Oxygen Consumption, Heart Rate, Rating of Perceived Exertion, and Systolic Blood Pressure With Water Treadmill Walking

David R. Dolbow, Richard S. Farley, Jwa K. Kim, and Jennifer L. Caputo

The purpose of this study was to examine the cardiovascular responses to water treadmill walking at 2.0 mph (3.2 km/hr), 2.5 mph (4.0 km/hr), and 3.0 mph (4.8 km/hr) in older adults. Responses to water treadmill walking in 92 °F (33 °C) water were compared with responses to land treadmill walking at 70 °F (21 °C) ambient temperature. After an accommodation period, participants performed 5-min bouts of walking at each speed on 2 occasions. Oxygen consumption ($VO_{2}$), heart rate (HR), systolic blood pressure (SBP), and rating of perceived exertion (RPE) were significantly higher during therapeutic water treadmill walking than during land treadmill walking. Furthermore, $VO_{2}$, HR, and RPE measures significantly increased with each speed increase during both land and water treadmill walking. SBP significantly increased with each speed during water treadmill walking but not land treadmill walking. Thus, it is imperative to monitor HR and blood pressure for safety during this mode of activity for older adults.

**Keywords:** buoyancy, hydrostatic pressure, weight bearing

Aquatic exercise is a popular mode of physical conditioning and rehabilitation. Water buoyancy reduces stress on joints during exercise while water resistance provides a means of muscle strengthening in a supported environment. The aquatic environment is especially useful for older adults because of their increased susceptibility to injuries and their disproportionate number of musculoskeletal problems compared with the general population (Takeshima, Masatoshi, Kobayashi, Tanaka, & Pollock, 1997). The importance of aquatic exercise is evident considering that older adults constitute the fastest growing segment of the population in the United States and the world (Longley, 2003).

Water exercise has been credited with improving muscular and cardiovascular fitness, reducing musculoskeletal stress, reducing pain, increasing flexibility, improving ambulation stability, and enhancing psychological wellness (Alexander, Butcher, & MacDonald, 2001; Byrne, Craig, & Wilmore, 1996; Lord, Mitchell, & Williams, 1993; Whitlach & Adema, 1996). In addition, when water temperature
is above 90 °F (32 °C), an analgesic effect results (Craig, 1996). The hydrostatic pressure of water, however, can alter the cardiovascular responses to exercise (Arbo-relius, Dalldin, & Lundgren, 1972). During water immersion, hydrostatic pressure causes blood to move from the periphery to the thorax, creating increases in stroke volume and cardiac output. Heart rate remains the same or decreases and systolic blood pressure remains the same or increases, depending on the ratio of cardiac output to vascular resistance. These effects might have an even greater impact on older adults when combined with the natural decline in cardiovascular efficiency associated with aging (Brooks, Fahey, & White, 1996).

Although several authors have studied the cardiovascular effects of water immersion at rest, the impact of walking or jogging in water at neck level, and the response to walking on the pool floor at various depths, few have compared the effects of water treadmill walking with land treadmill walking (Arbo-relius et al., 1972; Bishop, Frazier, Smith, & Jacobs, 1989; Brown, Chitwood, Beason, & McLemore, 1997; Butts, Tucker, & Greening, 1991; Butts, Tucker, & Smith, 1991; Byrne et al., 1996; Craig & Dvorak, 1968; Davidson & McNaughton, 2000; Derion et al., 1992; Farhi & Linnarsson, 1977; Gleim & Nicholas, 1989; Hall, Bisson, & O’Hare, 1990; Hall, MacDonald, Maddison, & O’Hare, 1998; Mercer & Jensen, 1998; Michaud, Rodriguez-Zayas, Andres, Flynn, & Lambert, 1995; Napoletan & Hicks, 1995; Svedenhag & Seger, 1992; Takeshima et al., 1997; Town & Bradley, 1990; Weston, O’Hare, Evans, & Corrall, 1987; Whitley & Schoene, 1987). In addition, very few studies have used older adults as participants (Shono et al., 2000).

For water treadmill walking to be a safe and effective form of exercise and rehabilitation for older adults, it is imperative that the cardiovascular responses to this activity be understood. Thus, the purpose of this study was to examine the effects of slow, medium, and fast treadmill walking in water at 92 °F (33 °C) on the cardiovascular responses of older adults. These responses were compared with walking on a land treadmill at an ambient temperature of 70 °F (21 °C).

**Methods**

**Participants**

Participants included 20 employees of a southeastern U.S. medical center (13 men and 7 women). All participants displayed joint range of motion and muscle strength within normal limits as described by Norkin and White (2003) and Hislop and Montgomery (2002), respectively, and were free of weight-bearing discomfort. Their blood pressure was checked during supine, sitting, and standing to rule out hypertension. The age range of the participants was 55–64 years.

**Instrumentation**

**Heart Rate.** Heart rate (HR) was measured with an Edge Polar heart-rate monitor (Polar USA, Lake Success, NY). This device has a transmitter that straps around the chest and a watch receiver that attaches around the wrist.

**Height and Weight.** The height and weight of participants, without shoes, were measured one time using a Healthometer scale (Continental Scale Corp., Bridge-water, IL).
**Musculoskeletal Screening.** Participants were measured for limitations in joint range of motion (amount of movement available in each motion that the joint provides) using a goniometer (M.A. Rallis Co., Monmouth Jct., NJ) and the American Academy of Orthopaedic Surgeons’ standards, which provide norms for each motion (Norkin & White, 2003). Joints measured were hips, knees, and ankles. In addition, the hip flexors and extensors, knee flexors and extensors, and ankle dorsiflexors and plantar flexors were tested for limitations in muscle strength (0 through 5 scale, 0 = absence of muscle contraction and 5 = able to move the body part through the entire motion against gravity and hold against maximal manual pressure) using manual muscle-testing techniques and scores recommended by Hislop and Montgomery (2002). Participants were also tested for weight-bearing discomfort during standing with full weight on each extremity alone and while walking.

**Physical Activity Readiness Questionnaire.** Participants completed a questionnaire to provide information concerning their readiness to participate in physical activities (American College of Sports Medicine, 2006).

**Rating of Perceived Exertion.** The Borg scale of rating of perceived exertion (RPE) was used as an exercise-intensity indicator. This scale is a simple 6–20 numerical RPE used by many exercise physiologists and coaches to assess subjective levels of intensity during training or physical testing (Borg, 1982). The scale allows the participant to rate the intensity of exercise using numbers.

**Systolic Blood Pressure.** Systolic blood pressure (SBP) was used as the blood-pressure-dependent variable because it rises with exercise, whereas diastolic blood pressure remains relatively unchanged (McArdle, Katch, & Katch, 2001). A standard medical stethoscope and sphygmomanometer (Tycos, Welch Allyn Co., Arden, NC) were used to measure SBP before and during the testing. SBP was recorded at the first sound of blood rush (first Korotkoff sound). During the screening process blood pressure was taken during supine, sitting, and standing. Because of difficulty accurately measuring SBP in water during walking because of the sound of the treadmill and water, SBP measures were taken immediately on cessation of each exercise bout at Minute 5. The blood-pressure cuff was inflated during the last 10 s of walking so that the SBP measures could be taken quickly on cessation of walking. Although not true walking SBP measures, each blood-pressure measurement was completed within 10 s of cessation of exercise. This method was used to enable the measured value to be as close to true walking blood pressure as possible.

**Treadmills.** A Pacer treadmill (Accumill C956, Dallas, TX) was used for the land treadmill tests, and an AquaGaiter (Ferno, Wilmington, OH) was used for the water treadmill tests.

**Oxygen Consumption.** Oxygen consumption (VO₂) was measured by calculating expired gas via a Moxus modular VO₂ system (AEI Technologies, Naperville, IL). The VO₂-testing equipment was manually calibrated (environmental settings and gas-analyzer calibration) at the start of every testing day. This process consisted of allowing the system to warm up and stabilize, then testing both ambient and tank-gas values (oxygen and carbon dioxide). The gases were calibrated to both high and low settings using the tank-gas values (O₂ = 21%, CO₂ = 5%, and O₂ = 16%, CO₂ = 0.04%, respectively). The calibration of the oxygen and carbon dioxide
analyzers was rechecked before each treadmill test. VO₂ measures at Minutes 4 and 5 were averaged for each walking bout.

Procedures

Institutional review board approval was obtained, and all participants reviewed and signed informed-consent forms before participation. Height, weight, HR, and blood-pressure measures, as well as the musculoskeletal screening, were performed by a registered kinesiotherapist. As part of the screening process, participants had HR and blood-pressure measurements taken during supine, sitting, and standing. All participants were free from known cardiovascular and metabolic disorders. A resting standing HR of 100 or greater was exclusionary in this study. A resting SBP greater than 155 mmHg or below 100 mmHg while standing was also considered exclusionary for this study, as was a resting diastolic blood pressure of greater than 95 mmHg or below 60 mmHg while standing.

Range-of-motion and manual muscle tests were performed on the lower extremities. If participants were found to have less than normal joint range of motion, they were excluded from the study. Likewise, participants found to have muscle strength graded as less than normal (5/5) were excluded from the study. Participants were also asked the number of days that they exercised for 30 min or more per week.

To acclimate to both land and water treadmill ambulation, each participant completed a 5-min session at each speed of 2.0 mph (3.2 km/hr), 2.5 mph (4.0 km/hr), and 3.0 mph (4.8 km/hr) on each treadmill the week before testing. These speeds were selected to be similar to those used in prior studies using younger adults (Byrne et al., 1996; Hall et al., 1998; Napoletan & Hicks, 1995). The ambient air during land treadmill walking was 70 °F (21 °C), and the water treadmill was in 92 °F (33 °C) water. The water depth was at the level of the waist (iliac crest).

Both land and water sessions and the speeds of walking were completed in a random, counterbalanced order. Each participant completed a 5-min bout at each speed. Participants were asked to walk in a normal fashion with reciprocal arm swing. Water and land treadmill tests were separated by 24 hr. Each participant’s VO₂, HR, and RPE were measured during the last 2 min of each exercise bout and the mean scores used for comparison. The SBP was measured immediately on cessation of walking at the end of each exercise bout. Participants ceased walking between bouts until their HR returned to within 10 beats/min of their starting HR.

All participants were asked to refrain from smoking and drinking tea, coffee, or other caffeinated drinks for 2 hr before each test. Participants were asked to arrive 2 hr postprandial.

Statistical Analyses

Descriptive statistics were calculated to describe the sample being tested. A 2 x 3 repeated-measures analysis of variance (ANOVA) with a multivariate analysis of variance (MANOVA) was used to test the main effects of condition (water or land) and speed (2.0 mph, 2.5 mph, or 3.0 mph) and interactions between condition and speed for each dependent variable (VO₂, HR, RPE, and SBP). Paired t tests were used as post hoc tests to analyze the simple effects. These analyses were calculated...
via the Statistical Analysis System, version 8.0. The level of significance was set at .001 familywise (for each of several comparisons). For the paired $t$ tests, Bonferroni corrections were used, resulting in a level of significance set at .0112 for the simple effects.

**Results**

Male and female participants had a mean age of 58.0 years. Their mean height was 68.2 in. (1.7 m; men $69.5 \pm 2.3$ in., women $65.7 \pm 1.6$ in.), and their mean weight was 82.1 kg (men $86.3 \pm 13.6$ kg, women $74.2 \pm 16.9$ kg). The mean resting HR of participants was $80.5 \pm 9.8$ beats/min, and their resting SBP was $124 \pm 12.7$ mm Hg. Demographic details and characteristics broken down for men and women appear in Table 1.

There was a significant interaction between the main effects of walking and speed on VO$_2$, $F(2, 18) = 32.36, p < .0001$, Wilks’s Lambda = .218. There was also a significant interaction between speed and condition for HR, $F(2, 18) = 55.21, p < .0001$, Wilks’s Lambda = .140. Likewise, there was a significant interaction between condition and speed for RPE, $F(2, 18) = 17.07, p < .0001$, Wilks’s Lambda = .345, and between the walking condition and walking speed on SBP, $F(2, 18) = 10.65, p < .0009$, Wilks’s Lambda = .458. To determine where the specific differences occurred, paired $t$ tests were run (see Table 2). Paired $t$ tests with Bonferroni corrections were completed to reveal significant simple effects at $\alpha < .0112$. All factor comparisons were found to be significant at the .0001 level except 2.0-mph speed on land with 2.0-mph speed in water. The combination of the water-walking condition and the highest speed (3.0 mph) produced the highest values of VO$_2$, HR, RPE, and SBP. There was just one difference for SBP, where the simple effects for 2.0 mph on land and 2.5 mph on land, as well as 2.0 mph on land and 3.0 mph on land, were not statistically significant. Statistical power was >.82 for all analyses.

<table>
<thead>
<tr>
<th>Table 1: Demographic Data of the Participants ($N = 20$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
</tr>
<tr>
<td><strong>$n$</strong></td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Body-mass index (kg/m$^2$)</td>
</tr>
<tr>
<td># of exercise days/week</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>5 or more</td>
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Discussion

There are limited data on the cardiovascular response of older adults to water walking. Previous researchers have focused primarily on the cardiovascular responses of young adults (Byrne et al., 1996; Gleim & Nicholas, 1989; Hall et al., 1998).

In addition to age differences, comparisons across studies are hampered by differences in water temperature and depth during the water treadmill condition. Water temperature and age of participants have been reported to affect VO$_2$, HR, and SBP (American College of Sports Medicine, 2006; Gleim & Nicholas, 1989).

Generally, water treadmill walking at depths from ankle to chest level have resulted in higher VO$_2$, HR, and RPE than during walking on a land treadmill (Byrne et al., 1996; Gleim & Nicholas, 1989; Hall et al., 1998; Napoletan & Hicks, 1995). This is because the buoyancy of the water at these levels is not great enough to compensate for the added energy needed to overcome the resistance that the water produces against the legs as they are moved through the water. Knee depth and midthigh depth have been documented as placing the highest demand on the cardiovascular system, whereas ankle and chest depths entail lower demands while still inducing higher VO$_2$, HR, and RPE levels than land treadmill walking (Gleim & Nicholas). Water at knee and midthigh levels produces high resistance as the legs are moved through the water. At chest depth water buoyancy is able to offset

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Table 2: Walking Condition and Speed Interactions on VO$_2$, Heart Rate, Ratings of Perceived Exertion, and Systolic Blood Pressure (N = 20), M ± SD

<table>
<thead>
<tr>
<th>Speed Condition</th>
<th>VO$_2$ (ml · kg$^{-1}$ · min$^{-1}$)</th>
<th>Heart rate (beats/min)</th>
<th>Ratings of perceived exertion (Borg scale)</th>
<th>Systolic blood pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 mph</td>
<td>land</td>
<td>9.4 ± 1.3$^a$</td>
<td>93.3 ± 9.9$^c$</td>
<td>7.9 ± 1.8$^i$</td>
</tr>
<tr>
<td></td>
<td>water</td>
<td>9.8 ± 2.5$^b$</td>
<td>98.0 ± 9.8$^f$</td>
<td>8.6 ± 1.6$^j$</td>
</tr>
<tr>
<td>2.5 mph</td>
<td>land</td>
<td>11.1 ± 1.3$^{a,c}$</td>
<td>96.9 ± 10.2$^{e,g}$</td>
<td>9.2 ± 2.2$^{k}$</td>
</tr>
<tr>
<td></td>
<td>water</td>
<td>13.5 ± 2.7$^{b,c}$</td>
<td>110.4 ± 11.4$^{i,g}$</td>
<td>11.1 ± 2.1$^{l,k}$</td>
</tr>
<tr>
<td>3.0 mph</td>
<td>land</td>
<td>12.9 ± 1.6$^{a,d}$</td>
<td>103.3 ± 11.6$^{e,h}$</td>
<td>10.4 ± 1.9$^{i,l}$</td>
</tr>
<tr>
<td></td>
<td>water</td>
<td>18.1 ± 2.6$^{b,d}$</td>
<td>129.5 ± 15.7$^{i,h}$</td>
<td>13.0 ± 2.1$^{j,l}$</td>
</tr>
</tbody>
</table>

Interaction of walking Condition and speed:

\[ F = (2, 18) \]  

Note. VO$_2$ = oxygen consumption; $F$ = the ratio of the between-groups mean square and the within-groups mean square; like letters = significantly different values (i.e., values with $^a$ are significantly different than other values with $^b$).

*p < .001.
some of the added cardiovascular demands of the water resistance. At ankle depth the amount of water resistance is limited compared with knee and midthigh depths, resulting in reduced cardiovascular demand.

In the current sample of older adults, VO$_2$, HR, and RPE levels significantly increased as speed increased during water and land treadmill walking, and water treadmill walking produced higher VO$_2$, HR, and RPE levels than land treadmill walking at speeds of 2.5 and 3.0 mph. At 2.0 mph, there was no difference in VO$_2$, HR, and RPE between land and water treadmill walking. Water resistance increases cardiovascular demand, so the physical effort needed to walk against water resistance at 2.5 mph and 3.0 mph creates greater cardiac demand than walking without water resistance on a land treadmill. At the slowest speed, 2.0 mph, body movement decreases in the water so water resistance is decreased. At this speed, there was likely not enough water resistance to create sufficient demand on the cardiovascular system to produce a greater demand than when walking on a land treadmill. These data (no difference at 2.0 mph with a significant difference at both 2.5 mph and 3.0 mph) support conclusions made by Hall et al. (1998). Those researchers, however, used young adults as participants, water temperatures at 82 °F and 97 °F, and a water depth of chest level. The results of the current study are also similar to those of Napoletan and Hicks (1995), who also noted that VO$_2$ values at 2.0 mph and at chest depth were not higher during water treadmill walking than during land treadmill walking. Napoletan and Hicks also found, however, that VO$_2$, HR, and RPE were higher during water treadmill walking than land treadmill walking at 2.0 mph at midthigh depth. Napoletan and Hicks used young adults as participants as opposed to older adults. At midthigh depth, water resistance is still near that of waist-level water walking, but water buoyancy is decreased so that more effort is required by antigravity muscles.

Byrne et al. (1996) found a significant difference in VO$_2$ and RPE between water and land treadmill walking at 2.0 mph at chest depth. A possible reason for this difference is that at the sternum water level, water resistance to arm swing during walking might have added to the overall water resistance relative to waist depth, when the arms are above the water. The current results also support those of Shono et al. (2000), who also documented that VO$_2$, HR, and RPE values increased as speed increased during water treadmill walking. Shono et al. studied older women (52–64 years of age), an age group similar to that in the current study, but used cooler water (86.5 °F), xiphoid-depth water, and slower speeds (0.75 mph [1.2 km/hr], 1.1 mph [1.8 km/hr], 1.5 mph [1.5 km/hr], and 1.8 mph [2.9 km/hr]) than in the current study.

In the current sample, SBP increased as the speed of water treadmill walking increased and was higher during water treadmill walking than during land treadmill walking only at 2.5 mph and 3.0 mph. As in the cases of VO$_2$, HR, and RPE, SBP was not significantly different between 2.0 mph walking on a land treadmill and 2.0 mph walking on a water treadmill. Again, at 2.0 mph, water resistance is less than at faster speeds. Thus, the activity was likely not intense enough to increase the cardiac workload and, in turn, increase SBP. An explanation of why SBP increased as speeds increased during water treadmill walking and not during land treadmill walking is that the hydrostatic pressure increased blood volume in the thorax, resulting in greater end-diastolic blood volume. A greater stroke volume and cardiac output might have resulted in higher SBP during water exercise. In addition, the added
resistance of walking against water might produce sufficient strain to mechanically compress the peripheral arterial system. This is the mechanism by which blood pressure increases during resistive exercise such as weight training (McArdle et al., 2001). Because of the increase in SBP during water treadmill walking, it might be prudent to monitor the blood pressure of water-exercise participants, especially those with history of hypertension. Results of the current study indicate that water treadmill walking at a speed of 2.5 mph or more might not be a safe activity for individuals with uncontrolled hypertension.

Although water temperature and age have been reported to affect VO$_2$, HR, and SBP (American College of Sports Medicine, 2006; Gleim & Nicholas, 1989), the current study showed results similar to those of other studies regardless of age and water temperature. HR is significantly higher during water treadmill walking at speeds 2.5 mph and above and depths of ankle to chest regardless of temperature. Higher water temperatures, however, might increase the degree to which HR is higher during water treadmill walking as opposed to land treadmill walking. Therefore, understanding the cardiovascular effects of water treadmill walking will allow for safe participation in this mode of exercise.

**Conclusions**

Practical information derived from the data include that for older adults, walking on a water treadmill at waist depth in warm water creates a greater demand on the cardiovascular system than walking on a land treadmill at speeds of 2.5 mph and 3.0 mph. In addition, SBP increases with increased speed during water treadmill walking at waist depth in 92 °F water, so caution should be used when prescribing water treadmill exercise to older individuals with hypertension. Blood pressure should be monitored during water treadmill walking, especially for those with a history of hypertension. Because of the difficulty measuring blood pressure during water exercise, it should be measured before water exercise and during scheduled stoppages in water activity. Walking duration and rate of walking speeds are inaccurate methods of monitoring exercise intensity when moving from a land treadmill program to a water treadmill program because of the increased cardiovascular demands of walking in water. HR and RPE are effective methods of monitoring exercise intensity during therapeutic water treadmill walking at waist depth.

**References**


