Journal of Aging and Physical Activity, 2002, **10**, 306-313

Maximal Physiological Responses to Deep-Water and Treadmill Running in Young and Older Women

Kelly S. Chu, Edward C. Rhodes, Jack E. Taunton, and Alan D. Martin

The purpose of this study was to assess the difference in maximal physiological responses between an acute bout of deep-water running (DWR) and treadmill running (TMR) in young and older adults. Participants were 9 young and 9 older women who performed maximal DWR and TMR tests. Maximal measures included oxygen consumption (VO_{2max}), heart rate (HR_{max}), ventilation (VE), respiratory-exchange ratio (RER), and blood lactate (BLac). The young women exhibited higher VO_{2max}, HR_{max}, VE, and BLac than did the older women for both exercise conditions ($p < .05$). Lower VO_{2max} and HR_{max} values were observed with DWR for both age groups ($p < .05$). No significant differences were found for VE, RER, and BLac in either group between exercise conditions, nor a significant interaction between exercise conditions or ages for any of the variables measured. The data suggest that although older adults exhibit lower maximal metabolic responses, differences between DWR and TMR responses occur irrespective of age.

Key Words: aging, cardiorespiratory fitness, training

The predisposition of the lower limbs to stress during land running presents a problem for those susceptible to repetitive-stress injuries, elderly adults prone to bone fractures, and people with musculoskeletal diseases. To avoid the orthopedic trauma associated with land running, many individuals have turned to water running, the aquatic equivalent of land running, as a modality for low-impact aerobic conditioning (Frangolias & Rhodes, 1996). Although water running has been used as a substitute for land running, it has been well documented that there are many physiological differences between the two forms of exercise. Deep-water running (DWR) elicits a lower maximal heart rate (HR_{max}) and oxygen consumption (VO_{2max}) than does land-based running, regardless of one's experience or fitness level (Brown, Chitwood, Beason, & McLemore, 1997; Butts, Tucker, & Greening, 1991; Butts, Tucker, & Smith, 1991; Dowzer, Reilly, Cable, & Nevill, 1999; Frangolias & Rhodes, 1995; Glass, Wilson, Blessing, & Miller, 1995; Michaud,

The authors are with the School of Human Kinetics, and Taunton also with the Allan McGavin Sports Medicine Clinic, University of British Columbia, Vancouver, BC, Canada V6T 1Z1.

Rodriguez-Zayas, Andres, Flynne, & Lambert, 1995; Svedenhag & Seger, 1992; Town & Bradley, 1991).

It has been proposed that HR_{max} reduction during DWR is a direct result of hydrostatic compression causing a redistribution of blood from the periphery to the central regions. The effect of this would be to acutely increase the preload stress of the heart, forcing a larger stroke volume and subsequently decreasing HR (Avellini, Shapiro, & Pandolf, 1983; Craig & Dvorak, 1969; McArdle, Magel, Lesmes, & Pechar, 1976; Sheldahl et al., 1987). In contrast, VO_{2max} reductions might be related to differences in the active musculature involved during DWR (Frangolias & Rhodes, 1996; Moening, Scheidt, Shepardson, & Davies, 1993). Differences in other physiological responses between water and land running appear not to be as clear. Blood lactate (BLac) levels have been reported to be higher (Glass et al., 1995; Svedenhag & Seger, 1992) and lower (Frangolias & Rhodes, 1995; Town & Bradley, 1991), and respiratory exchange ratios (RER) have been reported to be higher (Glass et al.) and lower (Butts, Tucker, & Greening, 1991; Frangolias & Rhodes, 1995; Svedenhag & Seger; Town & Bradley) during maximal DWR than during maximal treadmill running (TMR).

Differences between TMR and DWR appear to be similar across genders (Butts, Tucker, & Greening, 1991; Glass et al., 1995), as well as age groups up to 40 years (Nakanishi, Kimura, & Yokoo, 1999). Derion et al. (1992) reported significant differences in HR and stroke volumes during head-out water immersion between young and older individuals (40–54 years), suggesting that the mechanisms regulating these parameters in the water might be different in older age groups. To date, no study has compared the physiological response of young and older (i.e., 60 plus years) participants during DWR and TMR. The paucity of knowledge regarding the physiological changes associated with DWR in this population makes it difficult to ascertain whether this form of exercise would be beneficial for a population group at high risk of impact-related fractures. Determining the effects that water immersion and DWR have in this population would provide valuable information for generating exercise programs, particularly for those who are unable to participate in traditional land-based programs because of osteoporosis, osteoarthritis, or other musculoskeletal diseases. The first step toward generating such programs is to determine the type of exercise response that elderly individuals exhibit after an acute bout of DWR and how it differs from that of young individuals. Therefore, the purpose of this study was to investigate the responses of DWR compared with TMR in elderly women and to determine whether these responses are similar to those of young women.

Methodology

PARTICIPANTS

Eighteen women, 9 young (23.6 ± 4.7 years) and 9 older (63.3 ± 2.9 years), volunteered to participate in the study. All participants were inactive (participating in less than 1 hr/week of exercise) but otherwise healthy, with no history of cardiovascular, respiratory, or orthopedic disease. In addition, the older group was screened for medical history of arthritis and osteoporosis.

APPARATUS

Loading protocols during the DWR test required a tethered apparatus consisting of a double-pulley system with one end attached to a bucket and the other to a floatation belt worn by the participant. Workload (resistance) was increased by adding beanbags of a predetermined weight (in grams) to the bucket. Participants were required to run within 5 cm behind a visible marker extending from the edge of the pool. Increases in bucket weight would then force them to run harder and faster in order to maintain their position in the pool. Initial bucket weight and loading protocol for each participant were determined during the second familiarization session when mock tests were performed to determine the approximate weight at peak effort. Test protocols were then set so that maximal DWR tests would last approximately 8 min.

PROCEDURES

All participants were unfamiliar with DWR and thus given one instructional session (15 min) and two familiarization sessions (each 30 min) to ensure that proper deep-water running was performed during the maximal DWR test. All DWR tests were completed in an indoor pool. This study was approved by the University of British Columbia Clinical Research Ethics Board, and written informed consent was obtained from all participants.

The instructional session and first familiarization session involved the researcher demonstrating the proper movements of DWR to each participant on dry land. Participants then mimicked the instructor on land to prepare to perform this task in the water. All participants were fitted with a floatation belt to help keep their heads above water during DWR. Proper DWR form was defined as (a) trunk position slightly forward from upright, (b) swing-phase leg brought to a slightly less than horizontal position, (c) elbow flexion of approximately 90°, (d) forward and backward arm movement, and (e) hands open in the sagittal plane or in a closed fist to prevent paddling. During the second familiarization session each participant was attached to a tethered apparatus to become adept in DWR with added resistance. Once a participant performed DWR properly with the tethered apparatus she was scheduled for two tests: one maximal DWR and one maximal TMR test. Tests were administered at least 48 hr apart, and test sequences were randomly assigned to avoid any practice effects of the maximal-exercise test. All exercise tests (TMR, DWR) were performed with air temperatures kept constant at 21 °C.

Before the maximal DWR test, all participants were given 15 min to stretch and 10 min to warm up in the water with no resistance to acclimatize themselves to the pool temperature (~28 °C). Participants were fitted with special floatation belts that provided them with enough buoyancy to keep their heads above water and allowed for their attachment to a tethered apparatus. The tethered apparatus inhibited forward movement and allowed for increases in resistance every minute until exhaustion. The metabolic measuring system (Beckman Metabolic Cart, SensorMedics, Yorba Linda, CA) was placed poolside to allow for continuous monitoring of respiratory gases. The loading protocol for the young group was 500 g to start, with increases of 200 g/min. The older group started at a load of 200–300 g and increased 100–200 g/min, depending on their strength and fitness level. All tests were performed until exhaustion, which was defined as the inability to maintain position in the water, improper DWR form, VO_2 plateau (<2 ml · kg · min^{-1} change), RER >1.10, or volitional fatigue.

The maximal TMR test was completed in an exercise-physiology laboratory on a motor-driven treadmill. Participants were given 15 min for stretching and a 5-min warm-up on the treadmill. The protocols used for the TMR test were set to a slow jog for the young group and a brisk walk for the older group. The young group started with a speed of 5.5 miles/hr and 0% grade. The grade was increased 2% every minute until exhaustion. The protocol for the older group was the same, except their speed was set at 3.5 miles/hr. All tests were performed until exhaustion, which was defined as a VO_2 plateau (<2 ml · kg · min^{-1} change), RER >1.10, HR near the age-predicted maximum (220 – age), or volitional fatigue.

During both DWR and TMR tests, participants breathed into a mouthpiece connected to a metabolic cart so that we could measure VO_2, VCO_2, and VE, which were automatically calculated and output from the metabolic cart. Heart rates were monitored during both test protocols using a Polar heart-rate monitor (Polar Electro Inc., Woodbury, NY). Two minutes after the test, a 2-ml sample of blood (via finger prick) was taken to determine BLac concentrations using a handheld lactate analyzer (YSI Yellow Springs Instrument, Yellow Springs, OH).

DATA ANALYSIS

A 2 × 2 repeated-measures ANOVA (SPSS, Chicago, IL) was used to compare the maximal physiological responses (VO_{2max}, VE, HR, RER, and BLac) between DWR and TMR and between age groups. Mean differences were considered significant at $p < .05$.

Results

All participants reached maximal exercise capacity during DWR and TMR tests as reflected by a plateau in VO_{2max}. The participants' physical characteristics and maximal physiological responses during TMR and DWR tests are shown in Tables 1 and 2, respectively.

Maximal HR, VO_{2max}, VE, and BLac were significantly lower in the older group than in the young in the same testing condition. No differences in RER were apparent between the age groups in the same testing condition (Table 2).

Table 1 Mean Values of the Participants' Physical Characteristics (*N* = 18)

Physical characteristic	Young (n = 9)	Older (n = 9)
Age (years)	23.6 ± 4.7	63.3 ± 2.9
Height (cm)	165.5 ± 3.6	162.1 ± 9.1
Weight (kg)	58.4 ± 8.6	63.4 ± 9.4

Table 2 Mean Values of the Maximum Performance Parameters for DWR and TMR in Young and Older Age Groups (N = 18)

Parameter	DWR		TMR	
	Young	Older	Young	Older
VO_{2max} (L/min)	$2.46^{a,c} \pm 0.38$	$1.11^{b,c} \pm 0.14$	$2.70^{a,d} \pm 0.36$	$1.47^{b,d} \pm 0.36$
VO_{2max} ($ml \cdot kg \cdot min^{-1}$)	$43.17^{a,c} \pm 9.11$	$17.98^{b,c} \pm 2.95$	$47.06^{a,d} \pm 8.88$	$23.07^{b,d} \pm 3.31$
HR (beats/min)	$182.33^{a,c} \pm 9.14$	$156.44^{b,c} \pm 11.25$	$192.33^{a,d} \pm 8.75$	$167.11^{b,d} \pm 10.22$
VE (L/min)	$80.96^{c} \pm 10.48$	$49.82^{c} \pm 4.69$	$82.92^{d} \pm 14.41$	$56.89^{d} \pm 10.71$
RER	1.11 ± 0.06	1.04 ± 0.09	1.18 ± 0.09	1.15 ± 0.10
BLac (mmol/L)	$8.62^{c} \pm 2.07$	$5.73^{c} \pm 1.51$	$8.99^{d} \pm 1.38$	$6.39^{d} \pm 2.18$

Note. DWR = deep-water running; TMR = treadmill running; HR = heart rate; VE = ventilation; RER = respiratory-exchange ratio; BLac = blood lactate.
[a]Significant differences between TMR and DWR for the young group, $p < .05$. [b]Significant differences between TMR and DWR for the older group, $p < .05$. [c]Significant differences between the young and older during DWR test, $p < .05$. [d]Significant differences between the young and older during TMR test, $p < .05$.

Maximal HR and VO_{2max} were significantly greater during TMR than during DWR for both age groups, but these differences were not significantly different between the age groups (Table 2). No differences in VE, RER, or BLac were detected between TMR and DWR tests for either age group (Table 2).

Discussion

The reduction in orthopedic stress on the lower limbs during DWR makes this form of running more favorable than land-based running, especially for older adults at high risk of impact-related fractures. To minimize the risk of fracture for individuals with musculoskeletal diseases (i.e., osteoporosis, osteoarthritis), a non-weight-bearing form of exercise would be more favorable. Because the feasibility and popularity of DWR are so great, it would be of particular interest to determine whether it could be used as an alternative for elderly individuals seeking ways to aggressively train and improve cardiovascular health. Before such a program can be employed, however, acute responses to DWR in this population group need to be understood. To our knowledge, no studies thus far have investigated the role that water immersion plays in physiological responses during an acute bout of DWR in an elderly population group. Therefore, this study marks the first attempt to investigate maximal physiological responses between DWR and TMR across young and older population groups.

Age is associated with a reduction in maximal-exercise responses. VO_{2max} has been shown to decrease approximately 1% per year after the age of 25 (Heath, Hagberg, Ehsani, & Holloszy, 1981). Similar reductions in HR_{max} occur with advancing age, as represented by the age-predicted HR_{max} equation, 220 – age. The older participants in this study demonstrated similar age-related changes in VO_{2max} (~50% lower than young group) and slightly below-normal reductions in HR (~30 beats/min lower than the young group). When comparisons were made between DWR and TMR HR responses for age groups and testing conditions, however, similar differences were observed.

Data from the present study revealed appreciably lower VO_{2max} during the DWR than during TMR (43.17 vs. 47.06 ml · kg · min^{-1}) for the young group. These findings are consistent with those of previous studies (Brown et al., 1997; Butts, Tucker, & Greening, 1991; Butts, Tucker, & Smith, 1991; Frangolias & Rhodes, 1995; Glass et al., 1995; Michaud et al., 1995; Nakanishi et al., 1999; Svedenhag & Seger, 1992; Town & Bradley, 1991) that have suggested that differences in VO_{2max} might be a result of differences in muscle-recruitment patterns between DWR and TMR (Michaud et al.; Svedenhag & Seger). DWR elicits greater activation of the upper body musculature and decreased metabolic response from the larger inactive antigravity muscles (Frangolias & Rhodes, 1995; Glass et al.). A biomechanical study of DWR (Moening et al., 1993) revealed that muscle-recruitment patterns are in fact different between DWR and TMR, supporting the idea that differences in muscle-recruitment patterns contribute to the reduction in VO_{2max}. Changes in HR response might also be associated with the decline in VO_{2max} in the water (Craig & Dvorak, 1969; Frangolias & Rhodes, 1995). The results from our older women revealed similar differences between DWR and TMR VO_{2max} (17.98 vs. 23.07 ml · kg · min^{-1}), suggesting that changes in muscle-recruitment patterns might occur across all age groups, irrespective of age-associated reductions in maximal-exercise responses.

Maximal HRs were also lower during DWR than during TMR for both the young (182.3 ± 9.1 vs. 192.3 ± 8.7 beats/min) and older (156.4 ± 11.2 vs. 167.1 ± 10.2 beats/min) age groups in this study. There was no significant interaction between age and exercise modes on maximal HR values, suggesting that HR reductions in water occur independent of age. This is in agreement with the results of a study by Nakanishi et al. (1999), who observed similar decrements in HR between young and middle-aged men for both resting and exercise conditions. In part, these changes in HR in the water might be explained by the hydrostatic compression exerted against the legs and torso (Arborelius, Ballidin, & Lundgren, 1972; Hong, Cerretelli, Cruz, & Rahn, 1969). The compression at the periphery immediately increases venous return, central blood volume, and preload. This enhances stroke volume, allowing HR reductions to occur while maintaining cardiac output (Christie et al., 1990). Heart-rate reductions might also be related to cardiovascular adjustments to water temperature (Craig & Dvorak, 1969; McArdle et al., 1976). McArdle et al. suggested that exercising in water temperatures below 29 °C (thermoneutral) results in thermogenic response, effectively lowering HR. The pool temperature in this study was recorded at ~28 °C, which might partially explain the decrements in HR during DWR for both age groups.

Although the young group had significantly higher VE during both DWR (81.0 ± 10.5 vs. 49.8 ± 4.7 L/min) and TMR (82.9 ± 14.4 vs. 56.9 ± 10.7 L/min) tests, no significant differences were observed between exercise conditions for both age groups.

These findings support those of Butts, Tucker, and Greening (1991); Svedenhag & Seger (1992), and Frangolias & Rhodes (1995), but other studies have documented a significant decline in VE during maximal DWR (Butts, Tucker, & Smith, 1991; Nakanishi et al., 1999). The latter authors postulated that the decrease in VE was attributable to the combination of hydrostatic compression of the abdomen and elevation of the diaphragm, causing a reduction in total lung compliance and vital capacity. In view of the disparity among studies regarding ventilatory changes associated with DWR, it is unknown at this time what mechanisms control VE during maximal exercise in the water. Nonetheless, it appears that VE responses are not age dependent. Our findings concur with those of Nakanishi et al., who reported that there were insignificant differences in DWR and TMR VE between age groups.

Inconsistencies in BLac and RER responses with DWR also plague the literature regarding comparisons of physiological responses in TMR and DWR. The data in this study demonstrated similar BLac and RER responses for both age groups. These results agree with those of Town and Bradley (1991) and Frangolias and Rhodes (1995). In contrast, Svedenhag and Seger (1992) and Glass et al. (1995), who looked at young individuals, reported higher DWR BLac levels. These authors suggested that DWR evokes a greater reliance on anaerobic metabolism, partly because of lowered perfusion pressure in the legs caused by the redistribution of the blood to the central regions, changes in muscle-activation patterns, and a longer absolute muscle-contraction time. The cause of these inconsistencies is unknown, but it might be a result of differences in muscle-recruitment patterns or the familiarity of the participants with DWR (Frangolias & Rhodes, 1996). Although there are discrepancies in the literature regarding these variables, the data from the present study would suggest that elderly individuals exercise at equal intensities during DWR and TMR. To confirm this finding, more studies should be done in this area to ascertain the true effects that DWR has on anaerobic performance in this population.

In summary, DWR appears to elicit lower VO_{2max} and HR values than does TMR, with little effect on VE, BLac, and RER responses. These changes associated with DWR appear to be independent of age, because older individuals exhibit the same acute responses as their younger counterparts do. Bearing this in mind, further research is now warranted to determine whether elderly individuals can benefit from a long-term DWR training program to achieve the same benefits reported by studies investigating the effects of DWR training in previously inactive young individuals—this type of training program would have great implications for the health of our older population.

References

Arborelius, M., Ballidin, U.I., & Lundgren, C.E. (1972). Hemodynamic changes in man during immersion with the head above water. *Aerospace Medicine*, **43**, 592-598.

Avellini, B.A., Shapiro, Y., & Pandolf, K.B. (1983). Cardio-respiratory physical training in water and on land. *European Journal of Applied Physiology & Occupational Physiology*, **50**, 255-263.

Brown, S.P., Chitwood, L.F., Beason, K.R., & McLemore, D.R. (1997). Deep water running physiologic responses: gender differences at treadmill-matched walking/running cadences. *Journal of Strength and Conditioning Research,* **11**, 107-114.

Butts, N.K., Tucker, M., & Greening, C. (1991). Physiologic responses to maximal treadmill and deep water running in men and women. *American Journal of Sports Medicine*, **19**, 612-614.

Butts, N.K., Tucker, M., & Smith, R. (1991). Maximal responses to treadmill and deep water running in high school female cross country runners. *Research Quarterly for Exercise and Sport,* **62**, 236-239.

Christie, J.L., Sheldahl, L.M., Tristani, F.E., Wann, L.S., Sagar, K.B., Levandoski, S.G., et al. (1990). Cardiovascular regulation during head-out water immersion exercise. *Journal of Applied Physiology*, **69**, 657-664.

Craig, A.B., & Dvorak, M. (1969). Comparison of exercise in air and in water of different temperatures. *Medicine and Science in Sports,* **1**, 124-130.

Derion, T., Guy, H.J.B., Tsukimoto, K., Schaffartzik, W., Prediletto, R., Poole, D.C., et al. (1992). Ventilation-perfusion relationships in the lung during head-out water immersion. *Journal of Applied Physiology*, **72**, 64-72.

Dowzer, C., Reilly, T., Cable, N.T., & Nevill, A. (1999). Maximal physiological responses to deep and shallow water running. *Ergonomics,* **42**, 275-281.

Frangolias, D.D., & Rhodes, E.C. (1995). Maximal and ventilatory threshold responses to treadmill and water immersion running. *Medicine and Science in Sports and Exercise,* **27**, 1007-1013.

Frangolias, D.D., & Rhodes, E.C. (1996). Metabolic responses and mechanisms during water immersion running and exercise. *Sports Medicine,* **22**, 38-53.

Glass, B., Wilson, D., Blessing, D., & Miller, E. (1995). A physiological comparison of suspended deep water running to hard surface running. *Journal of Strength and Conditioning Research,* **9**, 17-21.

Heath, G.W., Hagberg, J.M., Ehsani, A.A., & Holloszy, J.O. (1981). A physiological comparison of young and older endurance athletes. *Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology*, **51**, 634-640.

Hong, S.K., Cerretelli, P., Cruz, J.C., & Rahn, H. (1969). Mechanics of respiration during submersion in water. *Journal of Applied Physiology*, **27**, 535-538.

McArdle, W.D., Magel, J.R., Lesmes, G.R., & Pechar, G.S. (1976). Metabolic and cardiovascular adjustment to work in air and water at 18, 25, and 33°C. *Journal of Applied Physiology*, **40**, 85-90.

Michaud, T.J., Rodriguez-Zayas, J., Andres, F.F., Flynn, M.G., & Lambert, C. P. (1995). Comparative exercise responses of deep-water and treadmill running. *Journal of Strength and Conditioning Research*, **9**, 104-109.

Moening, D., Scheidt, A., Shepardson, L., & Davies. G. J. (1993). Biomechanical comparison of water running and treadmill running. *Isokinetics and Exercise Science*, **3**, 207-215.

Nakanishi, Y., Kimura, T., & Yokoo, Y. (1999). Physiological responses to maximal treadmill and deep water running in the young and the middle aged males. *Applied Human Sciences,* **18**, 81-86.

Sheldahl, L., Tristani, F., Clifford, P., Kalbfleisch, J., Smits, G., & Hughes, C. (1987). Effect of head-out water immersion on response to exercise training. *Journal of Applied Physiology*, **60**, 1878-1881.

Svedenhag, J., & Seger, J. (1992). Running on land and in water: comparative exercise physiology. *Medicine and Science in Sports and Exercise,* **24**, 1155-1160.

Town, G.P., & Bradley, S.S. (1991). Maximal metabolic responses of deep and shallow water running in trained runners. *Medicine and Science in Sports and Exercise,* **23**, 238-241.