Aerobic Conditioning in Two Simulated Reduced-Gravity Environments Compared to Terrestrial Treadmill Training

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Abstract

This purpose of this study was to investigate an 8-week aerobic conditioning program under three different conditions. Participants were randomly assigned to one of three groups; a land-based treadmill (TM), anti-gravity treadmill (AG) or deep water running (DWR). Each group trained at vigorous intensity (70-85% of the heart rate reserve) for 30 minutes, 3 times per week non-consecutive days. A one-way ANOVA was used to determine between group differences and a dependent t-test was used to determine within group differences. No significant differences were found between groups after 8-weeks of training. Within groups, however, a significant difference ($p<0.05$) was found in the AG group with a decrease in weight, body mass index and body fat percentage. The DWR group was also found to have a significant ($p<0.05$) difference in aerobic capacity with an increase in $\dot{V}O_{2peak}$. Aerobic capacity can be maintained and improved while training in simulated reduced-gravity environments.

Key Words: simulated reduced-gravity environments, deep water running, aerobic capacity, cardiovascular conditioning, anti-gravity treadmill

1. *Introduction*

Aerobic fitness is measured by the amount of oxygen that an individual can utilize during peak performance or exercise; known as $\dot{V}O_{2peak}$. These values can be measured in absolute ($L \cdot min^{-1}$) or relative ($ml \cdot kg^{-1} min^{-1}$) units. Improvements in these values are achieved through various training modalities, which target oxidative metabolism of substrates for energy production. Along with improvements in aerobic fitness, several benefits are also associated with such training. These include, but are not limited to a reduction in resting heart rate (HR), blood pressure (BP), body weight (BW) and improved body composition by a reduction in body fat percentage (BF%) (Kenny, Wilmore, & Costill, 2015) (LaMonte, et al., 2005).

Jogging is a popular modality that is used for improvements in cardiovascular fitness. With regards to caloric expenditure, jogging has been shown to provide greater calories per minute when compared to other modalities such as cycling, swimming and stair stepping at similar intensities (American College of Sports Medicine, 2014) (Kenny, Wilmore, & Costill, 2015). Although jogging can provide the greatest amount of calories per unit time, it may not be the best form of exercise for every population. Individuals who are overweight and/or obese or have a weight-bearing injury would be limited to other forms of exercise. Exercising in simulated-reduced-gravity environments would be more favorable due to the decreased ground reaction forces applied to the affected joints. Two such types of environments that may offer a solution include deep water running (DWR) and the AlterG® Anti-Gravity Treadmill® (AG).

Reducing the weight of an individual, during exercise, has been shown to decrease musculoskeletal stress and strain (Grabowski, 2010) (Grabowski & Kram, 2008) (Grabowski & Kram, 2005) (Simonson, Shimon, Long, & Lester, 2011). DWR is a mode of aerobic exercise that is similar to treadmill running (TM), in which the individual uses a floatation device around the waist to maintain immersion up to the upper chest or neck in a water source (Figures 1 and 2).

This floatation does not allow the individual to make foot contact with the bottom of the pool. While floating, running is mimicked by the use of a form of kicking; usually a flutter kick. The greater the depth, the greater the reduction in body weight while being submerged (Butts, Tucker, & Greening, 1991) (Dowzer, Reilly, Cable, & Nevill, 1999) (Frangolias, Rhodes, Taunton, Belcastro, & Coutts, 2000) (Frangolias & Rhodes, 1996) (Haupenthal, Ruschel, Hubert, de Brito Fontana, & Roesler, 2010) (Reilly, Dowzer, & Cable, 2003) (Town & Bradley, 1991) (Wilder & Brennan, 1993). Since the buoyancy effect of water reduces impact on the joints, this may be an optimal environment for overweight and/or obese individuals (Silvers, Rutledge, & Dolny, 2007). According to Gleim & Nicholas, 1989 and Pohl & McNaughton, 2003, metabolic cost is higher when the water is below the waist, and in comparison, when water is at waist level or higher, the metabolic cost decreases. However, significant changes in gait patterns, walking speeds and muscle activity have been noted due to the drag forces on the lower extremities when compared to land walking (Alkurdi, Paul, Sadowski, & Dolny, 2010). Finally, drag resistance and the hydrostatic force that supports body weight have also been shown to influence energy expenditure (Alkurdi, Paul, Sadowski, & Dolny, 2010).

The AlterG® Anti-Gravity Treadmill® utilizes differential air pressure technology, developed by NASA. This device requires an individual to wear a pair of neoprene shorts, which are attached to an opening in the chamber of the AG treadmill (Figure 3). Once an airtight seal is created, air pressure can be increased in the chamber to decrease an individual's BW as low as 20% of their original weight. The reduction in weight occurs as a result of differential air pressure within the chamber. An advantage that this treadmill has over a traditional treadmill that uses a suspension system is that the AG treadmill allows a person to move their arms and legs freely without mechanical restrictions. (Figueroa, Manning, & Escamilla, 2011) (Grabowski, 2010) (LaSala, Pinto-Zipp, DeBari, & Figueroa, 2015). Furthermore, the AG treadmill eliminates the drag forces on the legs, allowing for similar gait patterns to normal-weight land walking, does not impede circulation and is more comfortable, adjustable and can be used for extended periods of time (Grabowski, 2010). Recent investigations demonstrate favorable changes in physical activity levels and exercise tolerance with similar results in cardiorespiratory responses compared to over-ground walking. (Figueroa, Manning, & Escamilla, 2011) (Figueroa, Wicke, Manning, Escamilla, & Santillo, 2012) (LaSala, Pinto-Zipp, DeBari, & Figueroa, 2015).

The purpose of this study was to compare the effects of aerobic conditioning on land and in two simulated reduced-gravity environments. In particular, training was performed on a land-based treadmill (TM), the AlterG® Anti-Gravity Treadmill® (AG) and with deep water running (DWR). It was hypothesized that each training modality would elicit comparable adaptations in aerobic capacity as measured by changes in peak oxygen consumption ($\dot{V}O_{2peak}$).

2. Methods

Data were collected on 19 college students (12 females, 7 males), 21 ± 1.5 years of age, who were randomly assigned to one of 3 different groups (Table 1). Prior to participation, potential subjects completed a Par-Q questionnaire in order to determine their ability to partake in testing and training. Only those students who were apparently healthy and not taking any medications were allowed to participate. All subjects provided written consent as required by the Institutional Review Board for Research on Human Subjects of the university.

Peak $\dot{V}O_2$, height, weight, and body fat percentage (BF%) were measured prior to training and again after 8 weeks. A Bruce protocol stress test was used; along with the MedGraphics Ultima Series open circuit spirometer (MMC) to measure $\dot{V}O_{2peak}$. Heart rate was monitored continuously throughout the testing using the Quinton Q® Stress ECG Machine 4.0 (Serial number – QS007122) (Figure 4). The procedures for testing and calibration have been previously described (Figueroa, Wicke, Manning, Escamilla, & Santillo, 2012) (Figueroa, Manning, & Escamilla, 2011) (LaSala, Pinto-Zipp, DeBari, & Figueroa, 2015). Prior to each test, the MMC was calibrated as per the manufacturer's specifications. Based on the criteria from the American College of Sports Medicine (ACSM), $\dot{V}O_{2peak}$ was determined when at least two of the following criteria were met: oxygen consumption did not rise greater than 150 ml with an increase in workload, the respiratory exchange ratio (RER) reached 1.15, or if

the participant asked to end testing due to volitional fatigue (American College of Sports Medicine, 2014).
Body fat percentages were determined by measuring body density using the underwater weighing procedure. Percent body fat was then calculated using the Siri equation: % Body Fat = (495 / density) – 450(American College of Sports Medicine, 2014) (Siri, 1956).

Subjects in each group trained three times per week on non-consecutive days. Subjects in the TM group trained on a traditional land-based treadmill while subjects in the AG group used the AlterG® Anti-Gravity Treadmill® (Figure 3). Subjects in the DWR group trained in the pool while wearing the Aquajogger Active Water Exercise Buoyancy Belt (Excel Sports Sport Science, Inc., Eugene, OR) (Figures 1 and 2).

Each session consisted of a warm-up until the target heart rate zone was achieved and then proceeded to jog for 30 minutes at 70-85% of the heart rate reserve (HRR). A Polar® FT1 Heart Rate monitor (Polar® Electro Inc., Lake Success, NY) was worn by all subjects during each session in order to ensure that the specific training intensities were achieved and maintained throughout. Subjects in the AG group trained at 80% of their original body weight while those in the DWR simulated running while being supported up to the level of the chest. Haupenthal et al., 2010 demonstrated that underwater immersion at chest and hip levels resulted in vertical forces that were comparable to 80% and 98% of body weight; respectively (Haupenthal, Ruschel, Hubert, de Brito Fontana, & Roesler, 2010).

A one-way ANOVA was used for analysis of pre- and post-training measures between the three groups. A dependent t-test was then used to determine within group differences. The level of significance was set at $p<0.05$. All data were analyzed using IBM PASW (SPSS 23.0).

3. Results

Table 1 displays the average pre-training values for height, weight, body mass index (BMI), body fat % and $\dot{V}O_{2peak}$ (ml•kg•$^{-1}$min^{-1}) for each group. There were no significant differences between groups prior to training. These variables were measured again after 8 weeks of training, which consisted of 3 times per week on non-consecutive days. Table 2 displays the difference between pre- and post-training values. Again, no significant differences were found in any of the variables between groups. Within groups, however, the AG group decreased weight -2.0 ± -0.4 kg (p=0.001), decreased BMI -0.6 ± -0.1 (p=0.006), and BF% -0.6 ± 0.2 (p=0.027). The DWR group increased $\dot{V}O_{2peak}$ 8.1 ± 0.9 ml•kg•$^{-1}$min^{-1} (p=0.001)

4. Discussion

Although no significant differences were found between group after training, benefits can still be obtained from utilizing any of the above modalities. The AG group demonstrated an average decrease in weight, BMI, BF%, which were found to be significant when comparing pre- vs. post-training values. The DWR group demonstrated an average increase in $\dot{V}O_{2peak}$ values, which were also found to be significant when comparing pre- vs. post-training values. Among all groups, a trend in the data revealed that there was between a 3.6 – 8.1 ml•kg•$^{-1}$min^{-1} increases in relative $\dot{V}O_{2peak}$ values. A larger sample size or longer training protocols may have revealed significant differences in both the AG and TM groups as well.

Other studies have demonstrated training in DWR elicited an increase in cardiovascular fitness in unfit young individuals (Davidson & McNaughton, 2000) (Michaud, Rodriguez-Zayas, Andres, Flynn, & Lambert, 1995) as well as maintained cardiovascular fitness in trained athletes (Bushman, Flynn, Andres, Lambert, Taylor, & Braun, 1997) (Wilber, Moffatt, Scott, Lee, & Cucuzzo, 1996). Furthermore, a randomized control trial with repeated measures was conducted by Grabowski, 2010, who found that manipulating speed and weight using the Alter-G® Anti-Gravity Treadmill® while walking, reduces force but maintains cardiorespiratory demand while ground reaction forces (GRFs) were lower when walking faster compared to normal weight walking. Additionally, when compared to normal weight walking, walking faster with body weight support elicited the same metabolic demand (Grabowski, 2010). It is worth noting that none of the groups in the current study showed a decrease in $\dot{V}O_{2peak}$, values after training. As a result, this is important with regards to maintaining aerobic capacity as DWR and AG training may be effective modalities that result in similar adaptations. Another advantage to using either the AG or DWR is the decrease in orthopedic stress on the musculoskeletal system. Individuals who have been injured, or have an orthopedic condition that would make jogging outdoors or on a land-based treadmill difficult, would be able to train in either of the two simulated reduced-gravity environments.

Similarly, they could be used as an adjunct to any therapeutic intervention. In addition, athletes who are either in the 'off-season' or 'in-season' of their respective sport would be able to reduce and/or minimize repetitive stress traumas that are often associated with such training. Caloric expenditure, which was not assessed in this study, has been shown to decrease as the percent body weight is removed due to the support provided from either the air pressure differential of the AG treadmill or the buoyancy from the DWR.

(Figueroa, Wicke, Manning, Escamilla, & Santillo, 2012) (LaSala, Pinto-Zipp, DeBari, & Figueroa, 2015). Simonson, Shimon, Long, & Lester, 2011, examined the effects of a 14-week walking program on one extremely obese female where the results showed a decrease in body weight due to a low caloric expenditure. The findings from this study suggested caloric expenditure should increase to further reduce body weight if the program were to continue.

Exercise intensity was determined using the Karvonen method of heart rate reserve (HRR) and was to be maintained between 70 – 85%. According the American College of Sports Medicine, this constituted vigorous intensity (American College of Sports Medicine, 2014). Due to the characteristics of each training protocol, HRR was used to equate training intensities on the cardiovascular system across groups. Subjects in the TM group trained at 100% body weight, whereas the AG and DWR groups trained at 80% body weight.

5. Conclusion

Regular physical activity has proven health benefits for improved cardiovascular function and the management of overweight and obese individuals. Walking and running, however, may present a challenge to the later population due to the additional weight loads on the joints in the lower extremities (Browning & Kram, 2007). Weight bearing exercise with an excess of body weight may increase the potential for injury or exacerbate existing joint conditions and may further influence one's ability to exercise. Therefore, optimizing exercise participation for obese individuals could include modalities that are non-weight bearing to minimize injury and increase caloric expenditure, which may reduce body weight and improve health outcomes (LaSala, Pinto-Zipp, DeBari, & Figueroa, 2015). Similarly, these modalities can provide an adjunct to therapies with individuals who have any weight bearing injuries of the lower extremity or back. As evidenced in the current study, aerobic capacity can be maintained and possibly improved while training in a simulated reduced-gravity environment. This is especially beneficial to athletes who are rehabilitating or in the 'off-season' since aerobic conditioning programs can continue, while reducing strain on the musculoskeletal system. In a severely deconditioned population, it could potentially improve $\dot{V}O_{2peak}$, while safely allowing the participant to exercise, which could improve quality of life and overall adherence to maintaining a healthy lifestyle.

6. Acknowledgements

Thank you Jim Manning for all of your guidance and support throughout the years. May you rest in peace.

Table 1: Pre-training data for each participant

Pre-Training	AG	TM	DWR	*p*
N	6	6	7	
Age (yr)	21.3 ± 1.3	21.5 ± 1.6	21.9 ± 1.6	Ns
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	Ns
Weight (kg)	77.9 ± 18.0	65.5 ± 14.7	76.1 ± 16.1	Ns
BMI	27.2 ± 4.8	23.9 ± 4.2	27.0 ± 2.6	Ns
Body Fat %	19.6 ± 5.5	22.7 ± 6.7	24.3 ± 11.0	Ns
$\dot{V}O_{2peak}$ (ml•kg•$^{-1}$min^{-1})	38.2 ± 9.4	35.5 ± 7.0	37.6 ± 8.3	Ns

AG = AlterG Treadmill, TM = Land-based Treadmill, DWR = Deep Water Running. *P* value reflects between group differences. Ns = no significant differences between groups.

Table 2: Changes in post-training data for each group

Post-Training	AG	TM	DWR	*p*
N	6	6	7	
Δ Weight	-2.0 ± -0.4*	-1.1 ± -0.7	-0.3 ± 1.5	Ns
Δ BMI	-0.6 ± -0.1*	-0.4 ± -0.1	-0.1 ± 0.7	Ns
Δ Body Fat %	-0.6 ± 0.2*	-0.7 ± 0.7	-0.6 ± -0.7	Ns
Δ $\dot{V}O_{2peak}$ (ml•kg•$^{-1}$min^{-1})	3.6 ± 1.4	4.1 ± 0.5	8.1 ± 0.9*	Ns

AG = AlterG Treadmill, TM = Land-based Treadmill, DWR = Deep Water Running. *P* value reflects between group differences. Δ = change. Ns = no significant differences between groups. * = significant differences within groups.

Figure 1: Aquajogger Active Water Exercise Buoyancy Belt.

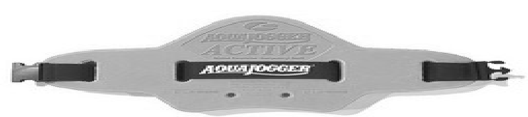
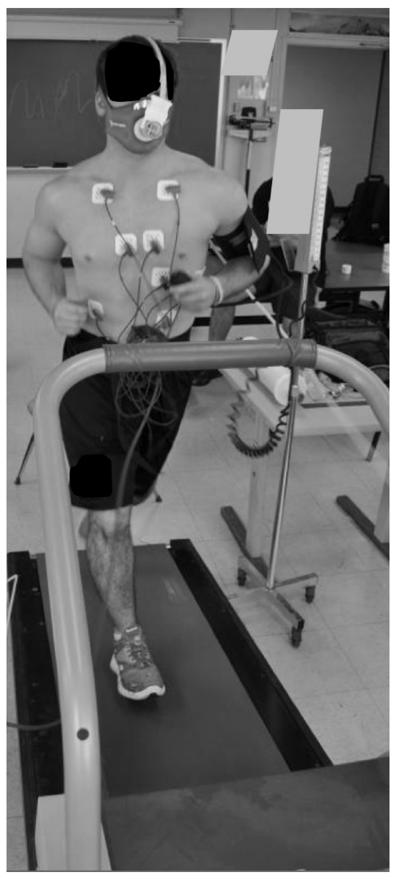


Figure 2: Subject wearing Polar® FT1 HR Monitor and Aquajogger Active Water Exercise Buoyancy Belt

Figure 3: Subject running on AlterG® Anti-Gravity Treadmill®

Figure 4: Subject testing using metabolic cart and ECG recordings



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