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Land Versus Water Treadmill Running: Lactate Threshold

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The lactate threshold (LT) is a valuable parameter for setting appropriate exercise intensities. Whether the intensity where the LT occurs is similar in water vs. land treadmill exercise has not been determined. The purpose of this study was to determine LT during aquatic vs. land treadmill running. On separate days, on land and in water (submerged at the xiphoid process), 15 participants performed on a multistage graded exercise treadmill LT test in random order. LT was determined using the DMax method. At LT, no statistically significant differences were identified for running speed (195.3 ± 31.5 m·min^{-1} land vs. 188.1 ± 22.9 m·min^{-1} water), lactate concentration (2.6 ± 0.8 land vs. 2.7 ± 0.8 water mmol·L^{-1}). At LT, there were statistically lower ($p < .004$) water vs. land VO_2 values (37.9 ± 5.4 land vs. 35.0 ± 5.4 water ml·kg^{-1}·min^{-1}), and heart rate (HR; 171 ± 14 land vs 159 ± 18 water bpm). The lower VO_2 and HR in water may reflect a lower energy requirement due to a decreased body weight support in the water. This is beneficial for those using aquatic treadmills and desiring to achieve threshold-intensity training while lowering the joint-stress caused by land running.

Keywords: exertion, aquatic exercise

Aquatic treadmill exercise has been promoted for rehabilitation and training purposes due to decreased joint impact on the lower extremities, which is beneficial for special populations such as the injured, elderly, arthritic, and obese (Greene et al., 2009; Hall, Grant, Blake, Taylor, & Garbutt, 2004). There also is an interest for healthy individuals to use the system to supplement land exercise training while limiting joint stress. Accordingly, researchers have compared the acute physiological response of land vs. aquatic treadmill exercise for variables such as heart rate (HR), oxygen consumption (VO_2), respiratory exchange ratio (RER), stride frequency, and rating of perceived exertion (RPE) for both maximal and submaximal efforts (Brubaker, Ozemek, Gonzalez, Wiley, & Collins, 2011; Rife, Myrer, Feland, Hunter, & Fellingham, 2010; Rutledge, Silvers, Browder, & Dolny, 2007; Silvers, Rutledge, & Dolny, 2007; Watson, Mendonca, Lehnhard, Tu, Butterfield, Bouchard & McKeever, 2012). In addition, Greene et al. (2009) demonstrated similar improvements in aerobic capacity and body composition

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when traditional endurance land walking exercise training was compared with an aquatic treadmill walking group.

In recent years the use of an aerobic interval training (AIT) or high intensity interval training (HIIT) exercise protocols have demonstrated superior cardiorespiratory adaptations to traditional endurance exercise training in both apparently healthy (Gibala & McGee, 2008) and heart failure patients (Wisløff et al., 2007) while reducing overall cardiometabolic disease risk (Kessler, Sisson, & Short, 2012). These protocols require subjects to exceed not only their individual lactate thresholds (LT) but approach at or near-maximal exercise efforts. LT represents an exercise intensity where it is believed lactate is being produced at a rate greater than it is being removed from the blood causing an increase in the blood lactate concentration above baseline (Weltman et al., 1990). The ability to extend an exercise effort is limited when exercise is performed at an intensity above LT. A question arises if the LT differs during exercise in land vs. an aquatic treadmill.

Silvers et al. (2007) revealed no statistical difference between peak lactate concentrations in VO_{2peak} tests run on land vs. aquatic treadmills suggesting perhaps the LT in water treadmill exercise may not differ from land. Zobell (2009) identified a LT value that occurred at a significantly lower VO_2 in water than land treadmill running (21.8 ± 1.6 vs. 27.0 ± 1.6 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively). That study adjusted blood lactate concentrations for changes in plasma solid concentration and reported LT units in $mM \cdot kg^{-1}$ H_2O, making interpretation for coaches and rehabilitation specialists difficult. Therefore the LT comparison using unadjusted blood lactate concentrations between land and water treadmill remains to be determined.

Therefore, the purpose of this study was to compare the LT while running on a land vs. an aquatic treadmill and determine if the LT occurs at similar levels of energy expenditure (VO_2) and treadmill running speeds.

Method

Participants

Fifteen participants (8 men, 7 women) free of musculoskeletal injury and recreationally active runners took part in the study (see Table 1). Total number of participants was based on an effect size of 1.0 with power at 0.8 and $\alpha = .05$ from previous pilot work. Participants were volunteers recruited by word of mouth. Any participant that had no previous water treadmill experience was given a familiarization session before VO_{2peak} tests. Participants filled out an informed consent before all testing. The study protocol and informed consent for each participant was approved by the university's institutional review board for human research.

Equipment

Metabolic data were collected and analyzed using a Parvo Medics True One 2400 Metabolic Measurement System (Sandy, UT). Water treadmill running was performed on a HydroWorx 2000 treadmill (HydroWorx, Middletown, PA), with water temperature maintained at 30 °C and water depth at the xiphoid process. Land treadmill protocols were completed on an Incline Trainer treadmill (Free Motion, Logan, UT). Heart rate was monitored using a T31 telemetric Polar heart

Table 1 Descriptive Statistics of Participants, Mean (*SD*)

	Age (yrs)	Height (cm)	Mass (kg)	Kilometers/ Week Run	VO_2Peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	Speed and Jet Resistance at VO_2Peak ($m \cdot min^{-1}$)
Total (n = 15)	25.6 (4.6)	173.6 (14.5)	71.0 (15.2)	42.4 (20.0)	49.5 (7.1)	218.0 + 78% (12.9 + 15%)
Male (n = 8)	27.1 (3.4)	183.7 (11.0)	81.6 (11.1)	42.7 (25.5)	53.3 (6.1)	224.5 + 85% (6.2 + 8%)
Female (n = 7)	23.9 (5.4)	162.0 (7.5)	58.9 (8.6)	41.9 (13.1)	45.2 (5.9)	210.6 + 70% (14.9 + 18%)

rate monitor (Polar Electro Oy, Lake Success, NY). For blood analyses, a 1.8 mm depth Haemolance soft lancet (HTL-STREFA, Inc., Marietta, GA) was used and the Lactate Plus hand model (Nova Biomedical, Waltham, MA) was used to analyze the blood for lactate concentration. The Lactate Plus model has a high test-retest reliability ($r = .95$; $SEM = 0.25$ mmol·L^{-1}; Kulandaivelan, Verma, Mukhopadhyay, and Vignesh, 2009). The Lactate Plus was calibrated once per week (recommended by the manufacturer) using sample solutions of a fixed mmol·L^{-1} concentration.

Procedures

A randomized cross-over design for land vs. water treadmill running LT test was used. Each participant performed a VO_{2peak} test on the water treadmill, with the dual purpose of obtaining VO_{2peak} and as a familiarization period to water treadmill running. Silvers et al. (2007) showed no statistical difference between VO_{2peak} values land vs. water, so only the water VO_{2peak} test was performed. On two separate visits, a random assignment to either land or water treadmill LT test was performed. Participants refrained from any strenuous physical activity 24 hr before testing with at least 48 hr of rest between tests. For female participants, both LT tests occurred in the same menstrual cycle phase (luteal or follicular) determined by the first day of the last menstrual cycle (Forsyth and Reilly, 2005).

VO_{2peak} Test

Water depth was set at the xiphoid process and participants ran for approximately 5 min while treadmill speed and jet intensity was manipulated to allow them to determine a comfortable running pace. The protocol described by Silvers et al. (2007) was followed. Participants warmed up with a walk/jog at a comfortable pace for 4–6 min with jets set to 40%. Speed was increased by 13.4 m·min^{-1} every minute thereafter until maximum treadmill speed was reached 227.8 m·min^{-1}, or to a speed determined by the participant that was considered somewhat hard. Jet resistance was then increased by 10% every minute thereafter until volitional fatigue. The test was considered maximal if participants reach two of the following three requirements: 1) a plateau in VO_2, despite an increase in work rate, 2) an RER ≥ 1.10, or 3) peak blood lactate values at least 8 mmol·L^{-1} (Howley, Bassett, & Welch, 1995). Peak lactate was obtained within 30 s of completion of the test. Participants wore a HR monitor and provided an RPE score at the end of the peak test.

Lactate Threshold Tests

For both land and water LT test, a slightly altered protocol as that described by Zobell (2009) and McGehee et al. (2005) for the water and land LT tests, respectively were followed. Each LT test was a discontinuous protocol with stages lasting three minutes (Bentley, Newell, & Bishop, 2007; Weltman et al., 1990). The test was progressive in nature, and a brief period for blood sampling (20–30 s) at the end of each stage was the only interruption to the protocol. Blood samples were drawn via earlobe puncture.

Participants completed a three minute warm-up to ensure good blood flow and to become acquainted with the testing procedure. Before each LT test, earlobe was washed thoroughly with warm water and soap as well as rubbing alcohol to

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remove any lactate on the skin. During blood sampling the first bead of blood was wiped away with gauze and the second bead was used to determine blood lactate. The same investigator with prior lactate sampling experience performed all blood analyses. A HR monitor was worn and at the end of each stage an RPE value was provided by the participant using the Borg 6–20 scale (Borg, 1982).

Each land LT test began at 1% grade and at a speed that represented ~40% of VO_{2peak}. The speed increased by 13.4 m·min^{-1} per stage until an RER of 1.0 was reached or participants could no longer sustain a 3-min stage at an increased work rate.

Each water LT test began at ~40% jet capacity in the water and a speed that represented ~40% of VO_{2peak}. Participants were submerged to the xiphoid process. The speed increased by 13.4 m·min^{-1} per stage. For participants who did not exceed suspected LT by the maximum water treadmill speed of 227.8 m·min^{-1}, jet resistance was then increased 10% each stage. Nine participants required the use of water jets, with only three of those requiring more than three stages with jets. During all trials subjects kept their arms submerged to simulate their arm carriage during running on land

LT was determined using the D_{Max} method where the first and last data point of the lactate curve was connected with a straight line. The lactate measure that represented the furthest perpendicular distance to this line is considered to be the LT value (Cheng et al., 1992; McGehee et al., 2005). Data were plotted as lactate concentration vs. VO_2. A custom written Matlab code (MathWorks, Natick, MA) determined the (x,y) point that was the farthest distance from the slope between the first and last coordinates of the lactate vs. VO_2 plot. Once the farthest point was obtained, all data (HR, lactate concentration, VO_2, speed, RPE, and RER) from that *stage* was used as the LT point. For each participant, the following information was determined for land and water LT tests: 1) running speed at which LT occurred, 2) percentage of VO_{2peak} at which LT occurred, and 3) absolute blood lactate concentration at which LT occurred.

Statistical Analysis

Paired *t* tests were used to compare VO_2, running speed, blood lactate concentration, RPE, RER, and HR at LT in water and on land with $\alpha = .05$.

Results

The LT point occurred at statistically significantly lower VO_2 and HR in the water compared with land ($p = .004$ and $p < .001$, respectively). There were no significant differences for speed, blood lactate concentration, RPE, or RER at the LT. Table 2 illustrates all group means and *t* test results between land and water. Figure 1 shows a comparison of land versus water group LT values for VO_2 and blood lactate.

Discussion

The LT point occurred at the same blood lactate concentration, perceived effort, running speed, and RER despite a lower HR and VO_2 response in water compared with land. These data indicate that a comparable lactate response can be elicited at the same running speeds and perceived effort on land vs. water.

Table 2 Value of Measures at LT in Land Vs. Water Tests, Mean (*SD*)

	Land	Water	p Value
Speed ($m \cdot min^{-1}$)	195.3 (31.5)	188.1 (22.9)	0.282
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	37.9 (5.4)	35.0 (5.4)	0.004
Lactate Concentration ($mmol \cdot L^{-1}$)	2.6 (0.8)	2.7 (0.8)	0.695
RPE (Borg Units)	14.0 (1.6)	14.1 (2.4)	0.825
Heart Rate ($beats \cdot min^{-1}$)	171 (14)	159 (18)	≤ 0.001
RER (VCO_2/VO_2)	0.94 (0.03)	0.93 (0.03)	0.137

In support of the current study, Zobell (2009) identified an LT value that occurred at a significantly lower VO_2 in water than land treadmill running (21.8 ± 1.6 vs. 27.0 ± 1.6 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively). The LT point in Zobell's study was determined using least squares regression method which creates intersecting lines before and after rising lactate values. While our methods to determine LT were different, the D_{Max} and least squares regression methods remove arbitrary selection of an LT point that may occur by visual analysis. However, Zobell also controlled for plasma protein values before determination of LT (expressed as $mmol \cdot kg\ H_20^{-1}$) while the current study used lactate concentration in the plasma ($mmol \cdot L^{-1}$)

Zobell also proposed that increased muscle activation in the water may help explain how blood lactate is increased in the water vs. land at a lower VO_2. Opposing the buoyant force in water is the drag force. Previous studies have revealed increased muscle activity of the tibialis anterior muscle as well as hip extensor muscles (in particular, the biceps femoris) but lower gastrocnemius in water running compared with land running (Silvers, Bressel, Killgore, Dickin, & Dolny, in press; Kaneda et al., 2007). The added fluid resistance against the legs compared with land may increase the metabolic response of those tissues (i.e., greater blood lactate production) yet still requiring a lower total body VO_2 in water due to the buoyant force supporting a significant portion of body weight (Harrison, Hillman & Bulstrode, 1992).

Previously (Bressel, Dolny, & Gibbons, 2011) demonstrated surface EMG activity of muscles rectus abdominis (RA), external oblique, lower abdominals, multifidus, and erector spinae were significantly lower performing trunk/pelvic stabilizing exercises in xiphoid-depth water versus land. Perhaps the lower trunk muscle activity overrides the greater leg muscle activity contributing to the lower VO_2 in water versus land. We acknowledge combining the results of two separate studies from our laboratory is speculative and the postural muscle responses during running in water vs. land await confirmation.

Our participants were asked to maintain a running form that was consistent between land and water treadmills. With water depth at the xiphoid process, this required submerging the arms in the water to allow normal arm swing while no "swimming motion" was allowed by cupping the hands through the water for propulsion. With indications for increased muscle activity of the lower extremities

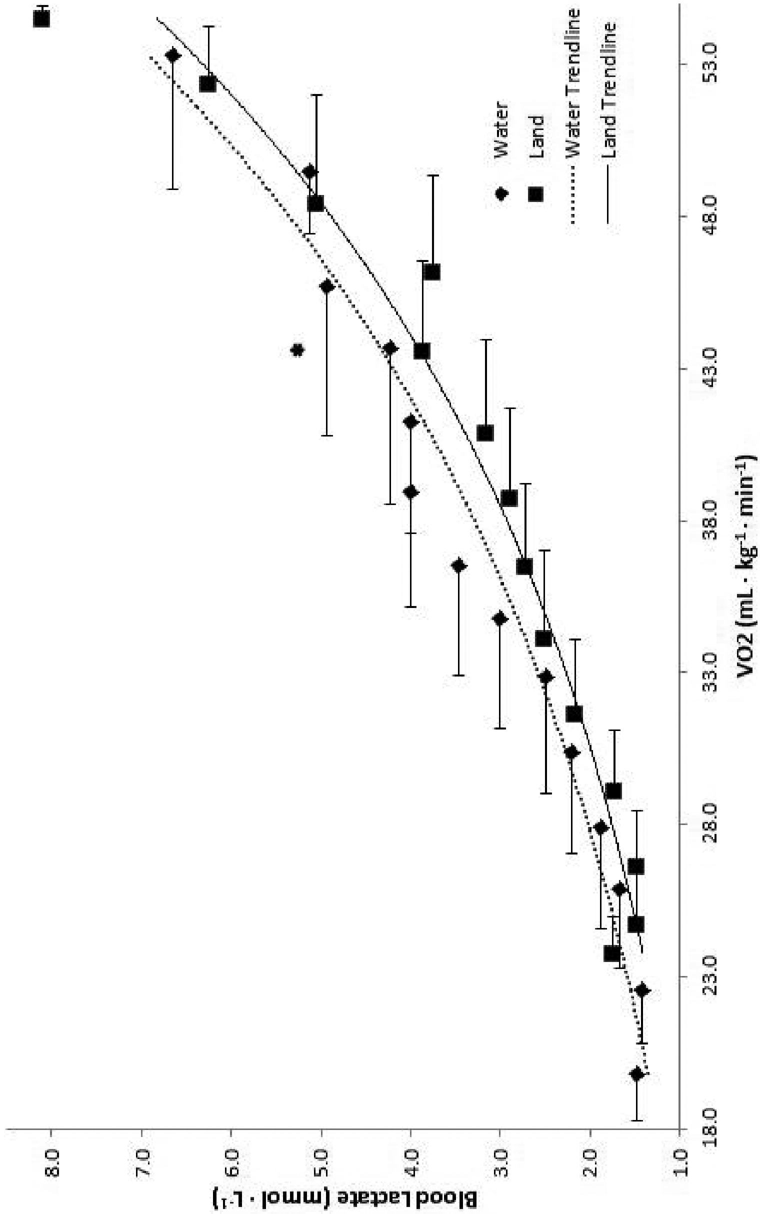

Figure 1 – Blood lactate vs. VO_2 across treadmill speeds during LT tests on land and in water. The first data point for each series begins at 107.2 $m \cdot min^{-1}$ and increase 13.4 $m \cdot min^{-1}$ per stage. *Indicates water LT curve added 10% jets each stage after 227.8 $m \cdot min^{-1}$.

in water, upper extremity movement through water may also cause an increase in muscle activity and lactate production compared with land. This concept requires future investigations.

In support of the current study, Rutledge et al. (2007) and Watson et al. (2012) have demonstrated linear increases in VO_2 with increasing aquatic and land treadmill running speeds. In addition, Watson et al. (2012) quantified lactate values while participants performed graded exercise tests in the aquatic treadmill. At 120.6, 160.8, and 201 m·min^{-1} and water jets at 1/3 of maximum capacity, the VO_2 response in Watson's group was 25.86 ± 4.33, 34.20 ± 4.37, and 41.28 ± 3.78 mL·kg^{-1}·min^{-1}, respectively. Lactate values were 3.12 ± 1.31, 4.56 ± 1.26, and 6.46 ± 1.95 mmol·L^{-1}, respectively. The current investigation had VO_2 and lactate data at 120.6, 160.8, and 201 m·min^{-1} and 40% of maximum jet capacity of 22.6 ± 1.8, 30.4 ± 3.3, and 36.5 ± 3.6 mL·kg^{-1}·min^{-1}, and 1.4 ± 0.5, 2.2 ± 0.8, and 3.5 ± 1.6 mmol·L^{-1}, respectively. A key difference between the two groups may have been the focus of training. Although each group reported above average VO_{2peak} values, the current study contained recreational runners who may be more economical with running compared with trained ice hockey players and help explain differences of blood lactate response to similar exercise intensities. In addition, Watson et al. evaluated male NCAA Division I hockey players while the present studied used male and female recreational runners, a difference in subject selection that may partially explain the disparity of results.

During the 1/3 water jet capacity trial Watson et al. (2012) also reported an onset of blood lactic acid accumulation (OBLA) of 3.51 ± 1.53 mM, however, OBLA occurred at a corresponding $\%VO_{2peak}$ of only 38%. This is quite low relative to previous research determining where OBLA or LT occurs. During trials using zero, 2/3 and full (100%) jet capacity OBLA occurred at 54.3, 66.1 and 76% of VO_{2peak}. Therefore, it appears in the aquatic treadmill environment where OBLA or even LT occurs may depend upon the water jet percentage selected. Perhaps with added jet resistance directed toward the trunk of the body, differences in cardiac return may occur. To fully appreciate the effect of jet resistance on lactate response as well as cardiac output, a future investigation would be required. Previous research has demonstrated similar peak VO_2 and lactate values between land and water (Greene et al. 2011; Silvers et al., 2007; Schaal, Collins, & Ashley, 2012). Therefore compared with land treadmill, water exercise does not appear to restrict blood lactate production providing the exercise workload is comparable.

In comparing the submaximal VO_2 and HR response at the same running speed for aquatic vs. land treadmill running, previous researchers have reported lower VO_2 and HR in water vs. land (Greene et al. 2011), lower on land vs. water (Rife et al., 2010) and no difference on land vs. water (Brubaker et al., 2011; Rutledge et al., 2007). Differences in VO_2 or HR at equivalent running speeds on land vs. water have been explained by the buoyancy of the body in the water compared with land (Brubaker et al., 2011; Rife et al., 2010). At the xiphoid process the buoyant force unloads the body by approximately 72% of on-land weight-bearing (Harrison, Hillman, & Bulstrode, 1992). In the current study, our group means support lower VO_2 and HR in water vs. land at the LT point.

The results of the current study also reflect what has been reported for deep water running. In their review Frangolias and Rhodes (1996) concluded that during submaximal intensities of deep water vs. land treadmill running, at the same relative VO_2 despite a lower HR water exercise resulted in a greater blood lactate concentration, RER, and RPE.

The methods used in previous studies to determine LT each have benefits and limitations (Faude et al., 2009). Visual identification of the LT can be difficult and involve using third party decisions if two investigators disagree as to the "inflection point" of the blood lactate. In the current study, using a fixed blood lactate concentration seemed inappropriate as there are no established guidelines as to a "normal" lactate response to running in the water. Using the D_{Max} method limited discrepancies inherent with visual identification of LT.

Using the D_{Max} method, LT values were produced at intensities ranging from 67.3–82.4% of VO_{2peak} on land, and 60.0–80.2% of VO_{2peak} in the water are very representative of the relative intensities whereby LT typically occurs (Gladden, 1989; Weltman et al., 1990). A recent article showed no statistical difference between using the D_{Max} method compared with a valid visual identification of LT (McGehee et al., 2005).

The importance of determining LT is supported by a large body of evidence to predict aerobic endurance capacity (Faude, Kindermann, & Meyer, 2009). As such, researchers have employed great efforts to predict LT via field tests to determine the correct training intensity for endurance athletes (McGehee, Tanner, & Houmard, 2005). An early study of LT revealed a strong relationship ($r \geq .91$) between treadmill velocity at the onset of plasma lactate accumulation and running performance at distances ranging from 3.2 km to 42 km (Farrell, Wilmore, Coyle, Billing, and Costill, 1979). A faster sustainable work rate before a lactate accumulation or threshold results in increased performance.

In addition, with the recent use of an aerobic interval training (AIT) or high intensity interval training (HIIT) exercise protocols demonstrating superior cardiorespiratory adaptations to traditional endurance exercise training in both apparently healthy (Gibala & McGee, 2008) and heart failure patients (Wisløff et al., 2007), while demonstrating reduction in cardiometabolic risk in several clinical populations (Kessler, Sisson, & Short, 2012). The interest in high-intensity exercise training may expand into aquatic treadmill exercise. This study provides insight for those using aquatic treadmills and desiring to achieve threshold-intensity training while lowering the joint-stress caused by land running.

Limitations of the study include an unknown amount of time required for familiarization to the aquatic treadmill setting. Despite the brief accommodation period in this study the LT results suggest subjects might adjust quite rapidly to this unique exercise environment. However, future research should investigate metabolic cost changes, if any, to repeated exposure with the aquatic treadmill.

In summary, individuals who want to achieve intensity for training at the LT in aquatic treadmill running, the RPE could provide useful information. Our participants reported a similar perceived effort in water as land at the LT point. This may allow subjects to select an exercise intensity in a water treadmill that mimics the intensity on a land treadmill at LT while decreasing joint stress related to training on land. As there was no statistical difference of speed at LT, this would serve as a starting point for exercise at the LT in water compared with land for training at the LT and adjust speed according to the RPE of the individual.

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