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AZEVEDO, Liane <http://orcid.org/0000-0001-9966-9414>, LAMBERT, Mike I <http://orcid.org/0000-0001-8979-1504>, ZOGAIB, Paulo S and BARROS NETO, Turibio L

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Maximal and Submaximal Physiological Responses to Adaptation to Deep Water Running

Liane Beretta de Azevedo B.Sc, PhD[1, 3]

Mike Lambert M.Sc, PhD[2]

Paulo Sérgio Martino Zogaib MB.BCH., M.Sc[3]

Turibio Leite de Barros Neto B.Sc, PhD[3]

[1] School of Health and Social Care, University of Teesside, Middleborough, UK

[2] MRC/UCT Research Unit for Exercise Science and Sports Medicine, Cape Town, South Africa

[3] CEMAFE, São Paulo Federal University, São Paulo, Brazil

Address for correspondence:
Liane Beretta de Azevedo
University of Teesside
School of Health and Social Care
Middlesbrough - UK
TS1 3BA
Phone +44 (0) 1642 342988
Fax: +44 (0) 1642 342983
e-mail: l.azevedo@tees.ac.uk

Abstract

The aim of the study was to compare physiological responses between runners adapted and non-adapted to deep water running (DWR) at maximal and ventilatory threshold (VT) intensities. Seventeen (17) runners, either adapted to DWR (N=10) or non-adapted to DWR (N=7) participated in the study. Subjects in both groups did a maximal treadmill running (TDR) and deep water running (DWR) graded exercise test in which cardio respiratory variables were measured. Interaction between adaptation (adapted vs. non adapted) and condition (TDR vs. DWR) were analysed. The main effects of adaptation and condition were also analysed in isolation. Runners adapted to DWR had a lower reduction in VO_2 max in DWR in relation to their VO_2 max in TDR than runners non-adapted to DWR. VO_2 max, HRmax, VE max, VO_2VT, HRVT, VEVT were significantly higher in TDR in comparison to DWR. No statistical differences were observed between TDR and DWR for RERmax, RPEVT, RERVT and $\%VO_2VT/VO_2$ max. Runners adapted to DWR presented a higher RER max and RER VT when compared to non-adapted runners. Therefore, it can be concluded that adaptation to DWR reduces the difference in VO_2 max between DWR and TDR, possibly as a result of the adapted runners recruit a larger muscle mass. However, the results of this study support previous findings with other populations demonstrating a lower maximal and submaximal physiological response on DWR for most of the measured parameters.

Key words: oxygen consumption, heart rate, ventilation, lactate, and muscle recruitment

Introduction

Beginners and high level runners have been using deep water running (DWR) to complement of their training sessions and for injury rehabilitation (DeMaere & Ruby, 1997; Thein & Brody, 1998; Reilly *et al*., 2003). More recently studies have shown that DWR improves aerobic capacity (Broman *et al*., 2006b) and balance ability (Kaneda *et al*., 2008a) in elderly people. DWR has also been shown to reduce pain and improve aerobic fitness in patients with fibromyalgia (Assis *et al*., 2006) and as an alternative aerobic exercise for women with large breasts (McGhee *et al*., 2007).

The literature has been consistent to report lower maximal oxygen consumption (VO_2 max) during a DWR test compared to VO_2 max elicited during a treadmill running (TDR) test (Mercer & Jensen, 1988; Town & Bradley, 1991; Butts *et al*., 1991a; Svedenhag & Seger, 1992; Frangolias & Rhodes, 1995; Glass *et al*., 1995; Michaud *et al*., 1995b; Brown *et al*., 1996a; Dowzer *et al*., 1999; Broman *et al*., 2006a; Phillips *et al*., 2008). Similar reduced responses for DWR compared to TDR also occurs for maximal heart rate (HR max) (Mercer & Jensen, 1988; Town & Bradley, 1991; Butts *et al*., 1991a; Butts *et al*., 1991b; Glass *et al*., 1995; Michaud *et al*., 1995a; Michaud *et al*., 1995b; Frangolias & Rhodes, 1996; Brown *et al*., 1997; Dowzer *et al*., 1999; Broman *et al*., 2006a; Phillips *et al*., 2008). However, the literature is contradicting in relation to ventilatory values, as some studies have shown a similar maximal ventilation (VE) between DWR and TDR (Butts *et al*., 1991a; Frangolias & Rhodes, 1995; Phillips *et al*., 2008) whereas other studies have shown a lower VE for DWR (Butts *et al*., 1991b; Broman *et al*., 2006a; Phillips *et al*., 2008). Similar contradictory responses have been observed for maximal respiratory exchange ratio (RER max) (Frangolias & Rhodes, 1995; Brown *et al*., 1997; Dowzer *et al*., 1999; Phillips

et al., 2008) and peak blood lactate concentrations (Svedenhag & Seger, 1992; Wilder *et al*., 1993; Frangolias & Rhodes, 1995; Glass *et al*., 1995). One of the reasons for these contradictory findings may be that studies have not always controlled for the familiarity of the subject with deep water running (Frangolias *et al*., 1996; Reilly *et al*., 2003). Indeed it has previously been reported that familiarity with DWR affects maximal responses between runners not adapted to DWR compared to runners who are accustomed to using different DWR training regimens (Frangolias *et al*., 1996).

At a submaximal level, the cardio respiratory responses also varied according to different studies (Mercer & Jensen, 1988; Bishop *et al*., 1989; Ritchie & Hopkins, 1991; Svedenhag & Seger, 1992; Frangolias & Rhodes, 1995; DeMaere & Ruby, 1997; Brown *et al*., 1997; Broman *et al*., 2006a). An explanation may be the method selected for these comparisons. For example some studies have compared the physiological responses at the same rate of perceived exertion (RPE) (Bishop *et al*., 1989; Ritchie & Hopkins, 1991), while other studies have used stride frequency (Brown *et al*., 1997), absolute VO_2 values (Svedenhag & Seger, 1992; Broman *et al*., 2006a), relative VO_2 values (Mercer & Jensen, 1988; DeMaere & Ruby, 1997) or VO_2 at ventilatory threshold (VO_2 VT) (Frangolias & Rhodes, 1995) as the source of comparison. Although several studies have investigated submaximal responses, none from our knowledge, have compared submaximal responses in individuals adapted and non-adapted with DWR.

Therefore, the aim of this study was to compare the maximal and submaximal physiological responses during a graded treadmill running test and deep water running test between

runners who follow similar DWR training and runners non-adapted to DWR. Comparison at submaximal level was established at the ventilatory threshold.

Methods

Participants

Seventeen (17) recreational runners were divided in two groups: non-adapted to DWR (7 runners; 6 female and 1 male) and adapted to DWR (10 runners; 5 female and 5 male). All participants ran three times a week for at least three months and the DWR adapted group practiced DWR two sessions per week (45 to 60 min) for at least two months prior to the experiment. Two qualified DWR instructors guided deep water running training sessions. The Ethics Committee of the Universidade Federal de São Paulo approves this study. Participants received information about the study and signed an informed consent.

Procedures

Two maximal tests were performed: (i) on the treadmill and (ii) on deep water running in a randomized order. There was a minimum period of 48 hours and a maximum period of one week between the two tests.

Treadmill

After a period of five minutes of familiarization and warm-up, the protocol started at 6 km/h and there was an increment of 1 km/h every one minute up to the speed of 14 km/h when the treadmill was inclined by 5% every minute until exhaustion.

Deep water running

The DWR test was performed in a swimming pool with the temperature ranging between 28 to 30°C. The subject used a flotation belt (Bionergetic Inc, Pelham,AL) around the waist and was tied to the swimming pool border by an elastic rope. The DWR movement was based on the technique described by Michaud et al. (1995a). The subject floated with his/her trunk in a vertical position, arms flexed, hands aligned with the forearm and the fingers relaxed. The arms moved in a sagittal plane while the leg movement simulated the running movement. All the participants had their technique checked during the test by one of the two qualified DWR instructors.

The graded increase of workload on DWR was determined by the increase in stride frequency. According to Wilder et al. (1993), there is a high correlation (r= 0.73) between heart rate and cadency during DWR. The test started with a cadence of 104 steps per minute, and then increased by 8 strides per minute every minute. A metronome (Yamaha QT1 VERT, USA) was used to control the stride rhythm. The end of the test was defined as the stage when the participant reached exhaustion, or when he/she could not follow the required stride frequency. To control the amplitude of the stride length a floatable PVC tube in T shape, was tied to a thread of nylon fixed to a brick submerged at the deep end of the swimming pool, in accordance with the method described elsewhere (Wilder et al., 1993). During the warm-up period the height of the floating tube was adjusted for each individual placing the tube to the highest point of knee flexion of the stride cycle. During the entire test, the subjects were instructed to touch the knee on the T tube.

Measures of Outcome

In both tests, continuous respiratory measurements were undertaken using a gas analyser (Vista Mini CPX, USA) and the software (Turbofit 4.0, USA). The gas analyser were calibrated prior each test with a known concentration of oxygen and carbon dioxide. The highest VO_2 achieved in each test were accepted as VO_2 max, regardless of whether the VO_2 max criteria had been fulfilled (Taylor et al., 1955).

The oxygen consumption at the ventilatory threshold (VO_2VT) was defined as the average VO_2 from the preceding load that fits in the following criteria: a. a non-linear increase of ventilation in response to increments in work rate and b. a systematic increase of respiratory oxygen equivalent (VE/VO_2) (Wasserman & Mcilroy, 1964).

The heart rate was recorded at the end of each stage (Polar Accurex, USA), and the rate of perceived exertion (RPE) was measured at 30 seconds during each stage using the Borg scale (Borg, 1973). After the test (third, fifth and eight minutes after ending the test), blood samples were collected to measure lactate concentration (Accusport, USA). . If the lactate concentration was still increasing progressively at the eighth minute, another blood sample was collected three minutes later, and this was repeated until a decrease in lactate concentration was observed. The highest lactate concentration was observed, recorded and used in the analysis.

Statistical Analyses

All data are expressed as means and standard deviation. An independent t test was used to compare the descriptive variables (weight, height, age and VO_2 max TDR) between adapted and non-adapted groups. The interaction between adaptation (adapted versus non-adapted)

and conditions (treadmill versus deep water running) were examined using two-way repeated measures ANOVA. Additionally statistical differences between the main effects of condition and adaptation were analysed in isolation. Statistical significance was accepted as $P < 0.05$.

Results

Subjects' height, weight, age and peak oxygen consumption on treadmill (VO_2 max TDR) are described on Table 1. There were no differences between groups for any of these variables.

Table 1. Subjects' characteristics and VO_2 max on adapted and non-adapted group.

Group	Non adapted (N=7)	Adapted (N=10)
Weight (kg)	59.8 ± 6.1	68.9 ± 17.1
Height (cm)	165.0 ± 5.7	172.2 ± 12.1
Age (years)	30.9 ± 5.3	32.3 ± 6.5
VO_2 TDR max (ml/kg/min)	55.1 ± 4.2	53.8 ± 6.0

Maximal parameters

The results in Table 2 indicate a significant interaction between adaptation and condition (p =0.032), suggesting that adaptation to DWR can affect the results between the different conditions. Results also indicate that all maximal physiological parameters, excluding RER max, were significantly higher in TDR compared to DWR in both groups. Additionally, the

adapted group presented a significantly higher RER max when compared to the non-adapted group for both conditions (TDR and DWR).

Table 2. Maximal physiological responses of adapted and non adapted group in treadmill running (TDR) and deep water running (DWR).

Variables	Non Adapted (*N*=7)		Adapted (*N*=10)		Interaction	Condition	Adaptation
	TDR	DWR	TDR	DWR			
VO$_2$ max (ml/kg/min)	55.1 ± 4.2	44.3 ± 3.3	53.8 ± 6.0	48.3 ± 8.4	p= 0.034	<0.0001	NS
HR max (bpm)	186 ± 11	172 ± 13	186 ± 9	177 ± 11	NS	0.0001	NS
VE max (ml/min)	102.5 ± 12.9	88.5 ± 16.1	121.6 ± 22.4	106.2 ± 29.0	NS	0.012	NS
RPE max	18 ± 2	19 ± 1	18 ± 2	19 ± 1	NS	0.036	NS
RER max	0.99 ± 0.11	0.97 ± 0.14	1.10 ± 0.11	1.09 ± 0.12	NS	NS	0.009
Lactate peak (mmol/l)	9.3 ± 2.0	8.0 ± 1.2	9.6 ± 1.9	7.0 ± 1.4	NS	0.005	NS

NS = non significant

Physiological Parameters at the Ventilatory Threshold (VT)

There were no significantly differences for the interaction (adaptation vs. condition) for the physiological parameters at anaerobic threshold (Table 3). However, VO_2 VT, HR VT, VEVT were significantly higher in the TDR in comparison to DWR. Respiratory exchange ratio at the ventilatory threshold (RER VT) was significantly higher in the adapted group than non-adapted group.

Table 3. Physiological responses at ventilatory threshold (VT) on adapted and non-adapted group in treadmill running (TDR) and deep water running (DWR).

Variables	Non Adapted (N= 7)		Adapted (N= 10)		Interaction	Condition	Adaptation
	TDR	DWR	TDR	DWR			
VO_2 AT (ml/kg/min)	41.0 ± 4.1	31.9 ± 7.4	40.4 ± 6.2	36.1 ± 4.8	NS	0.0002	NS
HR AT (bpm)	163 ± 19	149 ± 22	161 ± 15	151 ± 14	NS	0.002	NS
VE AT (ml/min)	63.6 ± 10.0	54.7 ± 15.5	72.5 ± 18.2	60.7 ± 14.5	NS	0.0006	NS
RPE AT	13 ± 2	13 ± 1	14 ± 2	13 ± 2	NS	NS	NS
RER AT	0.81 ± 0.08	0.83 ± 0.10	0.95 ± 0.06	0.90 ± 0.12	NS	NS	0.023
$\%VO_2AT/VO_2$ max	74.5 ± 6.8	71.7 ± 14.4	75.3 ± 10.0	75.5 ± 7.4	NS	NS	NS

NS = non significant

Discussion

The main finding of this study was that adaptation to DWR affected the maximal oxygen uptake (VO_2 max) in deep water running (Table 2, interaction). The results indicate that although VO_2 max was lower in DWR than in TDR in both adapted and non adapted groups, runners who were adapted to deep water running had a lower reduction in VO_2 max in DWR in comparison to their VO_2 max in TDR. The result of this study support previous findings (Frangolias *et al*., 1996), when greater magnitude difference between treadmill and deep water running was found in runners adapted to DWR who trained at or above ventilatory threshold using steady state or interval training compared to runners who were not adapted to DWR. Adaptation to DWR in this study (Frangolias *et al*., 1996), was defined as individuals who performed at least six sessions of 45 to 60 min. In the present study all runners performed similar training program with two qualified deep water running instructors for at least two months, twice a week. Although accurate measurements of training intensities were not performed the training sessions applied a range of intensities below and above ventilatory threshold during 45 to 60 min training sessions, which was sufficient to promote the observed benefits in the VO_2 max of DWR.

Some studies which compared maximal physiological responses between deep water running and treadmill running have investigated runners who were adapted to DWR (Mercer & Jensen, 1988; Town & Bradley, 1991; Frangolias & Rhodes, 1995; Frangolias *et al*., 1996; Phillips *et al*., 2008). However, in most of the studies (Bishop *et al*., 1989; Green *et al*., 1990; Butts *et al*., 1991a; Svedenhag & Seger, 1992; Glass *et al*., 1995; Michaud *et al*., 1995b; Brown *et al*., 1996a; Brown *et al*., 1996b; Dowzer *et al*., 1998) the DWR

technique was taught just before the test, which may have affected the results of the VO_2max in DWR.

In the present study the group adapted to deep water running had VO_2 max equivalent to 89% of the VO_2 max of the treadmill. Studies of runners that were adapted to DWR, showed that their VO_2 max during DWR was 74% of VO_2 max TDR (Town & Bradley, 1991), 81% of VO_2 max TDR (Phillips et al., 2008), 81.5% of VO_2 max TDR (Mercer & Jensen, 1988) and 91% of VO_2max TDR (Frangolias & Rhodes, 1995). In a longitudinal study, VO_2max of participants improved by 20% during DWR after eight weeks of training (Michaud et al., 1995a). The DWR-VO_2 max at the end of the training program was 86% of VO_2 maxTDR. In the study of Frangolias et al. (1996), with adapted DWR runners, the VO_2 max for the DWR was in a range of 78 to 96% of VO_2max TDR. This variance between participants was attributed to the intensity and type of training that the subjects performed in DWR. Therefore, it can be noticed that even when studies investigated runners adapted to DWR, there is a large variation on the VO_2 max of DWR in relation to VO_2 max TDR (73.5 to 96% of VO_2 max TDR). This variation is likely to be because of the different levels of familiarity with DWR, and also variations from different training frequency, intensity, volume or even DWR technique applied during the test.

In this study the running technique selected (Michaud et al., 1995a) was an attempt to mimic the land running style on land. However, to promote a graded exercise test a T-tube was used in an effort to maintain stride length and progressively increase stride frequency as the reduction in stride length during a graded protocol has been suggested to prevent the achievement of maximal values in DWR (Reilly et al., 2003). A recent study (Killgore et

al., 2006) has identified that although different DWR techniques (cross-country and high-knee) affect biomechanical parameters, they promote similar physiological stimulus. However, in the study of Killgore *et al*. (2006) individuals were only exposed to a short period of adaptation (3 sessions of 30 min). Some adapted individuals in the present study have reported that the technique during the test was slightly different from the technique learned from the instructor during the classes, which may have affected the results. The design of graded exercise test for DWR can be challenging and although, the use of increase in stride frequency (Wilder *et al*., 1993) or increase in weight placed in a bucket (Mercer & Jensen, 1997) have been validated as a graded protocol, both protocols may affect DWR technique.

Although VO_2 max was significantly different, in this study, we have not seen an interaction (adaptation vs. condition) for the other physiological variables measured (VEmax, HRmax, RPEmax, RERmax and peak lactate) (Table 2). Therefore, the extra gain in VO_2 max reported in the adapted group in DWR was not associated with changes in to these variables. A possible justification is that adaptation to DWR may increase muscle recruitment, most possibly oxidative muscle fibers as no interaction was seen in peak lactate levels and RERmax. Additionally, adaptation may promote an improvement in the arterial-venous difference due to physiologic aerobic adaptations that may have occurred in the muscle fiber. Therefore, further studies using EMG analysis need to be conducted comparing individuals adapted and non-adapted to DWR.

Although we expected that adaptation to DWR would affect the response between conditions (DWR and TDR) at the intensity of ventilatory threshold, no interaction

between these variables were observed in this study. One of the reasons could be that ventilatory threshold is influenced by training intensity (Gaskill *et al*., 2001) and this variable was not controlled in this study. Studies that control intensity, duration and frequency of training are necessary to evaluate the effect of adaptation on physiological variables of DWR and TDR.

Although significant interaction was only observed for VO_2 max, when the effect of condition (DWR versus TDR) was analysed in isolation there were significant differences for several maximal variables (VO_2 max, HRmax, VEmax, RPE max and peak lactate) (Table 2). The lower VO_2 max and HR max in DWR compared to TDR has consistently being reported by the literature (Mercer & Jensen, 1988; Town & Bradley, 1991; Butts *et al*., 1991a; Butts *et al*., 1991b; Svedenhag & Seger, 1992; Frangolias & Rhodes, 1995; Glass *et al*., 1995; Michaud *et al*., 1995a; Michaud *et al*., 1995b; Brown *et al*., 1997; Dowzer *et al*., 1999; Nakanishi *et al*., 1999; Broman *et al*., 2006a; Phillips *et al*., 2008). The cardiovascular hypotheses for the lower maximal responses in DWR than TDR are: 1) the increase of central blood volume, as results of the hydrostatic pressure causing a higher stroke volume and therefore lower heart rate for a similar cardiac output (Reilly *et al*., 2003); 2) the thermal effect of water, due the fact that water temperatures below thermo neutral (33-35ºC) reduced HR and increase in stroke volume (McArdle *et al*., 1976); 3) lower muscle activity in DWR because of the possible reduction of muscle activity of the weight bearing muscles. Recent studies (Kaneda *et al*., 2007; Kaneda *et al*., 2008b) have supported the hypothesis of lower muscle activity in DWR as there was a lower EMG activity of soleus and medial gastrocnemius in DWR compared to land water walking and water walking. However, the muscle activity of biceps femoris was significantly higher in

DWR compared to the two other activities (Kaneda *et al*., 2007; Kaneda *et al*., 2008b). The authors attributed the increase in muscle activity of biceps femoris to a greater knee flexion or hip extension of the knee joint during deep running movement. However, these studies (Kaneda *et al*., 2007; Kaneda *et al*., 2008b) have not compared DWR with land running, although differences in hip and knee kinematics were observed in another study which compared DWR with over ground running (Kilding *et al*., 2007). Kilding *et al*. (2007) suggested that individuals should familiarize with DWR before rehabilitation or exercise program due to differences in kinematics and in muscle activity between the two modalities.

The results of the present study contradict the results in the literature of maximal rate of perceived exertion (RPE max). In the present study RPE max was significantly higher in DWR compared to TDR whereas in other studies (Butts *et al*., 1991a; Svedenhag & Seger, 1992; Frangolias & Rhodes, 1995; Phillips *et al*., 2008) RPE max is similar during DWR or TDR.. However, there is not the same consensus on the literature concerning the results of RER max (Town & Bradley, 1991; Frangolias & Rhodes, 1995; Dowzer *et al*., 1999; Nakanishi *et al*., 1999; Phillips *et al*., 2008); VE max (Butts *et al*., 1991a; Frangolias & Rhodes, 1995; Phillips *et al*., 2008) and peak lactate (Svedenhag & Seger, 1992; Frangolias & Rhodes, 1995; Nakanishi *et al*., 1999). The varied response maybe associated with the different maximal protocols applied in different studies and the level of adaptation of the participants.

In the present study it was found that oxygen consumption at ventilatory threshold (VO_2 VT) and heart rate at ventilatory threshold (HR VT) were significantly lower in DWR

compared to TDR as also shown in (Frangolias & Rhodes, 1995). The reasons for this finding may be associated with the cardiovascular and peripheral responses to exercise in the water as previously mentioned (e.g. increase in stroke volume and reduced muscle activity). However, the results of the present study and previous study (Frangolias & Rhodes, 1995) have found that the percentage of ventilatory threshold in relation to VO_2 max ($\%VO_2VT/VO_2$ max) and RER VT were similar between TDR and DWR. Additionally, RPE VT was also similar between the two exercise conditions. This may indicate that intensity on DWR training should be monitored by RPE instead of HR to induce similar physiological responses to TDR at relative to maximal intensity.

The main effect of adaptation was also analysed in isolation in this study. Subjects adapted to DWR had a higher RER at maximal intensity (RER max) and at ventilatory threshold (RER VT) in both conditions (TDR and DWR) (Table 2 and 3). This result cannot be easily explained as there were no associated increases in peak lactate at RPE max or RPE VT to support the suggestion of an increased utilization of the anaerobic metabolism in the adapted group. It should be noted that RER during a incremental test is influenced by diet manipulation (Aitken & Thompson, 1989) and that diet was not controlled before the test in the present study.

It has been previously reported that the use of land-based VO_2 max criteria (Taylor et al., 1955) are not recommended for DWR graded exercise test, as according to Phillips et al. (2008), only 45% of the participants have achieved two or more of the VO_2 max criteria. Although, the present study has measured peak lactate which was not measured in the previous study (Phillips et al., 2008), only 40% of the runners in the adapted group and

57% of the non-adapted group achieved two or more of the VO_2 max, supporting previous recommendation.

One of the limitations of this study was the heterogeneous balance between males and females in the adapted and non-adapted group (Adapted: 50% females: 50% males; Non – Adapted: 86% females: 14% males), this may have affected the results. However, the physical characteristics and VO_2 max on treadmill (Table 1) between the two groups were similar, therefore allowing comparisons between the two groups.

Conclusions

In conclusion, the results of this study show that adaptation to DWR can approximate the difference in VO_2 max between TDR and DWR. These could be related to the ability of the adapted group to increase muscle recruitment during DWR. The results of this study also support the previous literature in relation to lower maximal physiological parameters in DWR compared to DWR. This study also indicates that ventilatory threshold occurs at the same percentage of maximal in DWR and TDR and that RPE, is a more appropriate method to indicate relative intensity than heart rate.

Acknowledgments

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