Physiological Responses to Maximal Treadmill and Deep Water Running in the Young and the Middle Aged Males

Yasuto Nakanishi, Tetsuya Kimura and Yoshinori Yokoo
Department of Science, Kobe University

Abstract. In this study we investigated the effects of age factors on physiological responses to deep water running (DWR) compared with those of treadmill running (TMR) while the water and ambient temperatures were kept in thermoneutral conditions. Fourteen young healthy non-smoker males (Age = 20.4 ± 3.3 years, Height = 170.7 ± 6.2 cm, Weight = 65.1 ± 11.4 kg) and fourteen middle aged healthy non-smoker males (Age = 38.6 ± 4.4 years, Height = 171.8 ± 4.7 cm, Weight = 75.4 ± 9.6 kg) were selected for the study. Two maximal tests, one on the treadmill and the other running in deep water using the Wet Vest (Lincoln life jacket) were completed by each subject. The order of trial was counterbalanced with half of the subjects in each group completing TMR first and the rest of those completing DWR first. Although the young males had significantly (P<0.05) higher relative VO2max, HRmax than the middle aged males, there were no significant differences in absolute VO2max, respiratory exchange ratio (RER), maximal ventilation (VEmax), ratings of perceived exhaustion (RPE), and peak blood lactate values between the two groups. In conclusion, the VO2max, HRmax, VEmax, and peak blood lactate value in response to DWR were significantly lower than those to TMR in both the young and the middle aged males in the thermoneutral conditions. However, there was no significant interaction between age and exercise modes other than RPE of legs at maximal efforts in the present study. We found that the decrease in the maximal physiological responses to DWR compared to TMR is not different between the young and middle aged males.


Keywords: VO2max, HRmax, VEmax, RPE, blood lactate

Introduction

Deep water running (DWR) is a form of aquatic exercise that simulates the movement of normal running on land. When performing DWR, the exerciser runs in the deep end of a swimming pool with the aid of a flotation device (vest or belt) to provide enough buoyancy for keeping the head above water. No contact is made with the bottom of the pool during DWR, which enables the exerciser to eliminate impact (Richie and Hopkins, 1991). DWR is thought to be an appropriate activity for developing fitness with less possibility of injury, especially for those individuals who have an initially low level of cardiovascular fitness, such as the aged.

Generally, the functional capacity of the cardiovascular system declines with aging, resulting in a decrease in maximal oxygen uptake (VO2max) (Astrand, 1960; Kasch et al., 1985; Dill et al., 1967; Robinson et al., 1976). The rate of decline in VO2max in healthy sedentary men during land-based exercise appears to average 10% per decade after 25 years of age (Buskirk and Hodgson, 1987; Dill et al., 1967; Hagberg, 1987; Pollock et al., 1987). This decline was attributed to a decrease in physical activity, a gain in body weight, and age-related changes in cardiovascular systems (Cunningham et al., 1968; Norris and Lundy, 1963; Parizkova, 1963). The development of disease also affects the value of VO2max. In the study of Rogers et al. (1990), sedentary subjects evidenced the expected 8 beats/min decline in maximal heart rate (HRmax) over 8 years span of the study, in keeping with the results of earlier studies (Grimby et al., 1960; Pollock et al., 1987) that indicated that the decline in VO2max is primarily the result of the reduction in HRmax.

Previous studies (Butts et al., 1991ab; Svendenhag and Seger, 1992; Town and Bradley, 1991) which compared maximal physiological responses during DWR with those during land-based running showed decreased values of VO2max and HRmax during DWR. Butts et al. (1991a) hypothesized that lower VO2max and HRmax values in response to DWR were due to a combination of factors, such as hydrostatic effects caused by water immersion (WI) and water temperature. The sensitivities of baroreflex decrease as we age (Smith and Kampine, 1989). Hydrostatic pressure is imposed on exercisers during DWR. To date, it is thought that the effects of age factors on physiological responses to DWR are different from those to land-based exercises. However, to our knowledge, no previous researches have investigated differences between the effects of age factors on physiological responses during
DWR and those during land-based exercises. In addition, it is desirable to investigate the effects of age factors on physiological responses to DWR in order to use DWR as a cardiovascular conditioning exercise for the aged.

This study was designed in order to better understand the effects of age factors on physiological responses to DWR compared with those to TMR while the water and ambient temperatures were kept in thermoneutral conditions.

Methods

Subjects
Fourteen young healthy non-smoker males (Age = 20.4 – 3.3 years) and fourteen middle aged healthy non-smoker males (Age = 38.6 – 4.4 years) were selected for the study. The reason why the middle aged subjects were selected for this study is as follows. Although it is desirable to directly measure the maximal physiological responses to exercises of aged people when the effects of age factors are investigated, it is dangerous for them to exercise with maximal efforts. Therefore, the middle aged males were selected in order to minimize risk factors which were associated with maximal efforts in exercises. None of the subjects participated in any regular exercise program.

Informed consents were obtained prior to participation in any practice and 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 the 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 in each group completing TMR first and the rest completing DWR first. At least 24 hours, but no more than 1 week elapsed between the tests. None of the subjects previously practiced DWR. All the subjects were required to receive technical instructions and adequate practice sessions for DWR and TMR prior to data collection. When they had developed the proper running form, they completed VO2max tests of DWR and TMR.

Protocol for TMR

TMR consists of a 4 min warm-up at 160 m/min at 0% elevation followed by an increase of 20 m/min every two minutes. If a treadmill speed of 220 m/min (at minute 10 of the test) was reached, further increases of the intensity were made by increasing the grade by 2% every 2 min until physiological or volitional fatigue. Throughout all treadmill tests, the ambient temperature was maintained at 22.5 – 1.0 C.

Protocol for DWR

DWR followed the Wilder/Brennan protocol (Wilder et al., 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 min for warm-up, followed by subsequent 2-min 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 degree of knee flexion through the swing phase with the succeeding coronal plane and b) the trail leg extended at least 0.5 feet posterior to the coronal plane. The running form of the subjects was videotaped and monitored simultaneously by one of the experimenters throughout the testing. 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 (RPE) for breathing and legs were measured. The 10-point Borg Scale (0-10 scale) was used to measure RPE at 2 min intervals (Borg, 1982). Resting HR on land was monitored with the subject in a seated position at the end of 5 min 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 min of quiet floating by Polar Vantage XL Heart Rate Monitor.

Statistical analysis

Data were analyzed using a two-factor (age · exercise mode) analysis of variance (ANOVA) with repeated measures. For all statistical measures, significance was established at the 0.05 level of probability.
Results

The physical characteristics of the subjects are presented in Table 1, with middle aged subjects being significantly (P<0.05) heavier than the young subjects. The maximal physiological responses to TMR and DWR of the two groups are shown in Table 2. Although young subjects had significantly (P<0.05) higher relative VO2max, HRmax than the middle aged subjects, there were no significant differences in absolute VO2max, RER, maximal ventilation (VEmax), RPE, and peak blood lactate values between the two groups.

Significantly (P<0.001) lower VE max, relative VO2max, absolute VO2max, and HRmax were obtained in response to maximal DWR compared to TMR regardless of age. Neither maximal RER of the middle aged group nor that of the young group were significantly different between the two exercise modes. The VO2max of the middle aged group in response to DWR was approximately 27% lower than that to TMR and the young group's value in response to DWR was approximately 21% lower than that to TMR. The ANOVA, however, indicated that there was no significant interaction for any of the responses to the tests other than that of RPE of legs for exercise modes and age.

Discussion

In this section, the details of each category will be discussed first, then the remarks of the present study will be given.

RPE

Similar RPE values were noted at maximal effort of the

### Table 1: Means and standard deviations of subjects' physical characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Young (n=14)</th>
<th>Middle aged (n=14)</th>
<th>Difference</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.4 ± 3.3</td>
<td>38.6 ± 4.4</td>
<td>18.2</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170.7 ± 6.2</td>
<td>171.8 ± 4.7</td>
<td>1.1</td>
<td>0.5732</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.1 ± 11.4</td>
<td>75.4 ± 9.6</td>
<td>10.3</td>
<td>0.0158*</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>18.6 ± 5.7</td>
<td>22.7 ± 6.5</td>
<td>4.1</td>
<td>0.0847</td>
</tr>
</tbody>
</table>

Mean – SD. *There is a significant difference between the young and the middle aged.

### Table 2: Maximal physiological responses to DWR and TMR in the young and middle aged males

<table>
<thead>
<tr>
<th>Variable</th>
<th>Exercise</th>
<th>Young</th>
<th>Middle aged</th>
<th>F-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(beats/min)</td>
<td>(beats/min)</td>
<td>Exercise Age Exercise X Age</td>
</tr>
<tr>
<td>RPE (Breath)</td>
<td>TMR</td>
<td>9.29 ± 0.91</td>
<td>9.64 ± 0.74</td>
<td>0.046 0.273 2.685</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>9.71 ± 0.61</td>
<td>9.21 ± 1.12</td>
<td></td>
</tr>
<tr>
<td>RPE (Leg)</td>
<td>TMR</td>
<td>8.57 ± 1.95</td>
<td>9.43 ± 1.60</td>
<td>0.692 0.167 5.889*</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>9.93 ± 0.27</td>
<td>8.79 ± 1.53</td>
<td></td>
</tr>
<tr>
<td>Resting HR</td>
<td>TMR</td>
<td>61.2 ± 6.1</td>
<td>66.6 ± 11.1</td>
<td>4.306* 4.985* 0.059</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>56.3 ± 6.8</td>
<td>61.1 ± 10.4</td>
<td></td>
</tr>
<tr>
<td>HRmax (beats/min)</td>
<td>TMR</td>
<td>193.9 ± 6.7</td>
<td>183.3 ± 13.4</td>
<td>36.545*** 6.202* 0.047</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>169.2 ± 15.1</td>
<td>158.4 ± 19.7</td>
<td></td>
</tr>
<tr>
<td>VE max (l/min)</td>
<td>TMR</td>
<td>107.0 ± 18.0</td>
<td>104.0 ± 18.4</td>
<td>15.108*** 1.069 0.652</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>89.4 ± 18.2</td>
<td>81.7 ± 20.8</td>
<td></td>
</tr>
<tr>
<td>VO2max (l/min)</td>
<td>TMR</td>
<td>3.20 ± 0.52</td>
<td>3.08 ± 0.47</td>
<td>25.083*** 1.660 0.677</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>2.51 ± 0.53</td>
<td>2.25 ± 0.47</td>
<td></td>
</tr>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>TMR</td>
<td>49.5 ± 7.6</td>
<td>41.3 ± 8.0</td>
<td>28.122*** 17.821*** 0.951</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>39.0 ± 7.8</td>
<td>30.2 ± 7.1</td>
<td></td>
</tr>
<tr>
<td>RER</td>
<td>TMR</td>
<td>1.07 ± 0.04</td>
<td>1.06 ± 0.05</td>
<td>0.854 0.030 1.549</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>1.03 ± 0.07</td>
<td>1.06 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>Blood lactate</td>
<td>TMR</td>
<td>13.8 ± 3.3</td>
<td>11.9 ± 3.1</td>
<td>15.408*** 0.351 3.012</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>9.2 ± 3.0</td>
<td>10.1 ± 2.8</td>
<td></td>
</tr>
<tr>
<td>VO2/HR</td>
<td>TMR</td>
<td>16.7 ± 3.5</td>
<td>17.1 ± 3.4</td>
<td>8.226* 0.031 0.373</td>
</tr>
<tr>
<td></td>
<td>DWR</td>
<td>15.0 ± 2.2</td>
<td>14.3 ± 2.4</td>
<td></td>
</tr>
</tbody>
</table>

Mean – SD. *; P<0.05, **; P<0.01, ***; P<0.001.
two exercises modes among each age group and there was no significant inter-group difference on RPE values in the present study. This verified that both groups exerted the same amount of effort in both conditions.

HR
In the present study the resting HR values of the young subjects were significantly lower than those of the middle aged subjects, regardless of environments. The resting HR in the water of the young subjects was 4.9 beats/min lower than that on land, while the resting HR in the water of the middle aged subjects was 5.5 beats/min lower than that 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 which enhances stroke volume. Cardiac output was maintained with lower HR due to enhanced stroke volume (Christie et al., 1990). The water temperature of 32.5°C is slightly lower than thermoneutral for the resting condition. Accordingly, decrease in skin blood flow could also have contributed to the depressed HR because the decrease in skin blood flow may maintain the central blood flow (Ikegami, 1997).

HRmax values of the young subjects during TMR and DWR were significantly higher than those of the middle aged subjects (193.9 beats/min vs. 183.3 beats/min for TMR, 169.2 beats/min vs. 158.4 beats/min for DWR). HRmax values of DWR were 24.7 beats/min (12.7%) and 24.9 beats/min (13.6%) lower than those of TMR for the young and the middle aged subjects, respectively. However, there was no significant interaction of age and exercise modes on the values of HRmax. This indicates that the decreases in HRmax during DWR compared with those of TMR were not different between the young and the middle aged subjects. The lower HRmax exhibited at the maximal effort in the two exercise modes among each age group. This verified that both groups exerted the same amount of effort in both conditions.

VO2
The absolute VO2max values of the young and the middle aged subjects during TMR in the present study were 3.20 l/min and 3.08 l/min, respectively, while those values during DWR were 2.51 l/min and 2.25 l/min. These results indicated that there was no significant difference between the two groups in absolute VO2max values, regardless of exercise modes.

The relative VO2max values of the young subjects in the present study were significantly higher than those of the middle aged subjects during TMR (49.5 ml/kg/min vs. 41.3 ml/kg/min) and DWR (39.0 ml/kg/min vs. 30.2 ml/kg/min). However, there was no interaction of age and exercise modes on the values of relative VO2max. This indicates that the decreases in VO2max during DWR compared with those during TMR were not different between young and middle aged males. The lower relative VO2max of the middle aged subjects compared to the young subjects is thought to be mainly due to the increased weight of the middle aged, as the average weight of the middle aged subjects was 10.3 kg heavier than those of the young subjects and absolute VO2max values were not different between the two groups.

In the present study, both water and ambient temperature 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 factors, such as cardiovascular responses to hydrostatic pressure and the different muscle recruitment patterns between the two exercise modes, although this theory was not supported by biomechanical analysis. During land exercises, the body's antigravity muscles are used to maintain body posture, but they are not necessary when being supported by the water, thus decreasing the metabolic cost of running in the water.

O2 Pulse
Cardiorespiratory efficiency as evidenced by O2 pulse is calculated as the VO2/HR. Similar O2 pulse values were noted at the maximal effort in the two exercise modes among each age group. However, O2 pulse values during DWR were significantly lower than those during TMR regardless of age. Bishop et al. (1989) reported that the lower O2 pulse during DWR was largely a result of lower VO2, not that of higher HR. The authors speculated that subjects were mechanically less efficient during DWR because of two reasons. The first is O2 transport capacity, thus demanding a higher HR responses to achieve a sufficient VO2 for the workload during DWR as Gehring et al. (1997) suggested. The second is the typical movements of both arms and legs during DWR as Town and Bradley (1991) mentioned, although this speculation has not been confirmed by biomechanical analysis. During DWR, the arms move in a typical running fashion but also assist in buoying up the subjects by making circular motions, similar to the arm movements executed while treading water. The
legs also move in an unfamiliar fashion because of the lack of firm footage and slower stride rate.

**VEmax**

There was no significant difference between the two groups in VEmax regardless of exercise modes. Lower VEmax in response to DWR is thought to be due to an increase in intrathoracic blood volume and hydrostatic chest compression during WI. The hydrostatic pressure of the water compresses the abdomen and raises the diaphragm to a position approaching full expiration (Agostoni et al., 1966). This results in the increase in the force required for inspiration by reducing total lung compliance and vital capacity (Agostoni et al., 1966; Dahlback et al., 1978). The increase in central blood volume has also been reported to attribute to the decrease in lung compliance during WI (Agostoni et al., 1966; Dahlback et al., 1978). There was no interaction of age and exercise modes on the values of VEmax. This indicates that the decreases in the values of VEmax during DWR compared with those during TMR were not different between the young and the middle aged males.

**Blood lactate**

The maximal blood lactate values of the young and the middle aged groups were comparable in both exercise modes (13.8 mmol/l vs. 11.9 mmol/l for TMR and 9.2 mmol/l vs. 10.1 mmol/l for DWR). This verified that the subjects exerted the same amount of physical effort in each condition. The lower maximal blood lactate value exhibited at DWR is thought to be due to a lower plasma epinephrine concentration during peak exercise in water as Connelly et al. (1990) suggested.

In the present study we investigated differences between the effects of age factors on physiological responses to DWR and TMR. The obtained results showed that the decrease in the maximal physiological responses to DWR compared to TMR is not influenced by age factors. Considering risk factors, the low impact nature of DWR is recommended as a cardiovascular conditioning for elderly people who are vulnerable to injury. However, careful consideration will be needed when we actually apply the results of the present study for elderly people, since in the present study only young and middle aged males were used to investigate the effects of age factors on physiological responses to DWR. In general elderly people tend to have a smaller amount of muscle mass, weaker muscle strength, and less bone density than normal healthy people due to reduced normal activity levels and/or disuse (Bloomfield, 1997). Characteristics of the above population might affect physiological responses to DWR.

**Conclusions**

In conclusion, the VO2max, HRmax, VEmax, and peak blood lactate values in response to DWR were significantly lower than those to TMR in both the young and the middle aged males under the thermoneutral conditions. However, there were no significant interactions for any of the responses to the tests other than that of RPE of legs for exercise modes and age. We found that the decrease in the maximal physiological responses to DWR compared to TMR is not different between young and middle aged males. The results suggest that the decrease in the maximal physiological responses to DWR compared to TMR is not influenced by age factors. However, further studies using elderly people will be needed to further detect the effects of age factors on physiological responses to DWR.

**References**


Craig AB, Dvorak M (1966) Thermal regulation of man
Cunningham D, Montoya H, Metzner H, Keller J (1968) Active leisure time activities as related to age among males in total population. J. Gerontol 23: 551-559

Received: August 8, 1998
Accepted: February 23, 1999
Correspondence to: Yasuto Nakanishi, 1-14-18 Oji Akashi Hyogo 673-0022, J Japan
e-mail: yassy@pb.highway.ne.jp