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Lactate Threshold: Land versus Water Treadmill Running

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Purpose: Due to lower joint stress in the water, aquatic treadmills have become increasingly popular for supplementing land run training and rehabilitation following injury and/or surgery. However, many physiological responses such as lactate threshold (LT) have not been examined while running in the water. The purpose of this study was to compare LT on an aquatic vs. land treadmill test. ***Methods:*** Fifteen participants (8 Male, 7 Female; age 25.6±4.6 yrs) performed a VO_2peak test on an aquatic treadmill. On separate days, participants completed a land and water multi-stage graded exercise LT test in random order. Following each three-minute stage, a blood sample was obtained via earlobe puncture and analyzed for blood lactate concentration. LT was determined using the D_{Max} method and land vs. water trials were compared using paired t-tests. ***Results:*** No statistically significant differences were identified for running speed (7.3±1.2 mph land vs. 7.0±0.9 mph water, p = 0.282), lactate concentration (2.6±0.8 land vs. 2.7±0.8 water mmol•L^{-1}, p = 0.695), rating of perceived exertion (RPE) (14.0±1.6 land vs. 14.1±2.4 water RPE units, p = 0.825) or respiratory exchange ratio (RER) (0.94±0.03 land vs. 0.93±0.03 water, p = 0.137). There was statistically lower water vs. land VO_2 values (37.9±5.4 land vs. 35.0±5.4 water ml•kg^{-1} •min^{-1}, p = 0.004), percentage of VO_2peak (76.8±4.6% land vs. 70.8±6.3% water, p = 0.004), and heart rate (HR) (171±14 land vs 159±18 water bpm, p = ≤0.001) at LT point. ***Discussion:*** The LT point occurred at the same absolute concentration, perceived effort, and speed despite a lower HR and VO_2 response in the water. The lower VO_2 and HR in water may reflect a lower energy requirement due to body weight body weight being partially supported in the water. This is beneficial for those using aquatic treadmills and wanting to achieve threshold-intensity training while lowering the joint-stress caused by land running.

Keywords: aquatic exercise, underwater treadmill, anaerobic

Aquatic treadmill running has become increasingly popular 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). Accordingly, researchers have compared key differences such as heart rate (HR), oxygen consumption (VO_2), respiratory exchange ratio (RER), stride frequency, and rating of perceived exertion (RPE) between land and water running at 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). As the benefits of aquatic treadmill running continue to be unveiled, there is an interest for healthy individuals to use the system to supplement training while limiting joint stress.

Rutledge et al. (2007) revealed VO_2 values at 6.5, 7.5 and 8.5 mph on an aquatic treadmill with no jet resistance to be 33.97 ± 4.0, 37.96 ± 4.0, and 43.6 ± 4.0 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. Watson et al. (2012) also revealed VO_2 values on an aquatic treadmill at 4.5, 6.0, and 7.5 mph with no jet resistance to be 20.58 ± 3.36, 29.27 ± 3.89, and 35.77 ± 4.02 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. These articles demonstrate the linear relationship that exists with increasing workloads with concomitant increases in VO_2 with aquatic treadmill running. As metabolic demands increase, a reliance on anaerobic metabolism ensues and the work rate at which lactate begins to accumulate in the blood is called the lactate threshold (LT) (Stainsby & Brooks, 1990). 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). In other words, a faster sustainable work rate prior to a lactate accumulation or threshold will increase performance.

Comparisons for lactate concentrations during deep water and land treadmill running have been examined previously. Frangolias and Rhodes (1996) reviewed that during submaximal intensities of deep water versus land running, at the same relative VO_2 water exercise resulted in a lower HR with higher blood lactate, RER, and RPE. These same authors previously reported that at maximal efforts on land versus deep water running, there was no statistical difference between lactate concentrations 30 s and 5 min post-exercise (Frangolias & Rhodes, 1995). However, not all water immersion running studies support similar peak lactate values (Frangolias & Rhodes, 1996; Svedenhag & Seger, 1992).

In a shallow water pool, a study by Town and Bradley (1991) revealed no statistical differences between land and water running for peak lactate values. However, lactate concentration in the water was 80% of that from land exercise. The authors stated that the “push-off” phase, which enabled ground contact, elicited similar running technique to land treadmills and could be partially responsible for similar physiological responses to land.

In recent years the availability of aquatic treadmills allows for a more favorable comparison of land and water running due to the implication of the “push-off” phase as discussed by Town and Bradley. Silvers et al. (2007) revealed no statistical difference between peak lactate concentrations in VO_2peak tests run on land versus aquatic treadmills. Zobell (2009) examined a comparison of LT between land and aquatic treadmill running which showed higher lactate levels in the water compared to land. However, no clear answers have developed as to a comparison of the LT on land vs. aquatic treadmill running. Therefore, the purpose of this study was to determine the LT while running on a land and an aquatic treadmill and compare to see if the intensities are equivalent.

Methods

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 was based on an effect size of 1.0 with power at 0.8 and $\alpha = 0.05$ from previous pilot work. Participants were volunteers recruited by word of mouth. Participants filled out an informed consent prior to all testing. The study protocol and informed consent was approved by the institutional review board.

Table 1 Descriptive Statistics of Participants, Mean (SD)

	Age (yrs)	**Height (cm)**	**Weight (kg)**	**Miles/Week**	**VO_2Peak ($mL \cdot kg^{-1} \cdot min^{-1}$)**
Total (n=15)	25.6	173.6	71.0	26.3	49.5
	(4.6)	(14.5)	(15.2)	(12.4)	(7.1)
Male (n=8)	27.1	183.7	81.6	26.6	53.3
	(3.4)	(11.0)	(11.1)	(15.9)	(6.1)
Female (n=7)	23.9	162.0	58.9	26.1	45.2
	(5.4)	(7.5)	(8.6)	(8.1)	(5.9)

Equipment

Metabolic data was 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). Land treadmill protocols were performed on an Incline Trainer treadmill (Free Motion, Logan, UT). Heart rate was monitored using a T31 telemetric Polar heart 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 $mmol \cdot L^{-1}$) (Kulandaivelan, Verma, Mukhopadhyay, and Vignesh, 2009). The Lactate Plus was calibrated once per week (recommended by the manufacturer) using sample solutions of a fixed $mmol \cdot L^{-1}$ concentration.

Procedures

A randomized cross-over design for land versus 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 on land versus in 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 hrs prior to testing with at least 48 hrs 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 were allowed to self-select a range of speeds and jets to experience a full range of intensity in the aquatic environment. The methodology described by Silvers et al. (2007) was then 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 0.5 mph (13.4 m•min^{-1}) every minute thereafter until maximum speed was reached (8.5 mph), 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. Test was considered maximal if participants reached two of the following three requirements: 1) a plateau in VO_2, despite an increase in work rate, 2) an RER $\geq$ 1.10, or 3) peak blood lactate values at least 8-10 mmol•L^{-1} (Howley, Basset, & Welch, 1995). Peak lactate was obtained within 30 s of completion of peak test. Participants wore a HR monitor and provided an RPE score at the end of the peak test using the Borg 6-20 scale.

Lactate Threshold Tests

For both land and water LT tests, a slightly altered methodology as that described by Zobell (2009) and McGehee et al. (2005) 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 would appropriately be called a continuous protocol, but for convenience of blood sampling, a brief (20-30 s) pause was required at the end of each stage. 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. Prior to each LT test, the earlobe was washed thoroughly with warm water and soap as well as rubbing alcohol to remove any lactate on the skin. 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.

For each land LT test, the trial began at 1% grade and a speed that represented approximately 40% of VO_2peak. The speed increased by 0.5 mph (13.4 m•min^{-1}) per stage until blood lactate values were rapidly increasing and the RER reached a minimum of 1.0.

For each water LT test, the trial began at 40% jets to minimize "float time" in the water and a speed that represented approximately 40% of VO_2peak. The speed increased by 0.5 mph (13.4 m•min^{-1}) per stage, in order to compare the same speeds on land and in water. For participants who did not exceed suspected LT by the max speed of 8.5 mph, jet resistance was then increased 10% each stage.

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 and the maximum distance from curve to line was determined as LT (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. 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

A paired t-test was used to compare the LT VO_2, LT speed, LT concentration, RPE at LT, RER, and HR at LT in water and on land for group means with $\alpha = 0.05$.

Results

The LT point occurred at statistically lower VO_2, percentage of VO_2peak, and HR in the water compared to land. There were no statistical differences at the LT point with speed, lactate concentration, RPE or RER. Table 2 illustrates all group means and t-test results between land and water. Figure's 1 and 2 show group LT values (M ± SD) for VO_2 and blood lactate at each intensity.

Table 2 Land vs. Water LT tests, Mean (SD)

	Land	Water	p Value
Speed (mph)	7.3 (1.2)	7.0 (0.9)	0.282
VO_2 (mL•kg^{-1}•min^{-1})	37.9 (5.4)	35.0 (5.4)	0.004
VO_2Peak %	76.8% (4.6%)	70.8% (6.1%)	0.004
Lactate Concentration (mmol•L^{-1})	2.6 (0.8)	2.7 (0.8)	0.695
RPE	14.0 (1.6)	14.1 (2.4)	0.825
Heart Rate (bpm)	171 (14)	159 (18)	≤0.001
RER	0.94 (0.03)	0.93 (0.03)	0.137

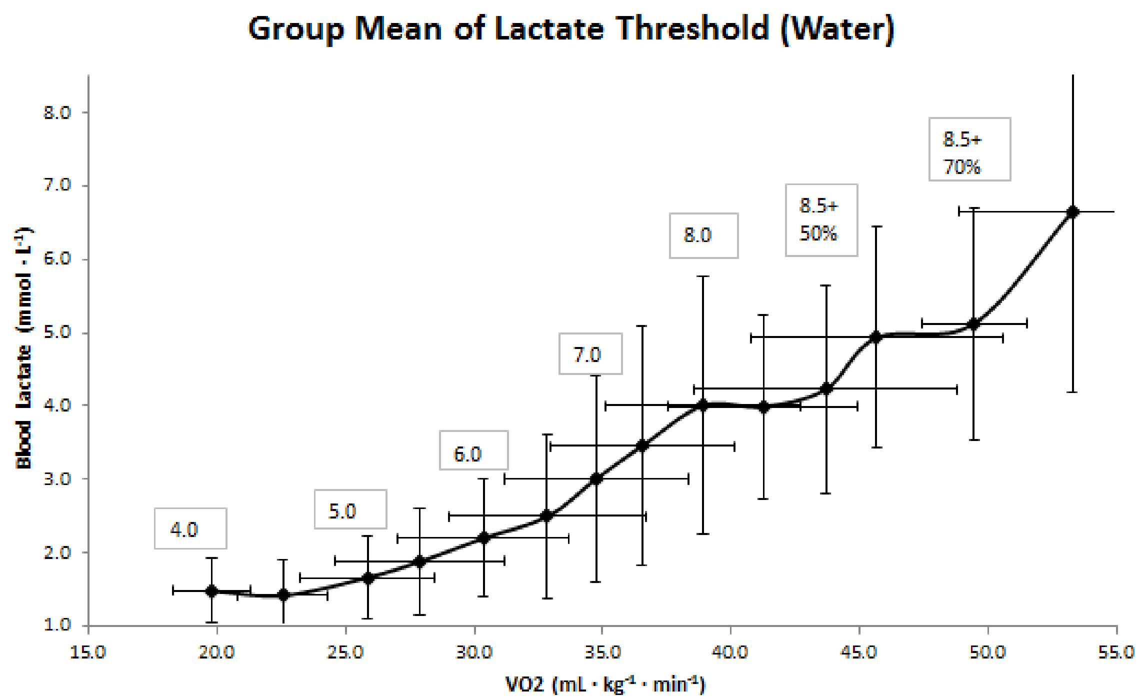

Figure 1 – Blood lactate vs. VO_2 across treadmill speeds during LT tests in water. Each point is marked above with speed (mph) and water jet intensity (% of maximum).

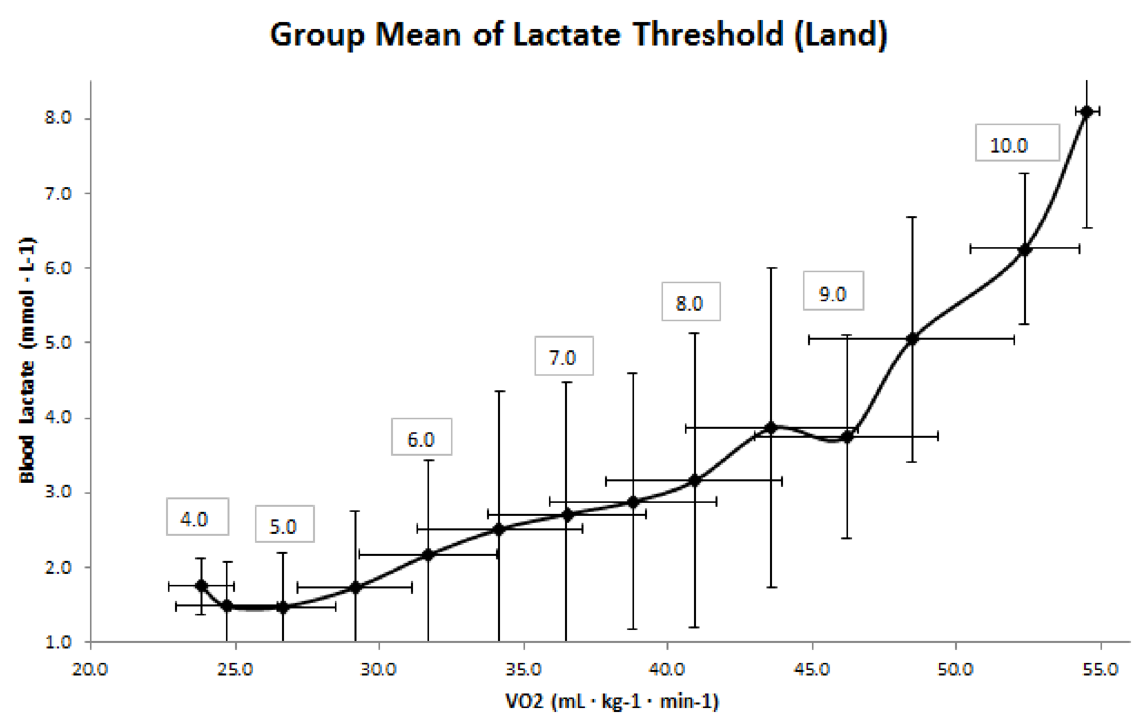

Figure 2 – Blood lactate vs. oxygen consumption across treadmill speeds during LT tests on land. Each point is marked above with the speed (mph).

Discussion

The LT point occurred at the same absolute concentration, perceived effort, speed, and RER despite a lower HR and VO_2 response in water. These data indicate that a comparable lactate response can be elicited at the same running speeds and perceived effort land vs. water. However, individual participants showed variations as to the speed at which LT occurred in the water vs. land as four participants achieved LT at exactly the same speed and four subjects were within 0.5 mph (aquatic treadmill speed was 0.5 mph slower in each of these four participants). The remaining eight participants contained four which achieved LT at 1.0-1.5 mph faster on land and three which achieved LT at 1.0-1.5 mph faster in the water.

Previous research has observed similar peak VO_2 and lactate values between land and water (Greene et al. 2011; Silvers et al., 2007; Schaal, Collins, & Ashley, 2012). It is well established that the human body is not restricted in the ability to produce lactate while exercising in water at equivalent workloads as land exercise with regards to maximal treadmill running.

In performing submaximal aquatic vs. land treadmill running, previous research has revealed varying data with VO_2 and HR. Some have reported lower VO_2 and HR in water vs. land (Greene et al. 2011), lower on land vs. water (Rife et al., 2009) and no difference land vs. water (Brubaker et al., 2011). Schaal et al. (2012) reported higher VO_2 on land at 70% VO_2peak with no statistical difference between HR for land vs. water. Differences in VO_2 or HR at equivalent work rates land vs. water have been explained by the buoyancy of the body in the water compared to 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.

A study by Benelli, Massimiliano, and De Vito (2004) compared lactate values during land, shallow water (leg/waist level), and deep water (chest/neck level) aerobics. While the study did not determine LT directly, a trend was observed for lactate concentration and HR values to be statistically higher on land than in water at fast (5.65 vs 3.15 & 1.75 mmol•L^{-1}) and slow (3.10 vs 1.75 & 1.70 mmol•L^{-1}) paced submaximal levels. The authors state this difference was due to lower physiological strain in water because of the buoyant force exerted on the participants. The current investigation supports lower HR values in the water, however, lactate concentration is the same between the two modalities.

Watson et al. (2012) quantified lactate values while participants performed graded exercise tests in the aquatic treadmill. The aquatic treadmill used in that study is slightly different from that of the current investigation; however, the data identifies a trend of lactate produced by the human body. At 4.5, 6.0, and 7.5 mph and 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 participants in this study were NCAA Division I ice hockey players. The current investigation had VO_2 and lactate data at 4.5, 6.0, and 7.5 mph and 40% of maximum jets 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 high average VO_2peak values, the current study contained recreational runners who may be more economical with running compared to trained ice hockey players and help explain differences of blood lactate response to similar exercise intensities. VO_2 values between the two groups remain fairly consistent and factoring in variability, there remains great overlap between them.

Frangolias and Rhodes (1996) reviewed deep water running at the same VO_2 on land and in water. Lactate, RER and RPE were each higher in the water with a lower HR compared to land. With our subjects running on the aquatic treadmill, the same trend was shown for a decreased lactate at the same VO_2 in the water compared to land (see figures 1 and 2). Our subjects also had lower HR values in water vs. land at the LT point but did not show significantly different RPE or RER values at the LT point.

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 $mL•kg^{-1}•min^{-1}$, 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 slightly different, the D_{Max} and least squares regression methods remove arbitrary selection of an LT point by visual analysis. The current investigation also shows significantly lower VO_2 in water vs land at the LT point.

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 evidence has revealed increased muscle activity of the tibialis anterior muscle as well as hip extensor muscles (in particular the biceps femoris) in water running compared to land running (Kaneda et al., 2007; Silvers, 2007). The added fluid resistance against the legs compared to land may increase the metabolic response of those tissues (i.e. higher blood lactate) while maintaining a lower VO_2 and HR in water due to the buoyancy of the participant. Similar to this idea, our participants were asked to maintain a running form that was consistent between land and water. 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 in water, upper extremity movement through water may also cause an increase in muscle activity and lactate production compared to land.

The variety of methods used 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 unusual as there are no established guidelines as to a "normal" lactate response to running in the water. Using the D_{Max} method instead of visual identification or fixed blood lactate concentration appeared to limit the amount of personal or physiological bias that may be introduced to a comparison of land and water LT tests.

A recent article by Janeba et al. (2010) questioned the validity of the D_{Max} method to determine LT. In the article, the authors removed the first and last data point from an LT test for cycling. By removing those points, the maximum distance from the line along the curve changed statistically for the workload at which LT occurred. Arbitrarily removing the first or last points in a data set during analysis may effectively change the LT point. As there were two LT tests per subject to compare (land and water) in the current investigation, we ensured that the beginning and ending points between the two modalities were consistent, which enabled a fair and accurate comparison. 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 which are generally accepted as normal values of LT (Gladden, 1989; Weltman et al., 1990). McGehee et al. (2005) showed no statistical difference between using the D_{Max} method compared to visual identification or a 1 mmol•L^{-1} increase to determine LT.

Limitations of the study include an unknown amount of time required for familiarization to the aquatic treadmill setting. In order to provide exposure to the aquatic treadmill, participants who had never used an aquatic treadmill previous to this study were given an introduction to the aquatic treadmill immediately prior to the VO_2peak test. Self-selected running speeds and jet intensities allowed participants to experience varying resistances in the water. Future research should investigate metabolic cost changes, if any, to repeated exposure with the aquatic treadmill as well as any biomechanical factors (i.e. kinematic movements) that change due to exposure to the aquatic treadmill.

This study provides insight for those using aquatic treadmills and wanting to achieve threshold-intensity training while lowering the joint-stress caused by land running. With the blood lactate levels having no statistical difference between the two modalities, it is proposed to improve the ability to use lactate as a fuel source while experiencing lower metabolic cost and limiting joint stress from traditional land treadmill running. As reviewed by Stainsby and Brookes (1990), the LT could be a result of clearance mechanisms failing to keep pace with the production of lactate.

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 the same perceived effort in water as land ($p=0.825$) at the LT point. The same perceived effort in water may allow similar lactate values to be achieved 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 to land for training at the LT and adjust speed according to the RPE of the individual.

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