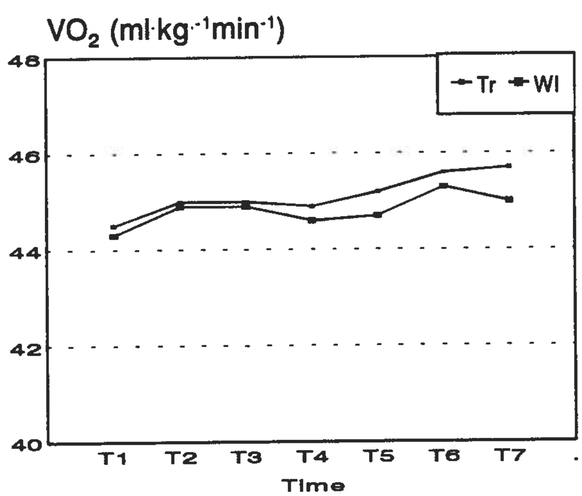


Figure 10.1. Mean VO_2 (in ml·kg^{-1}min^{-1}) response over the steady state performance tests over time. A. Table of mean VO_2 response over time for the 4 steady state tests and mean test. B. Comparison of mean VO_2 response over time for each test condition and Tvent.

A

TIME		T1	T2	T3	T4	T5	T6	T7
CONDITION	Tr	44.5	45.0	45.0	44.9	45.2	45.6	45.7
	WI	44.3	44.9	44.9	44.6	44.7	45.3	45.0
Tvent	Tr	46.4	47.1	47.1	46.9	47.0	47.6	47.5
	WI	42.5	42.8	42.8	42.7	42.9	43.3	43.2

B



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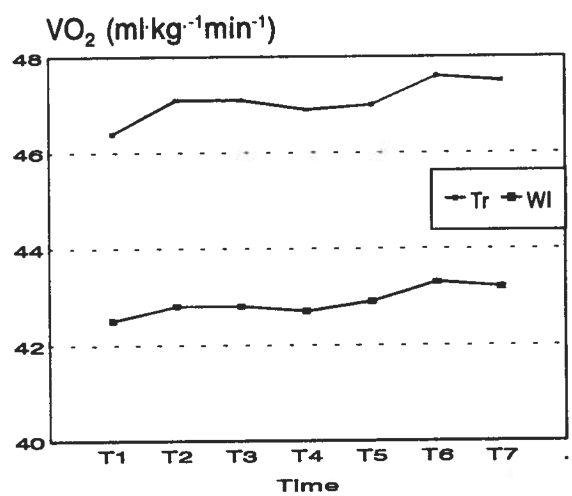


Figure 10.2. Mean VO_2 (ml·kg^{-1}min^{-1}) response for Condition X Time and Tvent X Time interactions. A. Table of mean VO_2 response for Condition X Time and Tvent X Time interactions. B. Comparison of mean VO_2 response over time for the mean steady state tests completed on the treadmill vs WI (ie. mean VO_2 at each time interval for Tr and WI Tvent combined) (Condition X Time). C. Comparison of mean VO_2 response over time for mean steady state tests completed at Tr vs WI (ie. mean VO_2 at each time interval for Tr and WI conditions combined) (Tvent X Time).

4.3.3 Ventilation

Minute Ventilation (Ve) responses during the steady state tests were examined in relation to Ve response during the duration of the performance tests in the 2 Conditions (treadmill and WI) and to the 2 Tvent (the Tr_{Tvent} and the WI_{Tvent}) intensities over the performance tests's time intervals and averaged over the Time factor.

There was no significant Condition main effect averaged over the Tvent and Time factors ($F_{1,9}=3.87$, $p>0.05$). Averaged over the two Tvent's and across all time intervals, the mean ventilation response on the Treadmill (Ve=68.0 $l\cdot min^{-1}$) was similar to the mean response in WI (Ve=73.5 $l\cdot min^{-1}$) (Figure 11.0 A and B).

There was a significant Tvent main effect when Ve was averaged over Condition and across the Time factor ($F_{1,9}=9.26$, $p<0.05$). Averaged over the two conditions and across all time intervals mean ventilation response at Tr_{Tvent} (Ve=76.2 $l\cdot min^{-1}$) was significantly higher than at WI_{Tvent} (Ve=65.3 $l\cdot min^{-1}$) (Figure 11.0 A and B).

There was a significant Condition by Tvent interaction averaged over the Time factor ($F_{1,9}=5.33$, $p=0.05$). Averaged across all time intervals mean ventilation response was 8.8 and 2.2 $l\cdot min^{-1}$ respectively lower when Tvent intensity was performed on the treadmill ($Ve_{TrTvent}=71.8$ $l\cdot min^{-1}$ and $Ve_{WITvent}=64.2$ $l\cdot min^{-1}$) versus WI ($Ve_{TrTvent}=80.6$ $l\cdot min^{-1}$ and $Ve_{WITvent}=66.4$ $l\cdot min^{-1}$). RM's analysis of mean Ve for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and for $Tr_{WITvent}$ vs $WI_{WITvent}$ found significantly higher mean Ve averaged over time for Tr_{Tvent} (and no difference for WI_{Tvent}) intensity test completed in WI versus completed on the treadmill (see Table 7.1 and 7.2 for RM's analysis results for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$). Averaged across all time intervals mean ventilation response was 7.6 and 14.2 $l \cdot min^{-1}$ significantly higher when Tr_{Tvent} intensity ($TrVe_{TrTvent}$=71.8 $l \cdot min^{-1}$ and $WIVe_{TrTvent}$=80.6 $l \cdot min^{-1}$) versus WI_{Tvent} intensity ($TrVe_{WITvent}$=64.2 $l \cdot min^{-1}$ and $WIVe_{WITvent}$=66.4 $l \cdot min^{-1}$) was performed. RM's analysis of $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ respectively found mean Ve averaged over time to be higher in the WI compared to the treadmill condition (Figure 11.0 A and C).

There was a significant Time main effect ($F_{6,54}$=7.09, $p<0.05$) with 97 percent of the variability accounted for by a significant Time linear trend as evidenced by the steady linear increase in mean ventilation from 68.5 $l \cdot min^{-1}$ at T1 to 72.7 $l \cdot min^{-1}$ at T7. RM's analysis of mean Ve for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and for $Tr_{WITvent}$ vs $WI_{WITvent}$ found significantly higher mean Ve over time for Tr_{Tvent} completed in the WI versus treadmill condition ($p<0.05$), with a significant linear trend exhibited over time ($p<0.05$) (Figure 11.1 A and B).

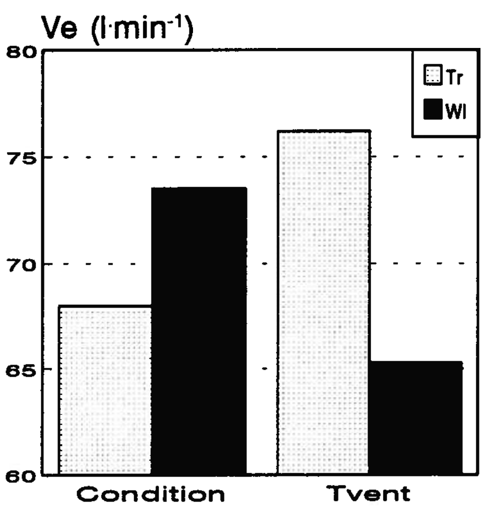
There was a significant Tvent by Time interaction ($F_{6,54}$=4.09, $p<0.05$) with mean ventilation response consistantly lower over Time with WI_{Tvent} (ie. $Tr_{WITvent}$ and $WI_{WITvent}$ combined) versus Tr_{Tvent} (ie. $Tr_{TrTvent}$ and $WI_{TrTvent}$ combined) tests. Ninety seven percent of the variability was accounted for by a significant linear trend ($F_{1,9}$=5.59, $p<0.05$) as evidenced by the steady linear increase in mean ventilation response in both the WI_{Tvent} and Tr_{Tvent} tests (with mean $Ve_{TrTvent}$ at T1=72.8 l·min^{-1} to T7=79.7 l·min^{-1} and mean $Ve_{WITvent}$ at T1=64.2 l·min^{-1} to T7=65.8 l·min^{-1}) (Figure 11.2 A and C).

There was no significant Condition by Time interaction ($F_{6,54}$=0.64, $p>0.05$) (Figure 11.2 A and B) and Condition by Tvent by Time interaction ($F_{6,54}$=0.79, $p>0.05$). See Table 7.0 for ventilation RM's analysis results.

A

Tvent		Tr	WI	Totals
CONDITION	Tr	71.8	64.2	68.0
	WI	80.6	66.4	73.5
	Totals	76.2	65.3	

B



C

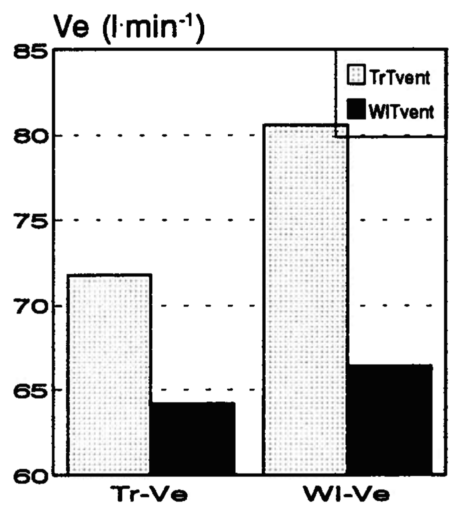


Figure 11.0. Mean Ve response for Condition and Tvent main effects, and Condition X Tvent interaction. A. Table of the mean Ve response by Condition and by Tvent. Comparison of the mean Ve response over Condition (Tr vs WI) and over Tvent (TrTvent vs WITvent) averaged over Time (Condition and Tvent main effects). C. Comparison of mean Ve response averaged over the steady state tests performed on the treadmill (ie. at Tr and WI Tvent) versus the steady state tests performed in WI (ie. at Tr and WI Tvent) (Condition X Tvent interaction).

A

Time		T1	T2	T3	T4	T5	T6	T7
TR	TrTvent	68.3	68.6	70.6	70.9	73.1	74.7	76.3
	WITvent	61.4	63.7	64.0	64.2	65.1	65.5	65.5
WI	TrTvent	77.3	79.3	79.9	80.3	81.3	82.9	83.1
	WITvent	67.0	66.6	67.2	66.0	66.2	66.0	66.0
Mean	Test	68.5	69.6	70.4	70.4	71.4	72.3	72.7

B

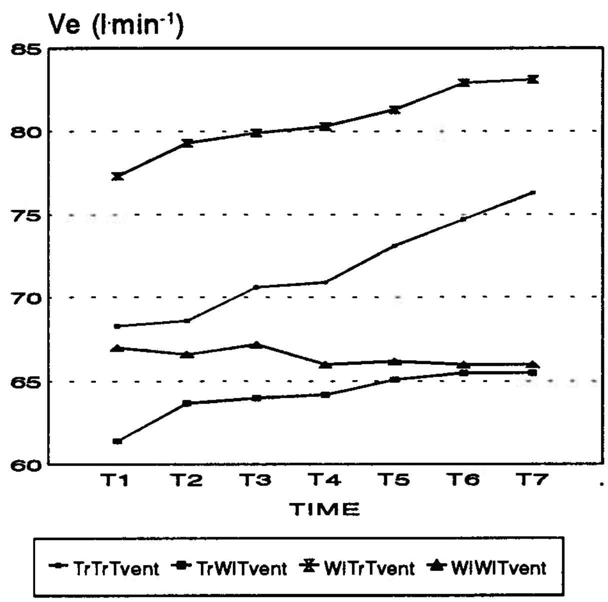
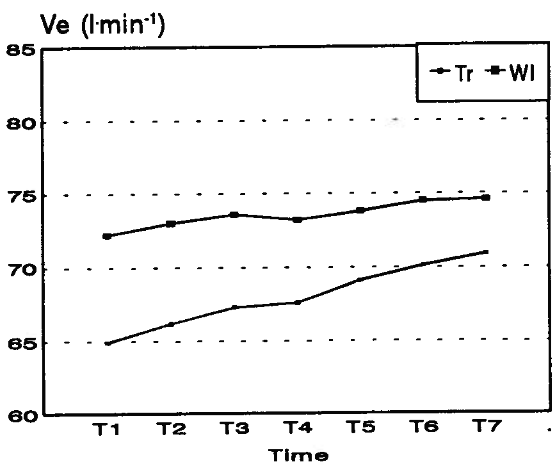


Figure 11.1. Mean Ve response over the steady state performance tests over time. A. Table of mean Ve over time for the 4 steady state tests and mean test. B. Comparison of the mean Ve response over time for each test condition and Tvent.

A

TIME		T1	T2	T3	T4	T5	T6	T7
CONDITION	Tr	64.9	66.2	67.3	67.6	69.1	70.1	70.9
	WI	72.2	73.0	73.6	73.2	73.8	74.5	74.6
Tvent	Tr	72.8	74.0	75.3	75.6	77.2	78.9	79.7
	WI	64.2	65.2	65.6	65.1	65.7	65.8	65.8

B



C

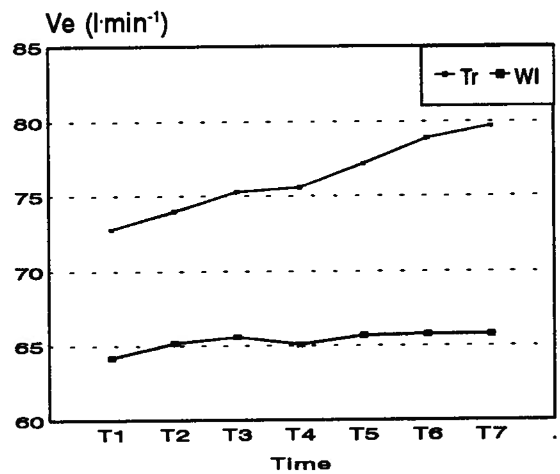


Figure 11.2. Mean Ve response for Condition X Time and Tvent X time interactions. A. Table of mean Ve response for Condition X Time and Tvent X Time interactions. B. Comparison of mean Ve response over time for mean steady state tests completed on the treadmill (Tr) vs in WI (ie. mean Ve at each time interval for Tr and WI Tvent combined) (Condition X Time). C. Comparison of mean Ve response over time for mean steady state tests completed at Tr vs WI Tvent (ie. mean Ve at each time interval for Tr and WI conditions combined) (Tvent X Time).

4.3.4 Blood Lactate Concentration

Blood lactate concentration ([BLa]) responses during the steady state performance tests were examined in relation to [BLa] response during the duration of the performance tests in the 2 Conditions (treadmill and WI) and to the 2 Tvent (the Tr_{Tvent} and the WI_{Tvent}) intensities over the performance tests's time intervals (T2 to T7) and averaged over the Time factor.

There was a significant Condition main effect averaged over the Tvent and Time factors exhibited ($F_{1,9}=5.57$, $p<0.05$). Averaged over the 2 Tvent's and across all time intervals the mean [Bla] response on the treadmill (4.86 $mmol \cdot l^{-1}$) was significantly higher than in WI (4.13 $mmol \cdot l^{-1}$) (Figure 12.0 A and B).

There was a significant Tvent main effect averaged over Condition and the Time factors exhibited ($F_{1,9}=12.29$, $p<0.05$). Averaged over the two conditions and across all time intervals the mean [BLa] response on Tr_{Tvent} (5.31 $mmol \cdot l^{-1}$) was significantly higher than on WI_{Tvent} (3.68 $mmol \cdot l^{-1}$) (Figure 12.1 A and B). There was no significant Condition by Tvent interaction averaged over the Time factor ($F_{1,9}=0.40$, $p>0.05$) (Figure 12.0 A and C). See Table 8.0 for [BLa] RM's results.

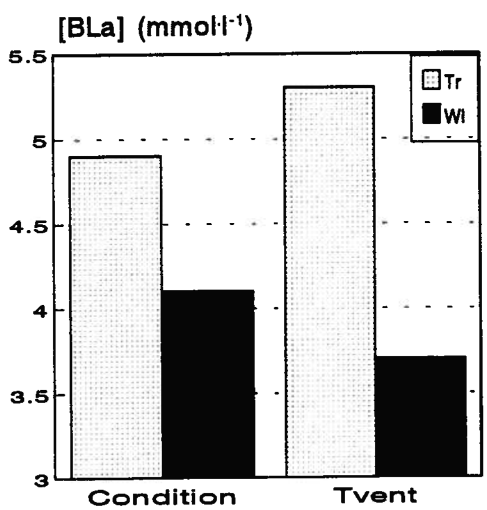
There was no significant Time main effect ($F_{5,45}=1.60$, $p>0.05$) (see Figure 12.1 A and B for individual test mean [BLa] responses over Time). There was a significant Condition by Time interaction ($F_{5,45}=6.17$, $p<0.05$) with mean [BLa] response consistantly higher over time on the treadmill versus the WI condition. Ninety eight percent of the variability is accounted for by a significant linear trend ($F_{1,9}=9.83$, $p<0.05$) as evidenced by the steady linear increase in mean blood lactate response on the treadmill tests and the steady (small) linear decline exhibited on the WI tests (Figure 12.2 A and and B). RM's analysis of mean [BLa] for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and for $Tr_{WITvent}$ vs $WI_{WITvent}$ found significant Condition by Time interactions ($p<0.05$). Significantly lower mean [BLa] responses over time were exhibited for Tr_{Tvent} and WI_{Tvent} intensity tests completed in the WI versus treadmill condition ($p<0.05$), with a significant decreasing linear trend over time exhibited for Tr_{Tvent} in WI and increasing linear trend over time exhibited in the treadmill condition ($p<0.05$) (see Table 8.1 and 8.2 for RM's analysis of $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ and Figure 12.2 A and B).

There was no significant Tvent by Time interaction ($F_{5,45}=2.13$, $p>0.05$) (Figure 12.2 A and C). There was no significant Condition by Tvent by Time interaction ($F_{5,45}=2.12$, $p>0.05$).

A

Tvent		Tr	WI	Totals
CONDITION	Tr	5.5	4.2	4.9
	WI	5.1	3.2	4.1
	Totals	5.3	3.7	

B



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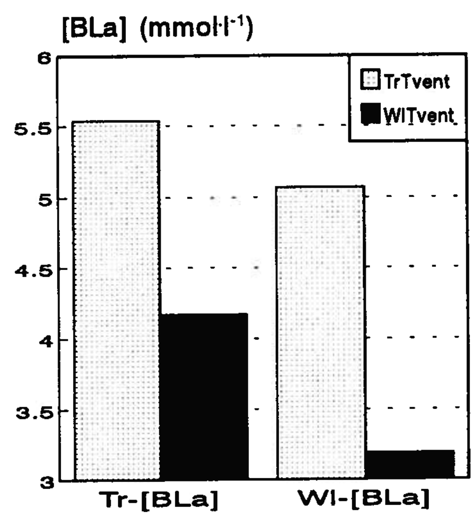


Figure 12.0. Mean [BLa] response for Condition and Tvent main effects, and Condition X Tvent interaction. A. Table of the mean [BLa] response by Condition and by Tvent. B. Comparison of mean [BLa] response over Condition (Tr vs WI) and over Tvent (TrTvent vs WITvent) averaged over Time (Condition and Tvent main effects). c. Comparison of mean [BLa] response averaged over the steady state tests performed on the treadmill (ie. Tr and WI Tvent) vs the steady state tests performed in WI (ie. at Tr and WI Tvent) (Condition X Tvent interaction).

A

Time		T2	T3	T4	T5	T6	T7
TR	TrTvent	4.7	4.9	5.4	5.3	6.2	6.8
	WITvent	3.8	3.8	3.9	4.4	4.8	4.4
WI	TrTvent	5.5	5.3	5.1	5.0	4.8	4.8
	WITvent	3.7	3.4	3.2	3.1	3.0	2.8
Mean	Test	4.4	4.3	4.4	4.4	4.7	4.7

B

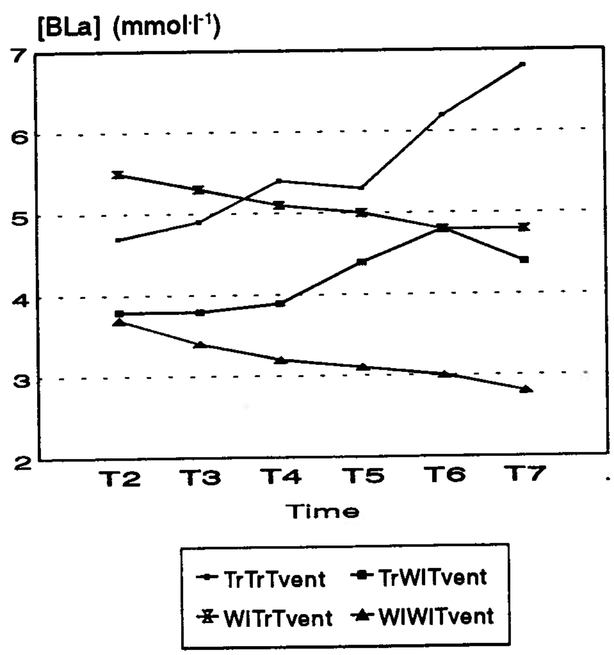
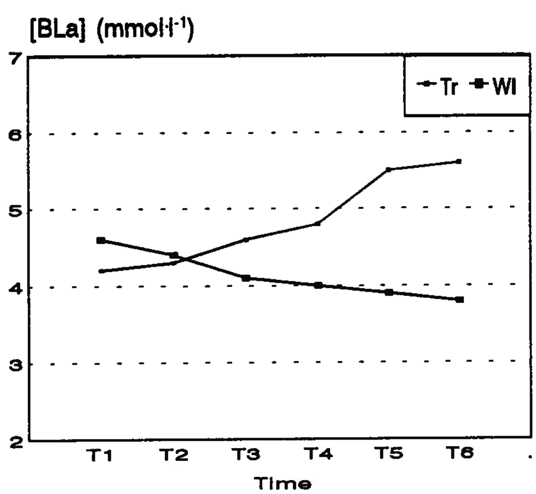


Figure 12.1. Mean [BLa] response over the steady state performance tests over time. A. Table of mean [BLa] response over time for the 4 steady state tests and mean Test. B. Comparison of mean [BLa] response over time for each test condition and Tvent.

A

TIME		T2	T3	T4	T5	T6	T7
CONDITION	Tr	4.2	4.3	4.6	4.8	5.5	5.6
	WI	4.6	4.4	4.1	4.0	3.9	3.8
Tvent	Tr	5.1	5.1	5.2	5.1	5.5	5.8
	WI	3.7	3.6	3.6	3.7	3.9	3.6

B



C

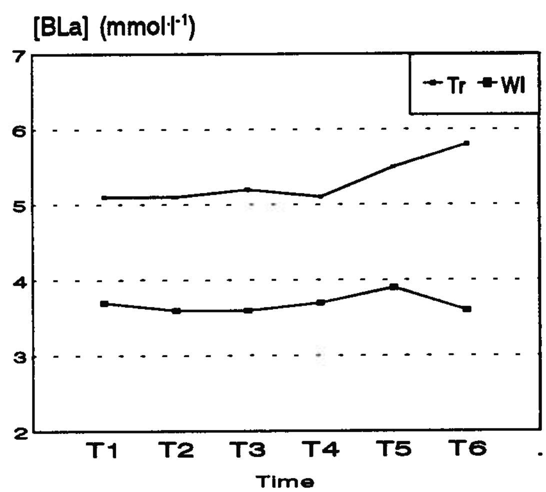


Figure 12.2. Mean [BLa] response for Condition X Time and Tvent X Time interactions. A. Table of mean [BLa] responses for Condition X Time and Tvent X Time interactions. B. Comparison of mean [BLa] over time for the mean steady state tests completed on the treadmill vs in WI (ie. mean [BLa] at each time interval for Tr and WI Tvent combined) (Condition X Time). C. Comparison of mean [BLa] response over time for mean steady state tests completed at Tr and WI Tvent (ie. mean [BLa] at each time interval for Tr and WI conditions combined) (Tvent X Time).

4.4 HYPOTHESIS VERIFICATION

4.4.1 Test of Hypothesis 1

The significant T-Test for VO_{2max} response on the treadmill versus WI running does not support Hypothesis 1, which predicted similar Tr_{VO2max} and WI_{VO2max} responses among elite distance runners trained in WI running (the level of significance as a one-tailed hypothesis was 0.0005, with T-value=4.11) (Figure 8.0).

4.4.2 Test of Hypothesis 2

The significant T-Test for VO_2 at Tr_{Tvent} versus WI_{Tvent} supports Hypothesis 2, which predicted a higher Tr_{Tvent} versus WI_{Tvent} VO_2. As a one-tailed hypothesis the tests has a level of significance equal to 0.02 (and T-value=2.46).

The hypothesis postulated equal treadmill and WI VO_{2max} responses (Hypothesis 1), which was however rejected. Expression of the Tvent VO_2's as a percentage of their respective VO_{2max} responses, indicates that both the Tr_{Tvent} and WI_{Tvent} occurred at approximately 78 % of their respective treadmill and WI VO_{2max} responses (see Table 3 for values and Figure 8.4). Therefore we conclude that although the absolute mean VO_2 at Tr_{Tvent} was greater than at WI_{Tvent}, expression of VO_2 at Tvent as a percentage of their respective treadmill and WI VO_{2max} reveals that Tvent occurred at the same mean relative intensity for the group.

The analysis of the Tvent tests for HR, VO_2, Ve [BLa] over time will follow for the hypotheses set for $Tr_{Tvent}>WI_{Tvent}$.

4.4.3 Test of Hypothesis 3

Significant Condition X Tvent interaction, Condition X Time and Tvent X Time interactions, a significant Condition main effects and Condition X Time interaction for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ comparisons, give support to hypothesis 3, which predicted higher HR responses at both Tr_{Tvent} and WI_{Tvent} intensity when the Tvent test was performed on the treadmill versus WI. Higher HR responses were also predicted at each collection interval and overall, when the Tr_{Tvent} and WI_{Tvent} intensity were performed on the treadmill versus WI (even for the $Tr_{TrTvent}$ test over $WI_{TrTvent}$ test) (Figures 9.0 to 9.2).

4.4.4 Test of Hypothesis 4

A significant Tvent main effect suggests that VO_2 at Tr_{Tvent} was higher than at WI_{Tvent}, however the nonsignificant Condition X Tvent, Condition X Time and Tvent X Time interactions, and Condition main effects and Condition X Time interactions for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ comparisons do not support Hypothesis 4 (Figures 10.0 to 10.2). Hypothesis 4 predicted that VO_2 would increase over time in WI tests due to a greater energy expenditure over time in WI versus treadmill work, related to the viscocity friction and turbulance of the WI environment and the larger muscle mass recruited for WI work.

4.4.5 Test of Hypothesis 5

A significant Condition X Tvent and Tvent X Time interaction, Time main effect, and Condition X Time interactions for $Tr_{TrTvent}$ vs $WI_{TrTvent}$ and $Tr_{WITvent}$ vs $WI_{WITvent}$ comparisons support hypothesis 5, which predicted higher Ve responses at WI_{Tvent} and Tr_{Tvent} when the Tvent test (that is the same absolute intensity) was performed in WI versus on the treadmill. The significant Time main effect, with a significant Time linear trend, suggests that over time Ve increased in a linear fashion as the intensity remained constant (Figure 11.1).

The significant Tvent X Time interaction, with a significant Tvent X Time linear trend suggests that the lower Ve responses which were exhibited over time , when the WI_{Tvent} (ie. in the $Tr_{WITvent}$ and $WI_{WITvent}$ tests) versus when the Tr_{Tvent} intensity was applied, were due to the absolute intensity of the test and the body's ability to cope with the demands placed on it (Figure 11.2 C).

The non-significant Condition X Time interaction supports Hypothesis 4, which presupposed that the WI condition would not be responsible for Ve behaviour, but that differences exhibited would be due to the Tvent applied in the test (Figure 11.2 B).

4.4.6 Test of Hypothesis 6

A significant Condition main effect suggests a higher mean [BLa] on the treadmill versus WI. This is in conflict with the expected trend.

Hypothesis 6 predicted that mean [BLa] would be higher in WI (ie $WI_{WITvent}$ and $WI_{TrTvent}$) versus treadmill (ie. $Tr_{WITvent}$ and $Tr_{TrTvent}$) tests and that mean [BLa] response would increase over time in WI tests due to the higher relative intensity performed during these Tvent tests when completed in WI.

The nonsignificant Condition X Tvent interaction suggests that mean [BLa] at Tr_{Tvent} and WI_{Tvent} intensities respectively, performed on the treadmill and the WI conditions did not differ. The nonsignificant Time main effect suggests that there were no differences in mean [BLa] response over time. The significant Condition X Time interaction and Condition X Time linear trend suggest a significant linear response of [BLa] over Time. The trend is, however contrary to our hypothesis, significantly higher in the treadmill tests with an increasing trend over time and significantly lower in the WI tests with a decreasing trend over time Figures 12.1 B and 12.2 B).

The nonsignificant T_{vent} X Time interaction and suggests that mean [BLa] was similar over time whether the test intensity completed was the WI_{Tvent} or the Tr_{Tvent} (Figure 12.2 C). The higher mean [Bla] over time on treadmill performance tests is contrary to Hypothesis 6 and is most likely due to the laboratory conditions with respect to air temperature and humidity.

4.5 SUMMARY OF HYPOTHESIS RESULTS

Hypothesis 1 :	$Tr_{VO2max} = WI_{VO2max}$	REJECT
Hypothesis 2 :	$Tr_{Tvent} > WI_{Tvent}$	ACCEPT
Hypothesis 3 :	$TrHR_{WITvent} > WIHR_{WITvent}$	ACCEPT
	$TrHR_{TrTvent} > WIHR_{TrTvent}$	ACCEPT
Hypothesis 4 :	$WIVO_{2WITvent} > TrVO_{2WITvent}$	REJECT
	$WIVO_{2TrTvent} > TrVO_{2TrTvent}$	REJECT
Hypothesis 5 :	$WIVe_{WITvent} > TrVe_{WITvent}$	ACCEPT
	$WIVe_{TrTvent} > TrVe_{TrTvent}$	ACCEPT
Hypothesis 6:	$WI[BLa]_{WITvent} > Tr[BLa]_{WITvent}$	REJECT
	$WI[BLa]_{TrTvent} > Tr[BLa]_{TrTvent}$	REJECT

CHAPTER 5

5.0 DISCUSSION

The primary purpose of this study was to compare the treadmill and WI running VO_{2max} values and Tvent responses in elite endurance runners familiar with WI running. A secondary purpose was to monitor the cardiorespiratory and metabolic responses to prolonged performance at exercise intensities reflecting the treadmill and WI Tvent on the treadmill and during WI running. It was postulated that VO_{2max} would be similar for runners accustomed to WI running when tested in both conditions (treadmill and WI). However, it was postulated that the Tvent (VO_2 at T_{vent}) would be lower in WI testing. The data do not fully support these hypotheses. The simulation of treadmill running in the water, the quality (intensity of exercise in WI running) and frequency of WI running training sessions, possibly explain the disagreement. Some of the limitations associated with WI running are the viscosity friction of water and the subsequent reduced stride frequency and increased upper body work. Also the non-weight bearing nature of WI running and subsequent reliance on concentric work of recruited musculature are implicated.

Prolonged performance (42 minutes) at treadmill and WI Tvent were explored to compare cardiorespiratory (HR, Ve, VO_2) and metabolic ([BLa]) responses during steady state exercise. The hypothesis tested for HR stated that WI would produce a central shift in blood volume.

This would result in facilitated venous return, preload and stroke volume which would be responsible for the lower HR exhibited (for similar VO_2) over time at both exercise intensities for the WI running tests. Higher Ve and [BLa] (for similar VO_2) were postulated for the WI condition for both the WI and treadmill Tvent. Data did not support all of the study's hypotheses.

5.1 Maximal and Tvent Responses from VO_{2max} Test Results

It was hypothesized that distance runners who regularly perform WI running workouts and simulate land-based running mechanics in WI running would exhibit similar treadmill and WI VO_{2max} values, conforming to previous studies comparing land vs WI ergometer cycling (Christie et al, 1991; Connelly et al, 1991; Sheldahl et al, 1987; Sheldahl et al, 1984; Dressendorfer et al, 1976). The similar post-test [BLa] (obtained at 30 seconds and 5 minutes post-test) and VO_{2max} RPE (RPE_{max}) for the treadmill and the WI condition lend support that maximal effort was achieved in the WI condition. However, lower VO_{2max} values were noted for WI versus treadmill running. This finding is in agreement with other WI running studies (Svedenhag and Seger, 1992; Town and Bradley, 1991; Butts et al, 1991; Welsh, 1988).

The premise, for equal WI and treadmill VO_{2max} values was that differences found between the two modalities in previous studies were primarily due to the following: a) classification and definition of an athlete 'trained in WI running', b) appropriate WI running style, c) WI VO_{2max} protocol and d) upper body musculature recruitment. The present study attempted to control these variables. Also, similar VO_{2max} values on land and WI stationary ergometer cycling demonstrate that controlling body position and musculature utilized for the activity results in no differences being exhibited due to the differing environmental condition (land vs WI) (Christie et al, 1991; Connelly et al, 1991; Sheldahl et al, 1987; Dressendorfer et al, 1976). Consequently, differences in VO_{2max} exhibited with WI versus treadmill running seems to be related to differences in WI and treadmill running style and training.

However, adherence to these criteria in controlling for the other studies' limitations still produced a lower WI versus treadmill VO_{2max}. To ensure that the runners achieved maximal effort, Borg's ratings of perceived exertion (RPE) and post-test blood lactate concentration ([BLa]) were compared. RPE_{max} of 20 at treadmill and WI VO_{2max} suggests that the subjects perceived that they had achieved maximal effort. Mean [BLa] exhibited immediately post-test and 5 minutes post-test are similar with peak [BLa] values observed at maximal effort by other studies (Luhtanen et al, 1990; Withers et al, 1981; Farrell et al, 1979; Costill et al, 1973). It would therefore seem that maximal effort was attained in both protocols. Svedenhag and Seger (1992) noted higher [BLa], whereas Town and Bradley (1991) noted lower [Bla] in the WI compared to the treadmill VO_{2max} condition. The discrepancy between studies may be related to the lower WI capabilities of the runners resulting in the recruitment of additional musculature and consequently higher [BLa]. Another implication may be the unfamiliarity of the runners with WI running in combination with limitations of the WI (4 min) VO_{2max} protocol to elicit maximal effort (Svedenhag and Seger, 1992).

A minimum RER_{max} of 1.10 also demonstrates that maximal effort was achieved in the WI and the treadmill protocols. The lower WI RER_{max} (1.10) compared to the treadmill RER_{max} (1.20) suggests dissimilarities in the two conditions. Similar values or relationships were reported by Svedenhag and Seger (1992), and Dressendorfer et al (1976) and Butts et al (1991) respectively. Town and Bradely (1991) reported a WI RER_{max} below 1.10 (ie. 1.07), which is below the criterion RER_{max} normally set for achieving VO_{2max}, and further suggests that this sample may not have achieved maximal effort in the WI condition.

It is unclear why lower RER_{max} values in WI versus treadmill running were exhibited in this study. The treadmill and WI VO_{2max} test protocols in this study were matched for progressive incremental load increases per minute, and the WI and treadmill mean test durations were not statistically different (15 versus 14.5 minutes respectively). This was not the case with the protocols in Svedenhag and Seger (1992) and Town and Bradley (1991) where the test duration for the WI VO_{2max} protocols were 4 minutes and the subjects were asked to subjectively increase their effort to maximal for the remaining 1-2 minutes of the test. The treadmill protocol which they utilized, more objectively controlled the maximum determination.

VO_2 at Tvent was lower in the WI compared to the treadmill condition for similar RPE and RER responses. Welsh (1988) also reported lower

WI_{Tvent} vs Tr_{Tvent}. When VO_2 at Tvent was expressed as a percentage of the respective WI and treadmill VO_{2max}, no differences were exhibited. The similar RPE (13 and 12) and RER (0.99 and 0.98) values at WI and treadmill Tvent support that Tvent was identified. This would seem to suggest that differences in VO_2 (and RER_{max}) exhibited were possibly related to factors which limited VO_{2max} in WI. The main implication would be that in WI there is an inability to simulate treadmill (land-based) running style due to the viscocity of the water medium producing a lower stride frequency and thus turn-over rate and increased work in the forward and backward motion of the arms.

The lower stride frequency with a similar pattern of increase over time with increasing load in the WI condition suggests the following: a) the runners were predominately utilizing their lower trunk musculature for the activity, b) the high viscocity friction of the water condition, does influence running style by interfering with 'how fast the runner can run in WI' and by increasing the work performed by the arms during the forward and backward pumping action, and c) the non-weight bearing characteristics of WI running lends to no push-off phase in the WI running cycle and therefore no eccentric contraction of the lower trunk musculature. These factors would not affect WI cycling and VO_{2max} (Welsh, 1988). The cyclist is stabilized on the cycle and holds the handle bars (thereby stabilizing and controlling upper body muscle mass involvement) whereas in WI running the arms are utilized in a forward and backward motion. The incremental increase in intensity of exercise to maximal effort on both the WI and land-based cycle ergometer were accomplished by increasing the force generation through increased resistance (Sheldahl et al, 1987; Dressendorfer et al, 1976). Thus, there is more similarity in the work required for cycling in both conditions than for WI and treadmill running. Welsh (1988) suggests, however, that WI running shows similarities to cycling which predominately involves concentric contraction which elicits restricted blood flow (Eiken et al, 1987).

Welsh (1988) suggests that lower WI VO_{2max} values may be due to task specificity, which he translates to: a) the total muscle mass recruited, b) the type of muscle mass recruited, c) the familiarity with the recruitment pattern, d) the type of muscular contractions and e) the state of muscular adaption. This study attempted to control the muscle mass recruited by selecting subjects who simulated in the WI condition treadmill running style. To reduce upper body muscular recruitment, subjects were provided with a boyuancy device to wear for WI running. Analysis of stride frequency in WI and treadmill running showed a similar increase in stride frequency over time with increasing load. This would indirectly indicate that the leg musculature was primarily involved in the activity. Use of the upper body musculature in WI running would result in the utilization of musculature with a higher fast twitch fiber composition. The resistance offered by the WI condition would increase upper body muscular involvement for similar arm running movements without a neccessary increase in recruitment due to a different pattern of movement in the WI condition (Welsh, 1988).

Another possible explanation for the differences in WI and treadmill VO_{2max} values in this study may lie in WI running training. This study attempted to control WI running style and familiarity with WI running (regular training). Although this study accounted for the quantity of WI running training completed over time (ie. minimum sessions per month, duration of each workout and minimum period involved in WI running), it did not account for the runners' quality (intensity) of their personal workouts (see Appendix E). There appears to be a greater magnitude difference in WI versus treadmill VO_{2max} on runners (N=2) who exclusively limit their WI running work-outs to low intensity (below Tvent) exercise. Subjects who performed WI running workouts similar to their land-based training (ie. in intensity and program type) exhibited smaller deviations in WI and treadmill VO_{2max}.

The lower HR's exhibited at Tvent (by 13 bpm) and at maximal effort (by 15 bpm) in the WI condition are attributed to the central shift in blood volume (approx. 700 ml). This results from the hydrostatic pressure gradient in WI, causing a facilitated central venous return and greater preload and stroke volume (Christie et al, 1990; Connelly et al, 1991; Arborelius et al, 1972). Lower maximal HR responses have been reported by WI running studies (Svedenhag and Seger, 1992; Town and Bradley, 1991; Butts et al, 1991; and Welsh, 1988) and WI ergometer studies (Christie et al, 1991; Connelly et al, 1991; Sheldahl et al, 1987; Dressendorfer et al, 1976). Welsh (1988) reported lower HR responses at WI Tvent (12 bpm) similar to the present study. Lower submaximal HR responses have also been reported by Svedenhag and Seger (1992), Richie and Hopkins (1991), Bishop et al (1991), and Yamaji et al (1991) during short and longer duration WI versus treadmill running tests at specified submaximal intensities ($\leq$80 %VO_{2max}).

Minute ventilation at maximal effort (Ve_{max}) and at T_{vent} (Ve_{Tvent}) did not differ in the WI condition compared to treadmill running. This is in agreement with the studies by Svedenhag and Seger (1992) and Sheldahl et al (1987) for Ve_{max} and Welsh (1988) for Ve_{max} and Ve_{Tvent}. It is in contrast to Butts et al (1991) and Dressendorfer et al (1976) who reported a 9 and 11 % lower WI Ve_{max} when comparing land-based Ve_{max}.

Similar Ve at maximal effort and Tvent suggest that the WI condition and related increase in intrathoracic blood volume and hydrostatic chest compression do not restrict Ve. Resting respiratory mechanics are affected (reduced) by the WI condition (Agostoni et al, 1966; Hong et al, 1969; Dressendorfer et al, 1976). Ve during exercise, however, is not limited by the WI condition. Expression of Ve relative to VO_2 (ventilatory equivalent for VO_2, Ve/VO_2), however, suggests a higher Ve for similar VO_2. A trend for higher Ve/VO_2 at Tvent in the WI compared to the treadmill condition was noted in this study (23.4 vs 21.9, $p>0.05$). A significantly higher Ve/VO_2 was noted for maximal effort in the WI compared to the treadmill condition (29.4 vs 27.8, $p<0.05$). These findings concur with Welsh (1988). This seems to suggest that there is a tendency to ventilate more air, for similar VO_2 in the WI condition at maximal effort. Higher Ve is normally exhibited in line with higher VO_2, indicating a higher muscle mass recruitment, or is exhibited with a greater [BLa] and RER_{max}, however in this study VO_{2max} and RER_{max} were lower in the WI condition.

Christie et al (1991) reported higher cardiac index (cardiac output per square meter of body surface area) in WI without an elevation in VO_{2max}. Higher cardiac output in WI has been noted by Sheldahl et al (1984), Nielson et al (1984), Lin (1984), Fahri and Linnarson (1977) and Arborelius et al (1972). Christie et al (1991) concluded that the additional oxygen consumption supplied by the heart to the exercising muscle is not utilized. This would seem to suggest that oxygen extraction in the muscle is lower or limited in the WI condition. There is some evidence that muscle blood flow is increased in WI (Connelly et al, 1991). It is also believed that other vascular beds accomodate this increased blood flow, but there is still no clear evidence on which compartments do so (Christie et al, 1991). Alterations in the blood flow-metabolic relationship are implicated (Christie et al, 1991).

In summary it appears that differences in WI and treadmill VO_{2max} and Tvent may be attributed to less familiarity of runners to WI running, with respect to WI training regimens (ie. mileage of steady state exercise per week, incorporation of high intensity interval work-outs) and dissimilar (less intense) WI compared to land-based training. The WI condition also accounts for the differences exhibited in VO_2, HR, Ve, RER in WI versus treadmill running at VO_{2max} and Tvent. The runners' perceived effort at VO_{2max} and Tvent is exercise intensity dependent. RPE and peak [BLa] appear not to be affected by the WI condition.

5.2 Comparison of the treadmill and WI steady state Tvent performance tests

There is paucity of research literature available on steady state exercise at Tvent on treadmill and WI running. Exercise at Tvent for one hour duration has been reported to maintain steady state VO_2, HR, Ve, and [BLa] over time (Loat, 1991). Literature comparing treadmill and WI running during submaximal exercise of a prolonged nature have produced conflicting results. These studies failed to utilize runners who regularly incorporate WI running into their training regimen. The subjects subjectively selected a preferred exercise intensity for completing 30 (Richie and Hopkins, 1991) or 45 minute (Bishop et al, 1989) WI running tests. The results from these WI running tests were then compared to the subjects' selected treadmill running pace for completing a similar duration test. The only conclusions, which can be drawn, are that subjects were possibly unable to exercise at the similar higher treadmill intensity in the WI condition because of their unfamiliarity with WI running. Consequently, the WI running pace was at a lower VO_2, or possibly the subjects were able to maintain a similar pace in WI for the specified time period, but due to their unfamiliarity with WI running did so at a higher VO_2 in WI.

This study is the first to compare WI and treadmill running during prolonged exercise at similar relative and absolute intensities of exercise. The WI and treadmill Tvent's were expressed as VO_2, and the VO_2 at Tvent was used to determine the WI and treadmill Tvent intensities for the 42 minute performance tests. The WI condition was not expected and did not influence VO_2 during the perfomance tests. A small increase in VO_2 was noted for the $WI_{TrTvent}$ test. This increase, however, was overshadowed by a similar increase during the $Tr_{TrTvent}$ test. Increases of greater magnitude in HR, Ve, and [BLa] were exhibited during the treadmill tests (at WI and treadmill Tvent).

This upward drift in HR, Ve, and [BLa], with very little change in VO_2, in the treadmill condition over the 42 minute tests (at both the treadmill and WI Tvent intensities) can possibly be attributed to the environmental conditions in the laboratory. The present study was conducted over a seven month period (over three seasons; summer (June/July), fall (September/October), and winter (December). During the summer and fall testing the mean temperature in the laboratory was 26.9 and 23.5 degrees celcius (^oC) respectively. During winter testing the mean temperature in the laboratory was lower, 18.4^o C. The barometric pressure ranged between 764-759 mm Hg during the 3 test periods (see Appendix F). Subjects participating in the summer test period were most affected by the hot humid conditions in the laboratory.

Similar patterns of cardiorespiratory drifts exhibited in this study during prolonged exercise in heat, have been reported in the literature. Martin et al (1981) noted an upward drift in Ve as core temperature rose, during exercise at Tvent. Ve and HR (by 23 bpm) increased from minute 12 to 60 without changes exhibited in [BLa] and pH. Foley et al (1993) compared 60 minutes of submaximal exercise at 20^o and 32.2^o C room temperature. An increase in CO and HR (by 20 bpm) with no change in $a\text{-}vO_2$ difference were noted during exercise at room temperature of

32.2° C. Heaney et al (1993) similarily reported an increasing Ve with increasing core temperature, with no change in VO_2 exhibited during prolonged exercise in a hot environment. The authors concluded that core temperature contributed to Ve drift.

Attempts were made to provide adequate cooling (electric fan) and unlimited cool water was provided to prevent dehydration during the steady state treadmill performance tests. The measures taken were unfortunately, unsuccessful in alleviating the heat problem for these subjects, resulting in inflated HR, Ve, and [BLa] values. There was increased sweating during the treadmill condition tests. Subject 1 lost 2.5 kg following performance of the treadmill TrTvent test at a room temperature of 27.8° C.

Perfuse sweating during the treadmill tests likely caused a decrease in plasma volume, resulting in increases in HR in an attempt to maintain CO. The increase in core temperature may have resulted in the increase in lactate production and / or the reduction in the lactate consumed (re-oxidized). The loss in blood volume as a consequence of perfuse sweating may also have resulted in increases in [BLa] due to haemo-concentration. Ve most likely increased due to the decrease in pH and increase in [BLa].

HR, Ve, and [BLa] responses were least affected during the first 15 minutes of the treadmill tests (similar to the patterns exhibited in Martin et al (1981)) and comparisons are made with the WI tests with this treadmill time period.

5.2.1 Heart-rate

HR response was similar at WI Tvent intensity performed in the two conditions over time, whereas HR response was lower at treadmill Tvent in the WI compared to the treadmill condition. Sheldahl et al (1987) observed similar cycle ergometer HR responses below workloads corresponding to 75 %VO_{2max} and lower HR responses above this intensity. Similar HR responses have also been reported by Connelly et al (1990), Christie et al (1990) and Svedenhag and Seger (1992) during 5 minute exercise bouts below 60%, 80% and 65% VO_{2max} respectively. The present study noted similar HR response at WI Tvent intensity corresponding to 78% of WI VO_{2max}, but lower HR response at treadmill Tvent corresponding to 84.8% of WI VO_{2max} in the WI condition. Differences in sympathetic neural outflow, baroreceptor activity and cardiac output have been suggested as possible explanations (Connelly et al, 1990; Christie et al, 1990; Sheldahl et al, 1987). Connelly et al (1991) suggest a possible relationship between cardiopulmonary baroreceptor activity and the increase in central blood volume. The present study does suggest an exercise intensity dependent HR response, which may be related to an increase in muscle glycogenolysis. HR response in the present study did show an increasing trend over the 42 minute test at the treadmill Tvent intensity performed in the WI condition. This would be expected for exercise above one's Tvent (Loat and Rhodes, 1992; Loat, 1991; Rusko et al, 1986; Hearst, 1982) in that (ie. WI) condition.

Determination of HR at Tvent from the WI VO_{2max} test produced a significantly lower HR compared to the HR at Tvent from the treadmill

VO_{2max} test. The results from the steady state performance tests demonstrate that differences in HR exhibited at Tvent during the VO_{2max} tests were simply related to the lower VO_2 at WI Tvent compared to the VO_2 at treadmill Tvent. Consequently, the lower WI HR response at Tvent reported by the present study and by Welsh (1988) from the progressive incremental load VO_{2max} tests, were the product of the lower absolute WI Tvent and not the result of the WI condition.

5.2.2 Ventilation

Although resting lung volumes are reduced in upright WI (Withers and Hamdorf, 1989; Hong et al, 1969; Agostoni et al, 1966), exercise Ve is not affected. Similar Ve responses (when averaged over time) were noted for exercise at WI Tvent in both the WI and the treadmill condition. The WI condition Ve responses during WI Tvent seemed to be higher if the upward drift in Ve during the treadmill performance was considered to be related to heat stress. This is not in agreement with Svedenhag and Seger (1992) and Sheldahl et al (1984) who reported similar Ve in both conditions during 5 minute exercise intervals at workloads corresponding to 62% and 87%, and 37% and 47% respectively of WI VO_{2max}. The exercise intensities in the above studies represent absolute workloads, however, which likely represent higher relative intensities of exercise in the WI condition.

The present study also noted higher Ve, with an increasing trend over the 42 minutes during the treadmill Tvent intensity test performed in WI. This is an expected finding since the runners were exercising above their Tvent (Loat, 1991; Rusko et al, 1986; Hearst, 1982). This is in conflict with Svedenhag and Seger (1992), who found no difference in Ve during WI running at 87% of WI VO_{2max}. This is most likely related to the small duration (5 minutes) of the exercise bout and confounded by the comparison of absolute workloads.

The upward drift in Ve during the treadmill performance tests (due to the heat stress) may be masking (statistically) significantly higher Ve responses in the WI condition performed at treadmill and possibly WI Tvent. It may be that the reduced vital capacity, total lung capacity and lung compliance exhibited during resting WI (Fahri and Linnarsson, 1977; Hong et al, 1969; Agostoni et al, 1966) and greater increase in breathing frequency to tidal volume during WI exercise versus tidal volume to breathing frequency exhibited during land exercise (Welsh, 1988; Sheldahl et al, 1987) may also be responsible for the higher Ve responses in WI.

5.2.3 Blood Lactate Concentration

A progressive increase in HR, Ve and VO_2, during exercise above one's Tvent, is related to the inability of the body to meet exercise demands aerobically and therefore must rely more on its anaerobic system for fuel. This results in the production of lactate at a greater rate than can be removed (Loat, 1991; Loat and Rhodes, 1991; Rusko et al, 1986; Hearst, 1982). A greater increase in VO_2 would have been expected during the 42 minute test at Tr_{Tvent} in the WI condition. Christie et al (1990) noted a higher cardiac output at a given VO_2 during WI versus land ergometer cycling exercise at 41%, 60%, 83%, and 100% VO_{2max}. They suggested that the additional oxygen supplied is not utilized by the exercising muscle. This would seem to indicate then that there was greater reliance on the anaerobic system for fuel, and as a result an increase in lactate production.

The higher WI [BLa] values noted by Svedenhag and Seger (1992), however, are most likely related to the higher relative intensity of the exercise workload in the WI versus treadmill condition. The similar [BLa] values noted in Connelly et al (1991) folllowing 5 minute exercise bouts concur with this study's finding during exercise at WI Tvent in the WI condition for the first 8-10 minutes of the test.

The present study noted initially higher [BLa] in the WI condition in the Tr_{Tvent} test, with [BLa] progressively declining during the test. Similar trend in [BLa] behavior was noted during the WI_{Tvent} test in the WI condition. Similar [BLa] values were noted in the WI_{Tvent} tests performed on the treadmill and the WI condition. [BLa] decreased progressively over the duration of the test in the WI condition. This is contrary to [BLa] behavior on land during steady state exercise at Tvent (Loat, 1991; Rusko et al, 1986). Stegmann and Kinderman (1982) and Schnabel et al (1982) report [BLa] to initially increase during exercise (up to the first 10-20 min of exercise), and thereafter to level off or decrease.

The initial rise in [BLa] is related to the oxygen debt incurred during the onset of exercise. This is later corrected by oxidation of the lactate produced within the muscle and by removal of the lactate into the bloodstream, where it will be eliminated (reoxidized) by nonexercising muscles and other tissues (ie cardiac muscle, liver, kidney etc.) (Favier et al, 1986; Karlsson and Jacobs, 1982). In the present study, the subjects performed a self selected warm-up (5-15 minutes) followed by a 5 minute test warm-up and 5 minutes of exercise to set the Tvent intensity. Since [BLa] is progressively reduced during WI exercise at treadmill and WI Tvent it would seem to suggest that there is either less pooling of lactate in the blood as a result of lower efflux of lactate from the muscle, or more re-oxidization of lactate in the muscle primarily by slow oxidative muscle fibers (Gollnick et al, 1986). It is also possible that less lactate is produced in the muscle, or lactate which initially appears in the blood is later removed by organ tissues and slow oxidative muscle and therefore less appears in the blood. The progressive increase in Ve (and decrease in RER, see Appendix D) seen with declining [BLa] over time supports the view of lactate re-oxidization during exercise. The process may also be hormonally mediated (lower epinephrine concentration during WI exercise) reducing the rate of muscle glycogenolysis or related to increase in muscle blood flow in WI. This would result in reduced [BLa] over time and enhanced aerobic metabolism (Connelly et al, 1990).

5.2.4 Respiratory Exchange Ratio

RER followed a similar pattern to [BLa]. A progressive decline in RER over the 42 minutes was exhibited in the WI condition for the treadmill and WI Tvent (see Appendix D for RER results). The decline in RER in both WI tests at treadmill and WI Tvent from 0.99 to 0.96 does suggest that the higher initial [BLa]'s exhibited in WI were the result of greater reliance on anaerobic processes during the first 15 minutes of exercise, resulting in an incurred oxygen debt. The RER pattern of decline also suggests the reliance on aerobic processes for fuel supply and the re-oxidation of accumulated lactate in the latter part of the WI tests (at WI and treadmill Tvent).

An increasing trend in RER over time was expected for the WI test at treadmill Tvent intensity. This would have supported a greater reliance on anaerobic processes with increasing lactate over time for exercise above one's Tvent. Svedenhag and Seger (1992) noted higher RER during 5 minutes of exercise at 87 percent of WI VO_{2max} with higher [BLa] and RPE compared to treadmill performance at a similar absolute VO_2 (81 percent of treadmill VO_{2max}). The authors concluded that the higher anaerobic metabolism during WI exercise was partly related to a lower perfusion pressure in the legs during WI running, with a decline or maldistribution in total muscle blood flow. However, the higher [BLa] and RER exhibited in the WI compared to treadmill condition, in the study by Svedenhag and Seger (1992) may be solely related to the relative intensity of the exercise in the latter condition. The subjects were most likely exercising above their Tvent in the WI condition, and so a higher [BLa] and RER as well as RPE responses would be expected.

5.2.5 Ratings of Perceived Exertion

RPE responses increased over the 42 minutes for the WI test completed at the treadmill Tvent. This confirms the fact that the subjects perceived this intensity as more difficult in WI than on the treadmill. This is an expected finding, since the subjects were working above their Tvent for the WI condition. [BLa] and RER do not support the subject's perceived effort, although an increasing trend over time was noted for HR and Ve.

Svedenhag and Seger (1992) reported higher RPE for WI running (RPE=14.6) at a VO_2 of 3.5 $l \cdot min^{-1}$ (corresponding to 87 % of WI VO_{2max}) compared to treadmill running (RPE=12.6) at the same absolute intensity (corresponding to 81 % of treadmill VO_{2max}). Similar higher RPE values were noted in the present study for WI exercise at treadmill Tvent intensity. This may suggest that the sample in Svedenhag and Seger (1992) were exercising above their Tvent in the WI condition, and as a result higher RPE ([BLa] and RER) are anticipated and can be attributed to the intensity of exercise and not to differences in physiological response to the WI condition.

In the present study mean RPE response at WI_{Tvent} performed in the WI condition was equal to the RPE response determined at WI_{Tvent} (RPE_{Tvent}=12) from the WI VO_{2max} test. Perceived effort at WI_{Tvent} was similar for the 42 minute test on the treadmill and WI condition. This finding further substantiates that higher RPE values reported for WI running by Svedenhag and Seger (1992) and Richie and Hopkins (1991) are related to the relative intensity of exercise and also familiarity with WI running and are not related to the WI condition.

In summary it appears that HR, Ve, RER and [BLa] responses to exercise at WI and treadmill Tvent are affected by the WI condition. HR is lower in WI at exercise intensities above WI Tvent. The declining trend over time exhibited in RER and [BLa] may be partially accounted for by the WI condition. Ve appears to be slightly higher in the WI condition. It is, however, unclear whether this is related to the WI condition or the relative exercise intensity. The runners' perceived effort of the activity is intensity dependent.

CHAPTER 6

6.0 CONCLUSIONS

1) WI VO_2 at Tvent and maximal effort were lower than treadmill responses in elite distance runners who regularly incorporate WI running in their training regimens, for similar peak [BLa] and RPE.

2) Although land-based running style was simulated by the runners during WI running the viscosity friction of the water medium reduced stride frequency to 60-65% of the treadmill values.

3) Heart-rate at Tvent and maximal effort were lower in the WI versus the treadmill condition. The lower HR at Tvent determined from the WI VO_{2max} test, however, was related to the lower VO_2 at WI Tvent and not to the WI condition. There is an intensity dependent response for submaximal HR in water immersion to the neck. HR response in WI is similar to treadmill values for VO_2 at and below WI Tvent and lower in WI during exercise above WI Tvent even though an upward drift associated with increased reliance on anaerobic metabolism is noted.

4) Ventilation at Tvent and maximal effort were not affected by the WI condition; responses were similar in WI and treadmill running. Ve during steady state exercise at and above WI Tvent in the WI condition was not affected by the WI condition, but differences exhibited were related to the exercise intensity.

5) [BLa] response during steady state exercise may be affected by the WI condition; a decreasing trend over the 42 minute tests in [BLa] was exhibited in the WI condition at and above WI Tvent.

6) Differences in RPE on the treadmill and WI condition are related to the relative intensity of exercise and the subjects' familiarity with WI running and not the WI condition.

6.1 RECOMMENDATIONS FOR FUTURE RESEARCH

1) To study VO_{2max} levels during water immersion to the neck (WI) and treadmill running among runners who incorporate WI running in their training regimens and meet all other criteria for WI running set by this researcher's study. In the proposed study the runners will be distinguished into groups according to the intensity of training utilized in their WI running workouts. Runners should be distinguished into at least two groups, that is: a) Runners who's WI running workouts are limited to exercising at and below ventilatory threshold (Tvent) and b) Runners who's WI running workouts incorporate exercising at and above Tvent level.

In this manner the relationship between the intensity of exercise for WI running workouts and the magnitude of the difference in WI versus treadmill running VO_{2max} and Tvent can be explored.

2) To study the cardiorespiratory and metabolic adapations to WI running training and the implications to land-based running performance.

a) To study cardiorespiratory and metabolic adapations to WI running following a long term WI running training regimen in individuals previously untrained in WI running. This group's improvements would be compared to a control group who will have been prescribed a similar intensity training program for land-based running. A treadmill and cycle ergometer would both be used for pre- and post-testing at Tvent and VO_{2max} level.

b) To compare cardiorespiratory and metabolic adapations to WI running, shallow water (weight-bearing) running and treadmill running following long term training. A treadmill and cycle ergometer would both be used for pre- and post-testing at Tvent and VO_{2max} level.

3) To compare WI and treadmill running style via biomechanical (kinematic) analysis combined with cardiorespiratory and metabolic analysis.

4) To replicate the Tvent steady state performance test portion of this researcher's study. WI running, or a cycle ergometer immersed in the water could be used as the mode of exercise for the WI condition compared to treadmill and stationary ergometer exercise on land, respectively. Also to ensure that land-based laboratory environmental conditions do not produce heat stress in the subjects. VO_2, HR, Ve, [BLa], RER, RPE responses would be monitored to determine whether WI response patterns exhibited in this study are reproduceable. Additional variables that should be considered for collection include the following:

a) Blood glucose and plasma catecholamine levels to provide some indication of the energy sources utilized for exercise and thereby provide additional information regarding [BLa] behavior.

b) Body weight before and after WI testing to determine the magnitude of fluid loss due to diuresis in WI versus sweating during treadmill testing.

4) To study HR response to various intensities of exercise in WI compared to land exercise to elucidate HR response in the WI condition. That is, to study HR responses in WI at rest, during exercise below WI Tvent, at WI Tvent and above WI Tvent to maximal effort intensities compared to similar absolute intensity exercise (matched for VO_2) on land.

6.2 TRAINING IMPLICATIONS

1) **WI running style and the ability to simulate land-based running motion in deep water.** WI running can be used to complement a runner's training regimen. It is, however, important that land-based running style be simulated in the WI condition to ensure peripheral training adaptations in the musculature utilized for land running. Turn-over rate (stride frequency) will be 30-40% lower in the WI condition related to the water resistance. The upper body energy expenditure for similar arm motion to land-based running will be higher in the WI condition and this is related to the increased resistance encountered in the water versus encountered by the air during land-based running. Upper body work can further be increased in the WI condition by utilizing the arms

and hands to propel the body forward, by reaching forward and cupping the water. This action will be visually and kinesthetically evident, because it results in an extreme forward lean of the body to an almost horizontal orientation. It is, therefore, important to maintain proper running form in the water. Unlike land running where improper running style (eg. extreme forward lean, improper arm motion, etc.) can result in a fall, this is unlikely with WI running. The ability to push through water is reduced with running in the water versus swimming and this may lead to the use of the upper body, as discussed above, to maintain the head above the water level. Utilizing a limited boyancy device can enhance simulating land-based running style in WI. The boyancy device will provide enough boyancy to keep the head above the water level and therefore the runner can concentrate on simulating land-based running motion during WI running sessions.

2) **Training intensity of WI running sessions.** The purpose of incorporating WI running in a runner's training regimen should be the following: a) to reduce stress on the joints by running some her weekly training mileage in the water and b) during injury as a method of maintaining physical conditioning and possibly continuing one's training immediately following injury and during the rehabilitation process. WI running training must incorporate similar work-outs as completed during land-based training with respect to exercise duration and intensity to be effective.

3) **The use of HR to monitor the training intensity of WI running work-outs.** In using HR to set the training intensity of a WI running work-

out session it is important to account for the following: a) HR values at low submaximal intensities, below WI Tvent level are not affected by the WI condition, b) HR values above WI Tvent are likely lower in the WI condition versus the land response for similar intensity of exercise (ie. matched for VO_2). A 10-13 bpm lower HR response should be expected and accounted for when setting the training HR values for one's work-out. For example if you know that Runner A has a HR of 165 bpm at his land-based Tvent, or HR_{max} of 186 bpm and would like him to complete an interval workout, or a run in the WI condition at 10% above his Tvent, or at 90% of his HR_{max} you would then want the runner to have the following target HR values:

a) for 10% above the runner's land-based Tvent (ie. 165 bpm), the target HR would be the following: 165 bpm - 11 bpm (adjusting for the lower WI HR response) = 154 bpm

154 bpm X 10% = 15.4 bpm , therefore the target HR for the exercise session would be: 154 bpm + 15.4 bpm = 169 bpm.

b) for 90% of the runner's land-based HR_{max}, the target HR would be the following: 186 bpm - 11 bpm (adjusting for the lower WI HR response) = 175 bpm

175 bpm X 90% = 158 bpm.

4) **Training implications of the declining [BLa] and RER responses during prolonged WI running exercise.** According to the [BLa] and RER responses during prolonged exercise at and above WI Tvent in the WI condition, the ability to exercise at a 'harder' intensity for a longer duration in WI seems to be suggested. More research is needed to look at lactate behaviour during exercise in WI. Present finding suggest

that the accumulation of lactate and ensuing metabolic acidosis may, consequently, be prevented by the shunting of the lactate produced in the exercising muscles to other tissues where it is catabolized and most likely used as fuel for the activity. This seems to be substatiated with the no change (increase) in VO_2, but increase in Ve as well as RPE responses during exercise above WI Tvent. Hard (ie. above WI Tvent) WI running work-outs would, therefore, seem to be of benefit.

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APPENDICES

Appendix A : Subject's Raw Data.

SUBJECT 1

Male subject, 28 yrs old. Competes in 10 km and half marathon runs, duathlons (5 km run-30 km cycle-5 km run), sprint distance triathlon (1.5 km swim-40 km cycle-10 km run). Has been WI running for 10 yrs. For the 6 months prior to participating in the study he had been WI running at least 4-10 times per month, 30-45 minute duration per session. WI running training consisted of interval training above his HR at WI Tvent to full exhaustion and also completed steady state runs at his WI Tvent HR (45 min). This subject used a HR monitor during his WI training to control his workout intensity. Used no floatation device. Comparison of subject's race pace from event completed close to the time when participating in the study found him to have completed the final 10 km from a sprint distance triathlon at 10.8 mph. The subject's calculated TrTvent pace was 10.0 mph.

Variable	Treadmill	WI
Height (cm)	180	180
Weight (kg)	67.7	67.7
VO2max (l/min)	4.24	4.15
VO2max (ml/kg/min)	62.6	61.6
HRmax (bpm)	200	180
Vemax (l/min)	131.1	123.4
RERmax	1.18	1.16
RPEmax	20	20
30 sec. post-test [BLa]	11.2	11.2
5 min. post-test [BLa]	11.5	11.1
Max. duration (min)	16:00	17:00
VO2 at Tvent (l/min)	3.65	3.26
VO2 at Tvent (ml/kg/min)	54.0	48.2
HR at Tvent (bpm)	176	161
Ve at Tvent (l/min)	87.0	73.2
RER at Tvent	0.96	0.99
RPE at Tvent	16	13
Time of Tvent	9:30	5:00

Stride frequency from Tr and Wl VO_{2max} tests.

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	82	88	98
Wl VO2max test	48	50	66

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	171	174	175	180	182	187	187
HR	TrWlTvent	153	162	163	165	169	172	173
	WlTrTvent	157	161	160	159	165	166	163
	WlWlTvent	146	146	144	146	144	150	147
	TrTrTvent	53.4	54.5	54.1	54.8	54.8	55.5	55.2
VO2	TrWlTvent	47.7	49.7	49.5	49.5	49.8	50.4	51.2
	WlTrTvent	52.4	54.2	54.6	54.3	55.4	55.6	56.1
	WlWlTvent	48.2	48.3	48.6	48.4	47.9	49.9	48.9
	TrTrTvent	90.0	91.5	92.4	93.8	98.0	102.4	104.7
Ve	TrWlTvent	77.0	83.1	85.5	85.9	87.4	88.5	88.0
	WlTrTvent	90.2	92.2	96.9	98.37	100.7	101.8	103.5
	WlWlTvent	79.9	79.8	82.1	82.0	78.3	82.5	80.1
	TrTrTvent		7.2	8.4	8.3	8.4	8.8	9.4
[BLa]	TrWlTvent		3.2	4.2	3.8	3.7	3.4	3.1
	WlTrTvent		3.6	3.4	5.7	5.3	5.5	2.9
	WlWlTvent		5.9	6.1	3.4	3.3	3.1	5.5

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	0.97	0.95	0.95	0.95	0.96	0.97	0.97
RER	TrWITvent	0.97	0.97	0.96	0.96	0.96	0.95	0.95
	WITrTvent	1.03	1.00	0.99	0.99	0.98	0.99	0.99
	WIWITvent	0.97	0.96	0.96	0.96	0.94	0.96	0.95
	TrTrTvent	13	14	15	16	16	17	18
RPE	TrWITvent	12	13	13	13	14	14	14
	WITrTvent	13	15	15	16	17	17	17
	WIWITvent	13	13	13	14	14	14	14

SUBJECT 2

Male subject, 29 yrs old. Competes in 10 km and marathon runs. Has been water running for 10 yrs. For the 6 months prior to participating in the study he had been WI running at least 12 times per month, 45-60 minute duration per session. WI running sessions consisted of steady state runs at his WITvent HR. This subject used a HR monitor during his WI training to control his workout intensity. Used no floatation device.

Comparison of the subject's race pace from an event completed close to the time participating in the study found him to have completed a marathon at 10.2 mph pace. The subject's calculated TrTvent pace was 10.4 mph.

Variable	Treadmill	WI
Height (cm)	182.0	182.0
Weight (kg)	78.0	78.0
VO2max (l/min)	4.85	4.40
VO2max (ml/kg/min)	60.0	56.0
HRmax (bpm)	190	178
Vemax (l/min)	126.9	109.4
RERmax	1.20	1.14
RPEmax	20	20
30 sec. post-test [BLa]	9.6	9.8
5 min. post-test [BLa]	10.9	10.5
Max. duration (min)	15:30	20:00
VO2 at Tvent (l/min)	3.87	3.74
VO2 at Tvent (ml/kg/min)	48.9	47.6
HR at Tvent (bpm)	163	149
Ve at Tvent (l/min)	97.9	93.5
RER at Tvent	1.01	1.00
RPE at Tvent	15	12
Time of Tvent	10:00	10:00

Stride frequency for Tr and WI VO_{2max} tests.

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	80	92	96
WI VO2max test	50	50	56

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	158	169	169	174	183	183	184
HR	TrWITvent	154	161	168	171	174	176	178
	WITrTvent	155	157	161	159	155	158	157
	WIWITvent	153	152	152	144	146	146	149
	TrTrTvent	50.4	50.3	52.4	52.2	53.2	55.7	57.6
VO2	TrWITvent	47.2	48.0	49.6	49.4	49.5	50.6	51.0
	WITrTvent	49.0	53.8	54.3	53.2	52.5	53.3	51.8
	WIWITvent	47.5	48.0	46.8	44.5	44.9	44.9	45.5
	TrTrTvent	90.4	94.9	95.9	105.0	109.1	115.4	63.3
Ve	TrWITvent	80.2	88.1	92.1	90.9	97.4	96.5	101.4
	WITrTvent	105.0	108.3	111.6	106.4	105.4	104.9	98.3
	WIWITvent	99.7	101.2	98.0	85.9	86.5	83.5	83.2
	TrTrTvent		4.8	6.4	8.8	6.9	9.7	8.8
[BLa]	TrWITvent		6.5	5.1	6.4	6.1	7.3	8.3
	WITrTvent		6.8	7.2	6.7	6.2	5.3	4.4
	WIWITvent		5.3	4.8	3.9	3.4	3.1	3.1

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	1.00	1.00	1.02	1.01	1.01	0.99	0.99
RER	TrWlTvent	0.98	0.99	1.00	1.01	1.02	1.00	0.99
	WlTrTvent	1.05	1.03	1.04	1.01	1.00	1.00	0.98
	WlWlTvent	1.02	0.99	0.99	0.94	0.93	0.91	0.92
	TrTrTvent	14	14	14	15	18	19	19
RPE	TrWlTvent	13	13	13	13	14	15	17
	WlTrTvent	14	14	14	14	14	14	14
	WlWlTvent	13	13	13	13	13	13	13

SUBJECT 3

Female subject, 22 yrs old. Competes in 3, 5, 10 km and cross country runs. Has been water running for 1.5 yrs. For the previous 6 months prior to participating in the study she has been WI running at least 12 times per month, 30-60 minute duration per session. WI running consisted predominately of progressive runs resulting in exhaustion by the end of the session. Also did some interval type training (15 min) when she missed a hard land training session and finished her session with steady state WI running (15-20 min). Used no floatation device.

No comparison with race pace from an event completed close to the time she participated in the study was possible for she was not competing at that time (during the summer months).

Variable	Treadmill	WI
Height (cm)	168.2	168.2
Weight (kg)	61.1	61.1
VO2max (l/min)	3.17	3.03
VO2max (ml/kg/min)	51.8	49.6
HRmax (bpm)	194	186
Vemax (l/min)	88.5	91.7
RERmax	1.03	1.08
RPEmax	20	20
30 sec. post-test [BLa]	10.2	11.0
5 min. post-test [BLa]	8.2	11.0
Max. duration (min)	11:00	11:00
VO2 at Tvent (l/min)	2.77	2.57
VO2 at Tvent (ml/kg/min)	45.3	42.0
HR at Tvent (bpm)	181	168
Ve at Tvent (l/min)	65.4	72.9
RER at Tvent	0.98	0.97
RPE at Tvent	16	12
Time of Tvent	7:00	5:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	84	88	92
WI VO2max test	52	54	58

SUBJECT 4

Male subject, 25 yrs old. Competes in 10 km and marathon runs. Has been water running for 8 months. For the 6 months prior to participating in the study he had been WI running at least 16 times per month, 40-50 minute duration per session. WI running training consisted of interval training above his HR at WITvent (15-20 min duration) and steady state runs at his WITvent HR and above (20-50 min duration). This subject used a HR monitor during his WI training to control his work intensity. Uses a floatation device ('aquajogger').

Comparison of the subject's race pace from an event completed close to the time participating in the study found him to have completed a marathon at 9.3 mph pace. The subject's calculated TrTvent pace was 9.0 mph.

Variable	Treadmill	WI
Height (cm)	183.3	183.3
Weight (kg)	71.6	71.6
VO2max (l/min)	4.71	4.47
VO2max (ml/kg/min)	65.7	62.4
HRmax (bpm)	183	175
Vemax (l/min)	123.1	126.7
RERmax	1.20	1.10
RPEmax	20	20
30 sec. post-test [BLa]	10.4	12.8
5 min. post-test [BLa]	8.1	11.2
Max. duration (min)	13:30	16:00
VO2 at Tvent (l/min)	3.83	3.32
VO2 at Tvent (ml/kg/min)	53.4	46.4
HR at Tvent (bpm)	160	140
Ve at Tvent (l/min)	76.7	78.6
RER at Tvent	0.99	0.99
RPE at Tvent	15	13
Time of Tvent	8:30	6:00

SUBJECT 5

Female subject, 20 yrs old. Competes in 3, 5, and 10 km runs, and cross country. Has been water running for 3 yrs. For the previous 6 months prior to participating in the study she had been WI running at least 7 times per month, 30-60 minute duration of each session. WI running training consisted of 15 minute interval training sessions and 30-60 minute steady state running sessions.

Variable	Treadmill	WI
Height (cm)	163.2	163.2
Weight (kg)	51.7	51.7
VO2max (l/min)	3.15	2.76
VO2max (ml/kg/min)	61.0	53.3
HRmax (bpm)	191	180
Vemax (l/min)	88.5	75.4
RERmax	1.19	1.14
RPEmax	20	20
30 sec. post-test [BLa]	8.0	7.7
5 min. post-test [BLa]	8.0	7.2
Max. duration (min)	14:00	15:30
VO2 at Tvent (l/min)	2.32	2.25
VO2 at Tvent (ml/kg/min)	45.0	43.5
HR at Tvent (bpm)	164	148
Ve at Tvent (l/min)	51.7	49.6
RER at Tvent	1.03	1.00
RPE at Tvent	14	12
Time of Tvent	8:00	8:00

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	78	84	94
WI VO2max test	44	54	64

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	155	161	164	170	173	174	175
HR	TrWlTvent	151	153	157	161	163	164	167
	WlTrTvent	151	161	154	162	164	166	166
	WlWlTvent	150	156	158	154	153	160	155
	TrTrTvent	45.5	44.3	45.2	44.8	44.7	45.0	44.7
VO2	TrWlTvent	43.5	44.0	43.4	44.0	44.9	44.3	44.5
	WlTrTvent	45.4	50.3	50.4	49.1	51.1	52.2	48.2
	WlWlTvent	43.0	44.5	43.1	43.2	42.7	42.6	41.0
	TrTrTvent	56.4	55.0	59.4	61.0	60.2	61.7	63.3
Ve	TrWlTvent	50.8	53.3	53.8	56.6	56.0	55.7	57.5
	WlTrTvent	53.2	65.2	63.9	63.9	64.5	65.7	60.2
	WlWlTvent	54.6	58.2	57.3	56.9	56.0	55.8	53.6
	TrTrTvent		4.1	4.5	3.4	4.9	7.7	11.3
[BLa]	TrWlTvent		2.2	2.7	1.9	2.7	4.6	5.3
	WlTrTvent		3.6	3.1	4.1	3.6	3.1	3.2
	WlWlTvent		2.5	2.0	2.0	2.0	1.8	1.6

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	1.00	1.00	0.99	1.00	0.99	0.98	1.00
RER	TrWlTvent	0.92	0.92	0.94	0.93	0.91	0.91	0.91
	WlTrTvent	1.02	1.05	1.01	1.02	1.00	1.00	1.00
	WlWlTvent	1.08	1.08	1.07	1.07	1.05	1.05	1.02
	TrTrTvent	14	15	17	17	17	17	17
RPE	TrWlTvent	13	13	13	13	13	13	13
	WlTrTvent	13	15	15	15	15	15	15
	WlWlTvent	13	13	13	13	13	13	13

SUBJECT 6

Female subject, 26 yrs old. Competes in 5 and 10 km runs and cross country runs. Has been water running for 2 yrs. For the previous 6 months prior to participating in the study she has been WI running at least 12 times per month, 45-60 minute duration of each session. Used no floatation devise. WI running training consisted of interval training above her WI Tvent HR and also completed steady state runs around her WI Tvent HR (60 min).

Comparison of the subject's race pace from event completed close to the time when participating in the study found her to have completed a 10 Km race at 8 mph pace. The subject's calculated TrTvent was 7.7 mph.

Variable	Treadmill	WI
Height (cm)	166.0	166.0
Weight (kg)	51.5	51.5
VO2max (l/min)	2.60	2.43
VO2max (ml/kg/min)	50.5	49.2
HRmax (bpm)	190	178
Vemax (l/min)	80.5	89.4
RERmax	1.19	1.20
RPEmax	20	20
30 sec. post-test [BLa]	12.4	12.9
5 min. post-test [BLa]	10.7	13.3
Max. duration (min)	10:15	13:00
VO2 at Tvent (l/min)	2.09	1.72
VO2 at Tvent (ml/kg/min)	40.5	33.4
HR at Tvent (bpm)	172	149
Ve at Tvent (l/min)	50.8	39.2
RER at Tvent	1.01	1.00
RPE at Tvent	11	7
Time of Tvent	5:00	4:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	84	88	92
WI VO2max test	56	60	70

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	170	176	175	175	179	181	184
HR	TrWlTvent	147	150	153	154	156	158	159
	WlTrTvent	161	161	159	162	163	164	160
	WlWlTvent	145	143	140	150	151	151	153
	TrTrTvent	40.0	42.6	43.2	40.0	40.8	41.6	41.4
VO2	TrWlTvent	33.1	33.5	33.0	33.1	33.8	34.1	32.7
	WlTrTvent	40.8	40.4	40.3	40.4	41.0	40.8	40.3
	WlWlTvent	33.3	29.7	31.9	33.3	35.1	35.9	35.5
	TrTrTvent	48.7	53.9	55.9	47.8	52.9	57.1	57.9
Ve	TrWlTvent	37.5	40.4	36.3	37.1	39.3	38.9	40.4
	WlTrTvent	59.2	55.8	58.0	60.9	63.3	66.4	66.6
	WlWlTvent	43.7	35.6	40.6	44.7	46.8	51.3	49.3
	TrTrTvent		8.2	6.3	7.3	5.6	6.6	8.6
[BLa]	TrWlTvent		4.7	2.8	2.3	2.8	2.2	3.2
	WlTrTvent		5.9	5.8	5.6	4.9	5.3	5.7
	WlWlTvent		2.4	2.3	3.1	3.2	3.3	2.7

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	0.98	0.97	0.97	0.92	0.95	0.96	0.96
RER	TrWlTvent	0.92	0.94	0.91	0.91	0.92	0.91	0.94
	WlTrTvent	1.03	0.96	0.98	0.97	0.97	0.97	0.95
	WlWlTvent	1.03	0.95	0.98	0.99	0.98	1.00	0.98
	TrTrTvent	12	13	13	14	16	17	18
RPE	TrWlTvent	7	9	11	11	13	12	12
	WlTrTvent	6	9	10	12	13	15	17
	WlWlTvent	8	9	9	10	10	11	11

SUBJECT 7

Male subject, 29 yrs old. Competes in marathons. Has been water running for 9 months. For the previous 6 months prior to participating in the study he has been WI running at least 16 times per month, 30-60 minute duration of each session. WI running training consisted solely of low intensity training below his WI Tvent HR (30-60 min). Used a flotation devise (water ski belt).

Comparison of the subject's race pace from an event completed close to the time of participating in the study found him to have completed a marathon at 10.7 mph pace. The subject's calculated TrTvent pace was 10.8 mph.

Variable	Treadmill	WI
Height (cm)	182.0	182.0
Weight (kg)	67.9	67.9
VO2max (l/min)	4.94	3.82
VO2max (ml/kg/min)	72.7	55.9
HRmax (bpm)	183	148
Vemax (l/min)	115.1	108.8
RERmax	1.14	1.09
RPEmax	20	20
30 sec. post-test [BLa]	11.2	6.7
5 min. post-test [BLa]	8.7	6.8
Max. duration (min)	16:45	16:00
VO2 at Tvent (l/min)	3.98	2.00
VO2 at Tvent (ml/kg/min)	58.8	44.0
HR at Tvent (bpm)	167	130
Ve at Tvent (l/min)	71.3	71.8
RER at Tvent	0.90	0.93
RPE at Tvent	12	14
Time of Tvent	11:45	8:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	88	94	98
WI VO2max test	60	58	68

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	163	167	168	168	172	174	177
HR	TrWITvent	133	132	131	134	134	133	150
	WITrTvent	151	149	148	148	148	148	152
	WIWITvent	126	131	128	130	129	129	128
	TrTrTvent	58.2	60.5	59.4	58.2	59.6	59.0	60.5
VO2	TrWITvent	44.3	44.4	44.0	44.2	43.9	45.4	44.9
	WITrTvent	57.9	56.9	56.7	56.4	53.9	54.7	42.0
	WIWITvent	43.7	44.8	44.6	44.2	45.8	45.1	43.1
	TrTrTvent	75.6	81.3	81.8	81.9	81.4	83.6	85.6
Ve	TrWITvent	57.6	57.1	57.1	54.7	56.1	56.3	55.6
	WITrTvent	109.4	106.2	106.2	108.7	105.6	95.71	101.1
	WIWITvent	71.8	77.2	77.3	78.5	77.7	73.4	69.2
	TrTrTvent		3.5	3.9	3.3	4.1	4.0	4.6
[BLa]	TrWITvent		4.6	5.2	4.5	5.9	6.4	3.9
	WITrTvent		6.9	6.1	5.5	5.8	4.6	4.9
	WIWITvent		2.4	2.2	1.9	1.8	1.9	1.8

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	0.97	0.99	0.96	0.96	0.94	0.97	0.97
RER	TrWITvent	0.83	0.84	0.81	0.81	0.84	0.81	0.82
	WITrTvent	0.94	0.93	0.90	0.90	0.89	0.88	0.90
	WIWITvent	0.92	0.94	0.95	0.95	0.91	0.91	0.92
	TrTrTvent	13	13	13	13	14	14	14
RPE	TrWITvent	9	9	9	9	9	9	9
	WITrTvent	16	18	18	18	19	19	20
	WIWITvent	12	13	13	13	13	13	13

SUBJECT 8

Male subject, 22 yrs old. Competes in 10 km, half marathon and cross country runs, is training for marathon distances. Has been water running for 4.5 yrs. For the previous 6 months prior to participating in the study he has been WI running at least 6 times per month, 30-60 minute duration of each session. Uses no floatation devise most of the time, sometimes uses a 'water ski belt'. WI running training consisted of interval training and 'hard' steady state runs.

Variable	Treadmill	WI
Height (cm)	187.7	187.7
Weight (kg)	69.8	69.8
VO2max (l/min)	4.27	3.86
VO2max (ml/kg/min)	61.1	55.2
HRmax (bpm)	197	172
Vemax (l/min)	112.1	109.6
RERmax	1.16	1.11
RPEmax	20	20
30 sec. post-test [BLa]	8.2	7.2
5 min. post-test [BLa]	7.0	6.2
Max. duration (min)	16:30	14:00
VO2 at Tvent (l/min)	2.75	3.00
VO2 at Tvent (ml/kg/min)	39.4	43.0
HR at Tvent (bpm)	164	153
Ve at Tvent (l/min)	58.6	72.2
RER at Tvent	0.98	0.99
RPE at Tvent	9	10
Time of Tvent	7:30	6:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	80	84	90
WI VO2max test	36	36	40

SUBJECT 9

Male subject, 34 yrs old. Competes in marathon and ultramarathon runs, and triathlons (2.4 mile swim-114.0 mile cycle-26.4 mile run). Has been water running for 4 yrs. For the previous 6 months prior to participating in the study he has been WI running at least 10 times per month, 30-60 minute duration of each session. Uses a floatation devise sometimes ('aquajogger'), but not always. WI running training consisted solely of low intensity exercise below WI Tvent HR.

Comparison of the subject's race pace from event completed close to the time when participating in the study found him to have completed a 50 mile run at 9.4 mph pace. The subject's calculated TrTvent pace was 9.0 mph.

Variable	Treadmill	WI
Height (cm)	174.7	174.7
Weight (kg)	69.3	69.3
VO2max (l/min)	4.18	3.40
VO2max (ml/kg/min)	60.3	49.1
HRmax (bpm)	176	168
Vemax (l/min)	124.3	117.5
RERmax	1.37	1.11
RPEmax	20	20
30 sec. post-test [BLa]	14.1	13.8
5 min. post-test [BLa]	13.5	13.3
Max. duration (min)	14:00	14:00
VO2 at Tvent (l/min)	2.90	2.49
VO2 at Tvent (ml/kg/min)	42.0	35.9
HR at Tvent (bpm)	156	146
Ve at Tvent (l/min)	60.1	59.2
RER at Tvent	1.02	1.01
RPE at Tvent	13	11
Time of Tvent	8:30	5:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	82	84	96
WI VO2max test	52	62	70

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	148	149	151	154	156	158	159
HR	TrWlTvent	131	132	133	133	133	133	134
	WlTrTvent	151	149	149	149	153	155	158
	WlWlTvent	137	135	138	136	135	138	140
	TrTrTvent	42.3	42.1	41.7	42.2	43.7	43.5	43.4
VO2	TrWlTvent	36.4	36.0	36.9	36.4	36.4	36.9	35.8
	WlTrTvent	41.4	41.3	41.6	40.6	40.8	43.1	44.2
	WlWlTvent	36.2	36.0	36.2	35.8	36.1	36.3	36.5
	TrTrTvent	65.1	63.5	63.5	68.1	72.2	73.5	72.4
Ve	TrWlTvent	51.7	52.5	52.6	52.1	50.7	54.2	49.8
	WlTrTvent	76.3	77.0	79.8	78.9	84.4	98.6	105.3
	WlWlTvent	60.6	56.4	58.9	55.4	54.8	54.0	56.7
	TrTrTvent		6.0	6.6	6.6	7.5	8.2	9.4
[BLa]	TrWlTvent		5.4	5.4	8.3	6.3	9.0	7.8
	WlTrTvent		9.6	9.6	8.9	9.1	8.9	9.6
	WlWlTvent		5.0	4.6	3.9	3.5	3.2	2.9

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	0.98	0.95	0.94	0.99	0.99	0.99	0.99
RER	TrWlTvent	0.98	0.96	0.95	0.92	0.91	0.94	0.91
	WlTrTvent	1.02	1.02	1.01	0.97	1.01	1.00	1.03
	WlWlTvent	0.97	0.94	0.95	0.92	0.91	0.92	0.93
	TrTrTvent	13	12	13	15	15	15	15
RPE	TrWlTvent	11	9	8	9	9	9	9
	WlTrTvent	15	15	15	15	15	15	17
	WlWlTvent	10	10	10	10	10	10	10

SUBJECT 10

Male subject, 22 yrs old. Competes in 800, 1500 m, 5 and 10 km runs. Has been water running for 2 yrs. For the previous 6 months prior to participating in the study he has been WI running at least 10-12 times per month, 50-60 minte duration of each session. Used no floatation devise. WI running training consisted of interval training and steady state runs about his WI Tvent HR.

Variable	Treadmill	WI
Height (cm)	191.0	191.0
Weight (kg)	79.4	79.4
VO2max (l/min)	5.03	4.63
VO2max (ml/kg/min)	63.3	59.1
HRmax (bpm)	194	184
Vemax (l/min)	131.2	123.6
RERmax	1.24	1.16
RPEmax	20	20
30 sec. post-test [BLa]	11.3	8.9
5 min. post-test [BLa]	12.4	7.5
Max. duration (min)	15:30	12:00
VO2 at Tvent (l/min)	3.57	3.96
VO2 at Tvent (ml/kg/min)	45.0	50.5
HR at Tvent (bpm)	148	164
Ve at Tvent (l/min)	69.7	77.0
RER at Tvent	0.95	1.02
RPE at Tvent	10	13
Time of Tvent	7:30	4:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	80	80	86
WI VO2max test	30	34	38

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	147	150	152	157	158	159	160
HR	TrWlTvent	161	164	166	171	174	176	178
	WlTrTvent	146	145	145	146	152	152	150
	WlWlTvent	162	163	164	165	168	170	173
	TrTrTvent	45.0	45.9	45.0	45.8	44.8	45.3	45.7
VO2	TrWlTvent	50.6	51.8	50.1	51.8	51.5	51.7	52.2
	WlTrTvent	45.2	45.2	45.1	45.6	44.7	46.7	45.2
	WlWlTvent	50.6	50.1	50.5	50.7	50.4	52.7	54.0
	TrTrTvent	77.6	78.1	78.8	81.0	80.0	78.0	80.2
Ve	TrWlTvent	88.8	93.8	90.7	94.6	93.2	92.3	92.3
	WlTrTvent	72.9	71.8	70.8	69.6	70.7	74.1	68.8
	WlWlTvent	79.5	79.3	80.4	81.7	79.5	84.7	87.8
	TrTrTvent		3.9	4.2	2.7	2.0	3.6	3.3
[BLa]	TrWlTvent		4.2	3.8	3.2	5.1	5.0	2.8
	WlTrTvent		3.6	3.4	3.2	3.4	3.6	3.1
	WlWlTvent		4.7	4.4	4.3	4.5	4.5	3.7

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	1.00	0.99	1.00	0.99	0.98	0.98	0.99
RER	TrWlTvent	1.01	1.01	1.00	1.01	1.01	1.01	1.00
	WlTrTvent	0.95	0.95	0.94	0.92	0.94	0.95	0.91
	WlWlTvent	0.96	0.96	0.95	0.95	0.94	0.94	0.95
	TrTrTvent	11	12	12	13	13	13	13
RPE	TrWlTvent	12	12	13	14	14	14	14
	WlTrTvent	10	11	12	12	12	12	12
	WlWlTvent	11	12	12	12	13	15	13

Subject 11

Female subject, 35 yrs old. Competes in 10 km and marathon runs. Has been water running for 3 yrs. For the previous 6 months prior to participating in the study she had been WI running at least 6 times per month, 45 minute duration of each session. Used no floatation devise. WI running training consisted of steady state runs aroung WI Tvent HR.

Comparison of subject's race pace from event completed close to the time of participating in the study found her to have completed a marathon at 8.7 mph. The subject's calculated TrTvent pace was 8.5 mph.

Variable	Treadmill	WI
Height (cm)	170.9	170.9
Weight (kg)	57.6	57.6
VO2max (l/min)	3.02	2.89
VO2max (ml/kg/min)	52.4	49.1
HRmax (bpm)	180	166
Vemax (l/min)	87.13	87.7
RERmax	1.28	1.10
RPEmax	20	20
30 sec. post-test [BLa]	8.7	8.0
5 min. post-test [BLa]	8.0	7.2
Max. duration (min)	13:00	14:00
VO2 at Tvent (l/min)	2.35	2.24
VO2 at Tvent (ml/kg/min)	40.8	38.0
HR at Tvent (bpm)	159	152
Ve at Tvent (l/min)	48.4	47.0
RER at Tvent	0.99	1.01
RPE at Tvent	14	12
Time of Tvent	7:00	6:00

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	88	88	94
WI VO2max test	42	56	60

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	162	159	158	159	162	163	164
HR	TrWlTvent	147	146	147	146	149	151	150
	WlTrTvent	154	155	155	155	157	155	160
	WlWlTvent	149	149	148	149	148	148	151
	TrTrTvent	40.8	40.9	39.8	40.0	40.5	40.1	40.3
VO2	TrWlTvent	38.0	38.2	38.3	38.2	38.6	37.9	38.9
	WlTrTvent	40.9	40.2	40.5	40.6	41.3	42.4	42.0
	WlWlTvent	38.4	38.2	38.5	38.7	38.1	37.8	38.2
	TrTrTvent	58.1	57.6	55.6	57.8	57.5	57.2	56.2
Ve	TrWlTvent	48.2	49.0	48.6	48.6	48.6	47.6	47.4
	WlTrTvent	61.0	58.5	57.2	58.2	62.1	64.0	65.3
	WlWlTvent	53.0	52.9	52.5	53.5	52.5	51.8	54.3
	TrTrTvent		2.7	1.7	2.9	2.3	1.9	2.4
[BLa]	TrWlTvent		1.5	1.8	2.2	2.3	2.4	1.5
	WlTrTvent		3.2	3.1	3.0	3.0	3.3	3.5
	WlWlTvent		2.6	2.7	2.5	2.6	2.4	2.5

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	1.05	1.02	1.02	1.04	1.03	1.03	1.02
RER	TrWlTvent	0.97	0.98	0.97	0.97	0.96	0.95	0.94
	WlTrTvent	0.97	0.91	0.90	0.90	0.90	0.91	0.91
	WlWlTvent	0.93	0.93	0.92	0.92	0.92	0.91	0.92
	TrTrTvent	12	12	12	12	12	12	12
RPE	TrWlTvent	12	12	12	12	12	12	12
	WlTrTvent	13	13	13	13	13	13	13
	WlWlTvent	12	12	12	12	12	12	12

SUBJECT 12

Female subject, 20 yrs old. Competes in 3-10 km track runs and cross country runs. Has been water running for 1 yr. For the previous 6 months prior to participating in the study she has been WI running at least 6 times per month, 40 minute duration per session. Used no floatation device. WI running training consisted of interval and steady state runs at and above WI Tvent HR.

Comparison of the subject's race pace from event completed close to the time when participating in the study found her to have completed a 10 km race at 9.4 mph pace. The subject's calculated TrTvent pace was 7.5 mph.

Variable	Treadmill	WI
Height (cm)	159.7	159.7
Weight (kg)	49.2	49.2
VO2max (l/min)	2.60	2.47
VO2max (ml/kg/min)	52.9	50.9
HRmax (bpm)	211	199
Vemax (l/min)	71.0	80.0
RERmax	1.18	1.10
RPEmax	20	0.99
30 sec. post-test [BLa]	11.9	9.1
5 min. post-test [BLa]	8.7	7.8
Max. duration (min)	12:30	16:00
VO2 at Tvent (l/min)	1.87	1.87
VO2 at Tvent (ml/kg/min)	38.5	38.6
HR at Tvent (bpm)	177	174
Ve at Tvent (l/min)	43.4	45.7
RER at Tvent	1.00	0.99
RPE at Tvent	12	12
Time of Tvent	5:30	6:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	92	92	99
WI VO2max test	64	72	88

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
HR	Tr(Tr/Wl)Tvent	175	180	184	187	190	192	194
	Wl(Tr/Wl)Tvent	169	169	169	170	168	167	169
VO2	Tr(Tr/Wl)Tvent	38.9	38.5	38.4	38.8	38.5	38.3	38.5
	Wl(Tr/Wl)Tvent	38.1	39.2	39.0	38.7	38.1	38.5	38.3
Ve	Tr(Tr/Wl)Tvent	51.7	49.7	52.0	51.6	51.5	51.1	50.4
	Wl(Tr/Wl)Tvent	50.4	52.1	52.7	52.5	51.5	53.0	47.4
[BLa]	Tr(Tr/Wl)TrTvent		2.5	3.3	4.3	5.4	5.1	3.9
	Wl(Tr/Wl)Tvent		3.9	3.5	3.2	3.2	3.2	3.1

		T1	T2	T3	TIME T4	T5	T6	T7
	Tr(Tr/Wl)Tvent	0.99	0.99	1.01	1.00	1.01	1.00	1.00
RER	Wl(Tr/Wl)Tvent	1.01	1.03	1.04	1.02	1.02	1.00	1.01
	Tr(Tr/Wl)Tvent	12	12	13	13	13	13	13
RPE	Wl(Tr/Wl)Tvent	11	13	13	13	13	13	13

SUBJECT 13

Male subject, 29 yrs old. Competes in marathons. Has been water running for 3 yrs. For the previous 6 months prior to participating in the study he had been WI running at least 6-8 times per month, 60 minute duration of each session. Uses floatation device ('aquajogger'). WI running training consisted of interval training above WI Tvent HR and steady state runs at WI Tvent HR.

Comparison of the subject's race pace from an event completed close to the time when participating in the study found him to have completed a marathon at 10.2 mph pace. The subject's calculated TrTvent pace was 10.0 mph.

Variable	Treadmill	WI
Height (cm)	179.6	179.6
Weight (kg)	68.4	68.4
VO2max (l/min)	4.22	4.04
VO2max (ml/kg/min)	61.7	60.2
HRmax (bpm)	177	163
Vemax (l/min)	137.6	132.9
RERmax	1.26	1.12
RPEmax	20	20
30 sec. post-test [BLa]	8.22	8.5
5 min. post-test [BLa]	8.8	7.9
Max. duration (min)	17:00	16:00
VO2 at Tvent (l/min)	3.48	3.05
VO2 at Tvent (ml/kg/min)	50.8	45.4
HR at Tvent (bpm)	152	140
Ve at Tvent (l/min)	82.2	73.2
RER at Tvent	1.02	0.91
RPE at Tvent	13	13
Time of Tvent	11:30	5:30

Time point in test (in strides/min)	Minute 1	Tvent Minute	VO2max Minute
Treadmill VO2max test	76	86	94
WI VO2max test	50	50	56

Prolonged performance tests.

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	153	156	160	162	162	166	167
HR	TrWITvent	140	142	142	142	144	146	145
	WITrTvent	140	146	147	147	148	147	151
	WIWITvent	142	141	141	139	141	141	142
	TrTrTvent	50.6	50.1	51.3	50.4	49.5	50.4	50.9
VO2	TrWITvent	45.9	46.0	46.7	45.5	45.8	49.9	45.9
	WITrTvent	49.5	50.3	49.7	50.9	50.3	51.0	51.6
	WIWITvent	45.7	46.1	45.5	44.8	45.1	45.0	46.0
	TrTrTvent	70.6	67.4	70.4	69.7	72.3	73.8	77.1
Ve	TrWITvent	71.0	70.3	71.7	69.9	70.6	73.7	72.3
	WITrTvent	95.4	102.7	102.4	105.2	104.7	104.8	108.5
	WIWITvent	77.2	74.2	72.0	69.4	78.3	69.9	72.3
	TrTrTvent		4.1	3.5	5.9	5.9	6.2	5.8
[BLa]	TrWITvent		3.0	3.2	2.2	3.4	2.4	2.3
	WITrTvent		5.1	5.2	5.0	5.2	5.2	5.2
	WIWITvent		4.1	4.0	3.7	3.4	3.5	3.4

		T1	T2	T3	TIME T4	T5	T6	T7
	TrTrTvent	0.95	0.92	0.93	0.92	0.94	0.95	0.96
RER	TrWITvent	0.98	0.98	0.98	0.98	0.98	0.99	0.99
	WITrTvent	0.95	0.97	0.96	0.94	0.95	0.94	0.95
	WIWITvent	1.05	1.00	0.98	0.95	0.98	0.96	0.96
	TrTrTvent	12	12	13	13	13	14	14
RPE	TrWITvent	10	11	11	11	11	11	11
	WITrTvent	14	14	15	15	16	16	17
	WIWITvent	13	13	14	14	15	15	15

Appendix B : Repeated measures analysis for HR, VO_2, Ve and [BLa].

Table 4.0. 2 X 2 X 7 Repeated Measures Analysis Results for Heart-rate.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	6934099.89	1	6934099.89	2428.95	0.0001
E1	25692.93	9	2854.77		
CONDITION	6634.89	1	6634.89	19.35	0.03
E2	3085.36	9	342.82		
TVENT	6791.58	1	6791.58	6.48	0.03
E3	9434.39	9	1048.27		
CON X TVENT	450.09	1	450.09	6.88	0.03
E4	588.45	9	65.38		
TIME	2358.29	6	393.05	40.34	0.001
E5	526.14	54	9.74		
TIME (1)	23337.43	1	2337.43	62.82	0.001
E(1)	334.85	9	37.21		
CON X TIME	786.19	6	131.03	10.96	0.001
E6	645.81	54	11.96		
CON X TIME (1)	745.89	1	745.89	14.23	0.004
E (1)	471.90	9	52.43		
TVENT X TIME	69.80	6	11.63	2.60	0.03
E7	241.49	54	4.47		
CON X TVENT X TIME	5.59	6	0.93	0.26	0.95
E8	192.13	54	3.56		

Table 4.1. 2 X 7 Repeated Measures Analysis Results $Tr_{TrTvent}$ vs $Wl_{TrTvent}$ for Heart-rate.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	3687456.01	1	3687456.01	3553.31	0.0001
E1	9339.78	9	1037.75		
CONDITION	5270.58	1	5270.58	34.91	0.0002
E2	1358.64	9	150.96		
TIME	1594.64	6	265.77	38.78	0.0001
E3	370.07	54	6.85		
TIME (1)	1567.80	1	1567.80	75.41	0.0001
E (1)	187.11	9	20.79		
CON X TIME	396.07	6	66.01	10.27	0.0004
E4	347.21	54	6.43		
CON X TIME (1)	382.80	1	382.80	16.97	0.003
E (1)	202.97	9	22.55		

Table 4.2. 2 X 7 Repeated Measures Analysis Results for $Tr_{WITvent}$ vs $Wl_{WITvent}$ for Heart-rate.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	3253435.46	1	3253435.46	1135.47	0.0001
E1	25787.54	9	2865.28		
CONDITION	1814.40	1	1814.40	7.05	0.03
E2	2315.17	9	257.24		
TIME	833.44	6	138.91	18.87	0.0001
E3	397.56	54	7.36		
TIME (1)	828.14	1	828.14	26.19	0.0006
E (1)	284.59	9	31.62		
CON X TIME	395.70	6	65.95	7.26	0.004
E4	490.73	54	9.09		
CON X TIME (1)	363.22	1	363.22	10.04	0.01
E (1)	325.59	9	36.18		

Table 5.0. 2 X 2 X 7 Repeated Measures Analysis Results of Oxygen Consumption.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	565630.85	1	565630.85	610.84	0.0001
E1	25692.93	9	925.99		
CONDITION	8.53	1	8.53	1.14	0.31
E2	67.50	9	7.50		
TVENT	1243.30	1	1243.30	7.27	0.03
E3	1538.38	9	170.93		
CON X TVENT	7.34	1	7.34	0.68	0.43
E4	97.44	9	10.83		
TIME	27.34	6	4.56	4.70	0.003
E5	52.31	54	0.97		
TIME (1)	19.76	1	19.76	6.96	0.03
E5 (1)	25.56	9	2.84		
CON X TIME	2.28	6	0.38	0.25	0.84
E6	81.68	54	1.51		
TVENT X TIME	2.77	6	0.46	0.47	0.71
E7	53.09	54	0.98		
CON X TVENT X TIME	4.34	6	0.72	0.82	0.50
E8	47.62	54	0.88		

Table 5.1. 2 X 7 Repeated Measures Analysis Results for $Tr_{TrTvent}$ vs $Wl_{TrTvent}$ for Oxygen consumption.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	309955.89	1	309955.89	515.85	0.0001
E1	5407.82	9	600.87		
CONDITION	0.02263	1	0.02263	0.00	0.97
E2	130.20	9	14.47		
TIME	21.51	6	3.59	2.92	0.05
E3	66.41	54	1.23		
CON X TIME	3.53	6	0.59	0.42	0.78
E4	75.42	54	1.40		

Table 5.2. 2 X 7 Repeated Measures Analysis Results for $Tr_{WlTvent}$ vs $Wl_{WlTvent}$ for Oxygen consumption.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	256918.25	1	256918.25	517.92	0.0001
E1	4464.49	9	496.05		
CONDITION	15.84	1	15.85	4.10	0.07
E2	34.74	9	3.86		
TIME	8.59	6	1.43	1.98	0.12
E3	38.99	54	0.72		
CON X TIME	3.09	6	0.51	0.52	0.66
E4	53.88	54	0.99		

Table 6.0. 2 X 2 X 7 Repeated Measures Analysis Results for Ventilation.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	1401356.29	1	1401356.29	174.21	0.001
E1	72398.29	9	8044.25		
CONDITION	2130.06	1	2130.06	3.87	0.08
E2	4953.24	9	550.36		
TVENT	8250.78	1	8250.78	9.26	0.01
E3	8023.30	9	891.48		
CON X TVENT	759.79	1	759.79	5.33	0.05
E4	1282.18	9	142.46		
TIME	537.99	6	89.66	7.09	0.003
E5	682.55	54	13.64		
TIME (1)	522.91	1	522.91	11.83	0.007
E5 (1)	397.87	9	44.21		
CON X TIME	110.43	6	18.40	0.64	0.70
E6	1553.26	54	28.76		
TVENT X TIME	265.89	6	44.31	4.09	0.03
E7	584.52	54	10.82		
TVENT X TIME (1)	257.49	1	257.49	5.59	0.04
E7 (1)	414.74	9	46.08		
CON X TVENT X TIME	36.84	6	6.14	0.79	0.51
E8	421.00	54	7.80		

Table 6.1. 2 X 7 Repeated Measures Analysis Results $Tr_{TrTvent}$ vs $Wl_{TrTvent}$ for Ventilation.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	812331.57	1	812331.57	172.32	0.0001
E1	42425.69	9	4713.97		
CONDITION	2717.09	1	2717.09	5.50	0.04
E2	4443.11	9	493.68		
TIME	768.71	6	128.12	7.63	0.007
E3	906.39	54	16.79		
TIME (1)	757.14	1	757.14	10.34	0.01
E (1)	685.89	9	73.21		
CON X TIME	48.32	6	8.05	0.38	0.69
E4	1130.63	54	20.94		

Table 6.2. 2 X 7 Repeated Measures Analysis Results for $Tr_{WlTvent}$ vs $Wl_{WlTvent}$ for Ventilation.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	597275.51	1	597275.51	141.48	0.0001
E1	37995.90	9	4221.77		
CONDITION	172.76	1	172.76	0.87	0.38
E2	1792.30	9	199.14		
TIME	35.16	6	5.86	0.88	0.49
E3	360.67	54	6.68		
CON X TIME	98.95	6	16.49	1.06	0.37
E4	843.64	54	15.62		

Table 7.0. 2 X 2 X 6 Repeated Measures Analysis Results for Blood Lactate Concentration.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	4850.64	1	4850.64	125.26	0.0001
E1	348.51	9	38.72		
CONDITION	31.62	1	31.62	5.89	0.04
E2	48.29	9	5.37		
TVENT	158.89	1	158.89	12.29	0.007
E3	116.35	9	12.93		
CON X TVENT	3.95	1	3.95	0.40	0.55
E4	89.92	9	9.99		
TIME	5.76	5	1.15	1.60	0.20
E5	32.45	45	0.72		
CON X TIME	37.30	5	7.46	6.17	0.004
E6	54.42	45	1.21		
CON X TIME (1)	36.59	1	36.59	9.83	0.01
E (1)	33.48	9	3.72		
TVENT X TIME	4.55	5	0.91	2.13	0.08
E7	19.22	45	0.43		
CON X TVENT X TIME	3.04	5	0.61	2.08	0.10
E8	13.17	45	0.29		

Table 7.1. 2 X 7 Repeated Measures Analysis Results $Tr_{TrTvent}$ vs $Wl_{TrTvent}$ for Blood Lactate concentration.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	3382.68	1	3382.68	87.96	0.0001
E1	346.11	9	38.46		
CONDITION	6.61	1	6.61	0.82	0.39
E2	72.68	9	8.08		
TIME	8.75	5	1.75	2.24	0.08
E3	35.09	45	0.78		
CON X TIME	28.46	5	5.69	6.67	0.002
E4	38.41	45	0.85		
CON X TIME (1)	27.30	1	27.30	11.54	0.008
E (1)	21.30	9	2.37		

Table 7.2. 2 X 7 Repeated Measures Analysis Results for $Tr_{WlTvent}$ vs $Wl_{WlTvent}$ for Blood Lactate concentration.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	1626.85	1	1626.85	123.29	0.0001
E1	118.76	9	13.20		
CONDITION	28.97	1	28.97	3.98	0.08
E2	65.52	9	7.28		
TIME	1.56	5	0.31	0.85	0.52
E3	16.58	45	0.37		
CON X TIME	11.88	5	2.38	3.66	0.03
E4	29.19	45	0.65		
CON X TIME (1)	11.08	1	11.08	5.77	0.04
E (1)	17.29	9	1.92		

Appendix C : Stride Frequency

Comparison of Stride Frequency during the Treadmill and WI VO_{2max} test

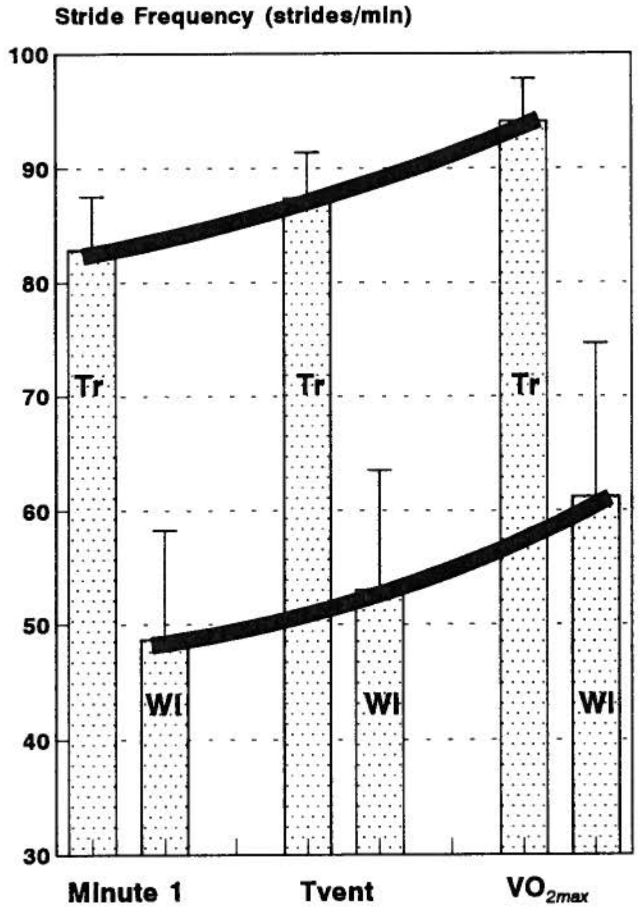
Stride frequency was measured during the treadmill and the WI VO_{2max} tests. Stride frequency was measured each minute in both tests, and commenced 15 seconds following loading for 30 second measurement periods for each minute (values were then multiplied by 2 for minute cadence values) of the tests. Three time points during the tests were used for comparison of treadmill and WI stride frequency, minute 1, minute at which Tvent occurred and the last minute of the tests at maximal effort (VO_{2max}). A 2 X 3 within subject repeated measures analysis of variance with trend analysis was used to analyze the data, with the level of significance set at 0.05. The analysis represents data collected from only 12 of the 13 subjects due to technical problems during WI test data collection for one subject.

A significant Condition main effect was exhibited for stride frequency ($p<0.05$). Averaged across the three time intervals mean stride frequency was significantly lower in the WI (54 strides/min) compared to the treadmill (88 strides/min) condition (Figure C1.0 B).

A significant increase in mean stride frequency over time was exhibited (Time main effect, $p<0.05$) with 98 percent of the variability in time accounted for by a significant time linear trend ($p<0.05$). A similar steady linear increase in mean cadence was exhibited for both the treadmill and the WI VO_{2max} tests (Figure C1.0 A, lines).

There was no significant Condition by Time interaction ($p>0.05$) and therefore conclude that a similar pattern of increase was exhibited in both conditions (see Figure C1.0 A and B and see Table C1.0 for RM's analysis results). Increases over time per interval were similar for the 2 conditions with a 4.5 (4.3) and 6.8 (8.2) percent increase from minute 1 to Tvent and from Tvent to VO_{2max} for the treadmill and WI (WI values are in parentheses) conditions. A total percent increase in stride frequency (from minute 1 to VO_{2max}) of 2.3 and 3.9 was exhibited in the treadmill and WI conditions repectively. The WI stride frequency at minute 1 to VO_{2max} represented 59, 61, and 65 % of the treadmill stride frequency.

A



B

Time Point in VO2max tests		Minute 1	Tvent	VO2max	Mean total
CONDITION	Treadmill	83	87	94	88
	WI	49	53	61	54

Figure C1.0. Comparison of stride frequency (strides/min) during the treadmill vs the WI VO_{2max} tests. Comparisons were made for stride frequency during the first minute of each test, at Tvent time and at maximal effort (VO_{2max}) time. A. Plot of mean stride frequency (+1 std) at each of the 3 intervals on the treadmill (Tr) and water immersion (WI), including plot of the change over time (lines). B. Table of mean stride frequency over time (at minute 1, Tvent and VO_{2max}) and totals for the treadmill and the WI VO_{2max} test conditions.

Appendix D : Repeated measures analysis for RER and RPE.

D1.0 Respiratory Exchange Ratio

RESULTS

Respiratory exchange ratio (RER) responses during the steady state tests were examined in relation to RER response during the performance tests in the 2 conditions (treadmill and WI) and to the 2 Tvent (the Tr_{Tvent} and WI_{Tvent}) intensities over the performance test's time intervals and averaged over the Time factor. A 2 X 2 X 7 within subject repeated measures analysis of variance with trend analysis, with a=0.05 was used to analyze the data.

Averaged over the two Tvent's and across all time intervals, the mean RER response on the treadmill (RER=0.96) was similar to the mean response in WI (RER=0.97) (Condition main effect; $F_{1,9}=0.27$, $p>0.05$) (Figure D1.1 A). Averaged over the two conditions and across all time intervals mean RER response at Tr_{Tvent} (RER=0.97) was similar to the WITvent response (RER=0.96) (Tvent main effect; $F_{1,9}=1.93$, $p>0.05$) (Figure D1.1 A).

Averaged across all time intervals mean RER response was similar when Tvent intensity was performed on the treadmill ($RER_{TrTvent}=0.98$ and $RER_{WITvent}=0.95$) versus WI ($RER_{TrTvent}=0.97$ and $RER_{WITvent}=0.97$) (Condition by Tvent interaction; $F_{1,9}=0.65$, $p>0.05$) (see Figure D1.1 B).

There was a significant Time main effect ($F_{6,54}=8.82$, $p<0.05$) with 89 percent of the variability accounted for by a significant Time linear trend as evidenced by the steady linear response in mean RER over time. Mean RER remained relatively constant over time for Tr_{Tvent} and WI_{Tvent} intensity tests performed on the treadmill. Mean RER exhibited a decline over time in the two WI tests (performed at Tr_{Tvent} and WI_{Tvent}). The pattern of decline is in line with [BLa] response in WI and supports the arguement of an oxygen debt incurred during the onset of WI exercise, which was most likely re-oxidized during the latter part of these tests (see discussion).

A mean change in RER values of 0.01 during treadmill performance at treadmill and WI Tvent does not represent a physiological change or difference in fuel utilization. During the WI tests at treadmill and WI Tvent, a significant declining trend for RER was exhibited. A change in RER from 0.99 during the initial 15 minutes of both tests to an RER of 0.96 in the latter part of both tests was noted. This pattern of decline does not represent a major physiological change in fuel utilization, although does suggest glycogenolysis as the major process of fuel utilization during the initial 15 minutes of WI exercise.

The significant Time ($F_{6,54}$=3.86, $p<0.05$), Time linear trend ($F_{1,9}$=8.01, $p<0.05$) and Condition by Time interaction ($F_{6,54}$=3.54, $p<0.05$) for RM's analysis of $Tr_{Trtvent}$ versus $WI_{TrTvent}$ confirm that a different response over time was exhibited at Tr_{Tvent} in the two conditions. The non-significant Condition by Time interaction ($F_{6,54}$=2.14, $p>0.05$), with a significant Time ($F_{6,54}$=7.59, $p<0.05$) and Time linear trend ($F_{1,9}$=19.92, $p<0.05$) for the RM's analysis for

$Tr_{WITvent}$ versus $WI_{WITvent}$ denotes the change over time in mean RER, but no difference in RER response related to the WI condition (Figure D1.2).

See Table D1.0 for RER RM's results and tables D1.1 and D1.2 for RER RM's results for $Tr_{Trtvent}$ versus $WI_{TrTvent}$ and $Tr_{WITvent}$ versus $WI_{WITvent}$ respectively.

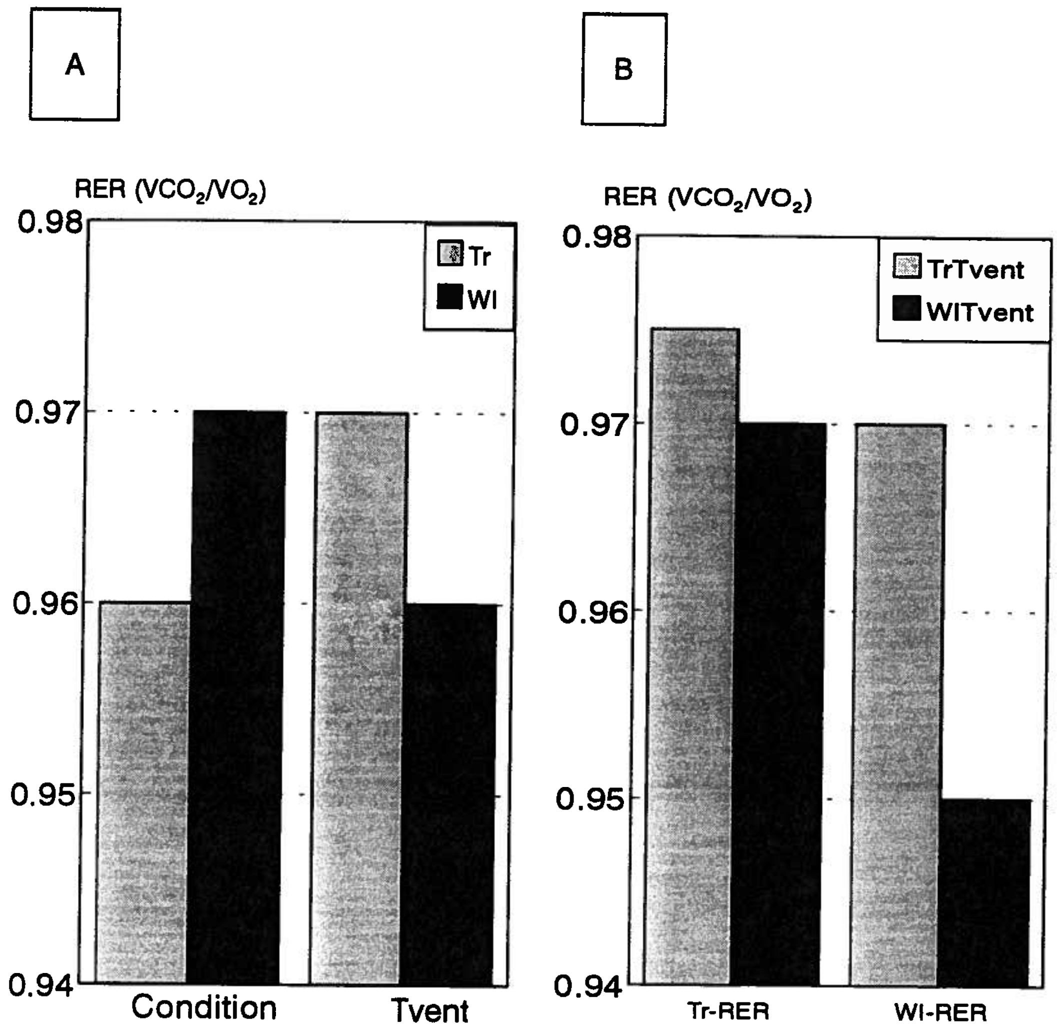


Figure D1.1. Mean RER response for Condition and Tvent main effects and Condition X Tvent interaction. A. Comparison of mean RER response over Condition (Tr vs WI) and over Tvent (TrTvent vs WITvent) averaged over time. B. Comparison of mean RER response averaged over the steady state tests performed on the treadmill (ie. at Tr and WI Tvent) versus the steady state tests performed in WI (ie. at Tr and WI Tvent).

A

Time		T1	T2	T3	T4	T5	T6	T7
TR	TrTvent	0.98	0.97	0.97	0.97	0.97	0.98	0.98
	WITvent	0.96	0.96	0.95	0.95	0.95	0.95	0.95
WI	TrTvent	0.99	0.99	0.98	0.96	0.96	0.96	0.96
	WITvent	0.99	0.98	0.98	0.97	0.96	0.96	0.96

B

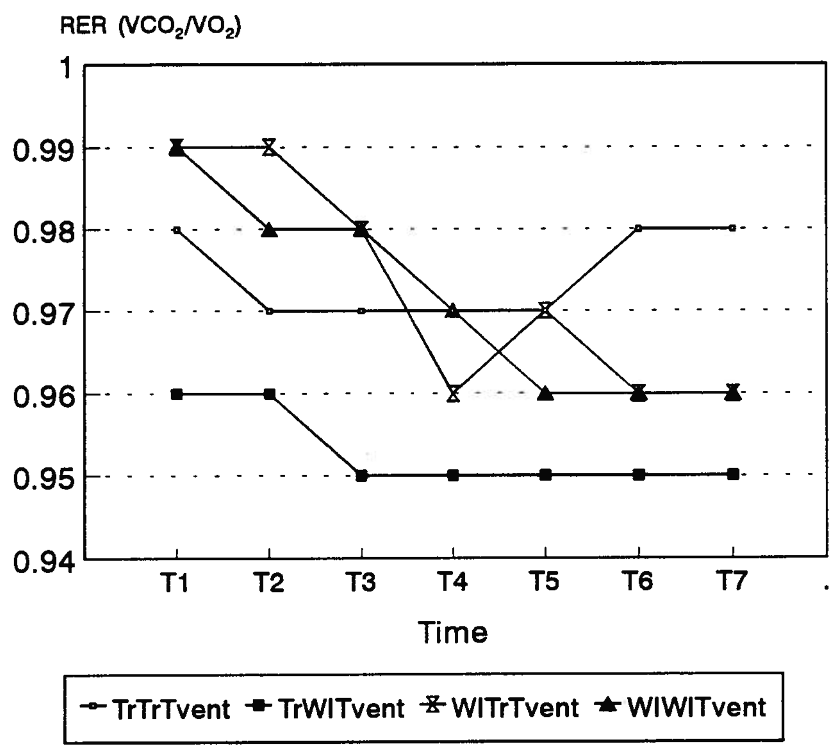


Figure D1.2. Mean RER response over the steady state performance tests over time. A. Table of mean RER over time for the 4 steady state tests. B. Comparison of mean RER response over time for each test condition and Tvent.

Table D1.0. 2 X 2 X 7 Repeated Measures Analysis Results for Respiratory Exchange Ratio.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	262.08	1	262.08	11145.68	0.001
E1	0.21	9	0.02		
CONDITION	0.004	1	0.004	0.27	0.61
E2	0.15	9	0.02		
TVENT	0.01	1	0.01	1.93	0.20
E3	0.06	9	0.01		
CON X TVENT	0.01	1	0.01	0.65	0.43
E4	0.11	9	0.01		
TIME	0.01	6	0.002	8.82	0.001
E5	0.02	54	0.0003		
CON X TIME	0.01	6	0.001	3.63	0.006
E6	0.02	54	0.0003		
TVENT X TIME	0.001	6	0.0002	0.88	0.45
E7	0.001	54	0.0002		
CON X TVENT X TIME	0.001	6	0.0001	0.85	0.50
E8	0.01	54	0.0002		

Table D1.1. 2 X 7 Repeated Measures Analysis Results $Tr_{TrTvent}$ vs $Wl_{TrTvent}$ for Respiratory Exchange Ratio.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	132.89	1	132.89	12361.27	0.0001
E1	0.09	9	0.01		
CONDITION	0.0002	1	0.0002	0.02	0.90
E2	0.12	9	0.01		
TIME	0.005	6	0.0009	3.86	0.004
E3	0.01	54	0.0002		
TIME (1)	0.004	1	0.004	8.01	0.02
E (1)	0.004	9	0.0005		
CON X TIME	0.003	6	0.0006	3.54	0.009
E4	0.009	54	0.0002		

Table D1.2. 2 X 7 Repeated Measures Analysis Results for $Tr_{WITvent}$ vs $Wl_{WITvent}$ for Respiratory Exchange Ratio.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	129.19	1	129.19	6617.18	0.0001
E1	0.18	9	0.02		
CONDITION	0.01	1	0.01	0.79	0.40
E2	0.14	9	0.02		
TIME	0.009	6	0.002	7.59	0.0001
E3	0.01	54	0.0002		
TIME (1)	0.009	1	0.009	19.92	0.002
E (1)	0.004	9	0.0005		
CON X TIME	0.004	6	0.0006	2.14	0.10
E4	0.02	54	0.0003		

D2.0 Ratings of Perceived Exertion

RESULTS

Ratings of perceived exertion (RPE) responses during the steady state tests were examined in relation to RPE response during the performance tests in the 2 conditions (treadmill and WI) and to the 2 Tvent (the Tr_{Tvent} and WI_{Tvent}) intensities over the performance test's time intervals and averaged over the Time factor. A 2 X 2 X 7 within subject repeated measures analysis of variance with trend analysis, with a=0.05 was used to analyze the data.

Averaged over the two Tvent's and across all time intervals, the mean RPE response on the treadmill (RPE=12.5) was similar to the mean response in WI (RPE=13) (Condition main effect; $F_{1,9}=1.38$, $p>0.05$) (Figure D2.1 A).

Averaged over the two conditions and across all time intervals mean RPE response at Tr_{Tvent} (RPE=13.5) was similar to the WI_{Tvent} (RPE=12) (Tvent main effect; $F_{1,9}=1.97$, $p>0.05$) (Figure D2.1 A).

Averaged across all time intervals mean RPE response was similar when Tvent intensity was performed on the treadmill ($RPE_{TrTvent}=13$ and $RPE_{WITvent}=12$) versus WI ($RPE_{TrTvent}=14$ and $RPE_{WITvent}=12$) (Condition by Tvent interaction; $F_{1,9}=0.53$, $p>0.05$). RM's analysis of mean RPE for

$Tr_{TrTvent}$ vs $WI_{TrTvent}$ and for $Tr_{WITvent}$ vs $WI_{WITvent}$ found no significant differences in RPE response (Figure D2.1 B).

There was a significant Time main effect ($F_{6,54}=11.01$, $p<0.05$) with 98 percent of the variability accounted for by a significant Time linear trend as evidenced by the steady linear increase in mean RPE over time (Figure D2.2).

There was no significant Condition by Time interaction ($F_{6,54}=0.65$, $p>0.05$). There was a significant Tvent by Time interaction ($F_{6,54}=4.74$, $p>0.05$) with mean RPE response lower over time with WITvent (ie. $WI_{TrTvent}$ and $Tr_{WITvent}$) versus TrTvent (ie. $Tr_{TrTvent}$ and $WI_{TrTvent}$). Ninety eight percent of the variability was accounted for by a significant linear trend ($F_{1,9}=7.31$, $p<0.05$) as evidenced by the steady linear increase in mean RPE response over time, averaged over the two conditions, in both the WI_{Tvent} and Tr_{Tvent} tests.

RM's analysis of TrTvent intensity performed on the treadmill compared to in WI reported a mean RPE increase over time for both the treadmill and WI tests at treadmill Tvent. Mean RPE at Tr_{Tvent} increased from 11.4 at T1 to 13.6 at T7 and from 12.5 at T1 to 15.5 at T7 performed on the treadmill and WI condition respectively. This suggests that the Tr_{Tvent} intensity in the WI condition was perceived by the subjects to be more difficult. Progressively over time perceived exertion ratings increased for the subjects. The [BLa] and RER, however, do not conform with the subjects' perceived effort. The RPE at Tr_{Tvent} intensity performed on the treadmill showed a small increase in

RPE over time, but this increase is most likely attributed to the laboratory conditions (ie. heat and humidity) and is in line with the (increased) [BLa], Ve and HR responses exhibited. The similar mean RPE at WI_{Tvent} in both the WI and treadmill conditions suggest that the exercise was perceived as_moderate.

See Table D2.0 for RRE RM's results and tables D2.1 and D2.2 for RPE RM's results for $Tr_{Trtvent}$ versus $WI_{TrTvent}$ and $Tr_{WITvent}$ versus $WI_{WITvent}$ respectively.

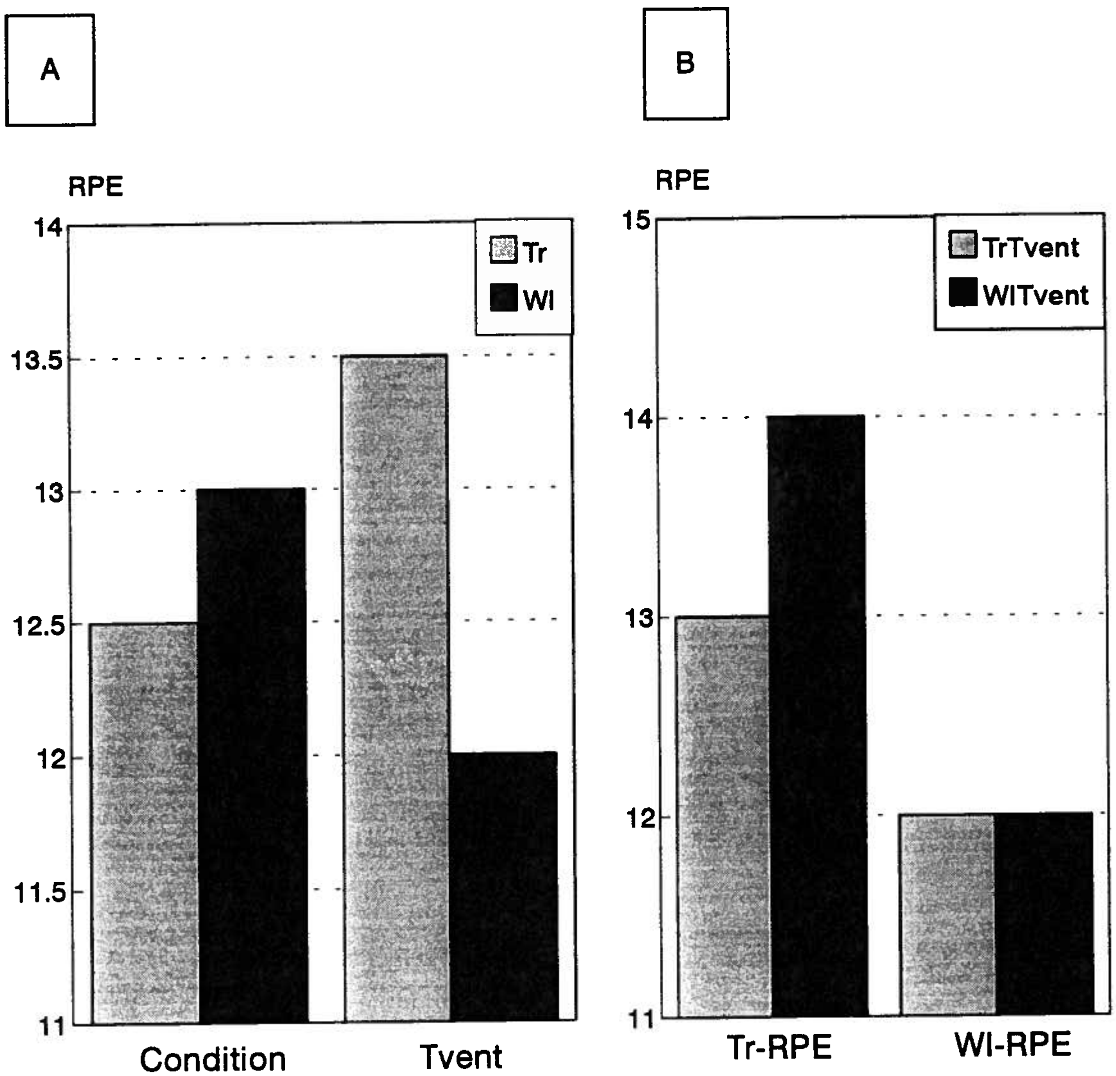


Figure D2.1. Mean RPE response for Condition and Tvent main effects and Condition X Tvent interaction. A. Comparison of mean RPE response over Condition (Tr vs WI) and over Tvent (Tr_{Tvent} vs WI_{Tvent}) averaged over time. B. Comparison of mean RPE response averaged over the steady state tests performed on the treadmill (ie. at Tr and WI Tvent) versus the steady state tests performed in WI (ie. at Tr and WI Tvent).

A

Time		T1	T2	T3	T4	T5	T6	T7
TR	TrTvent	11.4	11.6	12.1	12.6	13.2	13.5	13.6
	WITvent	11.1	11.3	11.6	11.8	12.2	12.2	12.4
WI	TrTvent	12.5	13.7	14.0	14.3	14.7	14.9	15.5
	WITvent	11.6	11.6	12.2	12.4	12.6	12.9	12.7

B

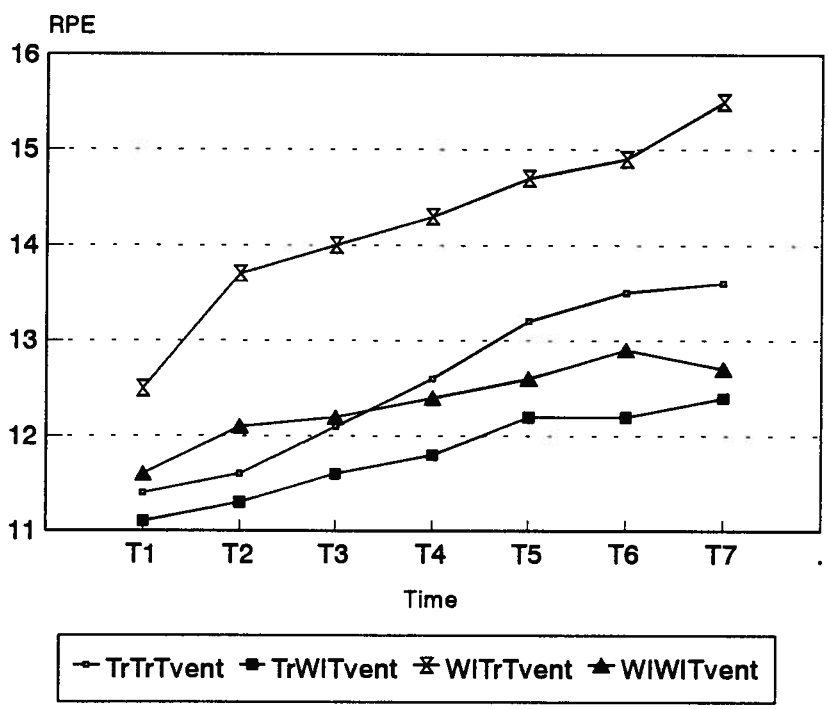


Figure D2.2. Mean RPE responses over the steady state performance tests over time. A. Table of mean RPE over time for the 4 steady state tests. B. Comparison of mean RPE responses over time for each test condition and Tvent.

Table D2.0. 2 X 2 X 7 Repeated Measures Analysis Results for Ratings of Perceived Exertion.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	45441.03	1	45441.03	1375.99	0.0001
E1	297.22	9	33.02		
CONDITION	85.80	1	85.80	1.38	0.27
E2	558.88	9	62.10		
TVENT	122.23	1	122.23	1.97	0.19
E3	558.59	9	62.07		
CON X TVENT	21.18	1	21.18	0.53	0.49
E4	362.36	9	40.26		
TIME	113.09	6	18.85	11.08	0.001
E5	92.41	54	1.71		
TIME (1)	110.63	1	110.63	12.99	0.006
E (1)	76.62	9	8.51		
CON X TIME	2.62	6	0.44	0.65	0.55
E6	36.45	54	0.68		
TVENT X TIME	13.09	6	2.18	4.74	0.01
E7	24.84	54	0.46		
TVENT X TIME (1)	12.86	6	12.86	7.31	0.02
E (1)	15.82	54	1.76		
CON X TVENT X TIME	1.85	6	0.31	0.71	0.48
E8	23.36	54	0.43		

Table D2.1. 2 X 7 Repeated Measures Analysis Results $Tr_{TrTvent}$ vs $Wl_{TrTvent}$ for Ratings of Perceived Exertion.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	25138.40	1	25138.40	366.92	0.0001
E1	616.60	9	68.51		
CONDITION	96.11	1	96.11	1.04	0.33
E2	830.60	9	92.29		
TIME	101.10	6	16.85	11.39	0.002
E3	79.90	54	1.47		
TIME (1)	99.46	1	99.46	13.50	0.005
E (1)	66.29	9	7.37		
CON X TIME	3.59	6	0.59	0.81	0.44
E4	39.70	54	0.74		

Table D2.2. 2 X 7 Repeated Measures Analysis Results for $Tr_{WlTvent}$ vs $Wl_{WlTvent}$ for Ratings of Perceived Exertion.

SOURCE	SS	DF	MS	F-RATIO	P-VALUE
MEAN	20424.86	1	20424.86	768.47	0.0001
E1	239.21	9	26.58		
CONDITION	10.86	1	10.86	1.08	0.32
E2	90.64	9	10.07		
TIME	25.09	6	4.18	6.05	0.01
E3	37.34	54	0.69		
TIME (1)	24.03	1	24.03	8.27	0.01
E (1)	26.15	9	2.91		
CON X TIME	0.89	6	0.15	0.40	0.84
E4	20.11	54	0.37		

Appendix E : Quality of Workouts.

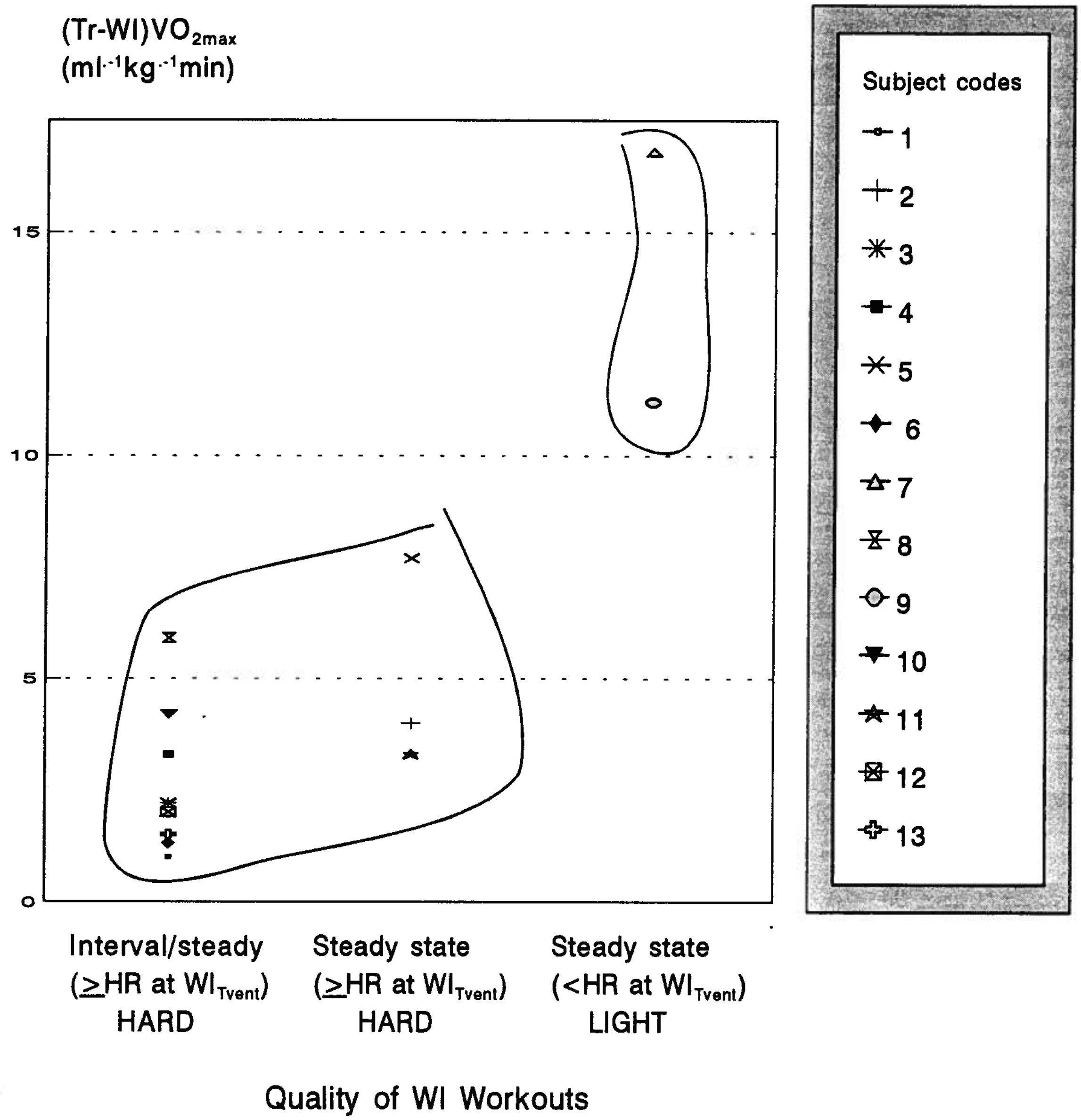


Figure E1.0. Comparison of the quality of the subjects' WI running workouts compared to the magnitude of difference in WI and treadmill VO_{2max} (in $ml^{-1}kg^{-1}min$). Although all the subjects met the present study's criteria for accetable WI running style and quantity of WI running (ie. # of sessions per month and duration of each workout for the previous 6 months prior to participation in the study), the type of WI workouts performed (hard vs light) distinguished the subjects. Subjects who performed exclusively low intensity workouts ($\leq$HR at WI_{Tvent}) during their WI workouts exhibited much lower WI_{VO2max} compared to their Tr_{VO2max} response (difference ranging btwn 11.2-16.8 $ml^{-1}kg^{-1}min$). The differences were smaller for the subjects performing hard WI workouts (ie. at $\geq$HR at WI_{Tvent}), differences of 1-5.9 and 3.3-7.7 $ml^{-1}kg^{-1}min$ for interval/steady and steady state respectively.

Appendix F : Laboratory Temperature and Barometric Pressure over Test Sessions.

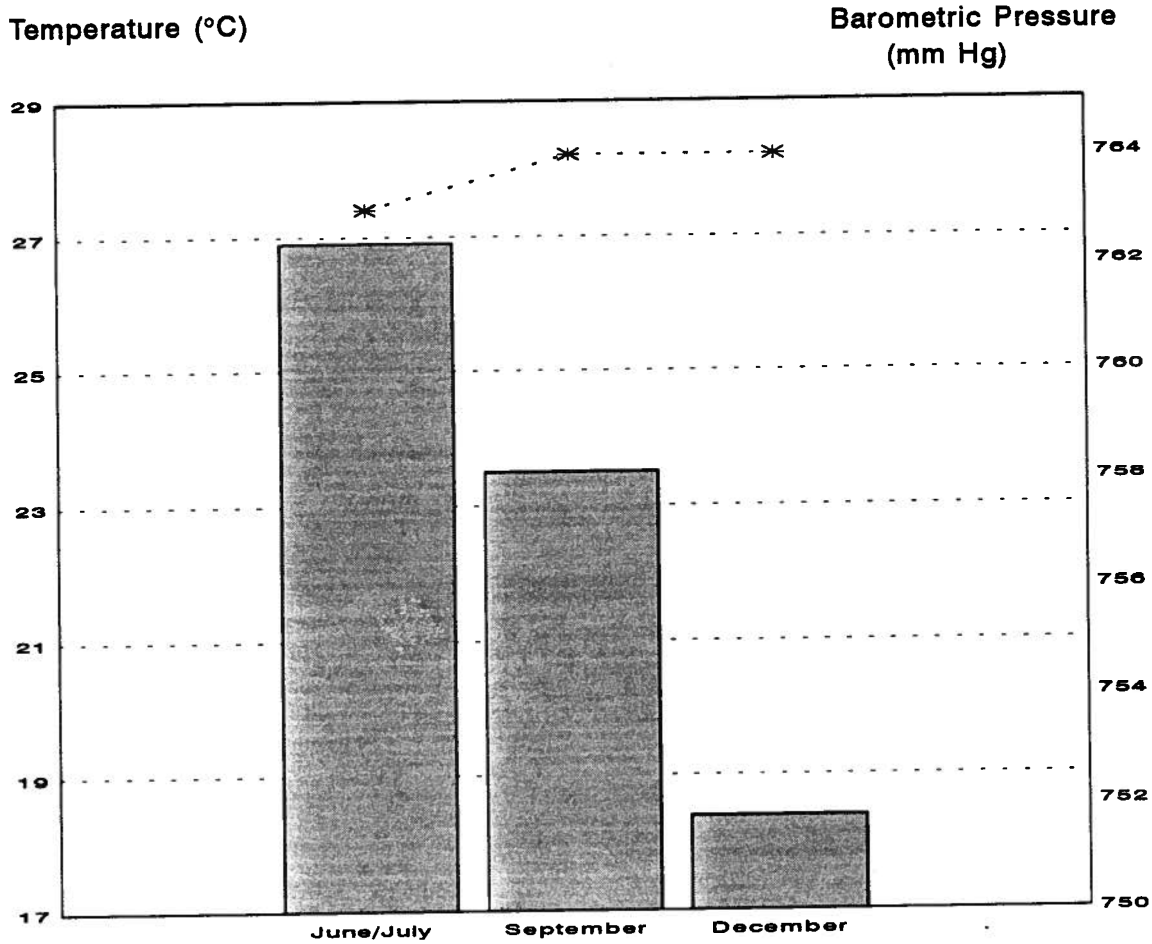


Figure F1.0. Graph of the mean laboratory room temperature (bars) and barometric pressure (*) during steady state Tvent performance tests. The temperature in the lab ranged between 23.2-30° C during June/July testing and mean HR for the $Tr_{TrTvent}$ tests increased from T1 to T7 by 19 bpm (N=4). The temperature in the lab during September testing ranged between 22-25° C and mean HR for the $Tr_{TrTvent}$ tests increased from T1 to T7 by 13 bpm (N=2). The temperature in the lab during December testing ranged between 13-19.8° C and mean HR for the $Tr_{TrTvent}$ increased from T1 to T7 by 12 bpm (N=4). The hot lab environment affected the subjects' 42 minute treadmill performance tests. HR, Ve and [BLa] exhibited an upward drift over the 42 minute treadmill tests at Tr and Wl Tvent intensity. The subjects were performing at and below their Tvent level. The exercise intensity of the 2 tests should have taxed predominately their aerobic system. Evaluation of the subjects' field race performances during the period of their participation in this study did substantiate their treadmill Tvent levels which were determined from the treadmill VO_{2max} tests.

Appendix G : Determination of Tvent from Ventilatory Parameters.

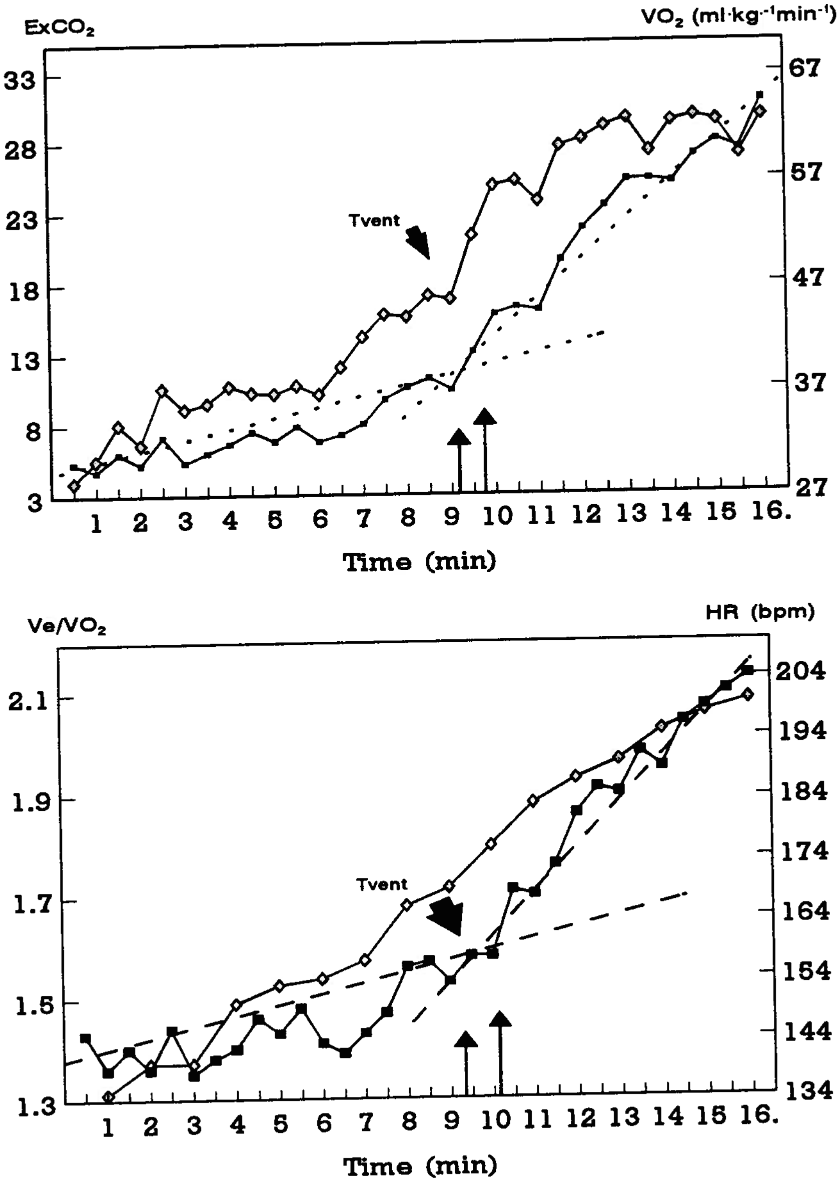


Figure G1.0. Determination of Tvent from ventilatory parameters ($ExCO_2$ and Ve/VO_2). Tvent is defined as the point of non-linear increase in $ExCO_2$. The Ve/VO_2 curve over time was also used to confirm the Tvent level. Nonmetabolic (excess) CO2 results from the buffering of lactate and will be generated for as long as the rate of lactic acid production is increasing. This generates additional hydrogen ions to buffer and because the hydrogen ion and CO_2 can readily diffuse from within the muscle cell into the bloodstream, increases in excess CO_2 will be detected sooner than the rise in blood lactate concentration. Consequently excess CO_2 will more accurately reflect muscle lactate production and accumulation (Rhodes and Anderson, 1989; Wasserman et al, 1973).
The minute VO_2 (in $ml{\cdot}kg^{-1}min^{-1}$) (and HR, Ve) at the point of Tvent was then calculated and used to determine the workload of the prolonged performance tests at treadmill and WI Tvent. VO_2 over the VO_{2max} test is shown on the top figure with the excess CO_2 curve and HR is plotted with the Ve/VO_2 curve.

Appendix H : Subject Informed Consent Form

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CARDIORESPIRATORY AND METABOLIC RESPONSES OF TREADMILL VERSUS WATER RUNNING IN ELITE DISTANCE RUNNERS

INFORMED CONSENT FORM

Investigators:

1. Dr. Edward C. Rhodes (office tel # 822-4585), Principal Investigator and Faculty Advisor
2. D. Daisy Frangolias, Co-Investigator
3. Dr. Angelo Belcastro
4. Dr. Kenneth Coutts
5. Dr. Jack C. Taunton
6. Dr. Igor Mekjavic

Purpose:

The purpose of this study is to investigate differences in response to treadmill vs water immersion to the neck (WI) exercise (running) in elite endurance male and female runners, familiar with water running. Specific questions to be addressed are: a) Can runners familiar with WI running perform to a similar maximal level (ie. VO_{2max}) in the WI as on the treadmill condition?, b) Are there differences in the ventilatory threshold (T_{vent}) levels in WI versus treadmill running?, c) Is the WI condition responsible for physiological differences exhibited during WI compared to treadmill running? Differences in VO_{2max} and ventilation threshold (T_{vent}), and responses to 42 minutes of running on the treadmill and WI T_{vent}'s will be examined in this study.

T_{vent} is the intensity of exercise above which fatique begins to set in, when working at T_{vent} intensity you are able to continue exercising aerobically for a long duration (ie. complete a marathon). VO_{2max} is the maximum amount of oxygen your muscles can consume and show no further increase in oxygen uptake workload. VO_{2max} provides a good indication of your aerobic fitness. The higher your aerobic fitness, the greater the workload you can achieve before exhaustion sets in during a VO_{2max} test.

Methodology:

You will perform a total of 6 tests, 3 on the treadmill and 3 in the deep end of the pool attached to a 'WI Ergometer' and wearing a 'Water Ski Belt' around your waist. The

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WI Ergometer consists of a series of pulley systems with a bucket,which is loaded with weights (400-750 grams on specified intervals) on one end and a belt which attaches to your waist on the other end. Specifically you will perform the following tests within a one month period:

1. You will perform a 5-10 min warm-up followed by a Treadmill VO_{2max} test (protocol: initial velocity 5 mph, increased by 0.5 mph/min until volitional fatigue; if volitional fatigue is not experienced within 15 minutes of treadmill running the velocity will remain at 12 mph and the grade will be increased by 2% per min until volitional fatigue). Blood lactate samples will be drawn from your finger (by finger pricking) at 30 sec and 5 min post-test. Complications during such a test are few and usually clear quickly with little or no treatment. You may stop the test when you wish to because of personal feelings of fatigue or discomfort. There will be a spotter by your side for the duration of the test to support and catch you if you loose your balance while running on the treadmill. Every effort will be made to conduct the test in such a way to minimize discomfort and risk.

2. You will perform a 5-10 min warm-up followed by a WI VO_{2max} test (protocol for female and (*male*) subjects: 500 (*750*) grams initial bucket weight, increased by 400 grams/min until volitional fatique; if volitional fatigue is not experienced within 15 minutes the weight will be increased from minute 16 by 500 (*750*) grams/min until volitional fatigue). Blood lactate samples will be drawn at 30 sec and 5 min post-test, as stated in 1. Underwater running motion (from the neck down only) will be videotaped, for analysis of water running style. Please refer to 1 above for symptoms and possible risks. There is no risk of ingesting water during the test, because you will be wearing a mouth piece and nose clip for the duration of the test.

3. You will be asked to run at T_{vent} intensity (determined from the treadmill VO_{2max} protocol) for 42-50 min continously and expired gases and blood lactate samples obtained at 7 minute intervals on the treadmill and WI (a total of 6 blood samples/test), on separate days.

4. You will be asked to run at Tvent intensity (determined from the WI VO_{2max} protocol) for 42-50 min continously and expired gases and blood lactate samples obtained at 7 minute intervals on the treadmill and WI (a total of 6 blood samples/test), on separate days.

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For all tests you will wear a nose clip and breath into a mouth piece attached via hoses to a Beckman Metabolic cart (which will measure your expired breaths for expired oxygen, carbon dioxide and amount of air you ventilate per minute) and wear a heart rate monitor around your chest. Slight discomfort may be experienced from finger pricking to collect the (20 microliter) blood samples. A total of 6 hours (1 hour/test) will be required to perform all tests within a 2.5 to 4 week period, on separate days. All information/data collected will be confidential and a copy of your results and report of your performance in the study will be provided for you. All data collected and videotape of your water running performance will be coded by a number from 01 to 15 and no reference to your identity will ever be made in order to maintain confidentiality. Data collected will be used for my Masters thesis in Human Kinetics and for possible publication in a scientific journal. There is no monetary compensation available for your participation in this study, except for my gratitude.

Consent:

At any time before or during testing you may withdraw from the study. Every effort will be made to ensure that you do not experience any unnecessary discomfort. **If you have any questions concerning the procedures, or anything else regarding this study, please feel free to ask me, Daisy Frangolias (my home phone number is 734-1912 and the J.M. Buchanan Lab phone # is 822-4356), or my Advisor Dr. E.C. Rhodes (office phone 822-4585).**

In signing this consent form you will have stated that you have read the consent form (and received a copy for your own records) and understood the description of the tests and that you have entered willingly and may withdraw at any time. I have read the above comments and understand the explanation and wish to proceed with all the tests in this study.

Date:______________________.

Subject's signature:______________________.

Witness's signature:______________________.