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Metabolic-Cost Comparison of Running on an Aquatic Treadmill With Water-Jets and Land Treadmill With Incline

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METABOLIC-COST COMPARISON OF RUNNING ON AN AQUATIC TREADMILL WITH WATER-JETS AND LAND TREADMILL WITH INCLINE

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ABSTRACT

Purpose: This study investigated whether running on a land treadmill (TM) at specific inclines corresponded to an equivalent metabolic cost (MC, oxygen consumption, VO_2) using water-jets on an aquatic treadmill (ATM) at equivalent running speeds. **Methods:** Sixteen participants completed two trials on separate days on a TM and ATM. For each trial subjects performed eighteen, 3-4 min submaximal runs at three self selected speeds (slow, medium, and fast) with either water-jet resistances of 0-100% of maximum jet flow capacity in 20% increments during ATM or inclines of 0-10% in 2% increments during TM. Trials were separated by at least 48 hours. Oxygen consumption (VO_2), heart rate (HR), and rating of perceived exertion (RPE) were recorded during each trial. Regression and 2x6 ANOVA analysis was employed to evaluate TM and ATM running speed x jet resistance/incline relationship. **Results:** When running at similar speeds with no resistance (jets or incline), ATM yielded lower VO_2 than TM. Adding 40% jets during ATM matched MC during TM at 0% incline. At 60% jets ATM MC simulated TM MC while running on a 4% incline. Comparable MC was observed during ATM 80% jets and 8% TM incline, while ATM 100% jets yielded greater MC than TM 10% incline. While TM yields a linear increase in MC with increasing incline, ATM yielded a non-linear, cubic, in MC with increased jet resistance. **Conclusion:** The relationship between MC and resistance settings in ATM is quite different than TM incline and may be a result of non-linear application of drag forces on the torso created by the water velocities of the water jets.

INTRODUCTION

In recent years aquatic exercise using deep or shallow water has become more popular. This method of training and rehabilitation has gained popularity because it combines the weight-reducing effect of water buoyancy with added drag resistance of moving limbs through water. These features allow individuals who have some orthopedic restriction or limitation to begin retraining before weight-bearing exercise is recommend on land. Populations with arthritis, musculoskeletal, neurological, and other limitations that could not otherwise maintain cardiovascular health and fitness through regular exercise are provided an environment in which they can exercise. Aquatic training is also used for cross training purposes to complement land-based training in athletes prone to overuse injuries. Exercising in an aquatic environment allows the body to undergo less stress and strain normally associated with land-based activities (Moening, Scheidt, Shepardson, & Davies, 1993).

Deep-water running (DWR), shallow-water running (SWR) and aquatic treadmill running (ATM) are all aquatic environments in which a patient or athlete could train. Though DWR and SWR may be sufficient for a patient recovering from an injury to maintain cardiorespiratory benefits, it does not allow for the same intensity as a land based exercise. DWR $VO_{2\,max}$ and HR are 84.2% and 91.4% of that found on land treadmill running (TM), respectively (Reilly, Dowzer, & Cable, 2003). SWR simulates TM $VO_{2\,max}$ and HR similar to DWR with 88.0% and 91.3% of TM values respectively (Dowzer, Reilly, Cable, & Nevill, 1999; Town & Bradley, 1991).

With ATM a patient can take advantage of the buoyancy effect without the consequences brought about by the frontal resistance created in SWR. This occurs because on the aquatic treadmill the subject remains in the same location, whereas in shallow water there is drag force created as the subject moves from one location to another. Therefore, the subject can use a more normal ambulatory posture and walking gait on an aquatic treadmill (Pohl, & McNaughton, 2003). A person also experiences a reduction of weight-bearing in an aquatic exercise environment due to buoyancy (Harrison, Hillman, & Bulstrode, 1992). Though weight bearing is reduced, aquatic walking training has been shown to yield health benefits similar to other forms of land walking exercise. Such benefits include: increased VO_{2max}, and decreased body weight, BMI, fat mass and body fat percentage (Greene et al., 2009). It should also be noted that a similar VO_{2peak} could be reached using an aquatic treadmill with the body submerged to the xiphoid process, compared to a land treadmill (Silvers, Rutledge & Dolny, 2007).

There are several factors that must be carefully controlled that influence VO_2 results in an aquatic treadmill. The first condition is water depth. Because water depth is so influential, it is difficult to compare most studies. When walking in water shallower than the waist, the metabolic cost dramatically increases with depth due to more body surface area creating resistance against the water (Gleim, & Nicholas, 1989; Pohl, & McNaughton, 2003). Even small adjustments in water depth have a significant impact on VO_2. At walking speeds of 1.1 m/s there is a significant difference in VO_2 when comparing a water depth of +10 cm from xiphoid and -10 cm from xiphoid. When comparing VO_2 at walking speeds greater than 1.1 m/s, there is a significant difference at least every 10 cm (xiphoid and +/- 10 cm from xiphoid) (Alkurdi, Paul, Sadowski, & Dolny, 2010). Different depths are equivalent to land metabolic costs at different speeds. At a walking pace, a water depth 10 cm above the xiphoid process yields a similar VO_2 as land treadmill walking (Alkurdi et al., 2010). ATM running between 2.95 – 3.8 m/s and submerged to the xiphoid process yields similar VO_2 results as TM at the same speeds (Rutledge, Silvers, Browder, & Dolny, 2007).

The second condition controlled in ATM is speed. Lack of consistency in data collection conditions makes it very difficult to draw a comparison. In all conditions there is a similar trend present. As ATM speed increases, so does VO_2. Increases range from 3.5 to 6.6 ml/kg/min VO_2 for every .5 m/s increase in speed (Greene, Greene, Carbuhn, Green, & Crouse, 2011; Hall, Macdonald, Madison, & O'Hare, 1998; Rutledge et al., 2007).

The final condition that must be controlled in ATM is resistance. In the aquatic treadmill, drag forces are created by moving limbs through water – a medium much more viscous than air. Additional resistance may be applied using pump-driven water jets. The effect of jet resistances increases drag forces applied to the body and is a product of the magnitude of water flow (usually expressed as a percent of jet capacity) and distance a subject stands from the jet port. Using an ATM with jets there were no significant differences in metabolic cost while walking comparing 0% to 25% jet resistances (Greene et al. 2011) while Rutledge et al. (2007) reported a significant increase (14.4%) in metabolic cost comparing 0% vs. 50% jet resistance. When comparing running (2.95 – 3.8 m/sec) at 50% and 75% jet resistances Rutledge et al. demonstrated an average increase in VO_2 of 5.4 ml/kg/min while Greene et al. (2011) reported an average increase of 7.4 ml/kg/min at running speeds between 2.68 – 3.1 m/s and an average increase of 3.5 ml/kg/min VO_2 comparing 75 to 100% jets when running 2.68 m/s. On average there is about a 2 ml/kg/min VO_2 increase for every 10% increase in jets.

The difference between TM vs. ATM is that in TM there are only two factors that need to be controlled, resistance and speed. Resistance on a land treadmill is controlled using the slope or incline of the treadmill belt. Though Staab, Agnew, and Siconolfi (1992) reported there was less then 1 ml/kg/min VO_2 increase for each 1% incline, Jones and Doust (1996) and Kline, Potteiger, and Zebas (1997) observed a 2 ml/kg/min and 2.5 ml/kg/min increase, respectively, for every 1% grade adjustment. Bassett, Giese, Nagle, Ward, Raab, & Blake (1985) developed a linear regression prediction equation for TM running at 0% and 5.7% incline. From these equations it is predicted that VO_2 will increase by 11.3 ml/kg/min from 0% to 5.7% grade on a treadmill at any running speed (Bassett et al. 1985). These results are consistent with Jones and Doust (1996) 2 ml/kg/min increase for every 1% increase in treadmill incline. Though the American College of Sports Medicine (ACSM) prediction equation (ACSM 2010) for treadmill running has been shown to over predict VO_2 (Ruiz & Sherman 1999), its predicted values are close to the above-mentioned values with a 1.7 ml/kg/min for each 1% increase in incline.

Similar to ATM, there is a lack of consistency concerning reported VO_2 values during TM running. Values range from 1 – 6.6 ml/kg/min increase for every 0.5 m/s difference in speed (ACSM 2010; Bassett et al. 1985; Rutledge et al. 2007; Saunders, Pyne, Telford, & Hawley 2004). These inconsistencies could be due to the physical fitness, running efficiency and biomechanical differences of the participants in each study. Bassett et al. (1985) and ACSM (2010) prediction equations estimate a 6.6 and 6.0 ml/kg/min VO_2 increase for every 0.5 m/s speed increase respectively.

If the ATM with jet resistances bcomes a prevelant mode of running exercise it seems prudent to compare the metabolic cost of ATM running with jet resistances with that of TM running on an incline. This comparison will allow comparable workouts between the modes and facilitate exercise training and rehabilitation efforts.

PURPOSE

The primary purpose of this study was to compare the cardiorespiratory and perceived exertion response of running on a land treadmill at selected speeds and grades with that of ATM exercise at selected jet resistances. It was hypothesized that HR and VO_2 will be similar between TM and ATM at identical running speeds and selected inclines and water-jet resistances.

METHODS

SUBJECTS

Seventeen subjects (9 men, 8 women) were recruited via word of mouth and flyer distribution. Participants came from the surrounding community and included members of the Utah State University (USU) track team, local running clubs and other well-trained volunteers from the Cache Valley area. Participants read and signed a release form that describes all study procedures prior to participation (Appendix B). All participants were well trained runners that had been participating in at least four aerobic training sessions/week, and at least 30 min/session (or an average of 25 – 30 miles/week) for at least six months. Participants were also free of acute illnesses, injuries, orthopedic conditions or disabling injuries that would have prevented them from running. They were also free of pain or any restrictions that would interfere with normal running form. The purpose for these criteria was so that the participants were fit enough to complete all the trials of this study. Details of this study and all procedures involved were reviewed and approved by the USU institutional review board (IRB). Based on a power analysis, a minimum of 14 participants was needed.

Table 1 Descriptive Statistics of Participants, M (SD)

Age	Height (cm)	Weight (kg)	Body Fat (%)	VO_{2peak}, $ml \cdot kg^{-1} \cdot min^{-1}$
26	173.0	65.9	13.6	53.53
(7)	(8.5)	(10.0)	(6.3)	(8.33)

EQUIPMENT

All ATM trials were completed on a HydroWorx 2000 (HydroWorx, Middletown, PA). Water temperature was maintained at 30 ^{o}C. TM trials were done on a FreeMotion Incline Trainer Basic (FreeMotion Fitness, Colorado Springs, CO). VO_2 was analyzed using a True One 2400 automated metabolic system (Parvo Medics, Sandy, UT). HR was monitored using a Polar T31 water-resistant chest-strap transmitter (Polar, Lake Success, NY). Skinfolds were measured using a Lange Skinfold Caliper (Beta Technology, Santa Cruz, CA). Ratings of perceived exertion were assessed using the Borg's 15-point scale (Borg, 1982).

PROCEDURES

There was a total of three sessions conducted. Each session was separated by at least 48 hours. All participants had a familiarization session in which they used both the land and underwater treadmills before testing began. The familiarization session consisted of:

1. Recording subject's age, height and weight (Appendix B);
2. Taking skinfold measurements at the chest, abdomen, and thigh locations for men (Jackson & Pollock, 1978), and at the triceps, suprailiac, and thigh locations on women (Jackson, Pollock, & Ward, 1980). These measurements were used to estimate each participant's body density (Db). Db was converted to body fat percentage (BF%) using the Siri equation (Siri, 1961);
3. A $VO_{2\ peak}$ test conducted on the water treadmill consisting of running beginning at a self selected pace and increasing 0.22 m/s for each minute until the subjects reached their fastest comfortable running speed. Each minute thereafter the percent water jet was increased 10% until $VO_{2\ peak}$ criteria were met, or until the subjects indicated they were unable to continue at that pace and water jet resistance. Criterion was met when

at least one of the following occurred: a respiratory exchange ratio (RER) greater than 1.15, a plateau of VO_2, and a HR within 10 beats of the age predicted max (220 – age). At that point the treadmill was immediately stopped ending the test. After the pulmonary valve and headgear were removed, the subject walked slowly while cooling down from the test.

Session two and three were randomized by either running on land or on the aquatic treadmill. Each session began with a five minute warm up at a self-selected pace. Each participant completed 18 trials for each session. Each trial ended when steady state was reached. Trials lasted a minimum of three minutes or until steady state was reached. Steady state was defined by two, 60-second averages of VO_2 being within 2 ml/kg/min. Each 60-second average was calculated using four consecutive readings taken in 15-second increments. Once steady state was reached, the trial ended. There was a rest period of three minutes between each trial. One session was completed on the aquatic treadmill and the other on the land treadmill. Trials within each session were randomized for each participant by drawing each of the 18 conditions out of a hat. The aquatic treadmill trials consisted of six resistances (0, 20, 40, 60, 80 and 100% jets; see Table 2) at each of three different self selected speeds (slow, medium, and fast; see Table 3). The water jet resistances were two adjustable jets aimed to cover the participant's umbilicus one meter from the heads of the jets. All subjects were submerged was to the level of the xiphoid process.

The land treadmill trials were conducted at the same three self-selected speeds as the aquatic treadmill trials. Land trials were done at 0, 2, 4, 6, 8 and 10% grades (Table 2). During all trials oxygen consumption (VO_2), expired ventilation (V_E), breathing frequency (f), tidal volume (V_T), oxygen (O_2) pulse and heart rate (HR) were monitored continuously and averaged for each minute. Rating of perceived exertion (RPE) was recorded immediately following each trial.

Table 2 **Resistance settings by trial for ATM and TM.**

Trial	ATM jet resistance (%)	TM incline (%)
1	0	0
2	20	2
3	40	4
4	60	6
5	80	8
6	100	10

Table 3 **Average Self-Selected Speeds,** M (SD)

Slow	Medium	Fast
2.32	2.68	3.04
(0.27)	(0.32)	(0.36)

All speeds measured in m/s.

STATISTICAL ANALYSIS

Descriptive statistics were calculated for all subjects. A paired samples t-test was used to evaluate any differences that existed between conditions with assumed comparable resistances (0, 2, 4, 6, 8, 10% TM to 0, 20, 40, 60, 80, 100% ATM respectively). In addition, three (one for each speed) 2x6 repeated measures ANOVA were used to determine any significant difference between land and water conditions and between resistance levels for VO_2, HR, and RPE. When necessary, an LSD analysis was used to determine the location of significance. The confidence level was $p < 0.05$ for all analysis.

RESULTS

One participant was not able to complete the study due to illness. One participant was unable to complete the ATM 100% jets at the medium and fast speeds. A number of subjects also struggled to complete several conditions and these trials were reviewed. If a subject's VO_2 did not increase on that trial compared to the immediately lower intensity trial, then the data for that trial were excluded. There were 8 trials excluded from ATM fast speed with 100% jets, 2 from ATM fast speed with 80% jets, 4 from TM fast speed at 10% incline, and 3 from TM fast speed with 8% incline. The assumption was made that the participant was at or near peak capacity if VO_2 did not increase with intensity. Therefore, the loss of subject data with ATM 100% jets, TM 10% incline and to a lesser extent ATM 80% and TM 8% should be reviewed with caution.

For all speeds a similar pattern was observed. Metabolic cost (MC) was higher for the TM compared to the ATM at lower resistances. As the resistance increases, TM and ATM MC became more similar until eventually reaching similar MC at trial 5 (8% incline vs. 80% jets). At the highest resistance, ATM MC was greater then that of TM. Even though there was a similar trend across all speeds, significance ($p < .05$) occurred for a different amount of trials in each of the three speeds. As speed increased, the points of significance decreased. Trial 1, 2, 3, 4 and 6 in the slow speed, trials 1, 2, 3 and 6 in the medium speed, and 2 and 3 in the fast speed were all determined to be significant (Table 4).

With speed removed as a factor, a 2 x 6 repeated measures ANOVA was done to determine what differences existed between TM and ATM across all trials. It was determined that TM trials 1 and 3 were not significantly different from ATM trials 3 and 4 respectively (Table 4). In other words, MC for TM 0% and 4% incline was comparable to MC for ATM 40% and 60% jet resistance respectively.

For HR, all three speeds follow the same regression trend per condition (Figures 1 & 2). Independent of speed, ATM has a cubic regression ($R^2 = 0.99$) while TM has a linear regression ($R^2 = .99$).

Table 4. Oxygen consumption M+(SD) across all running speeds and conditions for ATM and TM.

ATM	Slow	Medium	Fast	All Speeds Combined
1 - 0%	25.3 (4.9)	28.7 (5.7)	32.5 (7.4)	28.8 (6.7)
2 - 20%	26.0 (4.5)	29.6 (5.7)	34.0 (8.2)	29.9 (7.0)
3 - 40%	28.9 (5.7)	31.7 (6.0)	35.6 (6.5)	32.1 (6.6)
4 - 60%	33.1 (5.0)	38.5 (6.7)	41.5 (7.5)	37.7 (7.2)
5 - 80%	41.6 (5.3)	45.4 (6.4)	49.4 (5.8)	45.3 (6.5)
6 - 100%	49.9 (6.1)	50.8 (6.6)	53.5 (5.2)	51.1 (6.1)
TM				
1 - 0%	28.7 (4.1)	32.3 (5.0)	35.0 (4.5)	32.0 (5.1)
2 - 2%	30.9 (3.7)	34.6 (4.8)	38.4 (4.9)	34.6 (5.4)
3 - 4%	33.5 (4.1)	36.7 (4.8)	41.2 (5.2)	37.2 (5.6)
4 - 6%	36.9 (4.6)	41.1 (5.2)	44.8 (5.5)	40.9 (5.9)
5 - 8%	40.0 (5.2)	43.2 (4.8)	47.9 (5.4)	43.4 (5.9)
6 - 10%	42.8 (4.7)	47.0 (5.5)	50.2 (5.8)	46.4 (6.0)

All VO_2 measured in ml/kg/min

Figure 1. Oxygen consumption during all running speeds for ATM.

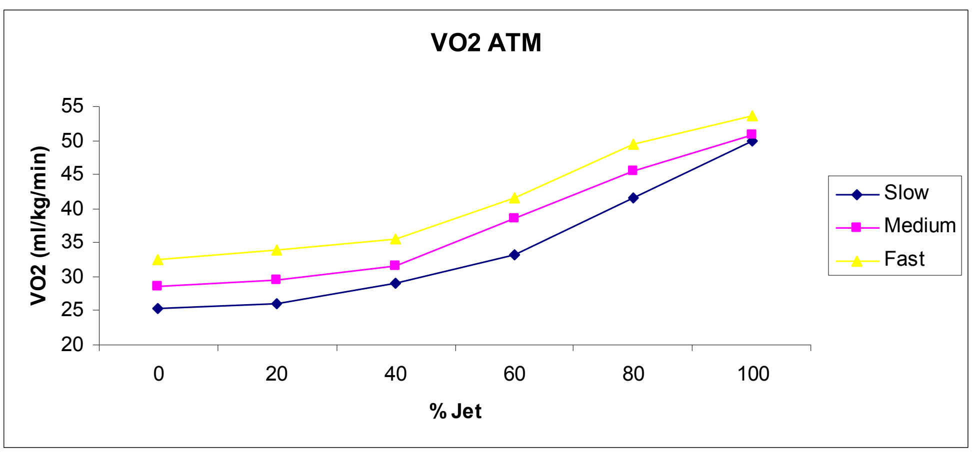
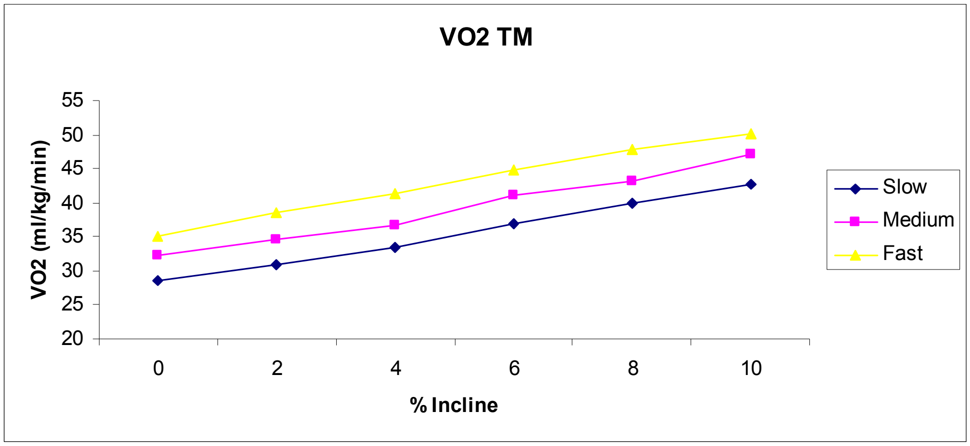


Figure 2. Oxygen consumption during all running speeds for TM.



HR followed the same trend as VO_2 in all speed. HR (Table 5) had varying points of significance ($p < .05$) when comparing the three speeds. Trials 1, 2, 3, 4 and 6 in the slow speed, 1, 2 and 3in the medium speed, and 1, 2, 3 and 4 in the fast speed were all determined to be significant.

When a 2 x 6 repeated measures ANOVA was done to determine what differences existed between TM and ATM across all trials for HR, there where six sets of trials that were not statistically different from each other. It was determined that trials TM 1 and ATM 3, TM 2 and ATM 4, TM 3 and ATM 4, TM 5 and ATM 5, TM 6 and ATM 5, and TM 6 and ATM 6 were not significantly different from each other (Table 5).

Similar to VO_2, HR followed the same regression trend per condition for all three speeds (Figures 3 & 4). Independent of speed, ATM has a cubic regression ($R^2 = 0.99$) while TM has a linear regression ($R^2 = .95$).

Table 5. Heart Rate M+(SD) across all running speeds and conditions for ATM and TM.

ATM	Slow	Medium	Fast	All Speeds Combined
1 - 0%	129 (16)	139 (14)	147 (16)	138 (17)
2 - 20%	135 (11)	141 (14)	150 (18)	142 (16)
3 - 40%	138 (12)	143 (12)	154 (14)	145 (14)
4 - 60%	146 (13)	159 (13)	163 (12)	156 (14)
5 - 80%	163 (11)	170 (7)	178 (8)	170 (11)
6 - 100%	177 (9)	181 (25)	183 (9)	176 (18)
TM				
1 - 0%	139 (15)	145 (15)	155 (17)	146 (17)
2 - 2%	145 (15)	150 (21)	161 (16)	152 (18)
3 - 4%	149 (14)	158 (14)	165 (14)	157 (15)
4 - 6%	158 (17)	164 (14)	170 (13)	164 (15)
5 - 8%	161 (15)	167 (13)	177 (11)	168 (14)
6 - 10%	163 (14)	173 (14)	180 (10)	172 (14)

All Heart Rates measured in beats per minute (bpm).

Figure 3. Heart Rate during all running speeds for ATM.

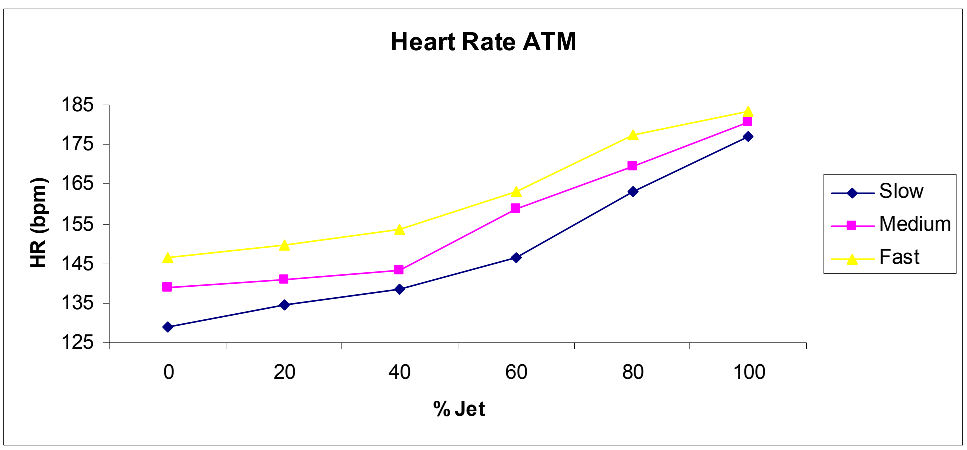
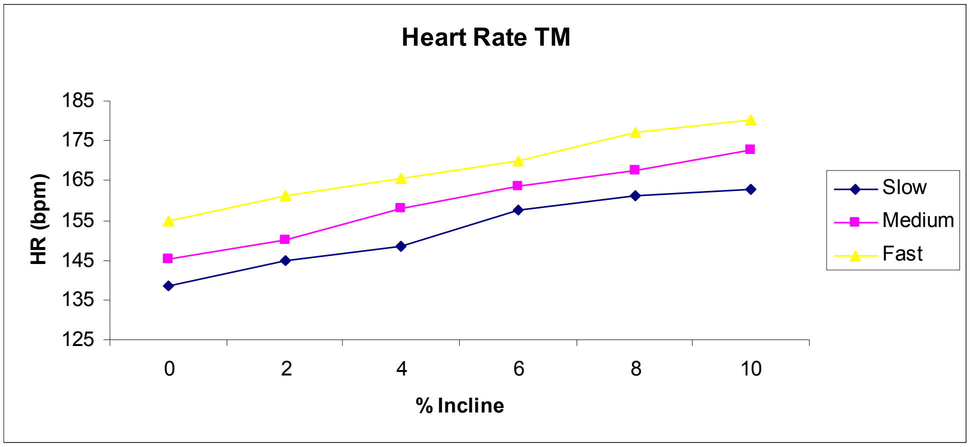


Figure 4. Heart Rate during all running speeds for TM.



RPE did not mimic the VO_2 and HR trend. The faster the speed, the more similar the RPE became across conditions (table 6). In the slow speed, there was significant difference between ATM and TM in trials 4, 5, and 6. In the medium speed there was significant difference in trials 5 and 6. In the fastest speed, the only significance occurred in trial 5 (Table 6).

When a 2 x 6 repeated measures ANOVA was done to determine what differences existed between TM and ATM across all trials for RPE, there where seven sets of trials that were not statistically different from each other. It was determined that trials TM 1 and ATM 1, TM 2 and ATM 2, TM 3 and ATM 2, TM 3 and ATM 3, TM 4 and ATM 4, TM 5 and ATM 4, and TM 6 and ATM 5 were not significantly different from each other (Table 6).

Similar to VO_2 and HR, RPE followed the same regression trend per condition for all three speeds (Figures 5 & 6). Independent of speed, ATM has a cubic regression ($R^2 = 0.99$) while TM has a linier regression ($R^2 = .99$).

Table 6. Rating of Perceived Exertion M+(SD) across all running speeds and conditions for ATM and TM.

ATM	Slow	Medium	Fast	All Speeds Combined
1 - 0%	7.5 (1.5)	9.1 (1.8)	10.3 (1.7)	9.0 (2.0)
2 - 20%	8.9 (1.7)	10.7 (1.9)	11.1 (1.4)	10.3 (1.9)
3 - 40%	9.8 (1.8)	11.5 (1.2)	12.1 (1.6)	11.1 (1.8)
4 - 60%	11.5 (1.7)	12.8 (1.6)	13.7 (1.2)	12.7 (1.7)
5 - 80%	13.8 (2.1)	15.1 (1.6)	16.5 (0.9)	15.0 (2.0)
6 - 100%	16.2 (1.5)	17.1 (1.6)	18.1 (1.1)	17.0 (1.6)
TM				
1 - 0%	7.7 (2.0)	9.2 (1.6)	10.7 (1.4)	9.2 (2.1)
2 - 2%	8.7 (1.6)	10.2 (1.9)	11.2 (1.6)	10.1 (1.9)
3 - 4%	9.7 (1.6)	10.8 (1.9)	12.7 (1.1)	11.1 (2.0)
4 - 6%	10.4 (2.1)	12.4 (1.7)	13.7 (1.6)	12.2 (2.2)
5 - 8%	11.7 (2.1)	13.3 (2.0)	15.3 (1.9)	13.3 (2.5)
6 - 10%	12.5 (2.5)	14.3 (1.9)	16.4 (1.5)	14.2 (2.5)

Figure 5. Rating of Perceived Exertion during all running speeds for ATM.

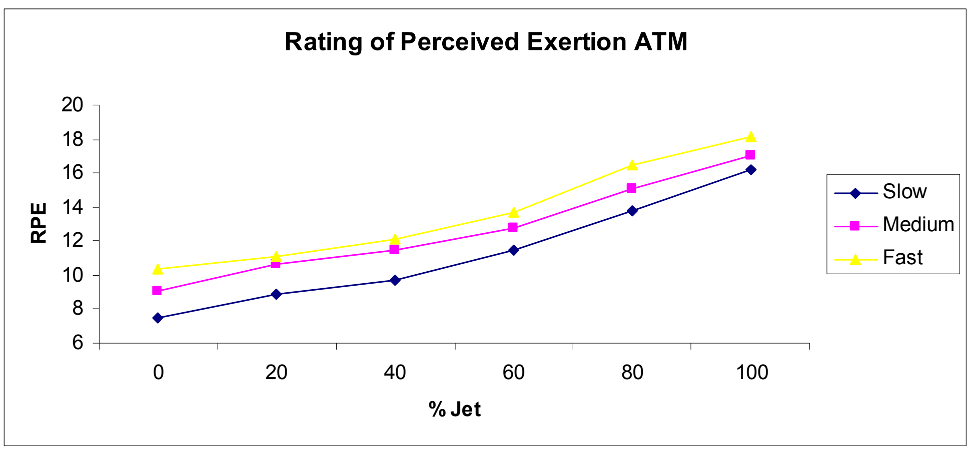
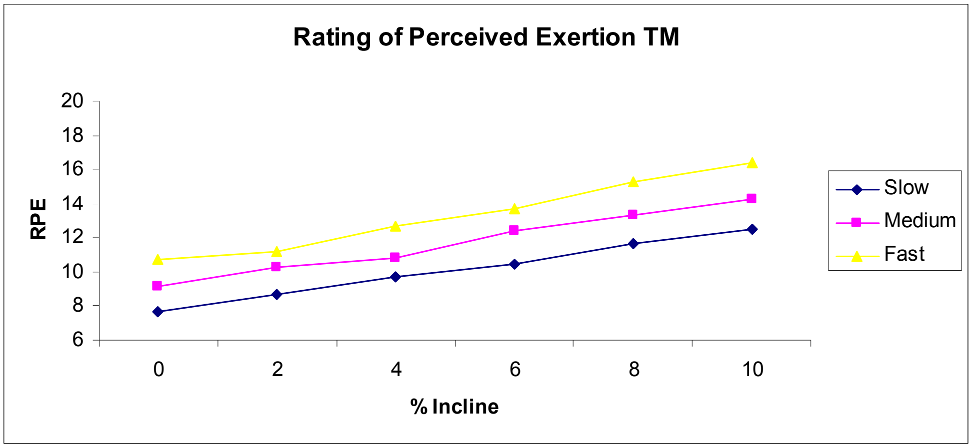


Figure 6. Rating of Perceived Exertion during all running speeds for TM.



DISCUSSION

There are few studies that have compared the MC of TM running and ATM running, and perhaps none that have compared the MC of incline TM with jet resistances from ATM. This comparison is important for both therapists and conditioning specialists for two reasons. First, weight bearing is reduced due to buoyancy in the aquatic environment (Harrison et al. 1992). This allows post surgery patients, arthritis patients, patients with limited mobility due to obesity, and other populations with mobility restrictions to become more mobile with less pain involved. Second, most therapists and conditioning specialists use land-based exercise for their prescription. To allow a clinician to prescribe aquatic treadmill exercise as training or rehabilitation supplement, there must be an understanding of how a land treadmill compares to an aquatic treadmill in terms of VO_2, HR and RPE.

Results of the current study show that the MC of the TM and ATM were significantly different across most comparable conditions. As was expected, the TM condition had a linear relationship as incline increased (Jones & Doust, 1996; Kline et al. 1997). On average, VO_2 increased ~3 ml/kg/min for every 2% increase in TM incline. This is consistent with previous research that reports anywhere from less than 2 ml/kg/min increase with 2% incline increase (Staab et al. 1992), up to 5 ml/kg/min increase with a 2% incline increase (Kline et al. 1997). Jones and Doust (1996) reported a 4 ml/kg/min increase with a 2% increase in incline. The change in MC with increasing incline during TM running in the present study reflects previously reported values.

In contrast the ATM condition displayed a cubic relationship. This relationship may be due to the application of the drag force of water flow acting on the body. When the drag force of jet settings ranging from 0 – 80% was directly measured using a force transducer (Bressel, Smith, Miller, & Dolny, 2011) it was determined that the drag force was proportional to the jet% resistance squared. Relatively little change in drag force was observed until the jet resistance settings reached ~30%. With the subjects placed one meter from the jet nozzle (identical to the present study) at these low jet flow rates it appears the jet flow pattern may essentially dissipate as it reaches the subject. At 40% jet resistance setting the flow velocity was great enough to produce a drag force that was very reproducible. This would account for the relatively small change in MC during ATM trials when the jet resistance settings were set at 0 and 20%. Under these conditions the effect of buoyancy (reducing MC) was not balanced by the cumulative drag forces of the limbs moving in water and a lower MC compared to land was observed. Beyond 40% jet settings the added drag forces combined with buoyancy raised the MC of ATM until the 80% jet resistance setting exceeded the MC observed at 8% TM incline.

The data gives much insight because no other studies have investigated such small increments of increase in jet percentage. A similar trend was noticed though, when increasing jet resistance by 25% between trials (Greene et al. 2011). In that study, Greene et al. developed regression equations for the prediction of VO_2 when running on an aquatic treadmill. One equation was for use of the aquatic treadmill between 0 – 25% jet resistance settings. The second equation was for use of the aquatic treadmill when >25% jet resistance settings were used. When the data from several subjects in the present study was inserted into Greene's equations VO_2 was largely underestimated. This could in part be due to the population used to develop the equation compared to the population of the current study. In Greene's study subjects mean age was 41 years and a mean weight of 87.2 kg. The present studies participants had a mean age of 26 years, and a mean weight of 65.9 kg. According to Porter, Alkurdi, and Dolny (2011), body mass index scores could account for greater buoyancy and therefore a lower VO_2. Perhaps some measure of body adiposity should be taken into consideration when attempting to predict MC during ATM.

As noted by Rutledge et al. (2007), comparison of studies at different water depths should be avoided because of the great impact water depth has on MC. In their study, they found that participants submerged to the xiphoid process, with no jet resistance, exerted similar amounts of MC as land running. The same depth was used in the current study, yet the MC on land was greater then in water with no added resistance. Because the populations in these two studies were nearly identical, further research is needed to understand why difference existed between the results of these studies.

In the current study it was noted that VO_2 at the fast speed 100% jets, and HR at the medium and fast speed 100% jets were not statistically different from their opposing TM condition. In about half the trials that were excluded from statistical analysis, the participant's VO_2 could not go any higher because it had already reached its peak at the 80% jet resistance setting. A greater increase in VO_2 and HR may have been noticed during these trials had participants not been so close to their peak performance. In the other half of the excluded trials, participants had not yet reached their peak VO_2. A lack of VO_2 increase in those participants may be due to an alteration in running form to accommodate the magnitude of the jet resistances.

At all speeds, RPE was not significantly different ($p < .05$) in the first three trials (0, 2, and 4% incline and 0, 20, and 40% jets). In the last three trials (6, 8, and 10% incline and 60, 80, and 100% jets), TM RPE continued to increase linearly while ATM PRE increased cubically with increased resistance. This trend follows that observed changes for VO_2 and HR and demonstrates the efficacy of RPE to reflect change in exercise intensity, especially when reflected in metabolic rate or heart rate (Borg, 1982). Though no other studies have involved as many trials for each mode, this supports the trends reported in previous research (Brubaker, Ozemek, Gonzalez, Wiley, & Collins, 2011; Rutledge et al. 2007). This could be due to the resistance (drag force) that existed in the water but not on the land.

Limitations

It is recognized that there were limitations to this study. Most participants did not have an extended degree of experience on the aquatic treadmill. This may have been a factor when participants self-selected their running speeds. Some participants may have underestimated the difficulty of the ATM jets that made it quite difficult to complete these trials. Therefore we recognize the 100% jet resistance trials may not reflect steady state exercise conditions. We recommend future research select a more conservative set of running speeds and/or recruit a more fit subject population in order to successfully complete the running trials at 100% jet settings, therefore causing fewer unusable results at the fast speed and 100% jets.

In conclusion, the relationship between MC and jet resistance settings in ATM is quite different than TM incline. The TM incline provided a linear increase in MC while the ATM jet resistance settings provided a cubic rise in MC. The ATM response may be a result of non-linear application of drag forces on the torso created by the water velocities of the water jets when subjects are positioned one meter from the jet nozzles.

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Appendix A

UtahState University

Institutional Review Board
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Logan, UT 84322-9530
Telephone: (435) 797-1821
Fax: (435) 797-3769

Full AAHRPP Accreditation

2/10/2011

USU Assurance: FWA#00003308
Protocol # 2867

SPO #:
AES #: UTA00

MEMORANDUM

TO: Dennis Dolny
Sarah Squires, Ryan Porter

FROM: Richard D. Gordin, Acting IRB Chair
True M. Fox, IRB Administrator

Richard D. Gordin
True M. Fox

SUBJECT: Comparison of Metabolic Costs of Aquatic Running and Land Running at Varying Conditions and Speeds

Your proposal has been reviewed by the Institutional Review Board and is approved under expedite procedure #4 .

X There is no more than minimal risk to the subjects.
There is greater than minimal risk to the subjects.

This approval applies only to the proposal currently on file for the period of one year. If your study extends beyond this approval period, you must contact this office to request an annual review of this research. Any change affecting human subjects must be approved by the Board prior to implementation. Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Institutional Review Board.

Prior to involving human subjects, properly executed informed consent must be obtained from each subject or from an authorized representative, and documentation of informed consent must be kept on file for at least three years after the project ends. Each subject must be furnished with a copy of the informed consent document for their personal records.

The research activities listed below are expedited from IRB review based on the Department of Health and Human Services (DHHS) regulations for the protection of human research subjects, 45 CFR Part 46, as amended to include provisions of the Federal Policy for the Protection of Human Subjects, November 9, 1998.

4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

Appendix B

INFORMED CONSENT

INFORMED CONSENT
Comparison of Metabolic Costs of Aquatic Running and Land Running at Varying Conditions and Speeds

Introduction/ Purpose Professor Dennis Dolny in the Department of Health, Physical Education and Recreation at Utah State University is conducting a research study to learn about the energy requirements of running on a water treadmill and how it compares to land running at different running speeds and inclines. There will be approximately 20 total participants in this research. If you currently are running (on average four or more times per week for at least thirty minutes or more per run) as a form of regular exercise training, have no leg orthopedic conditions and are currently free of illness you are eligible to be a participant in this study.

Procedures If you agree to be in this research study, you will be asked to come to the Sports Medicine Complex on the campus of Utah State University four separate times. Each visit will take 60-90 minutes and will be scheduled over a two week period. The four visits will consist of the following:
1. Preliminary data collection where age, height, weight and three skinfold measurements from the arm, abdomen and thigh. Then a running test of about 8-12 minutes to voluntary fatigue in order to determine your maximum oxygen consuming limit while running on a land treadmill followed by an aquatic running familiarization period at a low running intensity for about five minutes.
2. A session where a total of eighteen, 3-4 minute running bouts on the aquatic treadmill with 3 minutes recovery between each bout. For each bout you will run at one of three speeds (6, 7, or 8 miles/hour) and run against a water resistance set at either 0, 20, 40, 60, 80 or 100% of the jet water flow capacity.

3. A session where a total of eighteen, 3-4 minute running bouts on the land treadmill with 3 minutes recovery between each bout. For each bout you will run at one of three speeds (6, 7, or 8 miles/hour) and run with the treadmill set at an inclines of either 0, 2, 4, 6, 8 or 10%.

4. A final session where a total of about 8, 3-4 minute running bouts on the land treadmill with 3 minutes recovery between each bout. For each bout the treadmill speed will vary between 6 and 10 miles/hour with no incline.

For all tests, you will wear a heart rate monitor strap on your chest and breathe through a pulmonary valve to analyze your expired air. We request that you do not perform any strenuous exercise workouts the day prior to each test session.

New Findings During the course of this research study, you will be informed of any significant new findings (either good or bad), such as changes in the risks or benefits resulting from participation in the research, or new alternatives to participation that might cause you to change your mind about continuing in the study. If new information is obtained that is relevant or useful to you, or if the procedures and/or methods change at any time throughout this study, your consent to continue participating in this study will be obtained again.

Risks There are no anticipated risks involved in this study beyond the normal risks of participating in running exercise that you may experience regularly: These include:
1. Shortness of breath or dizziness due to exercising to exhaustion during session one- similar to what you may experience when you exercise on your own at high intensities.
2. A gradual increase in muscle fatigue as sessions 2- 4 proceed. Total running time will be about one hour and may lead to residual muscle fatigue. This sensation is temporary and should subside within 24 hours following each session. We will be able to provide bags of ice and suggest methods to facilitate recovery if necessary.

Benefits This study will provide you with knowledge of your maximum oxygen consuming capacity (VO2peak) which is an indicator of your cardiorespiratory endurance and aerobic fitness. It will also provide you with the opportunity to experience running on an aquatic treadmill. And your participation will help to contribute to research on the metabolic responses of aquatic running and may serve to provide useful training protocols for runners in the future.

Explanation & offer to answer questions Dr Dolny and his research associates have explained this research study to you and answered your questions. If you have other questions or research-related problems, you may reach Professor Dolny at (435)-797-7579

Voluntary nature of participation and right to withdraw without consequence Participation in this research project is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits; simply inform the researchers of your desire to withdraw from the study.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only Dr. Dolny and research assistants Ryan Porter and Sarah Squires will have access to the data which will be kept in a locked file cabinet in a locked room. Personal, identifiable information will be destroyed following the final data analyses within a year of the completion of the study.

IRB Approval Statement The Institutional Review Board for the protection of human participants at USU has approved this research study. If you have any pertinent questions or concerns about your rights or a research-related injury, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu. If you have a concern or complaint about the research and you would like to contact someone other than the research team, you may contact the IRB Administrator to obtain information or to offer input.

Copy of consent You have been given two copies of this Informed Consent. Please sign both copies and retain one copy for your files.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

Signature of PI & student or Co-PI

____

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dennis.dolny@usu.edu

____

Ryan Porter
Graduate Research Assistant
(208) 351-5337

____

Sarah Squires Blackwell
Graduate Research Assistant
(801) 634-5651

Signature of Participant By signing below, I agree to participate.

____

Participant's signature

____

Date

Appendix C

Data Collection Sheet

Aquatic and Land Treadmill Comparison
Data Collection Sheet

Date ____________________

Name ________________________________ Age_____ Height______________

Weight _____________

Skinfolds: Chest/Triceps _____ Abdomen/Suprailiac________ Thigh __________