Physiological Responses, Rating of Perceived Exertion, and Stride Characteristics During Walking on Dry Land and Walking in Water, Both With and Without a Water Current

Kenji Masumoto, Ayako Hamada, Hiro-omi Tomonaga, Kana Kodama, and Noboru Hotta

**Context:** Walking in water has been included in rehabilitation programs. However, there is a dearth of information regarding the influence of a water current on physiological responses, rating of perceived exertion (RPE), and stride characteristics of subjects while they walk in water. **Objective:** To compare physiological responses, RPE, and stride characteristics of subjects walking in water (with and without a current) with those of subjects walking on dry land. **Design:** Repeated measures. **Setting:** University laboratory. **Participants:** 7 male adults (mean age = 21.6 y). **Intervention:** Subjects walked on a treadmill on dry land and on an underwater treadmill immersed to the level of the xiphoid process. The walking speeds in water were set to be half of that on dry land. **Main Outcome Measures:** Oxygen consumption (VO$_2$), respiratory-exchange ratio (RER), heart rate (HR), minute ventilation (V$_E$), RPE (for breathing and legs, RPE-Br and RPE-Legs, respectively), systolic (SBP) and diastolic (DBP) blood pressures, and stride frequency (SF) were measured. In addition, stride length (SL) was calculated. **Results:** There was no significant difference in the VO$_2$, RER, HR, V$_E$, RPE-Br, and RPE-Legs while walking in water with a current compared with walking on dry land ($P > .05$). Furthermore, VO$_2$, RER, HR, V$_E$, RPE-Br, RPE-Legs, SF, and SBP while walking in water were significantly higher with a water current than without ($P < .05$). **Conclusions:** These observations suggest that half the speed should be required to work at the similar metabolic costs and RPE while walking in water with a current, compared with walking on dry land. Furthermore, it was suggested that the physiological responses and RPE would be higher while walking in water with a current than without.

**Keywords:** gait, immersion, drag force, locomotion

Aquatic exercise has been recommended as an advantageous physical activity. In particular, walking in water has been included in aquatic exercise programs for elderly and young individuals. When prescribing walking in water, drag force may be one of the important characteristics of the water environment. For instance, several authors have reported that muscle activity during exercise in water was higher with a water current (ie, drag force) than without a water current (eg, a 29% increase in erector spinae lumborum muscle activity). Furthermore, it has been reported that aquatic exercise using water-resistance equipment improved physical function (eg, an increase of 36% in plantar-flexion strength). A water current may influence physiological and perceptual responses, as well as stride characteristics, during walking in water. For example, Masumoto et al reported that muscle activity during walking in water with a current tended to be higher than that noted when walking in water without a current. Although some researchers have investigated the physiological responses (eg, oxygen consumption, VO$_2$; heart rate, HR) to walking in water, there is a dearth of information regarding the influence of a current on physiological and perceptual responses and on the stride characteristics of subjects while they walk in water. Such information is necessary to enable practitioners to refine the use of walking in water in rehabilitation programs.

To our knowledge, this study represents the first attempt to investigate the influence of a current on the metabolic costs (VO$_2$; respiratory exchange ratio, RER; and minute ventilation, V$_E$), blood pressure (SBP and DBP for systolic and diastolic blood pressures, respectively), perceptual responses (rating of perceived exertion, RPE: RPE-Br and RPE-Legs, for breathing and legs, respectively), and stride characteristics (stride frequency, SF; stride length, SL) of subjects while they walk in water.
We set out to explore whether such variables differ when individuals walk in water (with and without a current) and on dry land.

Accordingly, the purpose of this study was to compare these physiological responses, RPE, and stride characteristics while walking in water (with and without a current) with those observed when walking on dry land. This study used an underwater treadmill for which the treadmill speed and the current could be controlled independently, thereby enabling the specific influences of a current on physiological responses and RPE to be ascertained and the stride characteristics while walking in water to be clearly elucidated. We hypothesized that a water current would influence physiological responses, RPE, and stride characteristics during walking in water.

Methods

Subjects

Seven male subjects participated in this study (age 21.6 ± 1.1 y, height 172.8 ± 3.8 cm, body mass 64.5 ± 3.4 kg). The subjects were free from acute or chronic cardiopulmonary or musculoskeletal diseases at the time of the study. Each subject gave his written informed consent to participate in the study, the design of which had been approved by the university ethical committee.

Measurements

VO₂, RER, and V̇E were continuously measured using a portable breath-by-breath gas analyzer (K4b², Cosmed, Italy), and data from the final 30 seconds of each stage were analyzed. The gas analyzers were calibrated using known ambient-air and sample gas references, and the turbine flow meter of the K4b² was calibrated with a syringe of known volume before starting each test. HR was recorded continuously using a Polar portable device (Polar Electro, Kempele, Finland) and was analyzed for the final 30 seconds of each stage. SBP and DBP responses were measured with a manual sphygmomanometer at rest before and after the exercise bout with the left arm held horizontal at the level of the heart.10 RPE was measured using Borg’s 6–20 scale13 for breathing (RPE-Br) and legs (RPE-Legs) separately during the final minute of each exercise bout. SF was measured for 60 seconds by counting the number of strides observed during the final minute of each exercise bout. SL was calculated by dividing the walking speed by the SF.

Experimental Procedures

Each subject completed all the tests within a single day. The tests consisted of walking in water with a water current, walking in water without a water current, and walking on dry land. Subjects walked on a treadmill on dry land (ELG-2; Woodway, USA; Waukesha, WI) and on an underwater treadmill (Flowmill, FM-1200D, Japan Aqua Tech, Japan; Figure 1) immersed to the xiphoid-process level. Throughout the test, the water temperature and room temperature were maintained at 31°C and 26°C, respectively.

All subjects practiced walking in water and walking on dry land at various speeds, and they received instruction on the use of the RPE, before beginning the actual tests. After familiarization trials, they were asked to rest in a seated position for 10 minutes on dry land. Then, resting physiological data in water and on dry land were obtained for 5 minutes before each test began. Walking on dry land was carried out at 3 speeds (3.6, 4.8, and 6.0 km/h). The walking speeds in water were set to be half of those on dry land (1.8, 2.4, and 3.0 km/h), based on a previous study of walking in water. The speeds of the water current were 1.8, 2.4, and 3.0 km/h.9 During the trials in water with a current, the subjects walked against the current with it streaming against their chest. The 3 walking speeds were chosen to represent slow, moderate, and fast speeds, to facilitate a comparison of parameters during each condition within each of the speed conditions.9 Each subject completed 4-minute exercise bouts at each speed for each condition, with a 1-minute rest period between the 3 speed settings.11,12 A randomized testing order for the 3 walking conditions (ie, on dry land and in water with and without a current) was used. The order of walking-speed conditions was always slow, moderate, and fast for each walking condition. Each test commenced after the subjects had rested and after it had been ensured that their HR had recovered to its preexercise level. The subjects wore swimsuits and no shoes during the tests in water and on dry land.

Statistical Analysis

Data are expressed as mean ± SD. Normality was determined by visually examining the distribution of the data with a histogram. All parameters were analyzed using a 3 (mode: walking on dry land and in water with and without a current) × 3 (speed: slow, moderate, and fast) repeated-measures ANOVA, with Bonferroni post hoc tests. For all statistical comparisons, the level of significance was set at P < .05.

Results

There was no significant difference in VO₂, RER, HR, and V̇E among the 3 conditions at rest (P > .05; Table 1). VO₂, RER, HR, V̇E, RPE-Br, RPE-Legs, SF, and SL were significantly different among modes (P < .05) and across exercise intensities (P < .001).

The descriptive statistics for VO₂, RER, HR, V̇E, RPE-Br, RPE-Legs, SF, and SL in each condition are presented in Table 2. The VO₂, RER, HR, V̇E, RPE-Br, and RPE-Legs obtained while walking in water with a current were significantly higher than those obtained while walking in water without a current, at all speeds (P < .05). When walking in water, significantly higher SF (P < .05) and significantly lower SL (P < .01) were noted when there was a current than when there was no current.
Furthermore, there was no significant difference in the VO₂, RER, HR, \( V_E \), RPE-Br, and RPE-Legs obtained while walking in water with a current and those obtained while walking on dry land, at any speeds (\( P > .05 \)). However, the SF and SL obtained while walking in water with a current were significantly lower than when walking on dry land at all speeds (\( P < .001 \)). The VO₂, RER, HR, \( V_E \), RPE-Br, RPE-Legs, SF, and SL obtained while walking in water without a current were significantly lower than those when walking on dry land, at all speeds (\( P < .05 \)).

In addition, VO₂, RER, HR, \( V_E \), RPE-Br, RPE-Legs, SF, and SL increased significantly with increasing speed while walking in water (both with and without a current), as well as when walking on dry land (\( P < .05 \)).

The SBP and DBP for each condition are presented in Figure 2. There was no significant difference in the SBP and DBP obtained at rest and before exercise among the 3 conditions (\( P > .05 \)). SBP was significantly different across exercise intensities (\( P < .001 \)) and among modes (\( P < .001 \)). The SBP obtained while walking in water (both with and without a current) was significantly lower than that of walking on dry land, at all speeds (\( P < .05 \)). The SBP obtained at each speed was significantly higher after exercise for all conditions (\( P < .05 \)). DBP was not significantly different across exercise intensities (\( P > .05 \)) or among modes (\( P > .05 \)).

### Discussion

The most important new observation of this study was that VO₂, RER, HR, \( V_E \), RPE-Br, RPE-Legs, SBP, and SF had mean values that were 27%, 8%, 10%, 30%, 13%, 16%, 3%, and 5% higher, respectively, during walking in water with a current than without a current. It has been reported that muscle activations from the lower extremity and trunk muscles during walking in water with a current tended to be higher than without a current. These observations may have been due to the greater drag force experienced while walking in water with a current stream ing against the subjects than when there was no current.

Furthermore, it was evident from this study that the VO₂, RER, HR and \( V_E \), RPE-Br, and RPE-Legs obtained while walking in water with a current and those obtained while walking on dry land were similar at all speeds (ie, 1.8–3.0 km/h and 3.6–6.0 km/h for water and dry-land conditions). This confirms and extends the previously reported observation that approximately half the speed

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**Table 1**  Metabolic Responses at Rest for Each Condition, Mean ± SD

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dry land</th>
<th>Water + cur</th>
<th>Water − cur</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ (ml · kg⁻¹ · min⁻¹)</td>
<td>5.4 ± 1.1</td>
<td>5.5 ± 1.0</td>
<td>5.5 ± 1.2</td>
</tr>
<tr>
<td>RER</td>
<td>0.68 ± 0.02</td>
<td>0.67 ± 0.03</td>
<td>0.68 ± 0.03</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>72.1 ± 7.1</td>
<td>71.4 ± 7.7</td>
<td>72.4 ± 6.0</td>
</tr>
<tr>
<td>( V_E ) (L/min)</td>
<td>10.5 ± 2.0</td>
<td>11.1 ± 3.3</td>
<td>10.1 ± 1.1</td>
</tr>
</tbody>
</table>

**Abbreviations:** Dry land, walking on dry land; Water + cur, walking in water with a current; Water − cur, walking in water without a current; VO₂, oxygen consumption; RER, respiratory-exchange ratio; HR, heart rate; \( V_E \), minute ventilation.
Table 2  Metabolic Responses, Ratings of Perceived Exertion (RPE), and Stride Characteristics During Walking on Dry Land and in Water, With and Without a Current, Mean ± SD

<table>
<thead>
<tr>
<th>Variable</th>
<th>Slow Speed</th>
<th>Moderate Speed</th>
<th>Fast Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry land</td>
<td>Water + cur</td>
<td>Water – cur</td>
</tr>
<tr>
<td></td>
<td>(3.6 km/h)</td>
<td>(1.8 km/h)</td>
<td>(1.8 km/h)</td>
</tr>
<tr>
<td>VO2 (ml · kg(^{-1}) · min(^{-1}))</td>
<td>11.1 ± 1.6</td>
<td>9.9 ± 1.8†</td>
<td>7.8 ± 1.6§§§</td>
</tr>
<tr>
<td>RER</td>
<td>0.75 ± 0.03</td>
<td>0.74 ± 0.03†</td>
<td>0.69 ± 0.04§</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>100.4 ± 6.0</td>
<td>93.5 ± 5.7†</td>
<td>84.7 ± 7.5§§§</td>
</tr>
<tr>
<td>VE (L/min)</td>
<td>19.1 ± 3.5</td>
<td>16.9 ± 2.5†</td>
<td>13.0 ± 2.2§§§</td>
</tr>
<tr>
<td>RPE-Br</td>
<td>9.3 ± 1.1</td>
<td>9.1 ± 0.7†</td>
<td>8.0 ± 0.8§</td>
</tr>
<tr>
<td>RPE-Legs</td>
<td>9.3 ± 1.3</td>
<td>9.1 ± 0.9††</td>
<td>7.7 ± 0.8§§</td>
</tr>
<tr>
<td>SF (strides/min)</td>
<td>53.1 ± 0.9</td>
<td>29.4 ± 1.3***†</td>
<td>28.0 ± 1.1§§§</td>
</tr>
<tr>
<td>SL (m)</td>
<td>1.13 ± 0.02</td>
<td>1.02 ± 0.05***§§§</td>
<td>1.07 ± 0.04§§§</td>
</tr>
</tbody>
</table>

Abbreviations: Dry land, walking on dry land; Water + Cur, walking in water with a current; Water – Cur, walking in water without a current; VO2, oxygen consumption; RER, respiratory-exchange ratio; HR, heart rate; VE, minute ventilation; RPE-Br and RPE-Legs, RPE for breathing and legs; SF, stride frequency; SL, stride length.

***P < .001, dry land vs water + cur.  
†P < .05, ††P < .01, †††P < .001, water + cur vs water – cur.  
§P < .05, §§P < .01, §§§P < .001, dry land vs water – cur.
Walking in Water 179

may be required to induce similar levels of metabolic costs and RPE during walking in water with a current, as compared with walking on dry land (1.8–2.4 km/h and 3.6–4.8 km/h for water and dry-land conditions). On the other hand, VO₂, RER, HR, V̇E, RPE-Br, RPE-Legs, and SBP were lower while walking in water without a current than when walking on dry land. This suggests that the addition of a water current while walking on an underwater treadmill is a necessity if levels of metabolic costs and RPE similar to those obtained when walking on dry land are to be obtained.

We observed that VO₂, RER, HR, V̇E, RPE-Br, and RPE-Legs increased as speed increased while walking in water (both with and without a current), which is in accordance with earlier studies. In addition, it was observed that the SF and SL in water increased as speed increased. Furthermore, it is interesting to note that muscle activity during walking in water was reported to be higher with increasing walking speeds. It was thought that the increased metabolic costs and RPE with increasing walking speeds that we noted in our study may be related to the increase in drag force arising from an increase in movement speed in water (ie, drag increases as a function of velocity squared, v²).

Mean SF and SL while walking in water (with and without a current) were 54% and 93% of those observed on dry land at similar metabolic costs and RPE levels. This is in conformity with previous analyses using older subjects. A possible explanation for the decreased SF and SL noted in this study may be that subjects slowed their movement due to the effect of buoyancy or that drag forces influenced ankle plantar-flexor moment, knee-extension moment, and hip-flexion moment. Furthermore, it has been reported that there is lower muscle activity while walking in water (both with and without a current) than when walking on dry land at similar metabolic costs and RPE levels (~70% of that observed on dry land). These observations suggest...
that the biomechanical characteristics of walking in water and on dry land may be different when walking at similar metabolic costs and RPE levels. Investigating biomechanical parameters during exercise in water is an emerging area of research. Further kinetic and kinematic analyses are needed to better describe the actual mechanism behind the differences in the SF and SL that were noted in this study.

Our results of similar BP responses during rest in water and on dry land are in agreement with previously reported observations by Christie et al. In addition, we observed that SBP increased after walking in water both with and without a current, compared with the value noted before walking (ie, ~15% and ~10% increases for walking in water with and without a current, respectively). This is in agreement with previous studies on BP responses during cycle ergometry (a mean increase of 29%) and walking (a mean increase of 22%) in water. On the other hand, DBP did not change after walking in water either with or without a current compared with the value noted before walking in this study. This is in agreement with the previously reported observation of walking in water at 31°C. However, it has been reported that DBP decreased after walking in water at 35.8°C, compared with the value before exercise. Therefore, a similar experiment conducted in warm water (ie, >31°C) could result in different observations.

It is worth noting that SBP while walking in water (both with and without a current) was lower than that on dry land (approximately 6% and 9% decreases, respectively, for dry land vs water with a current and dry land vs water without a current). The actual physiological mechanism behind the decrease in SBP observed while walking in water remains uncertain. However, it has been reported that plasma norepinephrine and epinephrine concentration were both lower during exercise in water vs water without a current. The actual physiological responses and RPE would be higher while walking in water with a water current than without. Our results may provide a more precise starting point for the development of rehabilitation programs in water for healthy young individuals. However, future studies are required to confirm the current observations in pathological populations.

Acknowledgments

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