

Lactate Threshold: Land versus Water Treadmill Running

Introduction

Aquatic treadmill running has become increasingly popular for rehabilitation and training purposes due to decreased joint impact on the lower extremities, which can be beneficial for special populations such as the injured, elderly, arthritic, and obese (Greene, 2009; Hall). Accordingly, researchers have compared key physiological differences between land and water running, such as maximal and submaximal efforts, Heart Rate (HR), VO_2 , and stride frequency (Brubaker; Rutledge; Rife; Silvers). 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.

Deep and Shallow Water Running

Previously, deep water running was the primary source to “running” in water. However, the physiological stress of deep water running was not the same as land treadmill running with regards to VO_{2max} , HR_{max} , blood lactate concentration, and RER (Svedenhag; Frongolias, 1996). One study (Town and Bradley, 1991) showed a trend that is common with water immersion running compared to land treadmill running; a lower VO_2 max (74% of land VO_2 max) with a higher overall percentage of HR max (90% of land HR max). This is often explained by an increased hydrostatic pressure on the body, lowering the overall blood flow (Reilly). One study showed differing peak lactate values land versus water in young men, but with no statistical difference in middle aged men (Nakinishi).

Benefits of Aquatic Treadmills

With the innovation of technology, the modality of “water running” has changed with the ability to submerge a treadmill to any water depth to run while utilizing similar land running mechanics. Deep water or water immersion running often required participants be suspended with buoys or ropes, which in turn required more experience or skill in order to obtain satisfactory physiological demands (Frangolias et al., 1995). Aquatic treadmill running is a preferable method to deep water running because there are more inherent skills to running on a treadmill submerged in water.

A thorough understanding of the dynamics of aquatic treadmills is currently underway. When an individual is placed in water at the xiphoid process and told to walk both fast and slow, there is a general unloading of the body of approximately 72% of on-land weight-bearing (Harrison). These effects are due to buoyancy forces in the body, an important topic with aquatic exercise. As the unloading of the body has been well-known, aquatic therapy is regularly used for rehabilitative purposes or special populations (Greene, 2009; Hall et al.).

Another topic of interest is that of jet resistance in aquatic treadmills. Recently, direct values for drag forces were quantified at varying jet resistance while walking VO_2 was measured (Bressel, Smith, Miller, & Dolny, 2012). These investigators showed a linear increase in the flow velocity as jets increased from 0% to 80% as well as a nonlinear increase in the drag force “due to a second degree effect of relative velocity on drag forces” (Bressel). These drag forces can be used to calculate mechanical work performed, which will help identify the increase in metabolic work. At a walking pace, VO_2 was doubled from 0% to 80% jets ($11.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$).

¹ to 22.2 ml • kg⁻¹ • min⁻¹ respectively). This shows that by adding jet resistance, there will be an increase in metabolic demand.

As a benefit for training, Greene et al. (2009) showed that aquatic treadmill running three days per week for 12 weeks was an effective stimulus in an obese male and female population to increase aerobic capacities and lower BMI. This is the only known long term training program in the literature and more research in this area is sure to be conducted.

Land vs. Aquatic Treadmills (Maximal Values)

Comparisons of land and aquatic treadmill running show no statistical difference between maximal physiological variables with regards to VO₂ peak, HR max, lactate concentration, and Respiratory Exchange Ratio (RER) (Silvers et al., 2007; Greene et al., 2011). These values were obtained when subjects ran on an aquatic treadmill with water depth at the xiphoid process.

Silvers et al. (2007) showed no statistical difference in VO₂ peak values specifically with VO₂, HR, lactate concentration, ventilatory threshold (V_T), RER, RPE, test time, and final speed when water was compared to land. These values are critical in determining if an individual has achieved a true VO₂ peak test. Therefore, the use of either an aquatic treadmill or land treadmill is sufficient to determine a VO₂ peak. There was a statistical difference between minute ventilation and breathing frequency. This is explained that in order to achieve the same VO₂ on land and in water, the body must compensate for the hydrostatic pressure in the water by increasing minute ventilation, which will in turn increase the frequency of breathing.

Land vs. Aquatic Treadmills (Submaximal Values)

Studies have elucidated the submaximal metabolic cost comparison of aquatic treadmills and land treadmill running (Brubaker; Rutledge; Rife). In Brubaker et al.'s introduction, some studies showed that at the same relative VO_2 , HR was *higher* in water than on land treadmills with middle-aged healthy women. Their results then showed that for healthy college-aged individuals, there was a significantly *lower* HR response in water versus land treadmills in one of the four stages analyzed. At all other submaximal efforts, there was no statistical difference in HR between land and water. The trend of the HR- VO_2 relationship was not statistically different land versus water. They also showed no statistical difference in the RPE between the submaximal efforts, showing that in healthy college-aged individuals, there is no perceived effort that is different between the two modalities. The VO_2 at $7.3 \text{ km} \cdot \text{h}^{-1}$ and $9.6 \text{ km} \cdot \text{h}^{-1}$ was significantly different with VO_2 being lower in water than on land. A lower VO_2 in water may have implications for a lower workload experienced in water at the same relative speed.

Rutledge et al showed equivalent work rates between land and water intensities. For a fixed treadmill speed ($174 \text{ m} \cdot \text{min}^{-1}$) in the water with 50% jets, to obtain the equivalent metabolic cost on a land treadmill, speed would be $212 \text{ m} \cdot \text{min}^{-1}$. This study was the first to show equivalent workloads between land and water or to clarify how fast an individual would need to run in order to have similar metabolic demands during exercise. With this clearer understanding of relative intensities on land or in water, an equivalent intensity can be provided based on oxygen consumption to ensure a consistent workload is performed both on land and in water.

Lactate Threshold

Lactate is produced from glycolytic pathways during progressively higher intensities of exercise. The work rate at which lactate begins to accumulate in the blood is called the anaerobic, or lactate threshold (LT) (Stainsby). Lactate is released from skeletal muscle into the blood stream and can be identified by blood sampling techniques such as a finger or earlobe puncture where capillary blood is then analyzed. These blood samples are used to identify a LT based on a fixed concentration (2.0 or $4.0 \text{ mmol} \cdot \text{L}^{-1}$ blood) or by visual identification of a non-linear increase in lactate (Bentley; McGehee; Weltman; Faude). Depending on the fitness level of the individual, the LT varies as an overall percentage of the VO_2 max. An individual with higher fitness levels can sustain work at higher percentages of their VO_2 max without the accumulation of lactate (associated with acidosis) ultimately causing them to feel fatigue and require cessation of exercise.

Land vs. Water Lactate Threshold

A study by Benelli et al. compared lactate values during land aerobics versus shallow (leg/waist level) and deep water (chest/neck level) aerobics. While the study was not determining LT directly and participants were not running, a trend is seen for lactate concentration and HR values to be statistically higher on land than in water at fast and slow paced submaximal levels. Lactate values were on land was $5.65 \text{ mmol} \cdot \text{L}^{-1}$ versus water's $3.15 \text{ mmol} \cdot \text{L}^{-1}$, showing a higher intensity on land could be achieved. The same aerobic exercise was performed at the same fast and slow speed (2.3 hz and 1.15 hz respectively) in all three conditions. Benelli states that this difference is due to the lower physiological strain in water versus on land because of the unloading or buoyancy of the participants in water. Interestingly,

data variability of lactate concentration in water was very low compared to land, indicating a consistency in physiological response to a similar exercise performed.

Comparisons have been made between deep water running and land treadmill running in regard to lactate response. Frangolias et al. (1996) reviewed water versus land running at submaximal intensities, the same relative VO_2 demonstrated a lower HR with higher blood lactate, RER, and rating of perceived exertion (RPE). This same author in the previous year showed that after maximal efforts land versus deep water running, there was no statistical difference between lactate concentrations 30s and 5min post-exercise (Frangolias et al., 1995). However, not all water immersion running studies support similar peak lactate values (Frangolias et al., 1996; Svedenhag). Town and Bradley showed no *statistical* differences between land and water immersion running with peak lactate, however, water running showed lactate concentration to be 80% of the land treadmill values. Even though there was no statistical difference, a trend was shown for lactate concentration to be lower in water running conditions. In this study there was a shallow water run, and the authors state that the “push-off” phase with ground contact enabled a similar running modality to land treadmills, which partially enabled similar responses to land.

The implication of the “push-off” in the previous article is now the case with aquatic treadmills. Silvers et al. showed that peak lactate concentration was the same in max tests land versus water with no statistical differences between the two. In regards to peak lactate, the ability to run on a treadmill in the water has clearly enabled a nearly identical peak lactate response compared to the varying response of deep or shallow water running.

The only known source to have completed an aquatic treadmill LT test compared to a land treadmill LT is a thesis paper by Zobell. The LT was compared as an overall percentage of VO_2 max. Lactate values were also compared at the same relative VO_2 on land and in water. The study reports statistically different threshold points with LT occurring at a lower percentage of VO_2 max in the aquatic treadmill setting. At the same relative VO_2 , concentration of lactate was statistically higher in all running stages (5.5, 6.0, 6.5, 7.0 and 7.5mph). The methodology of this study did not seem to use the most ideal setting for training purposes. Lactate values were found after controlling for plasma protein concentrations and expressed as $\text{mmol} \cdot \text{kg H}_2\text{O}^{-1}$. In order to “equilibrate body chambers” Zobell required participants stand on the land treadmill or in the water for 30 minutes prior to baseline blood samples being obtained. Most training performed in an aquatic treadmill setting, whether for rehabilitation or general exercise, will be performed almost immediately upon entering the aquatic setting.

This raises a question as to what will occur during acute water exposure to the human body. Work performed by Hinghofer-Szalkay showed that 30 minutes of acute water immersion caused an 11% increase in blood plasma volume. Zobell reported statistically significant plasma volume decreases of $18.7\% \pm 1.7\%$ in water and a decrease of $6.4\% \pm 4.0\%$ on land. Due to such a large increase in plasma volume from acute water exposure, it is unclear if a large decrease in plasma volume in water was from the aquatic treadmill running or the 30 minutes of standing in water. This is critical because the values of lactate are expressed as $\text{mmol} \cdot \text{kgH}_2\text{O}^{-1}$, therefore if water concentration in the plasma became significantly different, it would be difficult to say that was from running on an aquatic treadmill or standing in water for 30 minutes. To substantiate these claims of differences in lactate threshold land and water, another investigation

is required. Perhaps to follow a more applicable setting of exercise, participants should not stand immersed in water for 30 minutes, but rather immediately start the workout.

Another subject of interest with Zobell's paper was that all 11 subject's LT data was identified as a percentage of VO_2 max. The average VO_2 max was relatively high (54.0 ± 1.8 ml/kg/min) implying a fit population. They were described as "active males" as the subjects worked out on a regular basis. However, when lactate threshold values were reported, the average value on land was $49.8\% \pm 7.9\% \text{VO}_2\text{max}$ and in water $40.3\% \pm 8.3\% \text{VO}_2\text{max}$. One subject reportedly hit lactate threshold at 26.3% of VO_2 max in the water, which for any moderately fit, regularly active populations, would be extremely low. The methods state that the LT test started at an intensity equivalent to 40% or the VO_2 max obtained from the previous session, so how could the LT be identified at 26.3% of VO_2 max if that is below the initial lactate values obtained?

The question is proposed: if maximal efforts are being achieved with no statistical difference between aquatic treadmills and land treadmills for lactate values, how would participants be able to endure the development of acidosis differently between the two modalities and have statistically similar end results? This is a key question to be answered. With peak lactate values being achieved similarly, what occurs through the progression of lactate concentration must be studied in order to give an accurate depiction of the accumulation period.

Methodology

A review by Bentley, Newell, & Bishop (2007) states that from the available literature, "tests containing 3-minute work increments provide the most reliable and valid measures of endurance performance." After a brief warm-up, participants will be required to run at

increasing submaximal intensities for three minutes, followed by a brief 10-20 s break in order to obtain blood samples via earlobe puncture. Statistically, blood draws from the earlobe have been lower than from a finger puncture. However, if the earlobe is the only site used, the point of threshold will remain consistent (Faude).

McGehee showed in a study that a fixed $4.0 \text{ mmol} \cdot \text{L}^{-1}$ to determine LT occurred at a significantly higher workrate than the LT visual identification (rise exponentially above the baseline values), the LT D-max (a line created by connecting the two end points of the lactate curve), and the $\text{LT}_{\Delta 1}$ (the point at which blood-lactate rises a sustained 1.0 mmol above baseline). This study used a fixed 1% grade on the treadmill and increased speed $0.22 \text{ m} \cdot \text{s}^{-1}$ every four minutes until LT was achieved. This protocol will be used in our study, but length of time will be three minute stages (Bentley; Weltman).

Forsyth and Reilly showed statistically different intensities at which a fixed blood lactate concentration was reached in women during different phases of the menstrual cycle. However, where the LT occurred by visual analysis was not statistically different. In order to use women as participants, they will be asked to perform the two LT tests within the same phase of the menstrual cycle, to limit the amount of estradiol concentration in the body that could alter the concentration of lactate in the blood.

Maximal Lactate Steady State

A concept similar to LT is the idea of a maximal lactate steady state (MLSS). Investigators realized that determining the LT itself did not necessarily correlate to all aspects of performance. For example, how long can a running or cycling effort be sustained without lactate accumulating in the body? This will not be the LT but somewhere below that point. In order to

determine MLSS, repeated submaximal efforts must be performed for sport specific intensities around the lactate threshold to determine where lactate maintains a consistently high value that is still lower than the point of threshold (Beneke, 1995; Beneke, 2000; Kilding). In other words, where is lactate produced in the body, but still cleared at a fast enough rates to avoid the accumulation?

While the concept of MLSS is very useful for performance, there are not any events that would require competition in the aquatic treadmills. For the purposes of this study, it would be more applicable to determine how the lactate threshold compares land and water, and perhaps as a follow up study, how MLSS is comparable, allowing individuals to train at race pace in the aquatic setting while limiting joint stress.

Conclusion

The importance of determining the LT is supported by a large body of evidence to predict aerobic endurance capacity (Faude et al.). Great efforts have been employed to predict the lactate threshold via field tests in order to determine the correct training intensity for endurance athletes (McGehee et al.). A crucial tool to use for training purposes would be for coaches and athletes to obtain correct training intensities for running in regards to LT, whether that training is in the water or on land. To this point, no articles have been published as to whether the LT occurs at the same intensity running on an aquatic treadmill compared to a land treadmill. Therefore, the purpose of this study is to determine the lactate thresholds while running on a land and an aquatic treadmill and compare to see if the intensities are equivalent.

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