CARDIORESPIRATORY RESPONSES FOLLOWING AN 8 WEEK DEEP WATER
RUNNING TRAINING PROGRAM IN ELDERLY WOMEN

by

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ABSTRACT

The study compared the acute and training responses of deep water running (DWR) to treadmill running (TMR) in elderly women. Twenty inactive, healthy women (64.5 ± 3.5 years) volunteered to participate in this study. Subjects were randomly and evenly divided into a control or exercise group. Maximal TMR exercise response was achieved using a graded protocol of 3.5mph, increasing 2% grade/min. Maximal DWR exercise response was achieved using a tethered apparatus starting at an initial load of 300g and increasing 100g/min. Training intensities were set at 70%, 75%, and 80% of pre-training DWR maximal heart rates (HR) during weeks 1-2, 3-5, and 6-8, respectively. Maximal oxygen consumption (VO_{2max}), ventilation (VE), heart rate (HR), and respiratory exchange ratio (RER) were measured during DWR and TMR maximal tests, both pre and post training. Blood samples were taken 2 minutes post exercise to determine blood lactate concentrations (Blac). Within subject repeated measures ANOVA was performed to determine whether statistical differences occurred across exercise conditions (TMR vs. DWR), over time (training effect), and with training responses between TMR and DWR (specificity of training). Data obtained pertaining to the acute responses of DWR and TMR revealed significantly higher TMR VO_{2max} (23.94 vs. 18.49 and 21.59 vs. 17.65 ml/kg/min, $p < 0.05$) and HR (164.50 vs. 157.70 and 161.75 vs. 156.13 beats/min, $p < 0.05$) compared to DWR for exercise and control groups, respectively. Training for 8 weeks with DWR increased TMR VE (14%, $p < 0.05$), TMR VO_{2max} (18%, $p < 0.05$), and DWR VE (15%, $p < 0.05$). Deep water running VO_{2max} did not statistically improve within the exercise group over 8 weeks ($p > 0.05$). However, significant differences did exist between exercise and control groups over time (group by

time interaction, $p < 0.05$), indicating a training effect. The inability to reach statistical significance in DWR VO_2max within the exercise group over time may be attributable to the characteristics of water immersion causing ventilation/ perfusion inequalities and/or the protocol used to assess DWR maximal exercise capacity, in which case muscular strength could have been a limiting factor. While the data obtained in this study did not show within group improvements in DWR VO_2max , differences across groups over time combined with improvements in TMR VO_2max , TMR VE, and DWR VE indicate that training adaptations do occur with DWR training protocols, despite the lower physiological stress induced with WI.

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Chapter 1

1.0 INTRODUCTION

Deep water running (DWR) has become a popular form of exercise for cardiovascular conditioning. DWR takes advantage of water buoyancy setting the stage for a high aerobic workout with literally no impact loading on the skeletal system (Sheldahl et al., 1986). This reduction in loading on the body makes DWR a viable alternative for athletes susceptible to repetitive stress injuries and elderly individuals vulnerable to bone fractures caused by aging bone degeneration.

Currently, many elite athletes and fitness enthusiasts are incorporating DWR in their traditional land-based training regimes to attenuate some of the loading experienced with on-land running (OLR) (Town and Bradley, 1991). Being immersed in a water environment, however, leads to alterations in physiological responses. It has been documented that water immersion (WI) alone causes vast changes in the respiratory and cardiovascular responses of a resting young individual immersed in water to the neck (Agostoni et al., 1966). The primary factors leading to the adjustments in resting respiratory and metabolic parameters are: 1) the increase in intrathoracic squeeze caused by the hydrostatic pressure of water, and 2) the redistribution of blood into the thoracic region (Dahlback et al., 1978).

Age appears to also play a vital role in the readjustments of physiological responses in water, such that older individuals do not seem to experience the same decrements in resting heart rate and oxygen uptake observed in young individuals when immersed in water to the level of the neck (Derion et al., 1992).

Aside from changes in resting values with WI, exercise responses are also dramatically blunted in the water. Variables such as maximal oxygen uptake (VO_2max), heart rate (HR), ventilation (V_E) and respiratory exchange ratios (RER) have been shown to be appreciably depressed during DWR compared to treadmill running (TMR) (Butts et al., 1991b).

Despite the variations in metabolic responses between a maximal DWR and TMR, training responses appear to be equivocal in young individuals when training programs of similar intensity, frequency and duration are compared (Bushman et al., 1997). More specifically, DWR training programs have been used to maintain cardiorespiratory fitness in highly trained individuals (Wilber et al., 1996) and used to improve cardiorespiratory fitness in young untrained individuals (Michaud et al., 1995a).

Although it seems likely that a DWR training program can be used with the elderly towards improving their fitness status, the physiological implications of exercising in a water medium may be strikingly different between the elderly and their younger counterparts. Derion et al. (1992) found that resting metabolic and respiratory responses were different between young and old individuals immediately following immersion in water. This suggests that the mechanisms regulating resting physiological responses in water may be different between the two age groups. It is unclear at this moment whether or not these mechanisms regulating resting parameters in the water govern the responses during exercise in water. Nakanishi et al. (1999) investigated the effect of age on the cardiorespiratory responses of DWR in the young and the middle aged (age 38.6 ± 4.4 years) and found that both age groups experienced similar decrements in cardiorespiratory parameters during DWR compared to TMR. Possibly, the age related

differences in DWR responses do not become apparent until later years in life as Derion et al. (1992) reported only decrements in resting physiological parameters in individuals aged 40-49 years. No study to date has examined the effects of DWR in elderly individuals (>60 years). Furthermore, there is a lack of literature to support or contest whether a DWR training program has the potential to improve fitness in this population group. Since there is a possibility that a DWR program may affect older individuals differently compared to their younger counterparts, it was the intent of this study to investigate the physiological effects of an 8-week DWR training program in healthy, untrained elderly women.

1.1 Statement of Problem

The purpose of this study was to determine whether 8 weeks of progressive, incremental DWR provided a sufficient stimulus for improving cardiorespiratory fitness in healthy, untrained elderly women.

1.2 Subproblems

The subproblems were:

- 1) To compare and contrast the cardiorespiratory and metabolic responses of a maximal effort TMR and DWR in healthy, untrained elderly women. Women were brought safely to maximal exercise capacity for both DWR and TMR tests. Maximal exercise capacity on land was determined by the using the age estimated maximal heart rate (HR) equation: $220 - \text{age}$. There are no known current markers to determine maximal exercise capacity in the water for this population group,

therefore, HR approaching land maximums and visible signs of fatigue were used as indications of maximal effort.

- 2) To determine whether 8 weeks of progressive, incremental DWR provided a sufficient stimulus for improving fitness in healthy, untrained elderly women. Women in the exercise group trained 30 minutes at target HR, 3 times per week for 8 weeks, while those in the control group continued with their daily routines for 8 weeks.
- 3) To determine the specificity of the training response following 8 weeks of DWR in healthy, untrained elderly women. Test analysis between maximum physiological responses during TMR and DWR were performed for pre- and post- values to determine whether greater improvements occurred in one condition over the other.

1.3 Hypotheses

1. DWR VO_2max and VE would be substantially lower than the TMR VO_2max and VE in healthy, untrained elderly women. Maximal HR will be similar for TMR and DWR in healthy, untrained elderly women. Maximal blood lactates (Blac^-) and RER will be higher during DWR than TMR in healthy, untrained elderly women.

Specific Hypotheses are:

DWR VO_2max < TMR VO_2max	at $p \leq 0.05$
DWR HR = TMR HR	at $p > 0.05$
DWR VE < TMR VE	at $p \leq 0.05$
DWR Blac > TMR Blac	at $p \leq 0.05$
DWR RER > TMR RER	at $p \leq 0.05$

Rationale (VO_2max):

All runners tried to simulate land-based running mechanics in an aqueous environment. One hundred percent replication of OLR patterns, however, cannot be done under these circumstances. This is primarily because there is no surface (ground) contact with DWR, consequently altering rebound responses and muscle activation patterns (Moening et al., 1993). Altered muscle activation patterns will subsequently lead to a decrease in oxygen consumption in the lower limb muscles (Moening et al., 1993). As a result, DWR VO_2max will be lower than its on-land counterpart, TMR VO_2max . This has been seen in younger and middle aged individuals, untrained in DWR, such that DWR VO_2max values were appreciably lower than TMR VO_2max (Butts et al., 1991a,b; Frangolias and Rhodes, 1993; Frangolias and Rhodes, 1995; Nakanishi et al., 1999; Svedenhag and Seger, 1992; Town and Bradley, 1991).

Rationale (VE):

There is conflicting evidence in the literature regarding the effects WI has on ventilatory parameters. Some have suggested that decreases in VE during DWR is a

direct result of the hydrostatic compression against the chest and the elevation of the diaphragm caused by water buoyancy making it more difficult to breath (Dahlback et al., 1978; Agostoni et al., 1966; Butts et al., 1991b; Dowzer et al., 1999; Nakanishi et al., 1999 a,b). Others who have found non-significant differences in VE during DWR (Butts et al., 1991a; Glass et al., 1995) explain that the limitations in lung expansion during inhalation caused by WI does not restrict ventilation because of the large reserve capacity of the lungs. As a result of the huge controversy in VE response during maximal DWR in young individuals, it is difficult to ascertain what the outcome would be in elderly women as no studies to date have examined the effects of this exercise in this population group. It is my hypothesis that VE would be affected by WI immersion based on the fact that advanced age causes deterioration in elastic support structures of the lungs and increased size of alveoli limiting ventilation (Stamford, 1988). These age related limitations in ventilation do not limit maximal aerobic exercise on land (Stamford, 1988), however, the combination of age related changes, chest compression, and elevated diaphragm with WI may increase the likelihood that VE is restricted in the water.

Rationale (maximal HR):

Lower maximal HR has been reported for DWR in younger individuals (Brown et al., 1997; Butts et al., 1991 a,b; Frangolias and Rhodes, 1995; Glass et al., 1995; Michaud et al., 1995b; Svedenhag and Seger, 1992; Town and Bradley, 1991) and middle-aged men (Nakanishi et al., 1999b). The lower maximal HR observed during DWR is suggested to be a result of higher stroke volumes caused by the cephalic redistribution of blood induced by WI (Svedenhag and Seger, 1992). However with increasing age,

particularly in the elderly, a marked decrease in maximal stroke volume becomes apparent as a result of a reduction in training volume and an increase in peripheral resistance (Seiler, 1996). Similarly, the relative elasticity of the heart decreases with age, consequently reducing the maximal preload capacity of the heart. As a result, the increased intrathoracic blood pool that occurs with WI plays little effect on increasing stroke volume, which consequently has little effect on altering maximal HR responses.

Rationale (Blac⁻):

Higher Blac⁻ has been reported following a maximal effort of DWR for individuals previously unfamiliar with DWR (Svedenhag and Seger, 1992). Investigations into the effects of DWR in trained individuals where DWR was a part of their training regime found that it elicited lower Blac⁻ levels when compared to TMR (Frangolias and Rhodes, 1995). Frangolias and Rhodes (1996) suggested that the difference in Blac⁻ levels between these studies was primarily due to the difference in the subjects' familiarity with DWR. Individuals who are unaccustomed to DWR will tend to recruit more untrained upper body musculature, resulting in more anaerobiosis in these muscles (Svedenhag and Seger, 1992). Attempts were made to familiarize all subjects in the present study by providing an instructional session followed by 2 practice sessions (30 minutes/session) of DWR. This attenuated some of the problems of recruiting extra upper body musculature, although, it did not eliminate the recruitment of these muscles altogether. In a water medium, the upper body musculature performs a proportionately greater quantity of work compared to TMR due to the resistance of water (Moening et al., 1993). Large muscle masses in the lower limb will also be worked to a greater capacity since the resistance in

water is 700 times than that of air. As a result, both the upper and lower body will recruit more muscle mass leading to a higher utilization of glycolytic fibers and consequently lactate production.

In addition, peripheral resistance is greatly increased with age, which consequently decreases the maximal blood flow to the working muscles (Seiler, 1996). This decrease in peripheral blood flow is amplified in the water due to a lowered perfusion pressure in the legs caused by the hydrostatic pressure of the water (Derion et al., 1992). Both these factors, increase recruitment of glycolytic fibers and decreased blood flow to working muscles, will work to produce greater blood lactate levels during DWR.

Rationale (RER):

Respiratory exchange ratios are indices that can be used to determine maximal effort (i.e. $RER > 1.1$). Indirectly it can estimate anaerobic exertion, as it is a ratio between VCO_2 and VO_2 . The larger this ratio becomes, the more Blac is assumed to be produced. Using this premise, if Blac is hypothesized to be higher during DWR (rationale above) than RER would correspondingly be higher.

2. Following 12 weeks of DWR, both DWR and TMR VO_{2max} and VE will increase substantially in healthy, untrained elderly women. Maximal HR and Blac⁻ will not change after 8 weeks of DWR.

Specific Hypotheses are:

DWR VO ₂ max: Pre-train < Post-train	at $p \leq 0.05$
DWR HR: Pre-train = Post-train	at $p > 0.05$
DWR VE: Pre-train < Post-train	at $p \leq 0.05$
DWR Blac: Pre-train = Post-train	at $p > 0.05$
TMR VO ₂ max: Pre-train < Post-train	at $p \leq 0.05$
TMR HR: Pre-train = Post-train	at $p > 0.05$
TMR VE: Pre-train < Post-train	at $p \leq 0.05$
TMR Blac: Pre-train = Post-train	at $p > 0.05$

**Note: The rationales given apply for DWR and TMR hypotheses for the respective variable in question*

Rationale (VO₂max):

Training responses are most apparent in untrained individuals exercising consistently at a moderate to high intensity. However, the magnitude of the improvement is dependent on the intensity, frequency and duration of exercise (Kohrt et al., 1991).

Training studies on land have shown significant improvements in maximal cardiovascular responses. Seals et al. (1984) and Hagberg et al. (1987) demonstrated that aerobic training attenuates the decline in VO₂max with advancing age and in some cases improvements in VO₂max were observed indicating possible improvements in

arteriovenous oxygen difference ((a-v)O₂ difference) with minimal changes in cardiac output (Seals et al., 1984). Seals et al. (1984) speculated that the (a-v)O₂ difference improvements might be related to adaptations in skeletal muscle to endurance training causing an increase in mitochondria and capillary density, which could play a role in the improvements in O₂ extraction. Hagberg et al. (1987) later suggested that individuals engaging in an exercise program during their later years would have the same relative adaptive capacity as their younger counterparts.

It is therefore evident that training responses are possible in the elder years. However, are these training adaptations possible with non-impact DWR? Michaud et al. (1995) found that DWR for 8 weeks at 3x/week for 1 hour/session, was enough to increase VO₂max by 17% in young, untrained individuals. Therefore, it would appear that DWR provides a high enough stimulus to elicit improvements in VO₂max. Although the resting physiological responses of older adults in the water are different from young individuals (Derion et al., 1992), improvements in VO₂max are to be anticipated when exercising at high enough intensities for a period of 8 weeks with a frequency of 3x/week and duration of 30min/session.

Rationale (VE):

Of the few studies that examined training effects following a DWR training program only 1 study reported VE responses in previously untrained young individuals (Quinn et al., 1994). They found non-significant improvements in VE following a 10-week training program. This may be related to the fact that VE is usually not the limiting factor in young individuals due to the large reserve capacity of the lungs in this population group

(Brooks et al., 1996). However in studies examining the training effects of land-based programs in elderly individuals, significant improvements in VE were observed. Seals et al. (1984) reported a 7% increase following a low intensity program and a 29% increase in VE following a high intensity program. These improvements in VE may be related to reconditioning of the respiratory muscles with endurance exercise and increases in maximal voluntary ventilation (MVV), as natural declines in these variables occur with advanced age. Breathing frequency, however, appears to be unaffected with training in elderly individuals following a high intensity land-based program indicating that breathing frequency may not play a role in augmenting VE with prolonged training (de Vries, 1971). Based on this evidence and the assumption that DWR provides a high enough exercise intensity to elicit improvements in cardiovascular and respiratory health, it is postulated that VE will improve with high intensity training.

Rationale (maximal HR):

Deep water running training appears to have little effect on improving maximal HR in young untrained individuals (Bushman et al., 1997; Lollgen et al., 1980; Michaud et al., 1995a). Michaud et al. (1995a) found that although DWR elicited a lower maximal HR compared to TMR, no improvements in either TMR or DWR maximal HR occurred following 8 weeks of DWR training. This finding is in agreement with the earlier study of Quinn et al. (1994) and the most recent study of Bushman et al. (1997). Although these studies investigated the effects of a training program on maximal HR in young individuals similar trends are expected for the older individual as Hagberg et al. (1985)

and Shephard et al. (1987) both reported that training had no effect on the age-related decrease in maximal HR.

Rationale (Blac⁻):

A high level of Blac⁻ is indicative of increased reliance on anaerobic metabolism. The elevation in Blac⁻ usually occurs near maximal effort as the body's ability to supply the muscles with energy derived from aerobic sources diminishes resulting in an increase in anaerobic metabolism. There is a lack of convincing evidence to suggest that maximal Blac⁻ levels and consequently, anaerobic capabilities improve with DWR training programs. Wilber et al. (1996) and Bushman et al. (1997) both found that 4-6 weeks of DWR training failed to elicit improvements in maximal Blac⁻ response.

3. Improvements in VO₂max will occur following 8 weeks of DWR. However, DWR VO₂max will improve far greater than TMR VO₂max.

Specific Hypothesis: $\uparrow \text{DWR}_{\text{VO}_{2\text{max}}} > \uparrow \text{TMR}_{\text{VO}_{2\text{max}}}$ at $p \leq 0.05$

Rationale:

As with any type of training program improvements in overall fitness are inevitable providing that the exercise is done consistently and at a high enough intensity. However, the "specificity of training" principle indicates that training adaptations are specific to the muscles involved in the activity (Stegeman, 1981). McArdle et al. (1978) found that 10 weeks of run training improved VO₂max for treadmill running nearly 3 times as much as

it did for tethered swimming. Similar trends have been reported for DWR. Michaud et al. (1995a) reported a 20.1% and 10.6% increase in VO_2max for DWR and TMR, respectively, following 8 weeks of DWR training in young individuals. Using the “specificity of training principle” DWR would have to have different muscle recruitment patterns to cause this two-fold increase in DWR VO_2max compared to TMR VO_2max . Therefore, there is reason to believe the DWR would cause a moderate increase in DWR aerobic performance in the elderly, with a partial carry-over or transfer effect to land-based fitness.

Chapter 2

2.0 REVIEW OF THE LITERATURE

The buoyancy characteristic of water makes any form of water exercise attractive for individuals seeking ways to improve fitness without the inherent risk of musculoskeletal injuries caused from continuous impact on the body. For this reason, water exercises have been used for decades in the area of physical medicine and rehabilitation (Wilder and Brennan, 1993). Deep water running, however, has only been widely used within the last decade. Deep water running was initially developed by athletic trainers and exercise physiologists as a means to minimize the amount of impact loading for elite runners (Quinn et al., 1994). The weight-independent nature of DWR eliminates the impact stresses typically observed during OLR, however, there are differences in the specificity of these two modes of running. Although, water running is not biomechanically specific to OLR in terms of muscle dynamics and ground reaction forces, DWR remains to be the most prominent form of cross training with elite runners (Moening et al., 1993). Similarly, DWR appears to be a popular exercise with young untrained individuals seeking ways to improve fitness without the excessive stresses placed on their bones and joints (Michaud et al., 1995a; Quinn et al., 1994). In order to comprehend the true benefits of adopting DWR as a primary training modality, it is important to understand the role hydrostatic pressure and water buoyancy has on the metabolic, respiratory and physiological responses of exercising in a water environment. Therefore, it is the intent of this literature review to present research pertaining to: 1) the cardiorespiratory adjustments associated with WI at rest, 2) the cardiorespiratory

responses during DWR, 3) training responses incurred with DWR training programs, and 4) water temperature effects.

2.1 What is Deep Water Running?

In simplest terms, DWR is simulated running in the deep end of a swimming pool. Deep water runners are typically suited with a buoyancy vest to help keep them afloat during the exercise.

Although running styles may vary, the general technique that should be used for DWR follow these criteria: 1) the trunk should remain upright with a maximum forward lean of 45 degrees, 2) the arms and legs should follow a unilateral forward motion, 3) the swing phase leg should be brought to the horizontal position, 4) the arms should be at a 90 degree angle, and 5) the hands should remain open at all times.

2.2 Influence of Water Immersion on Resting Physiological Parameters

2.2.1 *Respiratory and Pulmonary Parameters*

Water immersion induces a variety of respiratory and cardiovascular adjustments as a consequence of thoracic wall compression and intrathoracic blood pooling.

Collectively, these factors produce modifications in lung and chest mechanics leading to an overall reduction in lung capacity. Agostoni et al. (1966) were the first to report significant decrements in lung volumes with WI in eight healthy males. They found that submersion to the xiphoid in a seated position caused a small but significant decrease in residual volume (RV). Moreover, a large reduction in expiratory reserve volume (ERV) from 1.87L in air to 0.51L in water was detected with WI, resulting in an overall decline

in functional residual capacity (FRC) from 3.53L to 1.90L for air and WI conditions, respectively. They explained these observations by speculating that the combination of hydrostatic pressure and intrathoracic blood pooling, introduced with WI, caused a cranial displacement of the diaphragm to a position approaching full expiration (Agostoni et al., 1966). As a result, lung volume and capacity were compromised during WI causing impairments in respiratory functions.

These impairments in respiratory parameters were later shown to be strongly dependent on the level of immersion. Hong and coworkers (1969) conducted a study comparing the effects of xiphoid and neck level immersion on respiratory parameters. They reported no difference in tidal volume (V_T) between the different levels of WI, however, a significant decline in ERV (1150ml) and vital capacity (360ml) was observed during the neck level immersion compared to xiphoid level immersion. This decrease in ERV and vital capacity (VC) observed during neck level immersion was attributed to an increase in chest compression, which was represented by a rightward shift of the volume-pressure curve (Hong et al., 1969). Further experimentation revealed that a Valsalva maneuver following a maximal inspiration partially compensated for the decrease in VC observed during both levels of immersion. Hong and colleagues (1969) calculated that the performance of a Valsalva maneuver during xiphoid level immersion caused a 194ml increase in VC, which was equivalent to 4.4% of the initial VC. Furthermore, a 415ml improvement in VC (equivocal to a 60% reduction in normal VC) was observed during neck level immersion following a Valsalva maneuver. This increase in VC after a Valsalva maneuver was a result of a shift in blood from the thoracic cavity to the extrathoracic region (Hong et al., 1969). Therefore, they concluded that 60% of the

reduction in VC, observed during steady-state neck level immersion, was a result of an increase in intrathoracic blood volume caused by the redistribution of blood induced by hydrostatic pressure.

A more comprehensive examination of the role of WI levels revealed that hip level immersion induced only a minimal increase in thoracic blood volume, as reflected by an inappreciable decline in FRC (Farhi and Linnarsson, 1977). During xiphoid level immersion Farhi and Linnarsson (1977) reported a 400ml drop in FRC compared to the FRC value obtained in a dry air condition. They attributed this decline to the combination of diaphragmatic ascent and increased intrathoracic blood volume. A further reduction of 400ml in FRC was observed during neck level immersion compared to the xiphoid level FRC, in which case Farhi and Linnarsson (1977) attributed the difference to the introduction of chest compression.

The three studies cited thus far attributed the decrease in respiratory functions (ERV, VC, and FRC) to a combination of hydrostatic chest compression and increased intrathoracic blood volume. In contrast, Dahlback and colleagues (1978) suggested that the reduction in ERV is primarily a consequence of increased thoracic pressure, whereas, VC decrements are a result of intrathoracic blood pooling. Dahlback and co-workers (1978) were able to reach this assumption using an innovative apparatus that allowed them to separate the role of thoracic compression and intrathoracic blood pooling on ERV and VC. This apparatus (Fig.1) was equipped with two main water supplies: one located at the base of the tank and other near the hip region. A plug divided these water outlets, such that opening of the hip region water outlet allowed the pelvis region and legs to remain dry in open air, while the thorax region was immersed in water. This enabled

the investigators to observe the exclusive effects of thoracic compression on pulmonary functions. Conversely, head-out WI was achieved using the base water outlet resulting in an increase in venous return, intrathoracic blood volume and thoracic compression.

Fig 1. Experimental set-up for measurement of static lung volumes and pressure-volume curves of the lungs during different immersion conditions (Dahlback et al., 1978).

Using this design, Dahlback and colleagues (1978) observed a dramatic decline in ERV between the non-immersed ($2.10 \pm 0.08\text{L}$) and thorax-immersed conditions ($0.65 \pm 0.08\text{L}$), indicating that thoracic compression played a vital role in the adjustments of ERV during WI by limiting expiration. A further, but slight, reduction in ERV (0.13L) obtained during head-out WI demonstrates that ERV was also influenced by increases in intrathoracic volumes, although the relative contribution of this was minor compared to

increased chest compression. In addition, they reported non-significant differences in VC between non-immersed ($5.33 \pm 0.05\text{L}$) and thorax-immersed conditions ($5.28 \pm 0.08\text{L}$). In contrast, VC measurements during the head-out immersion condition were significantly lower than that observed during thorax level immersion (5.28 ± 0.08 vs. $5.05 \pm 0.1\text{L}$). These findings suggest that the reduction in VC during WI is entirely attributable to the redistribution of blood into the thorax.

The amalgamation of these findings suggests that: 1) ERV, RV, FRC and VC are all impaired with WI and 2) the severity of the respiratory adjustments induced by WI is strongly dependent on the level of immersion (Table 1). However, there appears to be a missing link to this phenomenon. All four of these papers cited that a large reduction in ERV was apparent during WI, in which case this reduction was far greater than that seen for VC (Dahlback et al., 1978). It would not be possible to see a large decrease in ERV without a comparable decline in VC values, unless some other variable affecting VC was altered during WI. Since VC is comprised of both the ERV and inspiratory reserve volume (IRV), it seems rather probable that the large reduction in ERV is somehow partially compensated by an increase in IRV causing only a modest decline in VC during WI. Although the sample spirogram (Fig. 2) provided by Dahlback and colleagues (1978) depicts a slight increase in IRV, no absolute values were given, therefore making it difficult to assess the true effects of IRV on VC during WI.

Other modifications in pulmonary functions seen during WI include variations in, 1) pulmonary flow resistance, 2) partial pressures of arterial (P_{aO_2} , P_{aCO_2}) and mixed venous (P_{vO_2} , P_{vCO_2}) gases, and 3) pulmonary ventilation and perfusion (Table 1).

Fig 2. Sample spirogram illustrating the vital capacity and expiratory reserve volumes of an individual submersed in water (Dahlback et al., 1978).

Pulmonary flow resistance has been shown to increase with WI. A study conducted by Lollgen and coworkers (1980) reported that head-out WI in 6 healthy male subjects caused an increase in resistance to breathing (0.235 ± 0.049 vs. 0.037 ± 0.059 kPa/l/s in air and water, respectively). They speculated that this was a result of a 70% increase in pulmonary capillary volume caused by the hydrostatic pressure on the lower limbs

(Lollgen et al., 1980). This finding corroborates the earlier study by Agostoni and coworkers (1966), in which similar increases in pulmonary flow resistance (58%) with xiphoid level immersion were observed.

Similar adjustments in the partial pressures of O_2 and CO_2 were also observed during WI, however, the proportion of change appeared to be strongly affected by the level of immersion. Farhi and Linnarsson (1977) investigated the effects of 3 different levels of immersion and found the greatest increase in mixed P_vO_2 during chin level immersion. Smaller improvements in P_vO_2 values were recorded during xiphoid level immersion, which diminished during hip level immersion. This enhancement in P_vO_2 corresponds to the increase in Q with higher levels of immersion (Farhi and Linnarsson, 1977). In contrast, the level of immersion appeared to have little influence on mixed P_vCO_2 . These observations correspond with recent findings regarding the lack of change in alveolar ventilation with WI (Lollgen et al., 1980). Since P_vCO_2 is highly dependent on alveolar ventilation, the absence of any change in alveolar ventilation with WI suggests that little or no change in P_vCO_2 will occur with WI at any level. In terms of arterial partial pressures of O_2 and CO_2 , Lollgen and associates (Lollgen et al., 1980) observed an increase in P_aO_2 during neck level immersion, with no changes in P_aCO_2 and pH during WI in six healthy subjects. These findings are in conformity with more recent evidence provided by Derion and coworkers (1992) who examined pulmonary ventilation and perfusion alterations in 12 healthy, non-smoking males with no history of respiratory disease ($n=6$ between age of 20-29 and $n=6$ between age of 40-54 years). They reported an increase the V_E/VO_2 relationship and Q with neck level immersion causing an increase in P_aO_2 in young individuals. In addition, they reported significant decreases in the

alveolar-arterial partial pressure difference (A-aPO₂) with no concomitant change in the V_A/Q relationship, P_aCO₂, and VO₂. Thus, it would appear that WI enhances gas exchange in the younger subjects.

Table 1. Respiratory and pulmonary adjustments that occur with submersion in water during the resting state

Study	Condition	Level of Immersion	FRC (L)	ERV (L)	VC (L)	P _v O ₂ (torr)	P _v CO ₂ (torr)	P _a O ₂ (torr)	P _a CO ₂ (torr)	A-aPO ₂ (torr)	V _E (L/min)	Resistance (% TMR)
1. Agostoni et al. (1966)	Air	-----	3.53	1.86	-----	5.2	-----	-----	-----	-----	-----	100%
	Water	Neck level	1.90	0.56	-----	-----	-----	-----	-----	-----	-----	158%
2. Hong et al. (1969)	Water	Xiphoid level	-----	1.60	4.462	-----	-----	-----	-----	-----	-----	-----
	Water	Neck level	-----	0.450	4.10	-----	-----	-----	-----	-----	-----	-----
3. Farhi & Linnarsson (1977)	Air	-----	3.03 (0.08)	-----	-----	35 (0.9)	35 (0.9)	-----	-----	-----	-----	-----
	Water	Hip level	2.85 (0.09)	-----	-----	36 (0.8)	36 (0.9)	-----	-----	-----	-----	-----
	Water	Xiphoid level	2.58 (0.09)	-----	-----	41 (0.9)	36 (0.9)	-----	-----	-----	-----	-----
	Water	Chin level	2.13 (0.06)	-----	-----	44 (0.7)	37 (1.0)	-----	-----	-----	-----	-----
4. Dahlback et al. (1978)	Air	-----	-----	2.10 (0.08)	5.33 (0.05)	-----	-----	-----	-----	-----	-----	-----
	Water	Thorax only	-----	0.65 (0.08)	5.28 (0.08)	-----	-----	-----	-----	-----	-----	-----
	Water	Neck level	-----	0.52	5.05	-----	-----	-----	-----	-----	-----	-----
5. Lollgen et al. (1980)	Air	-----	-----	-----	-----	40.7 (3.3)	42.8 (1.5)	-----	36 (3.5)	2.1 (0.7)	13.9 (2.6)	-----
	Water	Neck level	-----	-----	-----	44.7 (4.2)	40.5 (2.2)	-----	36.9 (2.6)	0.1 (0.6)	10.9 (2.5)	-----

NB: Values within the parentheses denote standard deviations.

Abbreviations: functional residual capacity (FRC), expiratory reserve volume (ERV), vital capacity (VC), partial pressure of venous O₂ (P_vO₂), partial pressure of venous CO₂ (P_vCO₂), partial pressure of arterial O₂ (P_aO₂), partial pressure of arterial CO₂ (P_aCO₂), alveolar-arterial pressure difference (A-aPO₂), minute ventilation (VE), flow resistance (resistance).

2.2.2 Cardiovascular Parameters

A number of adjustments in cardiovascular (CV) parameters have been reported to occur while immersed in water. Of all the CV changes that arise with WI, stroke volume increases are amongst the first changes to transpire. This is primarily a result of the

immediate increase in central blood volume caused by a negative trans-thoracic pressure and reduction in peripheral blood flow (Lin, 1984). Furthermore, Farhi and Linnarsson (1977) speculated that the level of immersion is strongly associated with the relative increase in SV observed during WI. They reported significantly lower stroke volumes on land (67 ± 1.5 ml/beat) than water. However, the values obtained in water varied depending on the level of immersion, such that stroke volumes increased with increased level of immersion (78 ± 2.3 , 110 ± 2.4 and 120 ± 2.5 ml/beat for hip, xiphoid and chin immersions respectively).

A similar phenomenon of water level dependence was reported for heart rate (HR) modifications. Farhi and Linnarsson (1977) reported a biphasic response in HR, such that HR appeared lower with hip and xiphoid level immersion compared to on-land values, but then increased with chin level immersion. Farhi and Linnarsson (1977) attempted to explain this phenomenon using a combination of two opposing processes. They suggested that HR reductions during the first two steps of the graded immersion (hip and xiphoid) were mediated by baroreceptors. This causes an increase in cardiac output, blood pressure thereby reflexly decreasing HR. The second response seen in the third step of the graded immersion (chin) suggests that the role of atrial stretch receptors has now become predominant, causing cardiac acceleration. However, in studies using similar levels of immersion (e.g. xiphoid level), HR responses were reported to decrease (Derion et al., 1992) or remain constant (Craig and Dvorak, 1968) during acute bouts of WI in young, healthy individuals. Furthermore, Derion et al. (1992) reported that HR response after 20 minute of submersion did not change in older individuals. It is difficult to attribute these differences in observed HR to a single reason since opposing factors act

together to determine HR during WI. This includes: 1) increases in atrial pressure triggering a tachycardial response through the Bainbridge reflex and 2) increases in stroke volume and cardiac output causing a concurrent opposition in tachycardia via the baroreceptor mechanism (Lin, 1984).

Despite the apparent discrepancies in heart rate response with WI, there is a general consensus amongst all researchers that cardiac output (Q) increases with WI in young, healthy individuals (Derion et al., 1992). This is attributable to the overcompensation in SV for the depressed HR, which has an overall effect in increasing Q. Again, Farhi and Linnarsson (1977) demonstrated that the increase in Q is relative to the level of immersion. They reported that immersion at the level of the hip caused an increase in cardiac output by ~10-15%. This increase in Q was a consequence of a decreased heart rate mediated by two factors: 1) an increase in systemic arterial pressure, and 2) a slight augmentation of stroke volume caused by a small increase in thoracic blood volume. However, abdominal immersion to the level of the xiphoid resulted in a greater compression of the abdomen, therefore, displacing most of the blood into the thoracic cavity. Consequently a larger stroke volume occurred accounting for a larger overall cardiac output. Finally, immersion to the chin caused a further increase in cardiac output due to a large enough increase in atrial pressure thereby triggering the atrial stretch receptors to cause a reflex increase in heart rate and stroke volume (Farhi and Linnarsson, 1977).

Another metabolic adjustment that has been observed to occur during WI is a slight increase in the respiratory exchange ratio (RER) (0.85 vs. 0.93 for air and WI conditions, respectively). Derion and coworkers (1992) suggested that the increase in RER was

primarily a result of the mal-distribution of blood to the lower extremities caused by the hydrostatic pressure of water. Therefore, the modest increase in RER would represent the slight shift from aerobic to anaerobic metabolism caused by the reduction in blood flow to the lower portions of the body.

2.2.3 *Age Effects*

Regardless of training status and independent of disease, there is an inevitable decline in exercise capacity with advancing age caused by natural deterioration of the cardiovascular and respiratory systems (Brooks et al., 1995). Although training may reduce the magnitude of these deteriorations, advanced age will eventually lead to decreases in: 1) cardiac output caused by reductions in both maximal HR and stroke volume, 2) ventilatory capacities, 3) muscle respiratory capacity, 4) strength and power (Table 2) (Green and Crouse, 1993; Stratton et al., 1994; Brooks et al., 1995).

The reduction in cardiac output is related to declines in both HR and stroke volumes. Maximal heart rate reductions are attributed to decreases in β -adrenergic stimulation during exercise and deconditioning of the heart muscle due to a decrease in physical activity with age (Green and Crouse, 1993; Stratton et al., 1994). Stroke volume reductions, on the other hand, are caused by: 1) a decrease in Ca^{++} -myosin ATPase activity resulting in a weaker contraction (Chesky and Rockstein, 1977; Lakatta and Yin, 1982), 2) increased stiffness of the heart wall (Green and Crouse, 1993), 3) poor venous return (Brooks et al., 1996), and 4) an increase in arterial blood pressure causing an increase in afterload (Brooks et al., 1996; Stamford, 1988). Coupled with these cardiovascular changes are reductions in ventilatory capacities. Inbar et al. (1994)

reported an average decline of 0.74L/min/year in ventilation over 50 years. This is primarily attributable to 1) decreases in maximal voluntary ventilation (MVV) and

Table 2. Physiological effects of aging

Effect	Functional Significance
Cardiovascular	
Capillary/fiber ratio ↓	Decreased muscle blood flow
Cardiac muscle and heart volume ↓	Decreased maximal stroke volume and cardiac output
Elasticity of blood vessels ↓	Increased peripheral resistance, blood pressure, and cardiac afterload
Elasticity of blood vessels ↓	Increased peripheral resistance, blood pressure, and cardiac afterload
Myocardial myosin-ATPase ↓	Decreased myocardial contractility
Sympathetic stimulation of SA node ↓	Decreased maximum heart rate
Respiration	
Condition of elastic lung support structures ↓	Increased work of breathing
Elasticity of support structures ↓	Decreased lung elastic recoil
Size of alveoli ↑	Decreased diffusion capacity and increased dead space
Number of pulmonary capillaries ↓	Decreased ventilation/perfusion equality
Muscle and joints	
Muscle mass ↓	
Number of type IIa and IIb fibers ↓	
Size of motor units ↓	
Action potential threshold ↓	Loss of strength and power
(Ca ²⁺ , Myosin)-ATPase ↓	
Total protein and N ₂ concentration ↓	
Size and number of mitochondria ↓	Decreased muscle respiratory capacity
Oxidative enzymes: SDH, cytochrome oxidase, and MDH ↓	Decreased muscle respiratory capacity
Lactate dehydrogenase ↓	Slows glycolysis
Stiffness of connective tissue in joints ↑	Decreased joint stability and mobility
Accumulated mechanical stress in joints ↑	Stiffness, loss of flexibility, and osteoarthritis
Muscle and joints	
Water content in intervertebral cartilage ↓	Atrophy and increased chance of compression fractures in spine
Bone	
Bone minerals ↓	Osteoporosis—increased risk of fracture
Body composition and stature	
Body fat ↑	Impaired mobility and increased risk of disease
Kyphosis ↑	Loss of height

(Brooks GA, Fahey TD, and White TP. *Aging*. In Exercise Physiology: Human Bioenergetics and Its Applications. 1996)

breathing frequency (Inbar et al., 1994), 2) deterioration of elastic support structures making it more difficult to breath, 3) increases in alveolar size (Brooks et al., 1996), and 4) weakened respiratory muscles (Brooks et al., 1996). In combination with these deteriorations in central factors, Proctor et al. (1997) found that oxygen extraction from the active are also diminished with age. Muscle oxygen uptake has been observed to decrease 0.50L/min/kg in appendicular muscle masses in chronically trained older individuals (Proctor et al., 1997). It has been estimated that the normal (a-v)O₂ difference of 16ml/kg/min in young individuals exercising at high intensities drop to 12-13ml/kg/min in elderly individuals working at similar relative intensities (Brooks et al., 1996). It has been hypothesized that these declines in muscle oxidative capacities are a direct result of two factors working in combination: 1) reduced O₂ extraction by the active muscles, and 2) reduced O₂ delivery to the active muscles. It is still unresolved as to which of these two mechanisms cause the most change in muscle O₂ extraction.

The combination of all these age related changes in cardiovascular and respiratory parameters (HR, SV, VE, O₂ extraction) inevitably cause VO₂max to drop significantly from the age of 25 years and onwards. Some researchers have reported average declines in VO₂max between 0.016 L/min/year (Posner et al., 1976) to 0.022 L/min/year (Jones et al., 1985), or approximately 10%/year in inactive individuals (Hagberg, 1987; Heath, 1985). Because of these changes, the exercise physiology and training adaptability of an elderly individual maybe drastically different from that of a young person, especially in different milieu (i.e. water vs. land).

Training studies on land with elderly participants have shown significant improvements in maximal cardiovascular responses. Hagberg et al. (1987) and Seals et

al. (1984) demonstrated that aerobic training attenuates the decline in VO_2max with advancing age and that in some cases improvements in VO_2max were observed showing possible improvements in $(a-v)\text{O}_2$ difference with minimal changes in cardiac output (Seals et al., 1984). Seals et al. (1984) speculated that the improvements in $(a-v)\text{O}_2$ difference might be related to adaptations in skeletal muscle to endurance training causing an increase in mitochondria and capillary density, which could play a role in the improvements in O_2 extraction. Hagberg et al. (1987) later suggested that engaging in an exercise program late in life would improve VO_2max in a similar fashion as to what is seen in young individuals (i.e. relative adaptive capacity is similar across age groups).

It is evident that moderate-high intensity land based training programs are useful for improving cardiovascular fitness in previously inactive elderly individuals. However, it would be exciting to establish whether non-impact water exercises would provide enough stimuli to see improvements.

Before engaging in water training programs, individuals should be aware of the acute effects water may have on physiological parameters. Little research has been done examining the acute effects of water exercise in elderly population groups. Of the few studies that have been done in this area, two things have been shown: gas exchange parameters and cardiac functions are distinctly different between young (<40 years old) and old individuals (>40 years old). Derion and colleagues (1992) provided compelling evidence to suggest that improvements in gas exchange parameters induced by WI were age dependent. Older individuals (40-49 years) experienced non-significant alterations in P_aO_2 , A-aPO_2 , P_aCO_2 , and VO_2 during WI, whereas their younger counterparts exhibited an increase in P_aO_2 and a decrease in A-aPO_2 . This difference may be a consequence of a

higher V_E/VO_2 relationship and lower Q for older individuals compared to the younger individuals (Derion et al., 1992). Cardiac output, heart rate, and stroke volume variability during WI also appears to be age dependent. Derion et al. (1992) reported that although Q increases in younger individuals, Q is unchanged after 20 minutes of WI in older individuals. The lack of change in Q in older individuals is attributed to the consistency of both SV and HR after 20 minutes of submersion. To date, no study has shown why SV and HR remains unchanged in the older population following 20 minutes of WI. A plausible explanation is that the heart of an older individual is unable to expand to the extent of a young heart, thereby limiting the pre-load of the heart. To give merit to this hypothesis more studies need to be conducted in this area to either support or give rise to new theories regarding the age dependence of acute WI cardiac functions.

In summary, the evidence presented thus far clearly illustrates the numerous respiratory, cardiovascular, and metabolic changes that occur with WI during the resting state. The ramifications of these adjustments are harmless at rest but become critical during high intensity exercise when respiration and metabolism are maximized. Therefore, it is important to understand how these physiological changes affect exercise performance.

2.3 Metabolic Responses during an Acute Bout of Deep Water Running

2.3.1 Maximal Exercise Response

The implications of WI on maximal exercise performance are great, as many researchers have reported extensive cardiovascular and metabolic dissimilarities between land and water exercise. More specifically, the greatest contrast in maximal physiological response emerges from comparisons made between land based and deep water running. In an attempt to account for these differences, Butts, Tucker and Smith (1991b) compared the physiological responses of maximal TMR to DWR in 12 competitive high school female cross country runners. They found that maximal heart rate (HR) was on average 17.6 beats/min lower during DWR than TMR (Table 3). Frangolias and Rhodes (1995) reported similar maximal HR reductions (15 beats/min) in elite middle and long distance runners familiar with DWR. This reduction in maximal HR during DWR was attributed to the increase in central blood volume caused by the hydrostatic pressure, which consequently enhances SV and depresses HR, while keeping Q constant (Butts et al., 1991b). In addition, a 17% (Butts et al., 1991b) and 8.5% (Frangolias and Rhodes, 1995) decrease in maximal oxygen consumption ($\text{VO}_{2\text{max}}$) during DWR was observed and attributed to a reduction in work by the antigravity muscles due to the body's buoyancy in water (Butts et al., 1991b). Additional evidence provided by Town and Bradley (1991) corroborated the idea of a "buoyancy mediated reduction in metabolic work" with DWR. Their study contrasted the metabolic demands during a maximal running exercise on the treadmill, in shallow water (subjects' feet were in contact with the bottom of the pool) and in deep water (subjects' feet were not in contact with the bottom of the pool). They found that DWR invoked a much lower

VO₂max and O₂ pulse and that SWR elicited maximal metabolic demands similar to that observed during TMR (Table 3). In contrast to these findings, a more recent study conducted by Dowzer et al. (1999) found that both DWR and SWR resulted in depressed VO₂max, maximal HR, maximal VE, and RER values compared to TMR. The discrepancies between studies maybe due to variations in water temperature (Dowzer et al., 1999) as it has been shown that exercising below thermoneutral temperatures (<29°C) results in lower cardiorespiratory responses (McArdle et al., 1976). Both studies, however, agree that DWR invokes lower cardiorespiratory responses compared to SWR. It was speculated that SWR responses are more similar to TMR because the movement patterns between these two running conditions are similar, such that they both consist of a push-off phase on solid surface (Dowzer et al., 1999; Town and Bradley, 1991).

In addition to these changes, Town and Bradley (1991) reported a lower O₂ pulse for DWR (3.40 beats/L O₂) compared to TMR (2.66 beats/L O₂) and SWR (2.63 beats/L O₂), indicating depression of cardiovascular efficiency during DWR. They speculated that the difference in efficiency was likely due to the atypical movements of both the arms and legs during DWR. Arm movements were reported to follow a circular pattern in attempts to assist the subject in staying afloat, while the legs were adjusting to running without a firm footage on a solid surface (Town and Bradley, 1991).

Other studies investigating the effects of DWR found strikingly similar metabolic responses. Svedenhag and Seger (1992) reported a 13% reduction in DWR VO₂max compared to TMR in 9 trained middle and long distance runners experienced with DWR. Concomitant decreases in maximal HR (172±3 vs. 188±2 beats/min), maximal RER (1.10±0.04 vs. 1.20±0.03) and O₂ pulse (23.4 vs. 24.5 mlO₂/beat) were recorded for

DWR compared to TMR. In contrast, DWR elicited a much higher blood lactate level following exhaustive exercise (12.4 ± 1.3 vs. 10.0 ± 0.6 mmol) (Table 3). This observation is in agreement with a more recent study investigating the difference in physiological response between suspended deep water running (SDWR) and hard surface running (TMR) (Glass et al., 1985). Glass et al. (1995) observed higher VO_2max and maximal HR responses coupled with lower blood lactate levels and RER values during TMR compared to SDWR (Table 3). The increase in blood lactates observed with DWR indicates an increase in anaerobic metabolism. This increase in anaerobic metabolism during DWR is partly due to a lowered perfusion pressure in the legs with a resultant decrease in total muscle blood flow and/or mal-distribution (Derion et al., 1992). Additional factors that may have contributed to the increase in anaerobic metabolism include: 1) an altered running technique in water resulting in an alteration in muscle activation patterns (due to the absence of the support phase), and 2) a longer absolute muscular contraction time (Svedenhag and Seger, 1992).

In contrast, Town and Bradley (1991) and Frangolias and Rhodes (1995) observed lower blood lactates following exhaustion in the DWR condition suggesting that WI did not elicit an increase in anaerobic metabolism. The cause of this discrepancy is unknown, however, it may be due to a possible increase in muscle recruitment with supported water running (Svedenhag and Seger, 1992) in contrast to unsupported running (Town and Bradley, 1991) or the increase in familiarity with DWR (Frangolias and Rhodes, 1995).

2.3.2 *Gender Effects*

Women typically exhibit a greater percentage of fat than their male counterparts primarily because of the reproductive functions in the female. The consequence of this increased adiposity is the increased tendency to float more in water. The increased buoyancy women experience in water may consequently result in different exercise responses in water compared to men. In an effort to delineate any possible gender effects on the physiological responses observed during DWR, Butts and coworkers (1991a) extended their initial investigation by comparing the maximal physiological responses of TMR to DWR in 12 female and 12 male active runners. Although the males exhibited much higher V_E and VO_{2max} throughout all tests, the differences in these parameters between TMR and DWR were equivocal in both genders (Table 3). Maximal HR and RER values were comparable between genders during TMR and declined to similar values during DWR. Glass and coworkers (1995) made similar observations in their study examining the difference in physiological response during suspended deep water running (SDWR) and hard surface running (TMR). They reported higher VO_{2max} values in men compared to women during both TMR and SDWR, however, the relative decline in VO_{2max} with SDWR was equivocal between genders (Table 3). In addition, maximal HR declined and blood lactates increased appreciatively during SDWR in both genders. A more recent study provided evidence to the contrary. Brown and colleagues (1997) found that although men and women both experienced declines in VO_{2max} and HR, the magnitude of change was different between genders. Greater decrements in VO_{2max} and HR were in fact observed in females indicating lower physiological stress during DWR, compared to men. It would therefore appear that decreases in cardiovascular responses

with DWR occur irrespective of gender, although the magnitude of change may be influenced by gender.

2.3.3 Age Effects

No study to date has examined the physiological ramifications of DWR in the elderly population. Nakanishi et al. (1999) addressed the issue of age related factors on DWR response in middle aged men and reported that healthy, untrained middle aged men (age 38.4 ± 4.4 years) had similar metabolic and cardiorespiratory responses compared to healthy, untrained young men (age 20.4 ± 3.3 years) during a maximal effort deep water run. They reported that although absolute HR and $\text{VO}_{2\text{max}}$ were considerably lower in the middle-aged group, the relative decrement in these variables during DWR compared to TMR were equivocal between both age groups.

All other the studies examining the effects of water exercises with the elderly population (age >60 years) used shallow end waters. Although impact is greatly reduced, impact loading is still present with this form of exercise. It would be of great benefit to this particular population to adopt a safe mode of exercise that completely eliminates impact loading on the bone and joints. Studies need to be initiated that examine the physiological responses of DWR in the elderly population before such exercises can be employed with this group.

In summary, there are vast differences in respiratory and metabolic responses between DWR and OLR for both males and females. In a review on water running, Frangolias and Rhodes (1996) summarized the possible factors causing the differences in

metabolic response between TMR and DWR. They stated that the differences observed between TMR and DWR were a result of: 1) the introduction of viscosity and friction from the water medium, 2) the element of weightlessness, and/or 3) the possible biomechanical differences between the two running conditions.

Table 3. Metabolic differences between maximal TMR and DWR.

Study	Condition	VO ₂ max (ml/kg/min)	VO ₂ max (L/min)	HR (beats/min)	V _E (L/min)	RER	[Blac] _{30sec} (mmol/L)
1. Butts et al. (1991)	TMR (men)	64.5 (2.8)	4.550 (0.368)	193.3 (5.8)	150.0 (11.6)	1.15 (0.04)	-----
	DWR (men)†	58.4 (3.9)	4.086 (0.405)	183.4 (5.6)	140.8 (17.8)	1.11 (0.03)	-----
	TMR (women)	55.7 (4.8)	3.321 (0.317)	188.7 (9.3)	116.6 (7.0)	1.13 (0.03)	-----
	DWR (women)†	46.8 (5.9)	2.786 (0.367)	179.5 (7.5)	97.7 (10.9)	1.09 (0.04)	-----
2. Butts et al. (1991)	TMR	54.7 (7.0)	3.0 (0.3)	197.9 (9.4)	93.6 (17.7)	1.05 (0.03)	-----
	DWR†	46.8 (9.1)	2.6 (0.5)	180.3 (6.0)	91.8 (19.3)	1.01 (0.08)	-----
3. Town & Bradley (1991)	TMR	66.7*	-----	183*	-----	1.15*	8*
	DWR	49*	-----	157*	-----	1.07*	6.5*
	SWR	60*	-----	162*	-----	1.03*	6.5*
4. Svedenhag & Seger (1992)	TMR	-----	4.60 (0.14)	188 (2)	135*	1.20 (0.03)	10.0 (0.6)
	DWR†	-----	4.03 (0.13)	177 (3)	125*	1.10 (0.04)	12.4 (1.3)
5. Frangolias & Rhodes (1995)	TMR	59.7	3.92	190	109.0	1.20	10.4
	DWR†	54.6	3.60	175	105.8	1.10	9.8
6. Michaud et al. (1995)	TMR	-----	4.3 (0.10)	184 (2.6)	-----	1.05 (0.04)	-----
	DWR†	-----	3.8 (0.11)	168.8 (5.2)	-----	1.00 (0.08)	-----
7. Glass et al. (1995)	TMR (men)	56.8 (6.5)	-----	191 (13.4)	-----	0.93 (0.08)	11.8 (4.7)
	DWR (men)†	51.2 (7.3)	-----	173 (13.4)	-----	0.98 (0.10)	15.2 (4.4)
	TMR (women)	49.3 (7.0)	-----	186 (11.3)	-----	0.94 (0.06)	10.6 (3.6)
	DWR (women)†	43.1 (7.1)	-----	174 (9.5)	-----	0.98 (0.11)	14.9 (3.3)
8. Brown et al. (1997)	TMR (men)	45.2 (4.4)	3.381 (0.405)	195.7 (5.2)	-----	-----	-----
	DWR (men)†	39.1 (8.3)	2.922 (0.679)	183.8 (7.7)	-----	-----	-----
	TMR (women)	40.1 (3.1)	2.338 (0.282)	194.6 (5.0)	-----	-----	-----
	DWR (women)†	30.1 (4.5)	1.804 (0.340)	173.9 (7.3)	-----	-----	-----
9. Nakanishi et al.	TMR (young men)	3.20 (0.52)	49.5 (7.6)	193.9 (6.7)	107.0 (18.0)	1.07 (0.04)	13.8 (3.3)
	DWR (young men)†	2.51 (0.53)	39.0 (7.8)	169.2 (15.1)	89.4 (18.2)	1.03 (0.07)	9.2 (3.0)
	TMR (middle aged men)	3.08 (0.47)	41.3 (8.0)	183.3 (13.4)	104.0 (18.4)	1.06 (0.05)	11.9 (3.1)
	DWR (middle aged men)†	2.25 (0.47)	30.2 (7.1)	158.4 (19.7)	81.7 (20.8)	1.06 (0.07)	10.1 (2.8)

* denotes approximate values that were extrapolated from graphs; † denotes studies that utilized a wet vest during water running (suspended water running)

NB: Values within the parentheses represent the standard deviation

Abbreviations: treadmill running (TMR), deep water running (DWR), shallow water running (SWR), maximal heart rate (HR), maximal ventilation (V_E), maximal respiratory exchange ratio (RER), blood lactate concentration 30 seconds post maximal exercise ([Blac]_{30sec})

2.4 Physiological Changes that Occur Following a Deep Water Running Program

2.4.1 *Trained Athletes*

Taking into account the vast dissimilarities in physiological responses between OLR and DWR: Can the training responses between these two training modalities be equivocal? Eyestone and coworkers (1993) reported evidence suggesting that water running elicited a training effect similar to that of road running and cycling when frequency, intensity and duration were kept constant between the training modalities. They reported that 6 weeks of training caused a small but significant decrease in VO_2max in all training groups (water running, road running and cycling) (Table 4). They speculated that the decrease in VO_2max observed across all training groups was primarily a tapering effect of the training protocol used. However, a subsequent study reported that 6 weeks of training resulted in non-significant intra- and intergroup differences in treadmill (pre= 58.4 ± 2.3 , post= 60.1 ± 3.6 ml/kg/min) and water running (pre= 58.7 ± 4.7 , post= 59.6 ± 5.4 ml/kg/min) VO_2max in 16 well trained runners (Wilber et al., 1996). In addition, ventilatory threshold (T_{vent}), running economy, maximal blood glucose, maximal blood lactate and body composition indices remained unchanged with both training programs (Table 4). More recently, Bushman and coworkers (1997) found that 4 weeks of DWR was a sufficient training stimulus to maintain OLR performance in 11 well trained runners (Table 4). They also showed that 4 weeks of DWR training caused no significant differences in running economy, lactate threshold, maximal HR, and VO_2max , which is consistent with the findings of Eyestone et al. (1993) and Wilber et al. (1996). Thus, it would appear that water run training programs are an effective alternative for land-based running in maintaining the physiological determinants of

aerobic fitness. However, it is difficult to conclude what the optimal training program should be, since the three studies examining the effects of a DWR training program on trained athletes adopted different exercise regimes. Eyestone and coworkers (1993) used an incremental training protocol for intensity and duration, while Wilber and colleagues (1996) adopted a protocol that involved daily alternations of intensities and duration. Both these intensities were based on either maximal HR (Eyestone et al., 1993) or VO_2max (Wilber et al., 1996), whereas Bushman and coworkers (1997) used a subjective exercise intensity dictated by the Brennan Scale (5 point perceived exertion scale) (Table 4). Since each of these exercise regimes resulted in comparable outcomes, it is impossible to make any concrete conclusion on which training program is the best for maintaining aerobic fitness. In general, an optimal training program should include: 1) an exercise intensity and duration that highly stimulates the cardiovascular system, 2) an exercise intensity that is monitored using objective measures (i.e. maximal HR, VO_2max) and 3) incremental exercise intensities, frequencies and duration to match improving fitness levels.

2.4.2 Untrained Individuals

The effect of DWR on maintaining aerobic fitness appears to be population specific. The studies conducted by Eyestone et al. (1993), Wilber et al. (1996), and Bushman et al. (1997) investigating the effect of a DWR program on maintaining aerobic fitness used only trained runners. When untrained individuals were used to determine the effectiveness of DWR on maintaining or improving aerobic fitness, strikingly different outcomes arose. Quinn and coworkers (1994) found that 10 weeks of TMR increased

VO₂max in 7 untrained female subjects, however, 4 weeks of DWR caused the VO₂max to return to pre-training levels. This shows that DWR performed by novice water exercisers is not a sufficient stimulus to maintain VO₂max. Quinn et al. (1994) speculated that a steady-state DWR training protocol combined with a submaximal exercise intensity (target HR of 80% VO₂max minus 10 beats/min) might have lead to the inability to maintain VO₂max. As a result, Quinn et al. (1994) proposed that untrained individuals adopting a water running program should: 1) perform water running exercises at a relatively higher intensity level as compared to land-based training, and 2) incorporate interval and tempo activities on a regular basis. These recommendations were taken into consideration in a subsequent study, as evident by the use of a progressive, aerobic, interval DWR training program (Michaud et al., 1995b). In this 8-week DWR training program, Michaud et al. (1995b) showed that DWR produced gains of 10.6 and 20.1% for treadmill and water running VO₂max, respectively (Table 4). This larger increase in DWR VO₂max demonstrates the “specificity of training” principle such that training adaptations are specific to the muscles involved in the activity. Since improvements in both treadmill and water running VO₂max occurred with 8 weeks of DWR, there is reason to believe that some of the cardiorespiratory benefits gained from water running can be transferred to land running, which shows that DWR can be a useful form of cross-training for runners.

In summary, overall improvements in VO₂max provides evidence to suggest that high intensity, interval DWR training is sufficient in maintaining aerobic fitness in

trained athletes (Bushman et al., 1997; Eyestone et al., 1993; Wilber et al., 1996) and in producing gains in aerobic fitness for relatively unfit individuals (Michaud et al., 1995b).

Table 4. Improvements in cardiovascular fitness following treadmill and deep water running training programs

Study	Training Protocol	Condition	VO _{2max} (L/min)	HR _{max} (b/min)	V _E _{max} (L/min)	RER	Blac _{max} (mMol)	Weight (kg)
Eyestone et al. (1993)	6 wks	Land Running						
	- wk1: 3x/wk for 20min/ day @ 70%HR _{max}	-Pretraining	57.41 (1.74)	-----	-----	-----	-----	-----
		-Posttraining	54.99 (1.68)	-----	-----	-----	-----	-----
	- wk2: 4x/wk for 25min/ day @ 75% HR _{max}	Water Running						
	- wk3-6: 5x/wk for 30min/ day @ 80%HR _{max}	-Pretraining	56.29 (1.46)	-----	-----	-----	-----	-----
		-Posttraining	53.52 (1.61)	-----	-----	-----	-----	-----
Quinn et al. (1994)	10 wks LBR (wk 1-10) & 4 wks DWR (wk 11-14)	LBR & DWR						
	- wk1-3: 4x/wk for 30 min/ day @ 60% HR _{max}	-Pretraining	39.9 (3.6)	190 (7)	85.4 (14.3)	1.17 (0.06)	-----	64.8 (9.2)
		-Post LBR	42.9 (3.2)	190 (6)	92.1 (14.3)	1.18 (0.06)	-----	64.3 (9.6)
		-Post DWR	40.0 (1.8)	192 (6)	91.4 (8.8)	1.20 (0.06)	-----	63.6 (9.3)
	- wk4-6: 4x/wk for 30min/ day @ 70% HR _{max}							
	- wk7-10: 4x/wk for 30 min/ day @ 80% HR _{max}							
	- wk11-14: 4x/wk for 30 min/ day @ 80% HR _{max} minus 10 beats/min							
Michaud et al. (1995)	8 wks	Treadmill						
	- wk1-8: 3x/wk for 1 hr/ day	-Pretraining	2.25 (0.57)	187 (11.9)	-----	1.29 (0.11)	-----	-----
		-Posttraining	2.49 (0.68)	189 (11.2)	-----	1.28 (0.07)	-----	-----
	- progressive, aerobic, interval training program (exercise varied with each session)	Water Running						
Wilber et al. (1993)	6 wks	Treadmill						
	- 2 work intensities:	-Pretraining	58.4 (2.3)	189.5 (4.8)	112.0 (14.5)	-----	7.9 (1.8)	69.9 (7.6)
	a) 30 min @ 90-100% VO _{2max}	-Posttraining	60.1 (3.6)	188.3 (7.2)	127.5 (18.1)	-----	8.5 (1.9)	70.8 (7.2)
	b) 60 min @ 70-75% VO _{2max}	Water Running						
	- intensities alternated daily 5 days/wk	-Pretraining	58.7 (4.7)	193.9 (8.8)	120.1 (13.3)	-----	7.8 (2.2)	69.7 (6.8)
		-Posttraining	59.6 (5.4)	192.1 (10.2)	131.1 (17.6)	-----	8.3 (2.0)	69.7 (6.3)
Bushman et al. (1994)	4 wks	Water Running						
	- 5x/wk to 6x/wk	-Pretraining	63.4 (1.3)	196.3 (2.9)	-----	-----	9.3 (0.6)	-----
	- Brennan scale used to determine exercise intensity (5pt perceived exertion scale)	-Posttraining	62.2 (1.3)	191.2 (3.3)	-----	-----	8.3 (0.5)	-----
	- alternating standardized short and long workouts							

NB: Values within parentheses denote standard deviations.

Abbreviations: maximal oxygen uptake (VO_{2max}), maximal heart rate (HR_{max}), maximum ventilation (VE), respiratory exchange ration (RER), maximal blood lactate (Blac_{max}), body weight (weight)

2.5 Temperature Effects

Temperature, whether in water or on land, plays a significant role on the regulation of cardiovascular parameters. Therefore, it is plausible that some of the discrepancies in cardiorespiratory responses reported in above mentioned studies are accounted for by the difference in water temperatures in which the subjects exercised at.

Craig and Dvorak (1968) were one of the first researchers to report considerable differences in cardiovascular responses in water temperatures varying from below 24°C to as high as 28°C. They reported significant decreases in HR and increases in VO_2 during low-moderate intensity exercises in water temperatures below 24°C. This suggests that low to moderate exercise intensities are inadequate in maintaining normal body temperature (37°C) in water temperatures below 24°C. Consequently, mechanisms to conserve and/or produce heat are activated to ensure that normal body temperatures are maintained. Conservation of heat is evident by the decrease in HR ultimately reducing cardiac output to the peripheral regions. Production of heat is accomplished by stimulating the hypothalamic centre triggering the thermogenesis response causing the observed increase in VO_2 . In contrast, no apparent differences in submaximal VO_2 were noted in temperatures ranging between 24°C and 28°C (Craig and Dvorak, 1968).

Using this data, Craig and Dvorak (1969) quantified the temperature gradient needed to elicit a change in cardiovascular response during exercise. They suggested that a gradient less than 8°C (between water and core temperature) would invoke vascular responses to maintain body temperature (i.e. vasoconstriction), whereas a gradient larger than 8°C caused metabolic changes to produce heat (i.e. shivering thermogenesis). In addition, Craig and Dvorak (1969) observed a linear relationship between the change in

ear temperature and water temperature when heat production is increased by exercise. As a result of this relationship, it was possible to make estimations of the water temperature needed to maintain neutrality while an individual is exercising at a known intensity in water. For example, it was suggested by Craig and Dvorak (1969) that high intensity exercise requires a water temperature of about 29°C to maintain core body temperature, whereas a light load requires a higher water temperature (34°C or higher) to prevent heat loss. Confirmation of this estimation was done in a recent study by Nakanishi et al. (1999a). They found decrements in cardiorespiratory responses in DWR compared to TMR in 32.5°C temperatures (both water and land) similar to that found in earlier studies of DWR using temperatures ranging from 29-33°C (Butts et al., 1991 a,b; Frangolias and Rhodes, 1993; Frangolias and Rhodes, 1995; Glass et al., 1995; Michaud et al., 1995b, Ritchie and Hopkins, 1991; Svedenhag and Seger, 1992; Town and Bradley, 1991).

McArdle and associates (1992) found that water temperature and intensity of exercise are not the two only factors affecting ear or rectal temperatures. They found significant decreases in core rectal temperatures in both the males and females at rest and during the first two workloads of exercise, despite a two-fold increase in resting VO_2 . The authors suggested that the combination of a large reduction in tissue insulation, an increased effective area for heat transfers as a result of increased cutaneous vasodilation with exercise, and forced convection due to limb movement, might account for the similarity in core temperature despite the two-fold increase in resting VO_2 . In addition, they reported that the relative decrease in core rectal temperature with prolonged immersion was much less in women than men. McArdle et al. (1992) attributed this difference between genders to tissue insulation, as it was recorded earlier that the men

and women had an average of 13% and 21.9% body fat, respectively. This is in accordance with Pate and Krista (1984) who speculated that the differences in body composition between genders, which facilitate buoyancy and heat retention in women, might influence their cardiorespiratory responses to WI differently than for men.

In summary, these findings suggest that exercise is a good way of offsetting the effects of cold WI, however, there are other contributing factors that may play a role in WI thermoregulation, such as exercise intensity (Craig and Dvorak, 1968; McArdle et al., 1992), water temperature (Craig and Dvorak, 1968), and percent body fat (McArdle et al., 1992; Pate and Kriska, 1984).

2.6 Implications of a Deep Water Running Program on an Older Population

The deterioration of muscles and bones caused by the aging process ultimately limits the amount of stress the body could sustain before injury ensues in elderly individuals. Consequently, many elderly individuals abstain from physical activities in order to prevent physical injuries. However, the reduction in musculoskeletal stress with water exercise makes this form of physical activity attractive for the older individual interested in improving their fitness and overall health status. Ruoti and coworkers (1994) demonstrated that a 12-week water exercise program involving a variety of exercises (i.e. jumping jacks in the water) improved cardiovascular fitness in healthy, sedentary individuals aged 50-75 years. These improvements in cardiovascular fitness were largely reflected by the decrease in resting HR and an increase in VO_2max and work

capacity. Similar findings were reported by Taunton and colleagues (1996) who compared and contrasted the difference in cardiovascular fitness between a water-based (WB) and land-based (LB) exercise program in 41 healthy, sedentary women. They reported that exercising for 12 weeks, 3 times/week for 45 minutes improved VO_{2peak} for both the WB and LB groups with no significant difference between the groups.

From the results of the latter study (Taunton et al., 1996), it is evident that WB exercises can produce equivocal responses compared to LB exercises in healthy, elderly women. This finding is paramount to the aging community because it suggests that exercising in the water can improve physical fitness in the elderly while minimizing the impact and stress on the body. However, does improvements in physical fitness occur with just any type of exercise in the water? At what exercise intensity should elderly individuals work at in the water to achieve significant improvements in cardiovascular fitness following a prescribed training program? No study thus far has been able to address these problems specifically.

One study, however, addressed the issue of exercise intensity for a land-based exercise program for elderly individuals (Posner et al., 1992). They found that 16 weeks of cycling at 70% peak heart rate caused an 8.5% and 3.5% increase in VO_{2max} and $Tvent$, respectively. So is it possible for elderly women to exercise in water at an intensity similar to the one prescribed by Posner et al. (1992) and gain similar cardiovascular improvements? Studies investigating the effects of a DWR training program using similar exercise intensities to the one prescribed by Posner et al. (1992) found that 4-8 weeks of DWR caused significant improvements in cardiorespiratory fitness in young and relatively untrained individuals (Quinn et al., 1994). Although, no

work has been done with elderly women DWR it is difficult to determine whether this modality of exercise provides a sufficient cardiovascular stimulus to induce improvements in fitness. Nakanishi et al. (1999b) provided evidence to show that DWR responses in the middle aged men were equivocal to young untrained men suggesting the possibility that DWR training programs with middle aged individuals may produce similar improvements as in the young population. Whether this trend holds true for a significantly older age group (i.e. >60 years) has yet to be determined. In light of this, it would be of particular interest to determine whether or not elderly, untrained individuals are able to reap the benefits of a DWR training program and improve their cardiovascular fitness, which has already been observed a number of times in the young population.

Therefore, it is the intent of this study to investigate the effects of an 8-week moderate to high intensity DWR training program in elderly women. In doing so, we will also be able examine the cardiorespiratory responses of exercising in water in elderly women, as it is already known that the cardiorespiratory responses in water is different between the young and old at rest (Derion et al., 1992).

Chapter 3

3.0 METHODS AND PROCEDURES

Subject selection involved extensive screening. All subjects given medical clearance to participate were required to attend familiarization sessions to learn proper techniques of DWR and TMR (description of sessions will be discussed in section 3.3). Extensive pre-study training in DWR and TMR was done in order to eliminate those subjects that were unable to complete VO_2max testing as well as to minimize the potential for training effects of DWR technique during the study.

Those subjects chosen for the study were required to perform two preliminary progressive, exhaustive, exercise tests. These tests were performed 1 week prior to the start of the training program. One VO_2max test was done in the water and the other on land. Tests were conducted on two different days, at the same time, with a minimum of one day rest in between. Variables that were measured for the study include oxygen consumption (VO_2), maximal heart rate (HR), minute ventilation (V_E), respiratory exchange ratios (RER) and blood lactates (Blac^-).

Subjects were randomly divided into the control or exercise group. For the exercise group, the 8-week DWR training program started the week following the completion of preliminary tests. Subjects in the training group were provided a specific workout schedule consisting of intense 30 minute DWR workouts, 3x/week. Subjects in the control group were asked to maintain their daily routines and not participate in additional activities. Following the 8 weeks, post-training VO_2max tests (DWR and TMR) were done on both the control and the training group.

3.1 Sample

Over one hundred potential candidates for the study responded to posters placed at community centres and an editorial printed in the Vancouver Sun. Of these candidates, 35 were selected to go through medical screening based on a telephone conversation regarding their age, training status (e.g. needed to be inactive for at least 3 months prior to the start of the training program), intent to participate, time commitment, and basic health restrictions (i.e. motor function limitations). Of the 35 selected, 23 received medical approval to participate (screening criteria listed as Appendix 1) in this training program and only 20 consequently participated in the study. This was because 1 candidate was unable to perform the proper techniques of DWR and 2 candidates returned to work. Therefore, the sample group eventually used for this study included 20 healthy, inactive women aging from 60 to 71 years of age (mean age 64.5 ± 3.5 years). They all were previously inexperienced with DWR, however when inducted into this study, all were able to perform this technique adequately.

3.2 Physiological Test Equipment

The following equipment was used for physiological testing:

1. A Beckman Metabolic Cart was used to measure gases and ventilation during both TMR and DWR maximal exercise tests.
2. An Accurex® Polar heart rate monitor was worn by all subjects at the level of the sternoxiphoid junction to monitor heart rates during the TMR VO_2max test, the

DWR VO_2max test, and all training sessions. This monitor is waterproof and has the ability to record and download heart rates for each test using an H-Polar Interface Plus program.

3. A waist adjustable floatation belt supplied by the UBC Aquatic Centre was used to provide buoyancy for our subjects during water running sessions. This belt, worn around the waist, helped subjects maintain proper running form by reducing the involvement of the upper body musculature for the purpose of staying afloat.
4. A YSI Yellow Springs Instrument 1500 Sport Lactate Analyzer was used to determine blood lactates. Blood lactates were measured 2 minutes following the pre- and post-training progressive, incremental TMR and DWR tests.
5. A Quinton Instruments treadmill was used for the land-based VO_2max test protocol.
6. A tethered apparatus was used to increase workloads during the DWR test. This apparatus is a two-pulley system, allowing for the subject to be attached at one end and a weight bucket at the other end. Workload increases were accomplished by adding weights to the bucket, which in turn pulled the subject back. In order for the subject to maintain their position in the water the subject ran harder to keep up with increased workloads (Figure 3a).

Figure 3a: Side view of the DWR tethering apparatus. This figure shows the proper height of the weight bucket and the rope that is used to attach the tethering apparatus to the subject.

Figure 3b. Top view of DWR set-up. This picture shows how the subject is connected to the tethering apparatus, the correct distance between the subject and the reference bar, and the position the researcher must be in to get optimal views of the subject's DWR form.

Figure 3c. Side view of DWR technique 1 meter from edge of the pool deck.

7. The researcher on the side of the pool deck continuously monitored correct DWR technique. In order to have optimal visibility of the subject by the poolside researcher, the subject ran approximately 1m away from the poolside while the poolside researcher positioned themselves immediately to the left of subject (in line for a sagittal view of the subject) at a distance approximately 1m from the edge of the pool (Figure 3 b,c).

3.3 Subject Screening and Familiarization Sessions

To prevent a training effect, all subjects attended 1 instructional session and 2 familiarization sessions to learn the proper techniques of DWR and TMR. One subject was unable to adequately perform the DWR technique properly following 2 sessions in the water and subsequently given 1 additional session before she was excluded from the study. Another subject was also given an additional session in the water and was subsequently accepted for the study.

The instructional session involved a 15-minute poolside demonstration of proper techniques and common mistakes of DWR. Questions from the subjects regarding this exercise were addressed during this time.

Each familiarization session was allotted 30 minutes, however, some sessions extended beyond this period depending on how fast each subject learned the technique of DWR. All water sessions took place in the deep end of the swimming pool. During session 1, subjects were asked to try and mimic the style of DWR shown previously by the demonstrator. Continuous feedback regarding their technique was given to the

subject throughout this session. In session 2 the subject was attached to the tethered apparatus in order for them to become accustomed to the loads that they would pull during the DWR test. Subjects who felt uncomfortable with the land-based or water-based test or were unable to DWR/TMR will be exempt from the study.

Determination of proper running technique for DWR was done by viewing each subject poolside. Subjects were viewed along the sagittal plane. Specific criteria that were looked at to determine whether the subject was able to DWR properly are listed in Section 3.4.2.

3.4 VO₂max Test Protocols and Procedures

Subjects were asked to refrain from eating 2 hours prior to test time and from excessive exercise 24 hours prior to the test. Subjects' height and weight were taken immediately after reporting to the lab on test day.

Expired gases and ventilation were measured using the Beckman Metabolic Cart for both the DWR and TMR VO₂max tests. Gases were sampled every 30 seconds and HR recorded every 30 seconds.

Two minutes after test termination blood was drawn from the fingertip using a pinprick. Blood was analyzed for blood lactate using the chemical lactate analyzer described above.

All but two aspects of the procedures were identical between the treadmill and water running protocols. The two differences between conditions were: 1) medical staff between testing conditions (a medical physician attended all TMR VO₂max tests and

lifeguards were on deck during all DWR VO_2 tests), and 2) DWR blood lactates were drawn only after the subject came out of the pool and dried off to prevent contamination of the blood sample (see Fig. 4 for schematic of procedures).

Deep Water Running VO₂max Testing Procedures

HEIGHT & WEIGHT	ON LAND STRETCHING	FLOATATION BELT & HR MONITOR	IN WATER WARM UP	EQUIPMENT HOOK-UP	RESTING VALUES	START TEST	TEST DONE	DRAW BLOOD (BLAC)
Time: (min)	-19.5	-18.5	-8.5	-7.5	-2.5	-0.5	0	+2
	↑	↑	↑	↑	↑	↑	↑	↑

Treadmill Running VO₂max Testing Procedures

HEIGHT & WEIGHT	ON LAND STRETCHING	LIGHT TREADMILL WARM-UP	EQUIPMENT HOOK UP	RESTING VALUES	START TEST	TEST DONE	DRAW BLOOD (BLAC)
Time: (min)	-17.5	-16.5	-6.5	-1.5	-0.5	0	+2
	↑	↑	↑	↑	↑	↑	↑

Figure 4. Schematic of deep water and treadmill running VO₂max test procedures.

3.4.1 Treadmill VO_2max Test Protocol and Procedures

A 15-minute warm-up preceding the continuous, incremental treadmill exercise test was performed by all subjects. The warm-up consisted of a series of stretches for the legs and lower torso (10 minutes) followed by a low to moderate intensity walk on the treadmill (5 minutes). Initial speed of the treadmill protocol was determined during the pre-training warm-up session as it allowed us to determine what speed the subject began walking at a brisk walking pace.

Following the warm-up, the subject was fitted with a mouthpiece connected to the metabolic cart. A nosepiece was then placed on the nose to prevent airflow through the nasal cavity. Once comfortable, 30 sec of baseline expired gases and ventilation were collected. Once completed, the subject began running at an initial treadmill speed of 3.5 mph (Note: This speed varied slightly depending of the height of the subject. Speeds were adjusted individually to ensure that all subjects were tested at a brisk walking pace). The treadmill speed remained constant throughout the test duration, however, treadmill grade increased 2%/min.

Termination of the test occurred when the subject reached exhaustion characterized by the point at which two of the following criteria were met: 1) a plateau in VO_2 , 2) maximal heart rate of $(220 - \text{age})$, 3) $\text{RER} \geq 1.10$, 4) volitional fatigue.

Figure 5. Photo showing a maximal TMR test session. In this picture the subject is just beginning her walking protocol with 2% grade increases/min. A headgear is worn by the subject to minimize the weight of the mouth-piece exerted on her mouth. Heart rate monitors are worn under the shirt. Subjects are permitted to hold the handrails during the test sessions as many finished the test with steep inclines.

3.4.2 Deep Water Running $VO_2\text{max}$ Test Protocol, Procedures and Equipment

For DWR $VO_2\text{max}$ tests the subjects were immersed to the level of the neck. Subjects were attached to the tethered apparatus by a rope connecting the tethered apparatus to the floatation belt. The tethered apparatus was placed at the end of the pool with the lower pulley rod extending over and into the pool surface. The subject was positioned 1 m away from the side of the pool to provide the researcher with a sagittal view of their running technique (Figure 3 a,b,c).

Subjects were required to maintain a proper running technique during the entire exercise test. Proper running technique was defined as (Frangolias and Rhodes, 1993):

- (i) an upright trunk with a maximum forward lean of approximately 45°
- (ii) a unilateral forward motion of the legs, in which the thigh approaches an almost horizontal position before descending back into leg extension
- (iii) dorsiflexion of the feet
- (iv) a unilateral forward motion of the arms corresponding with leg movement (i.e. right arm flexed at 90° angle to the elbow and swings forward when the left knee swings forward)
- (v) arms in an adducted position (i.e. close to the body)
- (vi) hands in a neutral position (i.e. absence of hand cupping and pronation) as to prevent the subject from dog paddling and propelling themselves in the water

The DWR $VO_2\text{max}$ test required the subject to maintain their position in the water against continuous load increments. A bar was projected from the side of the pool deck immediately in front of the subject. This bar was used as a marker for the subject to

maintain their position in the water (Figure 3b). Subjects were asked to keep within 5cm of this bar. With increasing loads in the bucket, the subject was forced to run “faster” (i.e. increase their cadence, stride length and/or power) in order to maintain their position in the water and keep the weight bucket at the cross bars of the tethered apparatus (Figure 3a).

Preceding the DWR VO_2max test, a 10 minute warm-up involving a series of leg and lower torso stretches was done by all subjects. Following this, the subject was fitted in the floatation belt. Once secured in the floatation belt the subject immersed herself to the level of the neck in the pool. The subject was given 5 minutes to warm up and become accustomed to the pool temperature. Following the brief warm-up, the subject was attached to the tethering apparatus and fitted to a mouthpiece connected to the metabolic cart. A nose clip was placed on the nose to prevent airflow through the nasal cavity. Baseline values were recorded for 30 seconds. After this, the test started with an initial load pre-determined for each subject during the second familiarization session. Loads were determined by calculating the bucket weight at approximate peak exercise capacity. To determine initial loads and loading increments, optimal test duration was set for 8 minutes in which the subject should be at or near their estimated maximal bucket weight. With some exceptions, initial loads were set at 300g with increases of 100g/min.

Termination of the test was determined when the subject reached exhaustion characterized by: 1) the inability of the subject to maintain proper running technique, as previously described, 2) the inability of the subject to maintain their position and consequently bucket position at the cross bars of the tethered apparatus, 3) a plateau in VO_2 , and 5) volitional fatigue. Estimated HR maximums was not used as a criterion for

subject exhaustive for two reasons: 1) it has been documented in the literature that WI decreases maximal HR in the young, and 2) heart rate monitors were worn by the subject in the water because signals were unable to be received on deck. Therefore, meeting of the first 2 criteria and at least one of the other criteria was necessary to establish a DWR VO_2max . The VO_2 value prior to the deviation in running style or the inability to maintain proper position was taken as the true DWR VO_2max .

Figure 6. A photo illustrating the equipment set-up and procedures during a maximal DWR test. The metabolic cart is positioned immediately to the left of the subject to minimize the length of tubing needed to collect gas samples. The researcher moves back to the weight bucket every minute to increase the resistance by adding weights to the bucket. After that, she returns to a position approximately 1 metre to the left of the subject to view the subject's DWR form. Subject maintains a distance within 5 cm of the reference bar throughout the test.

3.5 Deep Water Running Training Protocol

All subjects in the training group were assigned a specific training schedule requiring them to participate in 3 DWR sessions per week. Training schedules were assigned according to subject and swimming pool availability. All training sessions had a maximum of 4 subjects/session due to the limited availability of floatation belts and heart rate monitors.

Each DWR session began with 10 minutes of on-land stretching. Subjects then put on the floatation belt and heart rate monitor prior to entry into the swimming pool. Once in the pool, subjects warmed up for 10 minutes bringing their heart rates up to the prescribed level for that day. Following the warm-up each subject began DWR at her prescribed target heart rate for 30 minutes. Subjects maintained this intensity throughout the 30-minute exercise session. Following the DWR exercise session subjects cooled down and performed land-based stretches for 10 minutes. This particular exercise protocol (10 minute warm-up, 30 minute exercise, 10 minute cool-down) was chosen based on past studies using this protocol and achieving success with equivocal land-based activities in elderly individuals (Posner et al., 1992).

Workout intensities progressively increased from week 1 to week 8. During weeks 1-2, subjects were prescribed HR intensities equal to 70% of their DWR maximum. During weeks 3-5 and 6-7, target HR increased to 75% and 80% pre-training DWR maximums, respectively (see Figure 7 for a schematic of the training protocol). Two subjects were given a slightly modified training protocol as they exercised at a HR greater than 15 beats/min above their week 1 prescribed rates without any visible signs of effort. The protocol prescribed for these two subjects involved intensities of 70%, 75%,

80%, and 85% of pre-training DWR HR maximums for weeks 1-2, 3-4, 5-6 and 7-8, respectively (Figure 7). These target heart rates were chosen based on past literature showing that elderly individuals are able to exercise at these intensities for a prolonged period of time (i.e. 30 minutes) and that this intensity elicits a high enough stimulus to cause improvements in aerobic capacity following a prescribed training program (Posner et al., 1992).

3.6 Experimental Design

Subjects were randomly and evenly assigned to the DWR training group or to the control group. To prevent control subjects from withdrawing from the study, a training program was offered to them following completion of the study. All subjects were required to perform pre- and post-training VO_2max tests, which were administered in a randomized, crossover fashion.

The two independent variables in this study are condition/environment (factor 1) and training (factor 2). Factor 1 has two levels, treadmill and water running. The dependent variables for factor 1 are VO_2max , maximal HR, V_E , RER, and Blac^- . Factor 2 also has two levels, exercise group and control group, in which repeated measures will be performed on both (i.e. pre- and post-training). The dependent variables are VO_2max , maximal HR, V_E , and Blac^- .

3.7 Statistical Analysis

The data collected was analyzed in the following manner:

- 1) A within subject repeated measures analysis of variance was performed to test differences in VO_2max , maximal HR, V_E , RER and Blac^- between treadmill and water running VO_2max tests (Hypothesis 1).
- 2) A 2 x 2 within subject repeated measures analysis of variance was performed to test differences in VO_2max , maximal HR, V_E , and Blac^- between pre- and post-training TMR and DWR VO_2max tests (Hypothesis 2 and 3).

3.8 Assumptions

- 1) The subjects' cardiorespiratory responses during the TMR test were a true reflection of their land aerobic capacity once all of the following criteria were met: a) $<2\text{ml/kg/min}$ change in VO_2max over 2 workload increments, b) $<5\text{ beats/min}$ change in HR over 2 workload increments, and 3) $\text{RER} > 1.1$.
- 2) The subjects' cardiorespiratory responses during DWR were a true reflection of their water aerobic capacity once the subject satisfied one criterion: VO_2 did not change more than 2ml/kg/min over 2 workloads. Heart rates and RER were not used as markers for maximal effort as the validity of using these markers has not yet been established in this population group.
- 3) All subjects were able to run comfortably on the treadmill and simulate land running during DWR test and exercise sessions.
- 4) Familiarization sessions to equipment, environment, and test protocols were adequate.
- 5) All subjects performed maximally to exhaustion.

3.9 Study Limitations

- 1) The investigation was limited by the functioning of the Beckman Metabolic Cart and the accuracy of its readings. Multiple tests were performed within the same individual using the Beckman Metabolic cart to establish its reliability prior to the start of the study. Validity was also verified by testing individuals on both the Beckman Metabolic Cart and the Sensor Medic.
- 2) The researcher could not control temperature and humidity both in the laboratory and in the pool. Attempts were made to ensure that the subject was comfortable at all times by providing the subjects with water and cooling them with an electric fan.
- 3) Turbulence caused by other pool activities was limited throughout the study by scheduling test and exercise sessions during quiet times. However, rescheduling during large pool events (i.e. Storm the Wall) was impossible for the continuity of the study, therefore, during these times subjects deep water ran with excessive turbulence.
- 4) The lack of an underwater video camera posed a problem to accurately determine proper DWR technique. In the place of a camera, the researcher stood at the edge of the pool deck and looked down on the subject running. Clear views of the subjects' running technique could be seen at this angle (Figure 3C) and verbal commands were given to the subject during test and exercise sessions to correct their technique.

- 5) The subjects' ability to consistently DWR with proper technique was another study limitation. The researcher continuously provided feedback to correct running styles.
- 6) Limitations were also apparent in the ability of the subject to motivate themselves to reach maximal effort during both DWR and TMR tests. Exercise sessions were also limited by the ability of the subjects in the exercise group to reach their target HR and keep it there for the duration of the session (30 minutes).

Chapter 4

4.0 RESULTS

4.1 Physical Characteristics of the Sample

The mean physical characteristics of the 18 subjects who completed the study are listed in Table 5. There were no significant differences ($p>0.05$) in any maximal physiological responses measured between control and exercise groups when the subjects were randomly divided into their respective groups.

Table 5. Physical Characteristics of the Exercise and Control Group

Variable	Exercise Group (N = 10)		Control Group (N = 8)	
	Mean (SD)	Range	Mean (SD)	Range
Age (yrs)	64.00 (3.16)	60-71	64.63 (4.10)	60-71
Height (cm)	162.82 (10.29)	143.5-177.0	158.10 (9.70)	138.0-165.5
Weight (kg)	64.29 (10.07)	51.3-81.6	65.89 (10.42)	55.7-90.3

Note: No significant differences between the groups on any of the variables

4.2 Maximal Exercise Responses Between Treadmill and Deep Water Run Tests

The main purpose of this study was to determine whether significant improvements in cardiorespiratory fitness would be observed following 8 weeks of DWR training. In doing so, we were also able to compare the acute responses between TMR and DWR during a progressive, incremental exercise test to exhaustion in elderly women

Maximal oxygen uptake, expressed in absolute (L/min) and relative (ml/kg/min) terms, was significantly lower ($p < 0.05$) during the DWR test than that observed during the TMR test for both the control and exercise group, with no significant difference between groups. Furthermore, significantly lower DWR $\text{VO}_{2\text{max}}$ was observed when the groups were combined ($p < 0.05$).

Deep water running HR maximums were significantly lower than TMR in the exercise group and when the groups combined ($p < 0.05$). Respiratory exchange ratios were significantly higher during DWR in the control group and when the groups were combined ($p < 0.05$).

No significant differences in VE and Blac were observed between DWR and TMR in either exercise group, control group, or when the groups were combined ($p > 0.05$)

Table 6. Maximal physiological responses during the pre-training progressive, incremental treadmill and deep water running test to exhaustion in both exercise and control groups

Variable	Exercise		Control	
	TMR	DWR	TMR	DWR
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
VO ₂ max (L/min)* ^{†‡}	1.55 (0.35)	1.17 (0.19)	1.42 (0.28)	1.15 (0.24)
VO ₂ max (ml/kg/min) * ^{†‡}	23.94 (2.89)	18.49 (3.13)	21.59 (2.55)	17.65 (2.79)
VE (L/min)	52.75 (11.26)	47.03 (7.89)	50.46 (10.15)	48.06 (8.43)
HR (beats/min)* [‡]	164.50 (8.86)	157.70 (12.02)	161.75 (11.73)	156.13 (10.43)
RER ^{†‡}	1.13 (0.12)	1.05 (0.09)	1.08 (0.08)	0.99 (0.05)
Blac (mmol/L)	5.62 (1.97)	5.51 (1.57)	5.05 (2.22)	5.21 (1.18)

* indicates significant difference between TMR and DWR within exercise group

† indicates significant difference between TMR and DWR within control group

‡ indicates significance between TMR and DWR when groups are combined between

A **B**

C

D

E

Figure 8. Comparison of maximal exercise response following a single bout of DWR and TMR. Graphs A-E represent maximal oxygen consumption (VO_{2max}), ventilation (VE), heart rate (HR), respiratory exchange ratios (RER), and blood lactate (Blac) for deep water running (D) and treadmill running (T), respectively. Differences indicated by * (exercise) and ** (control) only represent significance within each group across exercise conditions. Differences that occur between exercise conditions when the groups are combined are represented by * (combined).**

4.3 Training Responses

Statistically significant improvements in the following variables were observed within the exercise group after completion of the 8-week DWR training program: DWR VE, absolute and relative TMR VO_2max and TMR VE ($p < 0.05$). Deep water running VO_2max did not statistically improve following 8 weeks of DWR within this group ($p > 0.05$, Table 7,8).

Statistical significance was also found in the control group in a few variables including a decrease in absolute and relative DWR VO_2max , an increase in DWR RER, and an increase in absolute and relative TMR VO_2max , following 8-weeks of non-training ($p < 0.05$, Table 7,8).

A 2 x 2 within subjects repeated measures ANOVA revealed statistically significant differences between groups across time in absolute ($p < 0.05$) and relative ($p < 0.05$) DWR VO_2max , DWR VE ($p < 0.05$), absolute ($p < 0.05$) and relative ($p < 0.05$) TMR VO_2max , TMR VE, and TMR RER ($p < 0.05$) (Figure 9).

Table 7. Means and p-values for pre- and post- test maximal exercise responses during DWR tests for both the control and exercise groups

Variable	Pre-test	Post-test	p-value
	Mean (SD)	Mean (SD)	
Weight (kg)			
Control	65.89 (10.42)	66.00 (10.05)	0.768
Exercise	64.29 (10.07)	64.41 (10.31)	0.779
VO ₂ max (L/min)†			
Control	1.15 (0.24)	1.10 (0.26)	0.045*
Exercise	1.17 (0.19)	1.32 (0.32)	0.063
VO ₂ max (ml/kg/min)†			
Control	17.65 (2.79)	16.73 (2.70)	0.035*
Exercise	18.49 (3.13)	20.58 (3.42)	0.067
VE (L/min)†			
Control	48.06 (8.43)	45.34 (8.87)	0.132
Exercise	47.03 (7.89)	55.43 (9.96)	0.002*
HR (beats/min)			
Control	156.13 (10.43)	155.88 (7.28)	0.939
Exercise	157.70 (12.02)	159.00 (8.59)	0.477
RER			
Control	0.99 (0.05)	1.11 (0.11)	0.035*
Exercise	1.02 (0.09)	1.09 (0.09)	0.375
Blac (mmol/L)			
Control	5.21 (1.18)	4.86 (1.40)	0.077
Exercise	5.51 (1.57)	5.40 (1.45)	1.00

* indicates within group x time significance (p<0.05)

† indicates between group x time significance (p<0.05)

Table 8. Means and p-values for pre- and post- test maximal exercise responses during TMR tests for both the control and exercise groups

Variable	Pre-test	Post-test	p-value
	Mean (SD)	Mean (SD)	
Weight (kg)			
Control	65.89 (10.42)	66.00 (10.05)	0.768
Exercise	64.29 (10.07)	64.41 (10.31)	0.779
VO ₂ max (L/min)†			
Control	1.42 (0.28)	1.60 (0.23)	0.013*
Exercise	1.55 (0.35)	1.88 (0.26)	0.000*
VO ₂ max (ml/kg/min)†			
Control	21.59 (2.55)	24.33 (1.89)	0.018*
Exercise	23.94 (2.89)	29.38 (3.64)	0.000*
VE (L/min)†			
Control	50.46 (10.15)	51.03 (13.00)	0.806
Exercise	52.75 (11.26)	61.58 (9.37)	0.015*
HR (beats/min)			
Control	161.75 (11.73)	159.50 (10.57)	0.325
Exercise	164.50 (8.86)	160.90 (10.63)	0.209
RER			
Control	1.08 (0.08)	1.08 (0.08)	0.879
Exercise	1.13 (0.12)	1.14 (0.05)	0.812
Blac (mmol/L)			
Control	5.05 (2.22)	5.35 (2.87)	0.458
Exercise	5.62 (1.97)	5.63 (1.72)	0.990

* indicates within group x time significance (p<0.05)

† indicates between group x time significance (p<0.05)

A

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J

Figure 9. Changes in maximal exercise response following 8 weeks of DWR (exercise group) or 8 weeks of inactivity (control group). All graphs contain 3 subgraphs illustrating: i) scatterplot of individual changes within exercise group over time, ii) scatterplot of individual changes within control group over time, iii) simple line graph comparing the means between groups over time (group by time interaction). Graphs A-L depict values for relative DWR VO_2max , DWR VE, DWR HR, DWR RER, DWR Blac, relative TMR VO_2max , TMR VE, TMR HR, TMR RER, and TMR Blac, respectively. Asterisks (*) indicate significant time by group interactions, cross (†) indicates significance within exercise group over time, and double cross (‡) indicates significance within control group over time ($p < 0.05$).

4.4 Specificity of Training Response

Contrasts were made to determine whether 8 weeks of training in the water would cause greater improvements in maximal exercise responses in the water compared to land. A within subject repeated measures ANOVA on the differences between pre- and post-training DWR and pre- and post-training TMR test scores in the exercise group revealed statistically non-significant differences between TMR and DWR $\text{VO}_{2\text{max}}$, expressed in absolute ($p>0.05$) and relative ($p>0.05$) terms. The magnitude of difference in VE improvement was also shown to be statistically non-significant ($p>0.05$).

Table 9. Means and p-values for the specificity of training response following 8-weeks of DWR training in the exercise group.

Variable	Difference between pre- and post scores		p-value
	DWR	TMR	
	Mean (SD)	Mean (SD)	
VO ₂ max (L/min)			
Control	-0.05 (0.06)	0.18 (0.15)	0.009*
Exercise	0.16 (0.23)	0.35 (0.16)	0.121
VO ₂ max (ml/kg/min)			
Control	-0.93 (1.00)	2.74 (2.51)	0.007*
Exercise	2.09 (3.18)	5.21 (3.65)	0.073
VE (L/min)			
Control	-2.73 (4.52)	0.56 (6.23)	0.330
Exercise	8.40 (5.97)	8.83 (9.28)	0.920
HR (beats/min)			
Control	-0.25 (8.94)	-2.25 (6.02)	0.707
Exercise	1.30 (5.54)	-3.60 (8.42)	0.159
RER			
Control	0.12 (0.13)	0.00 (0.07)	0.010*
Exercise	0.04 (0.14)	0.01 (0.10)	0.595
Blac (mmol/L)			
Control	-0.35 (0.48)	0.30 (1.08)	0.078
Exercise	0.00 (1.43)	0.01 (2.54)	0.970

* indicates within group significant differences, $p < 0.05$

4.5 Hypothesis Verification

Hypothesis 1: DWR VO_2max < TMR VO_2max	ACCEPT
DWR HR = TMR HR	REJECT
DWR VE < TMR VE	REJECT
DWR Blac > TMR Blac	REJECT
DWR RER > TMR RER	REJECT
Hypothesis 2: DWR VO_2max : Pre-train < Post-train	REJECT
DWR HR: Pre-train = Post-train	ACCEPT
DWR VE: Pre-train < Post-train	ACCEPT
DWR Blac: Pre-train = Post-train	ACCEPT
TMR VO_2max : Pre-train < Post-train	ACCEPT
TMR HR: Pre-train = Post-train	ACCEPT
TMR VE: Pre-train < Post-train	ACCEPT
TMR Blac: Pre-train = Post-train	ACCEPT
Hypothesis 3: $\uparrow$ DWR VO_2max > $\uparrow$ TMR VO_2max	REJECT

Chapter 5

5.0 DISCUSSION

The primary purpose of this study was to determine whether 8 weeks of DWR would significantly improve the fitness level of previous inactive elderly women. The secondary objectives were the following: 1) to perform a comparative analysis on the acute cardiorespiratory responses during DWR compared to TMR, and 2) to determine whether training with DWR would induce changes in cardiorespiratory responses specific to only DWR.

The first aspect of the study compared the physiological responses of DWR and TMR in elderly women. It was postulated that DWR VO_2max would be lower than TMR VO_2max in elderly women. In addition, VE was also hypothesized to be compromised in the water due to the added effects of an aged lung and intrathoracic squeeze of the water. Heart rate was hypothesized to be similar between exercise conditions based on resting responses reported by Derion et al. (1992). Blood lactates and RER were postulated to be elevated during DWR because of a combination of age related changes and WI conditions amplifying peripheral resistance causing a reduction of blood flow to the peripheral musculature. The data does not fully support all these hypotheses. This may be related to the attempts to accurately simulate land running in the water and the physical fitness of the sample population.

The second aspect that was examined was the effect of an 8-week DWR training program on the improvement of cardiorespiratory responses in previously inactive elderly women. It was hypothesized that although WI results in less physiological stress, DWR

elicits a sufficient stimulus to improve VO_2max and VE. Heart rate maximums and Blac responses would be unaltered following a mere 8 weeks of training. The data from the present study confirmed these hypotheses regarding improvements in TMR responses. Deep water running improvements were also observed when analyzed between groups across time.

The third aspect analyzed was the specificity of training response. It was hypothesized that DWR VO_2max would improve more significantly than TMR VO_2max due to the selective recruitment of muscles more often used during DWR and not during TMR (i.e. upper body musculature). Our hypothesis was not confirmed from the data obtained from this study.

5.1 Comparative Analysis of Maximal Physiological Response between Treadmill and Deep Water Running

The results from this study will help to completely understand how WI affects maximal exercise responses across various age groups. Currently, there is an abundance of literature suggesting that maximal exercise responses are compromised during DWR in young individuals (Butts et al., 1991 a,b; Dowzer et al., 1999; Frangolias and Rhodes, 1995; Glass et al., 1995; Michaud et al., 1995b; Nakanishi et al., 1999 a,b; Svedenhag and Seger, 1992; Town and Bradley, 1991). However, there is a paucity of knowledge regarding the effects that WI may have on elderly individuals during exhaustive DWR and how this compares with previous studies involving young individuals. A previous study conducted in this laboratory (unpublished) found that although absolute VO_2max , VE, HR and Blac were significantly higher in young individuals for both DWR and TMR conditions, the magnitude of depression of VO_2max and HR during DWR were

comparable between young and elderly age groups, suggesting that differences between acute DWR and TMR responses occur irrespective of age.

5.1.1 *Maximal Oxygen Consumption and Heart Rate*

The pre-training results from this study indicate that DWR VO_2max is 80% TMR VO_2max and DWR HR is 95% TMR HR in elderly women. This magnitude of reduction observed in our elderly group is similar to studies that have tested young individuals previously unfamiliar with DWR. Butts et al. (1991b) reported significant declines in maximal exercise response in the water such that DWR VO_2max and HR values were 84% and 91% of TMR values in female high school cross-country runners. Other studies looking at DWR responses in women observed a DWR VO_2max of 77% (Brown et al., 1997) and 87% (Glass et al., 1995) of TMR values and a DWR HR averaging 89-95% (Brown et al., 1997; Glass et al., 1995) compared to TMR.

The remaining existing literature pertaining to DWR responses have examined young males (Dowzer et al., 1999; Michaud et al., 1995b; Nakanishi et al., 1999 a,b) or amalgamated male and female responses (Frangolias and Rhodes, 1995; Town and Bradley, 1991). One study reported that the magnitude of depression in VO_2max and HR are different across genders (Brown et al., 1997), however, others have shown that gender plays no role on the magnitude of reduction in DWR response (Butts et al., 1991a; Glass et al., 1995). Irrespective of possible gender effects on the magnitude of change, all studies have shown a remarkable decrease in VO_2max and HR with DWR compared to TMR (Brown et al., 1997; Butts et al., 1991 a,b; Dowzer et al., 1999; Frangolias and

Rhodes, 1995; Glass et al., 1995; Michaud et al., 1995; Nakanishi et al., 1999 a,b; Svedenhag and Seger, 1992; Town and Bradley, 1991).

These studies have speculated that lower VO_2max values during DWR in young individuals were caused by: 1) a lower metabolic response from non-active antigravity muscles due to the non-weight bearing nature of DWR (Frangolias and Rhodes, 1995; Glass et al., 1995; Michaud et al., 1995b), 2) type of muscular contraction (Svedenhag and Seger, 1992), and 3) lower perfusion pressures in the legs during immersion causing a decrease in total muscle blood flow and O_2 extraction from the large muscle groups of the lower extremities (Svedenhag and Seger, 1992).

Explanations for HR reduction have primarily focused on the possibility that the hydrostatic pressure gradient of WI facilitates venous return causing a central shift in blood volume. This results in a greater maximal cardiac preload and stroke volume (Craig and Dvorak, 1969; McArdle et al., 1976; Sheldahl et al., 1987). Other theories are based on below thermoneutral water temperatures ($<32^\circ\text{C}$), which have been shown to reduce HR response in water (Craig and Dvorak, 1969).

Although the original hypotheses were that VO_2max would be compromised in the water and HR would remain unchanged, the data obtained from this study concur with previous studies examining the responses of DWR in young individuals. The magnitude of depression in DWR VO_2max observed this population group is quite similar to the decrements observed in young individuals, providing more evidence indicating that hydrostatic compression and water buoyancy play a vital role in the depression of VO_2max in the water. However, HR response was only depressed 6 beats/min during DWR compared to TMR, unlike the 10-25beats/min reduction observed in young

individuals. The fact that HR reductions in the water was significant illustrates that hydrostatic compression and buoyancy do play a role in down-regulating HR in water with elderly individuals. However, age related deterioration in cardiac functions may account for the small effect size observed in DWR HR compared to the large effect size (10-25 beats/min) observed in young adults (Butts et al., 1991ab; Town and Bradley, 1991; Svedenhag and Seger, 1992; Glass et al., 1995; Frangolias and Rhodes, 1995; Brown et al., 1997; Nakanishi et al., 1999).

5.1.2 *Ventilation*

Respiratory compromises during WI are questionable as some studies have shown decreases (Butts et al., 1991a), increases (Brown et al., 1997), and comparable (Butts et al., 1991b; Glass et al., 1995) VE during maximal DWR compared to TMR in young women. Other studies examining males exclusively (Svedenhag and Seger, 1992; Sheldahl et al., 1986) and a combination of male and female responses (Frangolias and Rhodes, 1995) reported similar VE responses between exercise conditions. However, the results from the present study showed similar VE responses between DWR and TMR for both young and elderly age groups. These findings contradict the observations made by Butts et al. (1991a) comparing DWR responses between genders, and Dowzer et al. (1999) and Nakanishi et al. (1999 a,b) who examined males exclusively and found significantly lower VE during DWR. They attributed this decrease to the hydrostatic chest compression of the water causing the abdomen to compress and the diaphragm to rise to a position approaching full expiration. In effect, this would cause an increase in the force required for inspiration by reducing total lung compliance and vital capacity

(Agostoni et al., 1966; Dahlback et al., 1978). Lung compliance was also thought to be affected by the increase in blood pooling in the central regions attributing in part to the decreased ventilatory capacity during WI (Agostoni et al., 1966; Dahlback et al., 1978). The non-significant difference in VE between exercise conditions found in our elderly group may be related to deteriorated elastic support structures of the lungs, increased size of alveoli, and deconditioning of the respiratory muscles, which accompanies advanced age (Brooks et al., 1996). These structural changes consequently lead to increased difficulty of breathing, increased dead space, and a decreased capacity for gas diffusion across the lungs (Brooks et al., 1996). These changes in lung functions may ultimately contribute to limitations in exercise capacity in older individuals both in water and on land. Therefore, age related declines in the ability to ventilate might transcend any added difficulties of breathing in water caused by the hydrostatic compression and an elevated diaphragm during WI. Alternatively, the increase in intrathoracic blood volume and hydrostatic chest compression may not restrict VE during exercise in this population group.

5.1.3 Blood Lactates and Respiratory Exchange Ratios

Similar Blac and RER responses between exercise conditions were observed in the elderly women. Of the four studies looking at female responses to DWR (Butts et al., 1991 a,b; Brown et al., 1997; Glass et al., 1995) one study reported values for Blac response. Glass et al. (1995) observed significantly higher Blac values during DWR trials and suggested that suspended DWR presents a greater body surface area in water causing more drag and resistance in an already high resistance medium (800x more resistance

than air). This added resistance employs a greater involvement of both arms and legs, potentially resulting in a greater lactate production (Glass et al., 1995). Svedenhag and Seger (1992) who tested males exclusively found higher blood lactate responses in the water and speculated that lower perfusion pressures in the legs during immersion with an ensuing decrease in total muscle blood flow may have influenced a higher anaerobic metabolism leading to augmented Blac during DWR. They further added that the increased anaerobic metabolism represented by elevated Blac could be caused by: 1) an altered running technique in water resulting in an alteration in muscle activation patterns, and 2) a longer absolute muscular contraction time. Other studies that have investigated Blac responses combined male and female responses and found that blood lactates were in fact lower if not equivocal during DWR compared to TMR (Frangolias and Rhodes, 1995; Town and Bradley, 1991). They postulated that increased familiarity with DWR might inhibit the reliance on upper body musculature during DWR and reduce the amount of anaerobic metabolism by these unconditioned muscles (Frangolias and Rhodes, 1995). The elderly women in the present study were all adept with DWR prior to the start of the study and individuals unable to DWR adequately were excluded from the study. It was apparent during test sessions and during exercise sessions that these women did not use much of the upper body musculature to propel themselves forward. Therefore, the theory presented by Frangolias and Rhodes (1995) suggesting that reduced if not similar Blac during DWR is based on familiarity and reduced reliance on upper body musculature, may bear some merit with the elderly group tested in this study.

In summary, it appears that DWR elicits lower physiological stress than TMR.

Maximal oxygen uptake and HR responses are considerably compromised during DWR possibly due to the hydrostatic compression and buoyancy characteristics of the water.

Ventilation, Blac and RER responses are comparable between DWR and TMR suggesting that hydrostatic compression, buoyancy and increased intrathoracic blood do not restrict VE during exercise, DWR does not employ different muscle recruitment patterns, and that equal physical effort is expended during both exercise conditions.

5.2 Cardiovascular Improvements with TMR Following 8 Weeks of Deep Water Running

Changes in cardiovascular capacity associated with advancing age in combination with a sedentary lifestyle can have severe repercussions on one's functional capacity and ability to perform activities of daily living. Over the last 30 years many studies have directed their focus on the trainability of individuals greater than 60 years of age. Of these studies, there are relatively few studies examining exercise programs designed to improve cardiovascular fitness in elderly individuals with attempts to eliminate impact and maximize aerobic conditioning.

Much of the current literature pertaining to trainability in elderly individuals has focused on land-based exercise programs primarily involving walking/jogging (Seals et al., 1984; Yerg et al., 1985; Coggen et al., 1992; Kohrt et al., 1991), calisthenic (de Vries, 1990,1991), and exercises on cycle ergometers (Posner et al., 1992; Ferketich et al., 1998). While these activities are low-moderate impact, it would be foolish to think that elderly individuals could only be limited to these low impact activities.

Ruoti and co-workers (1994) were the first to quantify the cardiorespiratory improvements following a 12-week water exercise program in elderly individuals involving a variety of exercises (i.e. jumping jacks in shallow end of a pool). They found that aerobic fitness improved following this training program as represented by decreases in resting HR, increases in VO_2 max and work capacity. Taunton and colleagues (1996) took this a step further to determine whether equivocal improvements in cardiovascular fitness would be evident between a 12-week water based and 12-week land-based exercise program. Keeping intensity, duration, and frequency consistent between exercise protocols, Taunton et al. (1996) found equivocal improvements between both exercise programs demonstrating for the first time that water-based programs may serve as an alternative for individuals wishing to pursue aerobic conditioning programs with little impact on bones and joints.

Even though Ruoti et al. (1994) and Taunton et al. (1996) confirmed that low impact water-based activities (performed exclusively in the shallow end) are adequate for improvements in cardiovascular fitness, it would be an even greater accomplishment to determine whether non-impact water activities could promote improvements in aerobic fitness to the same magnitude. Therefore, it was the intent of this study to determine whether DWR, a non-impact water-based activity, would elicit the same improvements in cardiovascular fitness in elderly women than what has been previously observed with low impact water and land based programs.

The present study using DWR, a rather novel form of exercise compared to the traditional land based exercise programs used in this population group, found strikingly similar improvements in TMR cardiorespiratory fitness to past studies. This would

suggest that WI does not limit cardiovascular conditioning and that DWR at the intensity prescribed in this study can be used as an alternative to land-based exercise regimes.

5.2.1 *Maximal Oxygen Uptake*

This study marks the first attempt to quantify improvements in elderly women following an 8-week non-impact DWR training program. Although DWR dampens many maximal physiological responses, it was expected not to influence the magnitude of improvement in VO_2max response following a prolonged moderate-high intensity training program in previously inactive elderly women. This postulation was based on a study that examined training responses in untrained individuals. Michaud et al. (1995a) reported 8 weeks of DWR caused substantial improvements in VO_2max in young untrained individuals during both maximal DWR and TMR tests (Michaud et al., 1995a). While this study was conducted on young individuals, it was suspected that similar improvements would be apparent in elderly individuals of the same training status since recent evidence has clearly shown that older adults elicit the same magnitude of VO_2max improvements as young adults using land-based protocols (Meredith et al., 1989).

Treadmill Running VO_2max Response:

The data from this study revealed statistically significant increases in TMR VO_2max following 8 weeks of inactivity for the control group and 8 weeks of DWR for the exercise group. The increase in TMR VO_2max seen in the control group might illustrate a possible practice effect in maximal exercise testing procedures, although de Vries (1970) documented a reliability of 0.83 in inactive elderly individuals previously

unfamiliar with maximal exercise tests. While test-retest procedures for maximal exercise capacity were not performed in the present study, it is possible that the combination of motivation and familiarization from pre-training tests contributed to the 2ml/kg/min increase in TMR VO_2max between pre- and post-training tests in the control group. Although the control group experienced a 2ml/kg/min increase in TMR VO_2max , increases in TMR VO_2max were statistically greater ($p < 0.05$) in the exercise group (5.2ml/kg/min vs. 2ml/kg/min), indicating that 8 weeks of DWR does improve TMR VO_2max in previously inactive elderly women.

The increase in TMR VO_2max observed in the exercise group is similar to the improvements observed in studies involving a moderate-high intensity land-based training program in elderly individuals. Meredith et al. (1989) found that 12 weeks of endurance training at 70% VO_2peak caused a 5.5-6.0ml/kg/min improvement in VO_2peak in previously sedentary elderly individuals. Similarly, Hagberg et al. (1989), Posner et al. (1992), Pickering et al. (1997), Ferketich et al. (1998), and Morio et al. (2000) all reported increases in VO_2max ranging from 8.5-24.8% following 7-16 weeks of training in elderly individuals. More intense training responses were observed in other studies examining variable training intensities and durations (i.e. low followed by high intensity programs for 9-12 months) (Seals et al., 1989, Kohrt et al., 1991; Coggan et al. 1992). Although intensity and duration are thought to be the predominant determinants of improvement magnitudes, Sidney and Shephard (1978) and Niinimaa and Shephard (1978) speculated that differences in intensity account for most of the variability in improvements between studies. This premise was based on data showing that improvements in fitness after 7 weeks of intense training accounted for most of the total

gains over a 1-year period of training (Sidney and Shephard, 1978). Training regimes involving similar intensities over a shorter duration (less than 2 hours/week) resulted in slightly lower improvements in overall fitness compared to regimes involving a duration greater than 2 hour/week, indicating that intensity rather than duration is the predominant factor governing the magnitude of training response (Sidney and Shephard, 1978).

Regardless of the magnitude of improvements, gains in VO_2max have been demonstrated in studies using an intensity as low as 40% (deVries et al., 1971) to as high as 85% (Seals et al., 1984; Pickering et al., 1997) in previously inactive elderly individuals. Improvements following low intensity training may just be a reflection of an initially low fitness level.

While intensity plays an inaugural role on the magnitude of improvements, increases in VO_2max following low or high intensity land-based training program are based on the same principles. It has been suggested that higher VO_2max associated with training in elderly individuals is due to a higher redistribution of blood flow to active muscles (Niinimaa and Shephard, 1978; Coggen et al., 1992), increases in muscle oxidative capacity (Meredith et al., 1989; Coggen et al., 1992) and capillary density (Coggen et al., 1992) accounting for the widening of the (a-v) O_2 difference (Niinimaa and Shephard, 1978; Seals et al., 1984; Coggen et al., 1992), increases in cardiac output primarily attributable to augmentations in SV (Seals et al., 1984; Ehsani et al., 1991) and increases in VE (Yerg et al., 1985). While DWR may recruit more upper body musculature than land-based running due to hydrostatic resistance, the motion of running is nevertheless similar between the two exercise conditions involving similar, although not exact, skeletal musculature and range of motion (Wilber et al., 1996). Therefore, it is

plausible that the adaptations observed in elderly individuals following land-based walking/jogging /running programs (Seals et al., 1984; Coggen et al., 1992; Kohrt et al., 1991) can also explain the improvements in VO_2max observed following a DWR training program in elderly women. It is, however, unclear at this time which of these mechanisms is most responsible for the changes in VO_2max observed in the present study as direct measurements of muscle metabolism and cardiac output were not performed in this study.

Deep Water Running VO_2max Response:

Deep water running VO_2max improved 2.09ml/kg/min following 8 weeks of DWR in the exercise group. Although this difference did not reach statistical significance ($p=0.063$), contrasts made between groups over time were statistically significant ($p<0.05$) indicating a definite training effect.

The failure to achieve statistical significance within the exercise group is rather unusual as 8 weeks of DWR should have conditioned the cardiovascular system to improve blood flow to working muscles and cause adaptations in the skeletal muscles sufficiently to elicit statistical improvements. In a previous study, Michaud et al. (1995) reported improvements of 20% in DWR VO_2max responses in untrained young individuals training for 8 weeks with DWR (Michaud et al., 1995). The apparent disparity in findings between studies is unclear at this time. Speculative at best, differences in testing protocol and/or differences across age groups in ventilation/perfusion (VE/Q) with WI could account for the vast difference in DWR VO_2max trainability.

The testing procedures used in the present study to determine maximal DWR capacity involved adding weights to a bucket that was suspended from a tethering apparatus (Figure 3a). Increased bucket weight functioned to increase workload by requiring the subject to run faster to maintain their position in the water. Once the subject was unable to maintain their position in the water or proper DWR technique was lost the test was terminated. In almost all cases the researcher terminated DWR tests, as subjects were unable to maintain their position in the water. In contrast, TMR tests were almost always terminated by request of the subject due to volitional fatigue. Therefore, the subjects' inability to pull weights greater than 1 kg in the water might have largely contributed to the cessation of most DWR tests. It is therefore possible that muscular strength rather than aerobic capacity limited maximal performance in the water in this study. In comparison, Michaud et al. (1995) used a DWR graded exercise protocol, which used increases in cadence to increase exercise intensity. Using this testing procedure would most likely eliminate muscular strength as a contributing factor to the termination of the DWR maximal exercise test.

Alternatively, VE/Q inequalities with WI may have blunted the trainability of DWR VO_2max in elderly individuals. It has been documented that WI causes: 1) an increase in thoracic blood volume (Arborelius et al., 1972), 2) elevation of the diaphragm to a position approaching full expiration (Agostoni et al., 1966), and 3) an increase in intrathoracic squeeze (Dahlback et al., 1978). In young individuals, the increase in thoracic blood volume and elevation of diaphragm causes an increase in apical perfusion, thereby augmenting the surface area in the lung for gas diffusion. Consequently, arterial O_2 concentration is elevated with WI in young individuals (Prefaut et al., 1976).

However, with older individuals whose respiratory capacity has deteriorated with age (Table 2), the changes associated with WI are not as favourable. Derion et al. (1992) reported that older individuals experience more physiological shunting in the lungs and higher VE/Q inequalities during WI than what is observed in younger individuals. Increases in trapped air volume, lung perfusion to the apices, and vascular engorgement shutting off terminal respiratory units have also been reported to occur with WI (Dahlback, 1975). Furthermore, WI appears to elicit a non-uniform distribution of VE causing in a drop in the partial pressure of arterial O₂ (P_aO₂) and an increase in the difference in alveolar-arterial O₂ concentration (AaDO₂) (Lollgen et al., 1980). Therefore, it is possible that the increase in blood volume causing pulmonary engorgement, increase in trapped air, and the non-uniform distribution of VE during WI combined with age related changes in lung physiology compromises respiration in elderly individuals, resulting in hypoxemia. Although speculative at best, impairments in VE/Q during WI could explain why 8 weeks of DWR training improved DWR VE with slight but non-significant increases in DWR VO₂max.

While the exercise group did not show statistical improvements in DWR VO₂max following 8 weeks of training, significant differences were found between groups over time. This suggests that although DWR VO₂max improvements were dampened by confounding variables (perhaps muscular strength, VE/Q inequality), small training improvements do occur with this population group with 8 weeks of DWR training.

5.2.2 Ventilation

More emphasis has been directed towards improvements in VO_2max following training in elderly individuals primarily because VO_2max changes reflect whole body adaptations involving alterations in muscle, heart, and lung physiology. In contrast, ventilatory responses reflect only adaptations in lung mechanics. Consequently, only few studies have directed their attention on possible improvements in VE following training in elderly individuals.

Seals et al. (1984) reported higher maximal VE responses following low intensity training (7%) and even larger increases (29%) following high intensity land-based exercise programs (walking/ jogging) in elderly individuals. The data from Yerg et al. (1985) indicated that 6 months of low intensity training (walking) followed by 6 months of high intensity training (cycling/graded treadmill walk/jogging) caused a significant reduction in the level of ventilation required to perform a given amount of submaximal work in elderly individuals. In addition, the 29% increase in VE indicates that training allows older individuals to retain the capability of tapping into their ventilatory reserve capacity during maximal exercise, since training does not seem to augment MVV values in either young or old, trained or untrained individuals (Yerg et al., 1985). More specifically, de Vries (1970) speculated that increases in the ability to utilize a greater proportion of the ventilatory reserve capacity following endurance training is a direct result of increases in TV, since breathing frequencies do not appear to be changed with training. These findings directly corroborate the observations made in the present study regarding ventilatory improvements. We found that following 8-weeks of DWR our

elderly women exhibited a 14% (8.8 L/min) increase in TMR VE and 15% (8.4L/min) increase in DWR VE, suggesting that possible re-conditioning of the respiratory muscles and the ability to utilize a greater proportion of their ventilatory reserve capacity are improved with prolonged training. It is unlikely that the changes in VE observed in the present study were caused by alterations in lung physiology (reduction of alveolar size, increased elasticity of pulmonary support structures) as many of these age related changes are irreversible, even with prolonged high intensity training programs (Brooks et al., 1996).

5.2.3 *Heart Rate Response*

Reductions in HR responses at a given sub-maximal workload were observed following training programs of durations longer than 11 weeks (Niinimaa and Shephard, 1978; Haber et al., 1984; Seals et al., 1984), although changes in maximal HR are not apparent (Seals et al., 1984; Kohrt et al., 1991, Coggen et al., 1992). Brooks et al. (1996) summarized that the reductions in submaximal HR following endurance training is a result of an increase in parasympathetic tone to the SA node from the vagus nerve and a reduction intrinsic rhythmicity of the heart.

The absence of a change in maximal HR following 8 weeks of DWR training in the present study reiterates the notion that endurance training does not enhance maximal HR response in elderly individuals. Since submaximal workloads were not tested in this group, it is impossible to assess whether DWR caused reductions in submaximal HR. It seems rather probable that submaximal HR reductions would be seen with this training protocol as similar cardiorespiratory adaptations have been observed between with this

training regime and land based programs having observed lower submaximal HR (Niinimaa and Shephard, 1978; Haber et al., 1984; Seals et al., 1984).

5.2.2 Blood Lactate Response

It has been suggested by Brooks et al. (1996) that Blac accumulation causing acidosis and pain in the muscle does not usually limit maximal exercise capacity. Instead, central factors (i.e. cardiac output) are the main determinants of maximal exercise capacity. Because oxidative capacities and increases in muscle blood flow are presumed to occur following aerobic training in older adults (Meredith et al., 1989; Coggen et al., 1992), it would seem likely that Blac levels would be lower during submaximal workloads and unchanged at maximal effort.

The data from the present study supports the assertion that maximal Blac response is not affected with prolonged aerobic training. Blood lactate, an indicator for anaerobic capacity (Green and Dawson, 1993), is thought to be improved only through high intensity, short duration, anaerobic training (Cahill et al., 1997). In fact, Cahill et al. (1997) suggested that for anaerobic training to occur, the dose must be of high intensity and performed to near-exhaustion. Given that the main objective of this study was to increase cardiovascular fitness in elderly women, the exercise intensity, duration, and frequency was prescribed to target improvements in aerobic fitness. This involved intensities far from near-exhaustion (70-80% $\text{VO}_{2\text{max}}$) for a duration of 30 minutes.

The change in lactate response with endurance training more likely encourages lower Blac values at submaximal workloads since it is believed that endurance training causes improvements in blood flow, muscle oxidative capacity, and ventilation (Niinimaa

and Shephard, 1978; Seals et al., 1984; Yerg et al., 1985; Meredith et al., 1989; Ehsani et al., 1991; Coggen et al., 1992). Hurley et al. (1984) reported that lactate concentrations at the same relative exercise intensities in the 55-75% of VO_2max range were significantly lower following 12 weeks of aerobic training. Similar findings were observed in a study examining the effects of aerobic training in an older population (Seals et al., 1984). Seals and colleagues (1984) observed appreciable lower lactate values at the same absolute work rate after 6 months of low intensity training in elderly individuals. Only slight reductions in submaximal lactate value were observed following an additional 6 months of high intensity training.

Given that submaximal Blac responses were not measured in the present study, we are unable to confirm the contention that 8 weeks of DWR induces lower submaximal lactate responses without change in maximal lactate response. However, it our belief that reductions in submaximal lactate response would occur following our training protocol based on the findings of other studies who have reported lactate responses and cardiovascular changes similar to the changes observed in the present study.

In summary, 8 weeks of DWR did not statistically improve DWR VO_2max when compared within the exercise group only. When DWR VO_2max changes were analyzed between groups across time, significant differences were observed ($p < 0.05$) indicating that 8 weeks of DWR did indeed elicit a small training effect. Failure to achieve statistical significance in DWR VO_2max within the exercise group over time might be attributable to muscular strength and VE/Q induced with WI. Even though statistical improvements did not occur with DWR VO_2max , large improvements in TMR

cardiorespiratory fitness were apparent following 8 weeks of DWR. These improvements are comparable to what has been previously reported with traditional land-based programs that employ similar intensity, frequency, and duration. Therefore, this form of exercise could be recommended to elderly individuals looking to improve cardiovascular fitness while avoiding skeletal impact altogether.

5.3 Specificity of Training

It was hypothesized that the magnitude of improvement in VO_2max would be larger during DWR compared to TMR based on the “specificity of training” principle. The premise of the specificity of training principle relies on basis that muscle adapts to adequately cope with the specific forms of exercise stress which are applied (Stegeman, 1981; Noakes, 1986). This means that the muscles, which are continuously recruited with prolonged training become more conditioned, are capable of working at higher intensities, and perform better. In a nutshell, training involving running will improve running performance, training involving cycling will improve cycling performance, and so forth.

McArdle et al. (1978) found that 10 weeks of run training increased treadmill VO_2max 3 times more than tethered swimming in young individuals. Using a specific reference to DWR training studies, Michaud et al. (1995) reported a 20.1% increase in DWR VO_2max in comparison to only a 10.6% improvement in TMR VO_2max following 8 weeks of DWR in young individuals.

However, the data from the present study contradicts this “specificity of training” principle. The data revealed that relative DWR VO_2max did not statistically increase

($p > 0.05$) within the exercise group following 8 weeks of DWR training. Instead relative TMR VO_2max statistically increased ($p < 0.05$) after the 8 weeks of DWR training. Many would argue that this observation seems rather improbable as the greatest improvements in VO_2max are typically observed in maximal exercise tests using the same modality of exercise as the training program (McArdle et al., 1978; Tanaka, 1994; Foster et al., 1995; Michaud et al., 1995). Although the data from this study seems to violate the specificity of training principle, the similarity in muscle recruitment patterns between TMR and DWR, the importance of muscular strength, and the possibility of an increase in VE/Q inequality induced with WI, may partially explain the results obtained in the present study.

In summary, although there was not a significant difference in the magnitude of change between DWR and TMR VO_2max ($p > 0.05$), TMR VO_2max improvements tended to be higher (5.21 vs. 2.09 ml/kg/min). These trends contradict the highly accepted notion relating to specificity of training. The theories introduced in this section attempts to explain why TMR improvements were large while improvements in DWR appeared to be dampened. These theories are merely speculative but the strength in these theories lie in the fact that they explain how each factor contributes to the improvements in VO_2max (muscle adaptations, VE) while complying with the specificity of training concept.

Chapter 6

6.0 CONCLUSIONS

- 1) Water immersion results in lower physiological stress as illustrated by the decrease in VO_2max and HR during a single bout of maximal DWR compared to TMR. The blunted responses of these variables are attributed to the same mechanisms previously suggested by other researchers examining the role of WI on DWR response in young untrained and trained individuals. The primary factors leading to VO_2max decrements include: 1) a lower metabolic response from non-active antigravity muscles due to the non-weight bearing nature of DWR, 2) type of muscular contraction, and 3) lower perfusion pressures in the legs during immersion causing a decrease in total muscle blood flow to the larger muscle groups. Explanations for HR reduction have primarily focused on the possibility that the hydrostatic pressure gradient of WI facilitates venous return causing a central shift in blood volume and below thermoneutral temperatures causing bradycardia. Although these mechanisms explain the significant reduction in DWR HR response, the small change in HR that was observed in this study (6 beats/min) compared to previously reported changes in young individuals (10-25 beat/min) may be attributed to age related deterioration in cardiac functions.
- 2) Water immersion does not affect maximal VE in elderly women. This indicates that the deterioration in lung physiology and ventilatory capacity caused by

advanced age may minimize the effects of hydrostatic chest compression on ventilation during WI.

- 3) Elderly women adept with DWR are able to recruit similar musculature during DWR and TMR represented by similar $\dot{V}_{O_2}$ between exercise modalities.
- 4) Irrespective of the dampened acute physiological responses in the water, DWR training programs can improve aerobic fitness in previously inactive elderly women by increasing TMR $\dot{V}_{O_2}$ max and VE response. Significant improvements in DWR $\dot{V}_{O_2}$ max within the exercise group was not observed, however, significant differences between groups provides evidence that a training effect does occur with DWR $\dot{V}_{O_2}$ max with 8 weeks of DWR training. The increase in TMR performance following training indicates that this form of exercise is greatly beneficial for elderly individuals wishing to improve cardiovascular fitness while eliminating potentially detrimental impact forces on the skeletal system.
- 3) Cross training is possible with this exercise modality as comparable improvements were seen in maximal DWR and TMR responses. These improvements suggest that similar muscle recruitment patterns and ROM occur between TMR and DWR in elderly women leading to improvements in both land and water based exercise tests.

6.1 RECOMMENDATIONS FOR FUTURE STUDIES

- 1) To determine whether muscular strength limits maximal DWR responses in elderly women, future studies need to be conducted which examines the difference in maximal DWR response using a tethered protocol (muscular strength a factor here) and a cadence controlled protocol (muscular strength not a factor).
- 2) To determine whether hypoxemia is induced with prolonged DWR, future studies need to be conducted which measures O₂ saturation in blood during DWR.
- 3) If strength were a factor limiting DWR response would strength training augment maximal DWR response? Future studies should be conducted in this area which addresses this question by implementing a concurrent strength training and DWR program in elderly population groups. In doing so, this type of program may prove to be more beneficial to this population group, as DWR training alone does not stimulate bones enough to prevent osteoporotic conditions.
- 4) To determine whether differences between land and water running exercise programs really exist in this population group, future studies should be done replicating this study while including a land-based training group engaging in treadmill walking/jogging. The limitation that we experienced in this study is that we based a lot of our findings on previous studies looking at young individuals

training with DWR or elderly individuals training on land (not necessarily running) and compared these findings to ours.

- 5) To determine the timeline of detraining following a DWR training program in elderly women, a follow-up on subjects previously engaged in a DWR training program.
- 6) To determine whether training responses between shallow water running and deep water running are different, future studies should be done involving 3 groups of elderly women: 1) shallow water running exercise group, 2) deep water running exercise group, and 3) control group. The biomechanics between these two modes of exercise are likely to be different since Moening et al. (1999) reported that land-based running and suspended running are slightly different biomechanically. Positive results from research in the area of shallow water running may prove to be more feasible than deep water running, especially for elderly individuals who do not have access to floatation belts.

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APPENDIX I

Dear Doctor:

Your patient has expressed interest in participating in our study investigating the effectiveness of an 8 week deep water running program in healthy women aged 60-65 years. Deep water running has been previously used by young adults and injured athletes as a way to improve or maintain overall fitness levels. It is the intent of this study to explore to possible benefits of this form of exercise in a more broad age category to include our senior population.

The study population will be evenly and randomly divided into two groups: control and program group. Those in the control group will be asked to maintain their daily activities from week 1 to week 8. At week 8 the control group will begin the exercise program. Individuals selected for the program group will enter the exercise program at week 1, which will last until week 8.

The exercise program will last 8 weeks in which participants will meet three times per week for approximately 1 hour. During this hour participants will engage in a light warm-up followed by 30 minutes of moderate intensity deep water running and a 10 minute cool down. All exercise sessions will be held at the UBC Aquatic Centre.

Subjects with the following shall be excluded from this study:

1. restricted limb or trunk movement
2. medical contraindications to submaximal to maximal aerobic exercise
3. uncontrolled hypertension or diabetes
4. symptomatic cardiorespiratory disease
5. severe renal or hepatic disease
6. uncontrolled epilepsy
7. progressive neurological disease
8. dementia
9. marked obesity with inability to exercise
10. medication with betablockers, Warafin or CNS stimulants
11. participation in intense cardiovascular exercise for more than 2 hours per week

We would be grateful if you would decide whether your patient would be suitable to participate in this exercise research study.

Sincerely,

Dr. Jack Taunton
Division of Sports Medicine
UBC Department of Family Practice

Sincerely,

Dr. Ted Rhodes
J.M. Buchanan Exercise Science Lab
UBC School of Human Kinetics

Patient Release

I agree to the release of medical information to the Deep Water Running for Senior Women study.

Signed: _____
Patient Signature

Please print patient's full name

Date: _____

Physician's Assessment

The above patient is suitable for the Deep Water Running for Senior Women study.

Signed: _____
Doctor's Signature

Please print Doctor's full name

Address

Date: _____

APPENDIX II

SUBJECT 1

Age: 63 years
Height: 170.5 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	70.2	70.4	71.2	70.4
VO ₂ max (L/min)	1.23	1.92	2.10	2.23
VO ₂ max (ml/kg/min)	17.7	27.2	29.5	31.7
HRmax (beat/min)	148	156	153	162
VEmax (L/min)	51.3	72.7	66.3	72.4
RER	1.23	0.95	0.95	1.06
Blac (mmol/L)	3.9	3.7	4.1	6.0

SUBJECT 2

Age: 63 years
Height: 163.5 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	74.6	78.7	75.1	78.4
VO ₂ max (L/min)	1.07	1.42	1.58	1.84
VO ₂ max (ml/kg/min)	14.3	18.0	21.1	23.4
HRmax (beat/min)	142	147	154	147
VEmax (L/min)	42	53.2	41.7	55.0
RER	1.06	1.06	1.02	1.17
Blac (mmol/L)	N/R*	4.4	3.9	4.4

*Note: Blood lactate was not recorded (N/R) during the Pre DWR test due to a malfunction of the blood lactate analyzer. The reading that appeared on the monitor seemed rather improbable for the effort and age of this subject (value shown on the monitor was 14.0)

SUBJECT 3

Age: 71 years
Height: 151.5 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	55.0	56.0	55.7	55.4
VO ₂ max (L/min)	0.91	0.91	1.33	1.34
VO ₂ max (ml/kg/min)	16.5	16.4	24.0	24.0
HRmax (beat/min)	169	166	166	164
VEmax (L/min)	30.5	28.0	40.4	35.7
RER	1.08	1.10	1.03	1.01
Blac (mmol/L)	5.4	4.4	4.5	4.0

SUBJECT 4

Age: 65 years
Height: 165.5 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	59.5	59.4	59.5	60.6
VO ₂ max (L/min)	1.37	1.31	1.27	1.38
VO ₂ max (ml/kg/min)	23.7	22.1	21.3	22.8
HRmax (beat/min)	171	152	147	156
VEmax (L/min)	52.2	52.0	35.8	36.9
RER	0.93	1.1	0.96	0.97
Blac (mmol/L)	4.1	3.9	3.8	3.7

SUBJECT 5

Age: 69 years
Height: 167 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	63.5	64.8	64.9	63.8
VO ₂ max (L/min)	1.21	1.14	1.41	1.67
VO ₂ max (ml/kg/min)	19.0	17.8	21.7	26.2
HRmax (beat/min)	153	155	176	175
VEmax (L/min)	53.8	45.7	58.3	52.7
RER	1.03	1.0	1.14	1.02
Blac (mmol/L)	4.5	4.3	3.5	5.5

SUBJECT 6

Age: 68 years
Height: 154.5 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	62.3	64.0	62.9	64.5
VO ₂ max (L/min)	1.03	0.97	1.30	1.46
VO ₂ max (ml/kg/min)	16.5	15.1	20.7	22.6
HRmax (beat/min)	146	158	153	143
VEmax (L/min)	47.9	47.4	45.4	43.3
RER	1.00	1.16	0.98	1.05
Blac (mmol/L)	4.4	4.4	5.0	4.3

SUBJECT 7

Age: 62 years
Height: 164 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	64.8	63.8	65.8	64.0
VO ₂ max (L/min)	0.95	0.96	1.21	1.50
VO ₂ max (ml/kg/min)	14.6	15.0	18.4	23.4
HRmax (beat/min)	148	149	159	153
VEmax (L/min)	41.8	40.7	48.6	47
RER	0.99	1.01	1.17	1.10
Blac (mmol/L)	5	3.9	4.9	4.3

SUBJECT 8

Age: 65 years
Height: 155 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	55.0	54.9	55.2	54.9
VO ₂ max (L/min)	1.09	1.12	1.12	1.71
VO ₂ max (ml/kg/min)	19.7	20.3	20.3	31.2
HRmax (beat/min)	165	164	166	161
VEmax (L/min)	49.7	53.0	41.2	54.7
RER	1.09	1.24	1.11	1.10
Blac (mmol/L)	7.4	6.7	7.2	6.7

SUBJECT 9

Age: 65 years
Height: 161 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test*
Weight (kg)	63.6	62.7	64.0	63.2
VO ₂ max (L/min)	1.00	1.21	1.59	1.89
VO ₂ max (ml/kg/min)	15.7	19.4	24.8	29.8
HRmax (beat/min)	148	158	177	163
VEmax (L/min)	42.8	55.8	71.2	70.5
RER	1.07	1.00	1.33	1.18
Blac (mmol/L)	4.7	5.1	8.7	3.9

*Note: Post TMR test was stopped prior to maximal effort due to subject complaining of knee pains. Immediately after cessation of the test ice was applied to the knee because of immediate and severe inflammation. Subject has had prior surgery on knee (October 1999). Sports medical physician diagnosed this problem as bursitis.

SUBJECT 10

Age: 60 years
Height: 157.3 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	62.0	63.2	62.8	63.0
VO ₂ max (L/min)	0.97	0.82	1.62	1.75
VO ₂ max (ml/kg/min)	15.6	13.0	25.7	27.7
HRmax (beat/min)	165	166	179	171
VEmax (L/min)	48.6	42.5	67.4	71.4
RER	0.97	1.24	1.12	1.20
Blac (mmol/L)	7.6	7.9	10.2	12.1

SUBJECT 11

Age: 62 years
Height: 157 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	64.9	63.9	65.2	65.2
VO ₂ max (L/min)	1.14	1.06	1.20	1.65
VO ₂ max (ml/kg/min)	17.5	16.5	18.3	25.3
HRmax (beat/min)	148	146	150	152
VEmax (L/min)	56.7	48.6	52.6	66.6
RER	0.94	1.27	1.16	1.16
Blac (mmol/L)	6.2	6.0	5.4	5.8

SUBJECT 12

Age: 67 years
Height: 177 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	67.0	66.0	67.4	66.7
VO ₂ max (L/min)	1.27	1.32	1.79	2.26
VO ₂ max (ml/kg/min)	18.9	20.0	26.7	33.8
HRmax (beat/min)	158	162	164	170
VEmax (L/min)	48.1	57.3	51.5	62.5
RER	0.92	1.05	1.07	1.06
Blac (mmol/L)	3.7	5.5	2.4	5.0

SUBJECT 13

Age: 60 years
Height: 143 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	53.2	54.1	53.9	54.3
VO ₂ max (L/min)	1.00	1.06	1.12	1.60
VO ₂ max (ml/kg/min)	18.8	19.6	20.9	29.6
HRmax (beat/min)	179	174	177	182
VEmax (L/min)	53.7	59.0	46.5	70.5
RER	1.05	1.18	1.14	1.17
Blac (mmol/L)	7.8	5.5	5.9	9.9

SUBJECT 16

Age: 63 years
Height: 164.5 cm
Group: Control

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	89.5	90.2	90.3	89.7
VO ₂ max (L/min)	1.59	1.61	2.03	2.03
VO ₂ max (ml/kg/min)	17.8	17.9	22.5	22.6
HRmax (beat/min)	149	155	164	162
VEmax (L/min)	53.0	58.1	55.2	55.4
RER	0.96	0.99	1.09	1.10
Blac (mmol/L)	4.5	4.1	6.4	3.1

SUBJECT 17

Age: 64 years
Height: 171.3 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test*
Weight (kg)	81.6	80.9	81.4	80.7
VO ₂ max (L/min)	1.34	1.60	1.92	1.79
VO ₂ max (ml/kg/min)	16.4	19.7	23.6	22.1
HRmax (beat/min)	157	160	157	145
VEmax (L/min)	52.2	62.2	62.9	52.8
RER	0.93	1.16	1.19	1.17
Blac (mmol/L)	6.0	8.5	7.3	5.1

*Note: Post TMR test was stopped prior to maximal effort due to an equilibrium imbalance experienced by the subject during the test. She did not want to perform the test again on a subsequent day.

SUBJECT 18

Age: 63 years
Height: 170.2 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	50.5	51.2	51.3	51.9
VO ₂ max (L/min)	1.23	1.21	1.16	1.68
VO ₂ max (ml/kg/min)	24.3	23.6	22.7	32.3
HRmax (beat/min)	145	144	160	156
VEmax (L/min)	54.5	58.5	49.6	65.6
RER	0.99	1.07	1.23	1.17
Blac (mmol/L)	4.7	4.5	5.7	5.8

SUBJECT 19

Age: 60 years
Height: 165 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	67.6	67.4	67.3	68.1
VO ₂ max (L/min)	1.54	1.57	1.74	2.12
VO ₂ max (ml/kg/min)	22.7	23.3	25.8	31.2
HRmax (beat/min)	169	163	173	159
VEmax (L/min)	48.0	48.8	55.5	67.4
RER	1.06	1.09	1.27	1.16
Blac (mmol/L)	7.0	6.2	7.0	5.2

SUBJECT 20

Age: 71 years
Height: 151.5 cm
Group: Exercise

Maximal Exercise Responses:

Variable	Deep Water Running		Treadmill Running	
	Pre-test	Post-test	Pre-test	Post-test
Weight (kg)	56.0	54.9	55.4	55.4
VO ₂ max (L/min)	0.91	0.81	1.34	1.55
VO ₂ max (ml/kg/min)	16.4	14.7	24.0	27.8
HRmax (beat/min)	166	162	164	164
VEmax (L/min)	28.0	33.8	35.7	44.4
RER	1.10	1.12	1.01	1.16
Blac (mmol/L)	4.4	3.9	4.0	4.3