Cardiorespiratory Responses During Underwater and Land Treadmill Exercise in College Athletes

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Context: Underwater treadmill (UTM) exercise is being used with increased frequency for rehabilitation of injured athletes, yet there has been little research conducted on this modality. Objective: To determine the cardiorespiratory responses of UTM vs land treadmill (LTM) exercise, particularly with respect to the relationship between heart rate (HR) and oxygen consumption (VO2). Design and Setting: This quantitative original research took place in sports medicine and athletic training facilities at Wake Forest University. Participants: 11 Wake Forest University student athletes (20.8 ± 0.6 y, 6 women and 5 men). Intervention: All participants completed the UTM and LTM exercise-testing protocols in random order. After 5 min of standing rest, both UTM and LTM protocols had 4 stages of increasing belt speed (2.3, 4.9, 7.3, and 9.6 km/h) followed by 3 exercise stages at 9.6 km/h with increasing water-jet resistance (30%, 40%, and 50% of jet capacity) or inclines (1%, 2%, and 4% grade). Main Outcome Measures: A Cosmed K4b2 device with Polar monitor was used to collect HR, ventilation (Ve), tidal volume (TV), breathing frequency (Bf), and VO2 every minute. Ratings of perceived exertion (RPE) were also obtained each minute. Results: There was no significant difference between UTM and LTM for VO2 at rest or during any stage of exercise except stage 3. Furthermore, there were no significant differences between UTM and LTM for HR, Ve, Bf, and RPE on any exercise stage. Linear regression of HR vs VO2, across all stages of exercise, indicates a similar relationship in these variables during UTM \( (r = .94, y = .269x - 10.86) \) and LTM \( (r = .95, y = .291x - 12.98) \). Conclusions: These data indicate that UTM and LTM exercise elicits similar cardiorespiratory responses and that HR can be used to guide appropriate exercise intensity for college athletes during UTM.

Keywords: aquatic, oxygen consumption, rehabilitation

The use of underwater treadmill (UTM) exercise therapy to maintain cardiorespiratory fitness of athletes during injury rehabilitation is rapidly expanding. Hootman et al., in collaboration with the National College Athletic Association,
documented 182,000 injuries over a 16-year period (1987–2003). Because approximately 50% of all injuries involved the lower extremities, UTM exercise therapy would be appropriately indicated. The effect of buoyancy while underwater relieves athletes from having to bear ground-reaction forces greater than their body weight while walking and running. These forces can reach nearly 2 times one’s body weight while walking and anywhere from 2 to 4 times body weight when running on land. However, when water is brought up to the level of the xiphoid process, ground-reaction forces are reduced to just slightly over one’s body weight. Significant reductions in impact forces have also been documented when comparing single-leg jumps performed underwater and on dry land. This is a relatively new therapeutic modality, and there has been limited research on the cardiorespiratory responses and methods for “prescribing” this type of exercise.

One study focusing on college-age runners determined that oxygen consumption (VO2), heart rate (HR), and ratings of perceived exertion (RPE) at maximal exertion were similar for UTM and land treadmill (LTM) running. That investigation concluded that despite slight differences in pulmonary measures (such as minute ventilation and breathing frequency) between UTM and LTM, the similarity in VO2max between the 2 modalities suggests that either can be used successfully to enhance cardiorespiratory conditioning of college runners. In contrast, a study evaluating submaximal-exercise responses of 8 healthy middle-aged women found that at moderate (4.5 km/h) and high (5.5 km/h) walking speeds, VO2, RPE, and ventilation were all significantly higher on UTM than LTM. Furthermore, at a given submaximal VO2, HR was substantially lower on UTM than LTM, suggesting that the HR–VO2 relationship may be different between the 2 modalities. A small study of older women with rheumatoid arthritis also reported that at similar levels of VO2, HR was approximately 9 beats/min higher during UTM than LTM. Finally, the physiological responses of UTM versus LTM running were evaluated in 25 men and 25 women runners using a treadmill protocol that increased the belt speed 2.4 km/h every 3 minutes from 3.2 km/h to 11.3 km/h. The findings of that study determined that although there were no physiological differences between the 2 modalities at speeds ≤6.4 km/h, at speeds >6.4 km/h VO2 and HR were significantly higher on UTM than LTM.

The aforementioned studies were limited by inconsistent HR–VO2 relationships between UTM and LTM studies and the use of older, nonathletic participants, with limited generalizability between sex and sport. Consequently, the purpose of this investigation was to compare the cardiorespiratory responses at matched submaximal workloads on UTM versus LTM in a group of college athletes from various sports. Of particular interest in this investigation was the HR–VO2 relationship on 2 modalities, because the relationship between these 2 variables has important implications for prescribing the appropriate intensity of exercise therapy on UTM to maintain cardiorespiratory fitness during injury rehabilitation.

**Methods**

**Participants**

Uninjured undergraduate student athletes were recruited from various intercollegiate athletic teams during the summer (noncompetitive season) if they were willing
and able to perform the exercise protocols. A total of 11 participants, 5 men and 6 women, took part in the study. Participants were current members of the following intercollegiate athletic teams: men’s soccer (2), women’s soccer (3), women’s volleyball (1), women’s field hockey (1), football (1), baseball (1), men’s track and field (1), and women’s track and field (1). To ensure generalizability of the findings, we intentionally recruited a variety of types of athletes and equal numbers of men and women. The group was representative of intercollegiate athletes, with a mean age of 20.8 ± 0.6 years, body weight of 72.7 ± 18.6 kg, and height of 178.4 ± 8.7 cm. The research project was reviewed and approved by the institutional review board at Wake Forest University. Before beginning the study, each of the participants read and signed an approved informed-consent form.

**Instruments**

**LTM.** All participants performed the LTM protocol on the Life Fitness 93T treadmill. This model can be set to various speeds ranging from 0.8 to 20 km/h, with an incline range of 0% to 15%.

**UTM.** The Hydroworx 1000 Series pool was used during the UTM protocol by all participants. A treadmill is incorporated in the pool’s design that is capable of transitioning from 0 to 12 km/h in 0.3-km/h increments. Resistance jets in the pool are used to increase exercise difficulty.

**Cosmed K4b².** A portable cardiopulmonary-exercise-testing system, the Cosmed K4b², was used to measure pulmonary gas-exchange and ventilatory variables including VO₂ (mL⁻¹ · kg⁻¹ · min), ventilation (L/min), tidal volume (L/breaths), and breathing frequency (breaths/min) on a breath-by-breath basis at rest and throughout both treadmill protocols. Breath-by-breath data were averaged over each minute for statistical analysis. The accuracy and reliability of this device have been established.

**HR Monitor.** HR was measured in beats per minute using a Polar heart-rate chest band that was compatible with the Cosmed K4b² unit.

**Experimental Procedures**

Each participant completed the UTM and LTM protocols on different days separated by no less than 48 hours but no more than 7 days. The order was randomly determined. Participants were asked to refrain from eating and drinking for at least 3 hours before the test and to avoid strenuous activity for 24 hours. None of the participants used prescription medication or smoked tobacco. In both trials, participants were fitted with a face mask (Han Rudolf) and a heart-rate chest band (Polar) so that expired gases and HR could be obtained at rest and throughout the test. All subjects had prior experience on and were familiar with UTMs and LTMs. Both protocols involved 5 minutes of data collection while subjects stood on the treadmill without moving, followed by 7 exercise stages of 2 minutes in duration that progressively increased in intensity for a total of 14 minutes (see Table 1).

**LTM Protocol.** The LTM used was a Life Fitness 93T that was calibrated for both speed and grade. After 5 minutes of standing, the exercise protocol began at 2.3 km/h at a 0% grade for 2 minutes. The treadmill was then increased to 4.9 km/h,
7.3 km/h, and 9.6 km/h, each for 2 minutes. The fifth stage remained at 9.6 km/h, but the percent grade was increased to 1% for 2 minutes. The sixth and seventh stages were also conducted at 9.6 km/h, but the grades were increased to 2% and 4%, respectively. At the conclusion of the seventh stage, the belt speed was reduced to walking speed and grade was reduced so that the participant could cool down sufficiently. In total, the participant exercised for 14 minutes (see Table 1). Gas-exchange and ventilatory measures were obtained breath by breath, and HR was recorded each minute. RPE, 6 (no exertion) to 20 (maximal exertion), was solicited each minute of the exercise protocol.

**UTM Protocol.** The Hydroworx 1000, calibrated to the manufacturer’s specification, was used for the UTM protocol. Water temperature was maintained at 28°C, and the water level of the pool was adjusted so that it reached each standing participant’s xiphoid process. After 5 minutes of standing at rest, the first 4 stages of the UTM exercise protocol were identical to the LTM protocol (ie, 2 minutes at each of the following: 2.3 km/h, 4.9 km/h, 7.3 km/h, and 9.6 km/h, all at 0% grade). The fifth stage consisted of exercising at 9.6 km/h with 30%-water resistance jets for a period of 2 minutes. The sixth and seventh stages maintained the same belt speed and increased the water-resistance jets to 40% and 50%, respectively. The water jets produced a current against the participant’s abdomen and thighs and provided resistance against forward treadmill movement. The intensity of the jet strength is expressed as a percentage of the maximum propulsive capability. The jet levels used on the UTM were based on pilot-testing data so that they approximated the percent grade used on the LTM. At the conclusion of the seventh stage, the belt speed was reduced to walking speed and jets were turned off so that the participant could cool down sufficiently. As in the LTM, the participant exercised for 14 minutes on the UTM. Gas-exchange and ventilatory measures were obtained breath by breath, and HR was recorded each minute in the same way as in the LTM protocol. RPE was solicited each minute of the exercise protocol.

### Statistical Analyses

All data were checked for normality, and descriptive statistics were collected for all variables. Data from stages 2, 5, 6, and 7 were not compared or analyzed because

### Table 1  Protocol Summary

<table>
<thead>
<tr>
<th>Stage</th>
<th>Speed (km/h)</th>
<th>Land-treadmill grade, underwater-treadmill jet velocity</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>2.3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>4.9</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>7.3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>9.6</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>9.6</td>
<td>15%, 30%</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>9.6</td>
<td>2%, 40%</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>9.6</td>
<td>4%, 50%</td>
<td>2</td>
</tr>
</tbody>
</table>
the workloads were not comparable between the UTM and LTM. Stage 2 (4.9 km/h at 0% grade) was a transitional stage in both protocols—some individuals chose to walk whereas others elected to run, which has obvious effects on cardiorespiratory responses. Stage 5, 6, and 7 were not compared between the 2 protocols because the grade on LTM and jet level on UTM were not comparable and produced different hemodynamic and metabolic responses. Consequently, data obtained at rest and stages 1, 3, and 4 on UTM and LTM were compared using paired t tests to determine whether there were differences between conditions, using SPSS 16.0. The relationship between HR and VO₂ for each stage of exercise was plotted (see Figure 1) and assessed for each modality by linear-regression analysis. Level of statistical significance for all analyses was established at $P \leq .05$.

Results

Cardiorespiratory Responses

Table 2 provides a comparison of the cardiorespiratory variables measured during LTM and UTM at matched submaximal workloads. As shown, VO₂ was not significantly different between LTM and UTM at rest or during stage 1 or stage 4. Although it was significantly lower during UTM than LTM in stage 3, the difference was only 2.6 mL⁻¹ · kg⁻¹ · min, or approximately 12%. Furthermore, there were no significant differences in HR between UTM and LTM for any stage of the protocol. Although there was no significant difference in ventilation between LTM and UTM across the stages of exercise, tidal volume was significantly lower on UTM than LTM at stage 3 (7.3 km/h at 0% grade). RPE was not significantly different

![Figure 1](image-url) — The relationship between heart rate (HR) and oxygen consumption (VO₂) on land treadmill (LTM; circles) and underwater treadmill (UTM; squares). The UTM regression line is represented by the dashed line, and the LTM’s, by the solid line.
Table 2  Cardiorespiratory Measures During Land Treadmill (LTM) and Underwater Treadmill (UTM) Protocols, Mean ± SD

<table>
<thead>
<tr>
<th>Measure</th>
<th>Rest</th>
<th>Stage 1</th>
<th>Stage 3</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LTM</td>
<td>UTM</td>
<td>LTM</td>
<td>UTM</td>
</tr>
<tr>
<td>VO₂ (mL⁻¹ · min⁻¹ · kg)</td>
<td>3.6 ± 0.06</td>
<td>3.78 ± 0.7</td>
<td>6.84 ± 1.4</td>
<td>6.49 ± 0.7</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>64.3 ± 9.9</td>
<td>60.4 ± 7.9</td>
<td>75.1 ± 10.6</td>
<td>73.3 ± 8.5</td>
</tr>
<tr>
<td>Ve (L/min)</td>
<td>10.81 ± 3.7</td>
<td>11.08 ± 3.0</td>
<td>16.58 ± 5.8</td>
<td>16.55 ± 3.9</td>
</tr>
<tr>
<td>V₅ (L/breath)</td>
<td>0.65 ± 0.2</td>
<td>0.58 ± 0.2</td>
<td>0.76 ± 0.2</td>
<td>0.72 ± 0.2</td>
</tr>
<tr>
<td>Rf (breaths/min)</td>
<td>16.9 ± 3.4*</td>
<td>19.3 ± 3.6*</td>
<td>21.6 ± 4.2</td>
<td>23.5 ± 5.4</td>
</tr>
<tr>
<td>RPE</td>
<td>6.0 ± 0.0</td>
<td>6.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
</tr>
</tbody>
</table>

VO₂, oxygen consumption; HR, heart rate; Ve, ventilation; V₅, tidal volume; Rf, breathing frequency; RPE, rating of perceived exertion.
* Significant difference (P < .05) between LTM and UTM.
between the 2 modalities at any level of exercise. These data suggest that, other than stage 3 (7.3 km/h at 0% grade), there is no difference in the cardiorespiratory responses to matched workload on LTM versus UTM.

**HR–VO₂ Relationship**

The plot of HR and VO₂ across all 7 exercise stages shows a positive linear correlation between UTM \( (r = .94) \) and LTM \( (r = .95) \). Furthermore, the regression equations generated for each modality for UTM \( (y = .27x – 10.86) \) and LTM \( (y = .29x – 12.98) \) are virtually identical and indicate that the HR–VO₂ relationship is similar between the 2 modalities.

**Discussion**

This study was the first to compare the cardiorespiratory responses of college athletes to underwater versus traditional treadmill exercise at matched submaximal levels of exertion. Our findings indicate that in all but 1 stage of the exercise protocol, there were no significant differences between the 2 treadmill modalities for any of the cardiorespiratory variables examined. Our data agree with an earlier study that concluded that at speeds less than 6.4 km/h (4.0 mph), VO₂ was similar for the 2 treadmill modalities.7 The lower VO₂ observed during stage 3 (7.3 km/h, or 5.0 mph) on UTM than on LTM in the current investigation is likely associated with a greater mechanical efficiency and reduced metabolic cost secondary to the buoyancy provided by the water.13

As described in the Methods section, we only compared cardiorespiratory responses obtained at rest and stages 1, 3, and 4 between UTM and LTM protocols. We did not compare the 2 modalities at stage 2, because this was a transitional stage (6.4 km/h) for both protocols in which some participants choose to run and others chose to walk. Walking and running result in different mechanical and, subsequently, cardiometabolic responses that make comparison between the UTM and LTM difficult.12 Furthermore, we did not compare stages 5, 6, or 7 because the LTM used increases in grade to increase the metabolic demands, whereas the UTM employed increases in water-jet velocity. Despite pilot testing to determine equivalency between these approaches, inspection of data collected during the study clearly indicated that matching of the metabolic costs was not attained.

The current investigation also demonstrated that there were no significant differences in minute ventilation, HR, or RPE between UTM and LTM on matched stages (stages 1, 3, 4) of submaximal exercise. None of the previous studies comparing these treadmill modalities specifically evaluated ventilatory responses or RPE during submaximal exercise in college athletes. In contrast, previous studies that examined HR response during UTM have produced conflicting results.7,8 At speeds greater than 6.4 km/h (4.0 mph), HR has been reported to be lower on UTM than on LTM,8 whereas HR is not significantly different on the 2 modalities at speeds less than 6.4 km/h.7,8 Furthermore, to our knowledge this was the first investigation to examine the components of minute ventilation, specifically, tidal volume and breathing frequency. Although the compressive forces of water could potentially affect tidal volume, the current results suggest that this did not occur.
Other than a slight, albeit significant, difference observed in stage 3, there were no significant differences in tidal volume between UTM and LTM during the other submaximal-exercise stages.

Perhaps the most unique and important finding of the current investigation was the observation that the relationships between HR and VO₂, measured across the full range of the exercise protocols, were virtually identical for UTM and LTM. This is particularly important because of the distinct differences between the 2 modalities. Buoyancy decreases the load one must propel through the water, but the dense water (nearly 800 times as dense as air) increases the force one must exert to overcome the drag force to move through the water.¹⁴⁻¹⁶ This relationship is imperative in creating a prescribed workload that can reduce ground-reaction forces while maintaining a high level of muscle work. To our knowledge, the current investigation is the first to examine HR, VO₂, and their relationship in a wide-ranging sample of college athletes. An early study⁷ indicated that at a given VO₂, HR was 9 beats/min lower on UTM than LTM, although a more recent study produced data suggesting no significant differences in the HR–VO₂ relationship.¹⁷ In contrast to our college athletes, the aforementioned studies⁷,¹⁷ evaluated subjects who were older, were obese, and had rheumatoid arthritis. The clinical condition of the latter population likely explains the differences observed for the HR–VO₂ relationship reported in those 2 studies.

The similarity of the HR–VO₂ relationship during UTM and LTM in college athletes is novel and important because these 2 variables form the basis for prescribing intensity of endurance-type exercise.¹⁸ Athletic trainers and physical therapists often wish to establish a UTM exercise level that would maintain the cardiorespiratory fitness level of their injured athletes. Bushman et al¹⁹ demonstrated this through an exclusive 4-week training intervention of deepwater running most days of the week with competitive runners. Thus, if an athlete’s target HR range for LTM or overground exercise is known, either empirically based on objectively measured data or subjectively from experience, the data generated in this investigation suggest that it would be appropriate to use the same HR range for cardiorespiratory conditioning conducted on the UTM.

In addition to UTM, other modalities of underwater exercise have been examined, particularly deepwater running, which is generally performed in a deep pool in which the subjects’ feet are not able to reach the floor. This allows for the complete relief of body weight while creating a running pattern. Similar to UTM studies, contrasting respiratory and metabolic results have been observed between studies. DeMaere and Ruby²⁰ tested seasonally trained college male cross-country runners at 60% and 80% of VO₂max on a treadmill, as well as deepwater running. Although ventilation during deepwater running at 80% of VO₂max was greater than with treadmill running, no significant differences were observed in VO₂ and HR values between trials. In contrast, Frangolias and Rhodes²¹ conducted a study on a population group similar to that in the previous study. However, respiratory and metabolic data were collected during a maximal-exercise test during both treadmill running and deepwater running. Results indicated greater VO₂max and HRmax for tests performed on a treadmill than with underwater running. Therefore, it may be more appropriate to formulate exercise prescriptions according to VO₂max and HR data collected during a treadmill test.
Like any clinical investigation, the current study has certain limitations and highlights potential areas for future research. The sample size of this investigation was small ($n = 11$), and we examined a homogeneous population (healthy college athletes). Thus, the findings are not generalizable to populations other than college athletes. We did intentionally recruit an equal number of men and women, as well as endurance- and power-trained athletes. Although a small sample size precluded any formal comparison of these subgroups, we did not notice any trends in the data. Furthermore, when examining the cardiorespiratory responses of UTM versus LTM, we were only able to compare several submaximal stages. It was inappropriate to compare several of the stages because the workloads and subsequent metabolic costs varied as a result of different mode of ambulation (walking vs running) and type of resistance provided by increasing water-jet velocity or treadmill grade. Greater speed distinctions between stages would have been more suitable to ensure comparable modes of ambulation.

Although it was not the intent of the current investigation, future research should further evaluate the biomechanical differences in locomotion during UTM and LTM exercise. Most participants in the current study perceived a difference in running gait despite similarities in RPE and cardiorespiratory responses on the 2 modalities. Although the gait patterns required to walk or run on these 2 modalities may be different, the cardiorespiratory responses and metabolic costs remain similar. It is also recommended that future studies investigate the HR–VO₂ relationship between the LTM and UTM while using increases in grade and jet velocity to allow for higher intensity prescriptions.

**Conclusion**

In conclusion, the current investigation demonstrated that matched UTM and LTM exercise levels elicited similar cardiorespiratory responses in college athletes. Furthermore, the relationship between HR and VO₂ in college athletes of varying athletic backgrounds is similar during UTM and LTM, suggesting that HR can be used appropriately to guide the exercise intensity of UTM exercise. The results of this investigation are valuable for clinicians employing UTM exercise to maintain cardiorespiratory conditioning of injured college athletes.

**References**