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# Maximal physiological responses to deep and shallow water running

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The maximal physiological responses to treadmill running (TMR), shallow water running (SWR) and deep water running (DWR) while wearing a buoyancy vest were compared in 15 trained male runners. Measurements included oxygen consumption ($\dot{V}O_{2\,max}$), respiratory exchange ratio (RER) and heart rate (HR). Treadmill running elicited $\dot{V}O_{2\,max}$ and $HR_{max}$, which were higher than the peaks attained in both water tests ($p < 0.01$). $\dot{V}O_{2\,peak}$ averaged 83.7 and 75.3% of $\dot{V}O_{2\,max}$ for SWR and DWR respectively. Peak HR for SWR and DWR were 94.1 and 87.2% of the $HR_{max}$ reached in the TMR. RER responses were similar between the three modalities. The observations suggest that the training stimulus provided by water is still adequate for supplementary training. While SWR is potentially an efficient method of maintaining cardiovascular fitness, it needs to be investigated further to establish if it is a viable technique for the injured athlete to employ.

## 1. Introduction

The weight-bearing nature and large muscle recruitment found in running make it one of the most demanding physical activities for the cardiovascular system. It is also responsible for numerous musculoskeletal injuries (Gross and Napoli 1993) with many runners having to reduce training due to injury (Maughan and Miller 1983). Deep water running (DWR) is an increasingly popular form of cardiovascular conditioning both for the injured and uninjured athlete who seeks an aerobic training activity with low impact forces. DWR in a swimming pool simulates the pattern of movement used for running on land with the aid of a flotation device. This enables the subject's head to remain above water and to help maintain an upright position.

Much of the physiological research that has been designed to measure responses in water, aside from swimming, has been focused on the cardiovascular effects of weightlessness encountered by space travellers (Arborelius *et al.* 1972) or on the therapeutic potential of hydrotherapy (Edlich *et al.* 1987, Danneskiold-Samsoe *et al.* 1987, Tsukahara *et al.* 1994). The physiological responses to exercise in air and water may be expected to vary due to the hydrostatic effect of water.

Heart rate has been reported to decrease during head-out water immersion exercise compared with air (Avellini *et al.* 1983, Christie *et al.* 1990, Connelly *et al.* 1990, Norsk *et al.* 1990). The mechanism responsible for the lower heart rate during

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immersion is the redistribution of blood volume from the periphery to the central region. The increased hydrostatic pressure of the water, concomitant with peripheral vascoconstriction to reduce heat loss forces peripheral blood into the thorax. This results in an enhanced venous return and a decreased stroke volume while maintaining cardiac output (Avellini *et al.* 1983).

Several studies have shown that maximal oxygen uptake ($VO_{2\ max}$) attained during treadmill running is lowered during DWR (Navia 1986, Glass 1987, Butts *et al.* 1991a, b, Town and Bradley 1991, Frangolis and Rhodes 1995). Town and Bradley (1991) found that the highest values reached for $VO_2$ and HR were 73.5 and 86% of $VO_{2\ max}$ and $HR_{max}$ on land, respectively. Butts *et al.* (1991b) found $VO_2$ and HR during DWR to be 86 and 91% of those obtained on land. These findings are similar to those reported in other studies (Navia 1986, Butts *et al.* 1991a, Svedenhag and Seger 1992). Responses to submaximal exercise on the treadmill and when immersed to the neck have also been investigated (Navia 1986, Bishop *et al.* 1989, Ritchie and Hopkins 1991, Svedenhag and Seger 1992). Svedenhag and Seger (1992) reported lower HR during DWR than treadmill running at any given $VO_2$. A similar finding was noted by Navia (1986), suggesting that the same metabolic loading is associated with a lower HR during DWR compared with treadmill running (TMR).

Studies into the effects of shallow water running (SWR) have been scarce. Town and Bradley (1991) found that the highest values reached for $VO_2$ and HR in water 1.3 m deep were 90.3 and 88.6% of $VO_{2\ max}$ and $HR_{max}$ on land. A greater HR was required during SWR to elicit the same oxygen consumption, supporting the work of Gleim and Nicholas (1989) who demonstrated that $VO_2$ was lower for a given HR when exercising in waist depth water compared with exercise in air. Sheldahl *et al.* (1984) noted that during cycle ergometry in water, HRs were 10 beats.min$^{-1}$ lower compared with cycling on land for a given $VO_2$.

The physiological responses to DWR have been the focus of research investigating the use of water running as an alternative training mode to training on land. However, runners may prefer to train in shallow water as this technique requires no flotation device and is less threatening to those who fear deep water. It is not clear to what extent the normal exercise intensities associated with strenuous training on land can be induced when training is performed in water. Thus, to improve the understanding of the physiological responses to water running, the maximal metabolic responses of trained runners to DWR and SWR running were compared with TMR.

## 2. Method

Fifteen male runners were recruited in response to information distributed at a number of running events around the north-west of England between March and May 1995. Mean age ($\pm$SD), height ($\pm$SD) and mass ($\pm$SD) for the group were 40.93 ($\pm$9.48) years, 1.72 ($\pm$0.07) m and 69 ($\pm$9.03) kg respectively. Subjects were asked to limit the intensity and duration of their training the day prior to testing by not performing speed work or running $> 30$ min. Subjects were also instructed not to run on the morning prior to testing. Written informed consent to participate was obtained from all subjects and the study had been approved by the institution's Human Ethics Committee.

The subjects undertook three experimental sessions on three separate days including running on a motor-driven treadmill (Woodway, Germany), and running in the shallow and deep ends of a swimming pool while wearing a buoyancy device

(Wet Vest, Bioenergetics Inc., Pelham, AL, USA). The order of the three test conditions was counterbalanced to eliminate sequence bias. Each subject was tested between 08:00 and 10:00 h. Prior to the experimental testing, all subjects were familiarized with treadmill and water running. The latter included being instructed on the correct technique of running in deep and shallow water and being allowed to practice the technique. Two of the subjects who had not mastered the technique of DWR by the end of the familiarization lesson were given a further practice session.

### 2.1. *Treadmill tests*

Each subject performed a continuous maximal oxygen uptake test on a motor-driven treadmill. Upon completing a standardized 4 min warm-up an individualized predetermined treadmill velocity (mean 13.7 $km.h^{-1}$, range 11.3 – 16.1 $km.h^{-1}$) was undertaken. At 3-min intervals thereafter the inclination was increased by 2.5% until the subject reached volitional exhaustion. Oxygen uptake, minute ventilation (VE), respiratory exchange ratio (RER) and HR were measured during the last 30 s of each workload. The subject gave a signal when he approached 1 min to exhaustion, whereupon measurement of $VO_2$ and HR measurements were recommenced. Verbal encouragement was given to the subject during the last minute of the test to give his maximal effort.

### 2.2. *Water tests*

An indoor swimming pool was used for the two water tests with a water temperature of 29°C. All subjects could swim. During the water running, subjects were fitted with a Wet Vest with the water being between chin and nose level while maintaining a motionless, vertical position in the deep water and waist height in the shallow water (1.2 m deep). Each subject was tethered approximately 1 m from the side of the pool with a cord. Aqua pool shoes (Swim Shop, Luton, UK) were worn for the SWR to prevent slippage on the pool floor and to protect the subjects feet from sharp tiles. Workloads for the water running were measured in leg alternations $min^{-1}$ starting at 120 strides $min^{-1}$ for the DWR and 132 strides $min^{-1}$ for the SWR going up in increments of 12 strides $min^{-1}$ for the initial workload then 8 strides $min^{-1}$ until volitional exhaustion had been reached. A metronome was used to maintain an accurate pace which was placed at the pool side.

Oxygen uptake, VE and RER were determined from meteorological balloons (Cranlea, Birmingham, UK). Subjects wore a nose-clip and breathed through a one-way non-rebreathing valve (Hans Rudolf Inc., Kansas City, MO, USA). Immediately following the $VO_2$ max test, the collected samples were taken to the laboratory and analysed for $CO_2$ and $O_2$ concentrations using calibrated Servomex (Crowborough, Sussex, UK) gas analysers. A Harvard dry gas meter (Scientific and Research Instruments, Ltd, Edenbridge, Kent, UK) was used to quantify the expired air volume at which time the temperature of the collected air was determined. HR was monitored during all three conditions using a short-range radio telemetry system (Sports Tester 3,000, Kempele, Finland). A transmitter was worn at the base of the sternum at the xiphisternal joint and signals were transmitted to a receiver attached to the back of the Wet Vest in the water and to the treadmill on land. Repeated measures ANOVA was used in statistical analysis. The Tukey *post hoc* test was employed to locate differences among the means. Regression analysis was used to assess the relationship between HR and oxygen consumption in each of the three running media.

## 3. Results

Table 1 displays the mean ($\pm$SD) maximal physiological responses to running in the three media. Treadmill running was found to elicit $VO_{2\,max}$ and $HR_{max}$ which were higher than the peaks achieved in both water tests ($p < 0.05$). Oxygen consumption and HR were also greater when comparing SWR with DWR at maximal exercise ($p < 0.05$). The peak $VO_2$ averaged 83.7 and 75.3% of TMR for SWR and DWR respectively. Peak HR for SWR and DWR were 94.1 and 87.2% of the responses to the TMR run. Maximal minute ventilation were 137.1 ($\pm$21.9), 124.9 ($\pm$24.5) and 110.9 ($\pm$17) $l.min^{-1}$ for the TMR, SWR and DWR conditions respectively. Significant differences occurred between all three conditions ($p < 0.05$).

No method existed to determine whether subjects had obtained maximal exertion during the $VO_{2\,max}$ test until after its completion. Table 1 represents the respiratory exchange ratios (RER). Values were > 1.1 for the treadmill condition indicating a true maximal test. SWR and DWR tests produced lower RERs of 1.07 ($\pm$0.08) and 1.08 ($\pm$0.05) respectively, although differences among treatments were non-significant.

The relationship between HR and $VO_2$ as exercise intensity increased was assessed during the three running conditions. When the data for the whole group were examined, significant differences were found between the slope and intercept regression line parameters of the three running conditions. However, no significant differences were found between the regression lines of the two water conditions and

Table 1. Maximal physiological responses to running under the three conditions.

| | Running on land | Shallow water running | Deep water running |
|---|---|---|---|
| $VO_{2\,max}$ ($ml.kg^{-1}.min^{-1}$) | 55.39 ($\pm$8.46)*# | 45.94 ($\pm$6.1)## | 41.27 ($\pm$6.37) |
| $VE_{max}$ (BTPS) | 137.1 ($\pm$21.9)*# | 124.9 ($\pm$24.5)## | 110.9 ($\pm$17.0) |
| $HR_{max}$ ($b.min^{-1}$) | 176 ($\pm$12)*# | 165 ($\pm$16)## | 153 ($\pm$16) |
| RER ($VCO_2.VO_2^{-1}$) | 1.11 ($\pm$0.1) | 1.07 ($\pm$0.1) | 1.08 ($\pm$0.1) |

*Significant at $p < 0.05$ land versus shallow water running. #Significant at $p < 0.05$ land versus deep water running. ##Significant at $p < 0.05$ shallow water running versus deep water running.

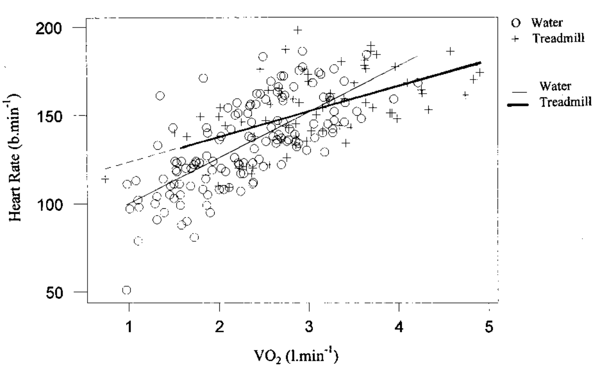


Figure 1. Relationship between heart rate and oxygen consumption while running on land and in water.

therefore these data were pooled. As such, two regression lines were required to describe the relationship between HR and $VO_2$, one for the treadmill condition and the second for the water conditions. The fitted regression lines are plotted in Figure 1. The two regression lines met at a point where $VO_2$ was 3.05 $l.min^{-1}$ and HR was 153 $b.min^{-1}$. The regression models suggest that the majority of heart rate observations recorded in the water were lower than those observed when running on the treadmill, below this intersection point of $VO_2$ = 3.05 $l.min^{-1}$.

## 4. Discussion

Previous studies have reported that the $VO_2$ obtained during DWR ranged from 73.5 (Town and Bradley 1991) to 90% (Glass 1987) of the $VO_{2\ max}$ observed during TMR. The present study lies within this range with 75.3% of values determined during TMR. The SWR technique better simulates the land-based running with peak $VO_2$ and HR reaching 83.7 and 94.1% of treadmill values respectively. These data are comparable with those of Town and Bradley (1991) who reported $VO_2$ and HR of 90.3 and 88.6% of maximal values respectively. They failed to state the temperature of the water in which the subjects were exercising. During water immersion, water attenuates cardiorespiratory dynamics (McArdle *et al.* 1976, Avellini *et al.* 1983, Gleim and Nicholas 1989) and reduces HR, the decreases depending on the water temperature.

In the present study, subjects exercised in a water temperature of 29°C which is considerably lower than the thermoneutral temperature during exercise in water (30 – 34°C). It has been shown that performing upright exercise in below thermoneutral temperatures produces lower peak $VO_2$ compared with exercising on land with HR increasing or decreasing to a corresponding increase or decrease in water temperature (Avellini *et al.* 1983). A water temperature of 29°C could have contributed to the lowered HR found during DWR and SWR. In addition, during DWR, the eradication of weight-bearing and the addition of resistance is likely to decrease the work performed by the large muscle groups of the legs. While this is concomitant with an increased proportion of work being performed by the upper extremities compared with land-based exercise, the overall effect is a lowering of $VO_2$. Holmer *et al.* (1974) attributed lower $VO_{2\ max}$ to a decrease in the arterio-venous difference during swimming compared with land running. This indicates that less $O_2$ is extracted from the blood, possibly the result of a reduction in muscle blood flow during water immersion.

One research group has previously examined the HR – $VO_2$ relationship in response to incremental treadmill and water running (Yamaji *et al.* 1990), concluding that there was considerable variability of the slope and intercept of the linear regressions between subjects. This was attributed to different skill levels in the subjects chosen. Those who were more proficient at running in water produced lower HR responses for a given $VO_2$ during water running while the less skilled in water running had higher HR for a given $VO_2$ during water running. The subjects in the present study were considered skilled at the water running technique as a result of prior training in the procedures. From Figure 1 it is evident that the HR – $VO_2$ relationship in water was different from that observed on land with HR being lower for a given $VO_2$ at lower exercise intensities, but higher when reaching maximal exercise. This might be explained by elevations in stroke volume (Rennie *et al.* 1971). In the present study, the cross-over point at 3.05 $l.min^{-1}$ is thought to be the result of increased arm motions during water running when approaching maximal exercise compared with running on land. Arm exercise is associated with a higher HR than observed during leg exercise at the same $VO_2$ (Lewis *et al.* 1983).

The enhanced responses of SWR compared with DWR are probably due to a push-off phase being provided by the surface of the swimming pool floor. During SWR the weight-bearing nature of the exercise far outweighs the buoyancy effect of the water, thus simulating the land running action better. Further analysis of how closely running in shallow water replicates that of land running is needed.

These observations support the benefits of running in deep water to supplement training while decreasing the orthopaedic trauma linked with running on land. Despite the reduction in physiological responses when exercising in the water at a $VO_2 < 3.05$ l.min$^{-1}$, the observations suggest that the training stimulus provided by the water is still adequate for supplementary training. While the SWR is potentially an efficient method of maintaining cardiovascular fitness, it needs to be investigated further to establish if this is a viable technique for injured athletes to employ.

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