Maximal Physiological Responses to Deep Water Running at Thermoneutral Temperature

Yasuto Nakanishi, Tetsuya Kimura and Yoshinori Yokoo

Department of Science, Kobe University

Abstract. This study investigated the metabolic demands of deep water running (DWR) compared with those of treadmill running (TMR) while the water and ambient temperatures were kept under thermoneutral condition. Two maximal tests, one on treadmill and the other running in deep water using the Wet Vest (Lincoln life jacket) were undertaken by twenty healthy non-smoker males (Age = 28.0 ± 9.2 years). The order of trials was counterbalanced with half of the subjects completing the treadmill first and the rest completing the water running first. Oxygen consumption (VO2), ventilation, heart rate (HR), respiratory exchange ratio (RQ), ratings of perceived exertion (RPE) and blood lactate were measured. VO2max (2.68 vs 3.40 ml/kg/min), HRmax (171.5 vs 190.8 beats/min), maximal minute ventilation (98.5 vs 113.3 l/min), and peak blood lactate value (10.44 vs 12.47 mmol/l) in response to DWR were significantly lower than those of TMR in the thermoneutral conditions. The lower VO2max and HRmax values of DWR compared to those of TMR are shown to be attributed to the hydrostatic effects caused by water and different muscle recruitment patterns between DWR and TMR.

Keywords: VO2max, HRmax, resting HR, RPE, and blood lactate

Introduction

In recent years, deep water running (DWR) has become one of the popular modes of cardiovascular conditioning exercises among the injured athletes as well as others who desire a low impact aerobic workout. DWR consists of simulated running in the deep end of a pool aided by a flotation device (vest or belt) to provide enough buoyancy for keeping the head above water.

Previous studies (Butts et al., 1991ab; Svendenhag and Seger, 1992; Town and Bradley, 1991) which compared maximal physiological responses during DWR with those of land-based running showed decreased values of maximal oxygen uptake (VO2max) and maximal heart rate (HRmax) during DWR. Butts et al. (1991a) hypothesized that lower VO2max and HRmax values in response to DWR were due to the combined factors, such as hydrostatic effects caused by water immersion (WI) and water temperature.

Water temperature of 35°C is considered thermoneutral for resting WI. Craig and Dvorak (1968) showed that the water temperature required for thermoneutrality was lower during dynamic exercises than at rest. Water temperature of between 29°C and 33°C is thought to be thermoneutral during dynamic exercises (Choukroun and Varene, 1990; Israel et al., 1989; Choukroun and Varene, 1989; McArdle et al., 1976). WI below thermoneutral water temperature causes peripheral vasoconstriction resulting in an increase of the central blood volume (McArdle et al., 1976), which then leads to a decrease of HR and an increase of stroke volume (SV). When exercising above thermoneutral water temperature, HR increases more rapidly because a greater cardiac output is directed to the skin (Nadel, 1984). Imposing the additional heat load due to exercise in this environment is likely to cause a significant effect on the circulation (Gleim and Nicholas, 1989). To our knowledge, almost all previous studies (Frangolias and Rhodes, 1995; Svendenhag and Seger, 1992; Town and Bradley, 1991; Butts et al., 1991ab) which compared maximal physiological responses to DWR with treadmill running (TMR) has been conducted below the thermoneutral water temperature. Consequently, there would always be thermal effects of water, which cannot be ignored when investigating physiological responses to DWR. It would be desirable to elicit the effects of water temperature in order to understand the metabolic demands of DWR better.

This study was designed in order to better understand the metabolic demands of DWR compared with those of TMR while the water and ambient temperatures were kept under thermoneutral condition.

Methods

Subjects

Twenty healthy non-smoker males (Age = 28.0 ± 9.2 years) were selected and asked to participate in the study. All participants were students at the University of Kobe and were instructed to follow a normal diet and fasting for at least 4 hours before the maximal tests.

Experimental Protocol

The study was conducted in a thermoneutral environment with water temperature of 30°C. The subjects were asked to perform two maximal tests, one on a treadmill and the other running in deep water using the Wet Vest (Lincoln life jacket). The order of trials was counterbalanced with half of the subjects completing the treadmill first and the rest completing the water running first. Oxygen consumption (VO2), ventilation, heart rate (HR), respiratory exchange ratio (RQ), ratings of perceived exertion (RPE) and blood lactate were measured.

Data Analysis

Data were analyzed using the paired t-test. Differences were considered significant at p < 0.05.
years, Height=172.0 – 6.9 cm, Weight=67.1 – 11.8 kg) were selected for the study. Informed consents were obtained prior to participation in any practice or data collection sessions. Subjects were also required to complete the Physical Activity Readiness Questionnaire (PAR-Q). The PAR-Q medical screening evaluation used in this study was developed by the British Columbia Ministry of Health as a conservative, objective, self-administered test. In addition, subjects received a monetary stipend for their participation.

Methods and procedures

Two maximal tests, one on treadmill and the other running in deep water using the Wet Vest (Lincoln life jacket) were completed by each subject. The order of trials was counterbalanced with half of the subjects completing the treadmill first and the rest of those completing the water running first. At least 24 hours, but no more than 1 week elapsed between tests. Prior to any testing, all subjects underwent practice sessions of running on treadmill and in deep water.

Protocol for TMR

TMR consists of a 4 minute warm-up at 160 m/min and at 0% elevation followed by an increase of 20 m/min every two minutes. If treadmill speed of 220 m/min (at 10th minute of the test) was reached, further increases of the intensity were made by increasing the grade by 2% every 2 minutes until physiological or volitional fatigue. Air temperature of between 21 C and 26 C is considered to be thermoneutral during dynamic exercise (Wilmore and Costill, 1994). Throughout all treadmill tests, the ambient temperature was maintained at 22.5 – 1.0 C.

Protocol for DWR

DWR followed the Wilder/Brennan protocol (1993) for graded exercise tests of aqua running, beginning at an initial rate of 48 cycles/min. Each cycle consisted of one complete cadence cycle (two steps). Subjects exercised at the rate of 48 cycles/min for a total of 4 minutes for warm-up, followed by subsequent 2-minute stages. Cadence was increased to 66 cycles/min in the second stage and thereafter by 3 to 4 cycles/min. When subjects fell behind the cadence, or when their physiological responses did not increase in response to the higher cadence, they were strongly encouraged to complete at least another full minute. They had been previously instructed to “go all out” during this final minute. The highest oxygen consumption value obtained for a complete minute was used to represent the subject’s peak value. An acceptable stride was one in which a) the leading leg maintained at least 90 degrees of knee flexion through the swing phase with the succeeding coronal plane and b) the trail leg extended at least 0.5 foot posterior to the coronal plane.

It is desirable to set the water temperature within high range of thermoneural since DWR is often used as one of the rehabilitation exercises for injured athletes and as cardiac conditioning for the elderly. The water temperature was kept constant at 32.5 – 0.2 C throughout the testing.

In both conditions, to establish VO2max, two of the three criteria were to be met. The criteria included a plateau of VO2 and HR with increasing workload and a respiratory exchange ratio (RER) ≤ 1.1.

Metabolic measurements were obtained at 20 second intervals using a Teem-100 Metabolic Analysis System (Aerosport Inc.). HR was monitored continuously using a Polar Vantage XL Heart Rate Monitor at 20 second interval. Blood samples were drawn from the fingertip at 30 second after finishing the test and subsequently analyzed for blood lactate values with a Lactate Pro Blood Lactate Analyzer (Kyoto Daiichi Kagaku Co.). At the same time, ratings of perceived exertion (breathing and legs separately) were measured. The 10-point Borg Scale (0–10 scale) was used to measure RPE at 2 minute intervals (Borg 1982). Resting HR on land was measured with the subject in a seated position at the end of 5 minutes of quiet sitting by Polar Vantage XL Heart Rate Monitor. Resting HR in the water was measured with the subject floating head above the water at the end of 5 minutes of quiet floating by Polar Vantage XL Heart Rate Monitor.

Statistical analysis

Data were analyzed using a series of dependent t-tests. Significance was established at the 95% confidence level (p ≤ 0.05). Data were presented as mean ± SD.

Results

The physiological responses to both TMR and DWR, and results of t-test are presented in Table 1.

At maximal effort there were no significant differences in RPE and RQ between the treadmill and water running values. HRmax, resting HR, maximal minute ventilation, and VO2max values were significantly lower (p<0.001) in response to DWR than those for TMR.

Discussion

RPE

Similar RPE values were noted at maximal effort of the two conditions in the present study. This verified that the subjects perceived the same amount of effort in both conditions. In spite of this, we found significant differences in physiological responses between DWR and TMR.
HR

Alternation in cardiovascular dynamics is found to occur when the body is exposed to hydrostatic forces. In the study of Johnson et al. (1977) the depressed heart rate was noted in all subjects after entering the water and standing submerged to the shoulder level. In the present study the resting HR in water were 4.7 beats/min lower than those on land. This significantly lower resting HR in the water as compared to that on land is thought to be largely due to the effect of hydrostatic water pressure exerted against the legs and torso (Arborelius et al., 1972; Hong et al., 1969). The hydrostatic pressure causes an immediate increase in venous return, right atrium pressure and, hence, stroke volume. Increased stroke volume allows for the maintenance of cardiac output with lower HR (Christie et al., 1990). A reflex response of the cardiovascular system to the cold receptors in the skin could also have contributed to the depressed HR in the water as the water temperature of 32.5 C is slightly lower than thermoneutral for the resting condition (McArdle et al., 1976; Gleim et al., 1989).

Maximal heart rate responses to DWR were 19 beats/min lower than those obtained during TMR. The difference in maximal HR is similar in magnitude to the 17% difference reported by Butts (1991b). On the other hand, no difference was detected in VO2 value in the previous studies (McArdle et al., 1976; Craig and Dvorak, 1969) which compared physiological responses to submaximal modified semireclining cycle ergometer exercise in air and in water under the thermoneutral and equal workload conditions.

In the present study, both water and ambient temperatures were kept within the range of thermoneutral. The lower VO2max value in response to DWR obtained is believed to be due to a combination of cardiovascular responses to hydrostatic pressure and the mechanical constraints imposed on the body when exercising against water resistance. During land exercise, the antigravity muscles of the body are used to maintain body posture, but they are not necessary when being supported by water, thus decreasing the metabolic cost of running in the water.

The difference in DWR and TMR VO2max could also be attributed to limitations of limb movement due to the viscosity friction of water, which would reduce the amount of work done by working muscles.

O2 Pulse

Cardiorespiratory efficiency as evidenced by O2 pulse is calculated as the HR/VO2. Bishop et al., (1989) reported a higher O2 pulse during DWR compared with TMR. These differences in VO2max responses between TMR and DWR in the present study are similar to the 17% difference reported by Butts (1991b). On the other hand, no difference was detected in VO2 value in the previous studies (McArdle et al., 1976; Craig and Dvorak, 1969) which compared physiological responses to submaximal modified semireclining cycle ergometer exercise in air and in water under the thermoneutral and equal workload conditions.

In the present study, both water and ambient temperatures were kept within the range of thermoneutral. The lower VO2max value in response to DWR obtained is believed to be due to a combination of cardiovascular responses to hydrostatic pressure and the mechanical constraints imposed on the body when exercising against water resistance. During land exercise, the antigravity muscles of the body are used to maintain body posture, but they are not necessary when being supported by water, thus decreasing the metabolic cost of running in the water.

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Table 1 Summary of results for physiological responses to maximal TMR and DWR

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Treadmill</th>
<th>DWR</th>
<th>Difference</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE (Breath)</td>
<td>9.65 ± 0.67</td>
<td>9.60 ± 0.82</td>
<td>0.05</td>
<td>0.8474</td>
</tr>
<tr>
<td>RPE (Leg)</td>
<td>9.10 ± 1.86</td>
<td>9.65 ± 0.59</td>
<td>0.55</td>
<td>0.2366</td>
</tr>
<tr>
<td>Resting HR (beats/min)</td>
<td>64.6 ± 11.8</td>
<td>59.9 ± 12.5</td>
<td>4.7</td>
<td>0.0001</td>
</tr>
<tr>
<td>HRmax (beats/min)</td>
<td>190.8 ± 9.1</td>
<td>171.5 ± 13.6</td>
<td>19.3</td>
<td>0.0001</td>
</tr>
<tr>
<td>Ventilation (l/min)</td>
<td>113.3 ± 12.4</td>
<td>98.5 ± 13.9</td>
<td>14.8</td>
<td>0.0001</td>
</tr>
<tr>
<td>VO2max (l/min)</td>
<td>3.40 ± 0.46</td>
<td>2.68 ± 0.43</td>
<td>0.72</td>
<td>0.0001</td>
</tr>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>51.8 ± 9.2</td>
<td>41.0 ± 8.7</td>
<td>10.8</td>
<td>0.0001</td>
</tr>
<tr>
<td>RQ</td>
<td>1.05 ± 0.05</td>
<td>1.05 ± 0.08</td>
<td>0.00</td>
<td>0.8474</td>
</tr>
<tr>
<td>Blood Lactate (mmol/l)</td>
<td>12.47 ± 3.49</td>
<td>10.44 ± 2.73</td>
<td>2.03</td>
<td>0.0239</td>
</tr>
<tr>
<td>HR/VO2</td>
<td>3.81 ± 0.75</td>
<td>4.34 ± 0.86</td>
<td>0.54</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Mean ± SD.
cardiovascular efficiency during TMR. The authors speculated that subjects were mechanically less efficient during DWR.

Maximal minute Ventilation

Maximal minute ventilation value was 12% lower in DWR compared to that of TMR, which is in agreement with the studies by Butts et al. (1991ab) and Dressendorfer et al. (1976), who reported 9%, 12%, and 11% lower WI maximal ventilation values. Lower maximal ventilation in response to DWR suggests that the increase in intrathoracic blood volume and hydrostatic chest compression during WI restrict ventilation values. The hydrostatic pressure of the water compresses the abdomen and raises the diaphragm to a position approaching full expiration (Agostoni et al., 1966). The increase in intrathoracic blood volume has also been reported to contribute to the decrease in lung compliance during WI (Agostoni et al., 1966; Dahlback et al., 1978).

Blood Lactate

Blood lactate value for the DWR was lower than the value for the TMR. This result is comparable to the data reported by the previous studies (Town and Bradley, 1991; Frangolias and Rhodes, 1995). The restricted blood flow may be responsible for the lower blood lactate value exhibited at DWR VO2max as Town and Bradley (1991) suggested.

Conclusions

In conclusion, we found that the VO2max, HRmax, maximal minute ventilation, and peak blood lactate value in response to DWR were significantly lower than those of TMR in the thermoneutral conditions. The lower VO2max and HRmax values of DWR compared to those of TMR are shown to be attributed to the hydrostatic effects caused by water and different muscle recruitment patterns between DWR and TMR.

References

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Correspondence to: Yasuto Nakanishi, 1-14-18 Oji Akashi, Hyogo 673-0022, Japan