Physiological Responses to the AlterG Anti-Gravity Treadmill

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Abstract

The purpose of this study was to determine whether there would be any significant differences in metabolic work when jogging to maximal aerobic capacity on an anti-gravity treadmill, using differential air pressure, at different percentages of body weight (100%, 90% and 80%). Data were collected on 10 subjects (5 males, 5 females). Absolute VO_2max values (L/min) were significantly different between, but not within genders, at each percent of body weight. Relative VO_2max (ml/kg/min), RER values and substrate utilization were not significantly different between 100%, 90% or 80%. Removal of up to 20% bodyweight did not show to alter metabolic responses (VO_2, HR, RER) during jogging. Prescribed cardiovascular training intensities can be achieved with a reduction in ground reaction forces in individuals who are overweight, obese or injured. This weight-assisted device may be an effective alternative during rehabilitation or recovery after an event in order to maintain cardiovascular fitness.

Key Words: body weight support, treadmill, metabolic, physiologic response

1. INTRODUCTION

Jogging is an aerobic activity that many people utilize in order to improve cardiovascular function and expend calories, which can lead to decreases in both body fat percentage and weight. An individual who is jogging can experience ground reaction forces (GRF) of up to three times their body weight with each heel strike of the running stride (Grabowski &Kram, 2008; Grabowski, 2010; Nilsson&Thorstenssen, 1989).This can often be counterproductive for an individual who is either injured and/or overweight. The AlterG Anti-Gravity Treadmill (Fremont, CA) uses Differential Air Pressure (DAP) technology, developed by NASA, to alter the weight of an individual while jogging. This technology allows for the manipulation of unweighting up to 80% of the original body weight. One advantage of this is a reduction in ground reaction forces, which from a rehabilitative perspective, is favorable for individuals who are experiencing injuries such as Achilles tendinitis, plantar fasciitis or other overuse or weight bearing injuries. Such body weight support devices have been implemented in rehabilitation of military service members who have experienced injuries in the combat theater or other locations (Goldberg et al., 2009).

Gait analyses with body weight support using harnesses have revealed a reduction in both vertical GRF and metabolic work when compared to similar velocities and workloads without support (Aaslund& Moe-Nilssen, 2008; Grabowski &Kram, 2008; Grabowski, 2010). Body weight support training may assist in rehabilitation without overstressing the individual. Gait kinematics have been shown to be similar in individuals when comparing weight bearing and weight assisted devices (Hesse&Uhlenbrock, 1999).Water immersion has been shown to alter gait mechanics and increase resistance to forward propulsion due to drag forces from the fluid (Haupenthal, Ruschel, Hubert, de BritoFontan,&Roesler, 2010). Buoyancy from water, when individuals are immersed up to the anterior superior iliac spine, can reduce body weight by up to 47% (Hall, Grant, Blake, Taylor,&Garbutt,2004).Increased immersion decreases body weight, ground reaction forces, and both anterior and posterior force components (Haupenthal et al., 2010).Such support has been shown to reduce the metabolic demand (VO_2) and heart rate (HR) response when running in water. The long-term effects of space flight have demonstrated bone demineralization, immune dysregulation, neurovestibular alterations leading to motion sickness, and fluid redistribution affecting blood pressure (Williams, Kuipers, Mukai, &Thirsk, 2009; Yates, 2004).

The ability to maintain cardiovascular conditioning, using terrestrial based recommendations, would render exercise prescription inefficient in such an environment. Physiologically, the cardiovascular responses to exercising on an anti-gravity device have yet to be thoroughly explored.

The purpose of this study was to measure maximal oxygen consumption (VO_2max), caloric expenditure (kcals), substrate utilization, rating of perceived exertion (RPE), and HR response of subjects while jogging at 100%, 90% and 80% of their original body weight (BW). Accordingly, the hypotheses included an attenuated heart rate response, an increased oxygen consumption (VO_2max), and substrate utilization in favor of greater fatty acid oxidation when jogging at 90% and 80% bodyweight when compared to 100%.

2. METHODS

Data were collected on 10 subjects (5 males, 5 females) on three separate days, at different percentages of their body weight (100%, 90%, 80%). The selection of percent body weight was randomly assigned on each day of testing. Subjects were recruited from students in the Department of Kinesiology at William Paterson University, Wayne, NJ, USA. Subject selection was determined after the completion of a Par-Q questionnaire. Only healthy subjects who were not on any prescription medications were considered for participation. All subjects provided consent as per the directives of the Institutional Review Board for Research on Human Subjects at William Paterson University, Wayne, NJ.

Initial testing consisted of anthropometric measures of height, weight and body fat percentage using the hydrostatic weighing method. This method followed the procedures set forth by Heyward (2006). Metabolic data were collected on three dates, which were separated by two weeks. The sequence of percent body weight manipulation (100%, 90%, 80%) was randomized between subjects to avoid an order effect. Maximal oxygen consumption was assessed using a modified version of the Bruce Protocol, which consisted of several stages. Each stage was three minutes in duration of increasing speed and grade (angle) on the AlterG Treadmill(Table 1). The limitation of this treadmill did not allow for the grade to exceed 15percent. Prior to being placed in this device, all subjects were required to wear a pair of neoprene shorts, which were supplied by the manufacturer. In order to create an air-tight seal and allow for changes in air pressure, the shorts were attached to the opening of the chamber by a zipper. The height of this opening was set to be level with the subject's waist, which allowed for full range of motion in the upper and lower body. The chamber was calibrated and pressurized for each subject as per the instructions of the manufacturer.

Heart rate (HR) was monitored and recorded during the last minute of each stage using electrocardiography (ECG) (Ultima^{TM} CardiO_2). Blood pressure was obtained manually during the last minute of each stage using a sphygmomanometer and stethoscope. Oxygen consumption, caloric expenditure and substrate utilization were recorded using the MedGraphicsUltima Series (St. Paul, MN) open exchange spirometer. The tests were terminated when either of the following criteria were met: oxygen consumption reached a plateau or did not rise more than 100ml with subsequent increases in intensity, respiratory exchange ratio (RER) reached 1.15, or volitional fatigue on the part of the subject.

The metabolic cart was calibrated, as per the manufacturer's instructions, prior to data collection on each subject. A mask with a pneumotach was placed over the mouths of each subject to collect and measure O_2 uptake and expired CO_2. Ten surface electrodes were placed on the subjects' torso for the recording of the standard 12 lead ECGs. Pre-exercise HR and BP were recorded after the subject was placed in the AlterG treadmill. Metabolic data, including Respiratory Exchange Ratio (RER) and kcal data, were obtained and calculated by the Breeze software (St. Paul, MN) that is used in conjunction with the MedGraphicsUltima system. The dependent variables were analyzed from stages 1 through 5, during each test condition, since not all subjects were able to progress beyond stage 6. Data were analyzed using SPSS version 14 (IBM SPSS, Chicago, IL). An Independent *t*-test was used to determine whether or not there were significant differences in the dependent variables between genders. Analysis of variance with repeated measures were used to measure significant differences in these variables at 100%, 90% and 80% bodyweight. Significance level was set at $p<0.05$.

3. RESULTS

Table 2 illustrates the descriptive data for the subjects (mean ± standard deviation). The *t*-test revealed that significant differences were found in height ($p=0.02$) and weight ($p=0.02$) between genders, but not in age, body fat %, BMI or VO_2max (ml/kg/min).

Absolute VO_2max values (L/min), however, were significantly different between genders ($p = 0.001$) (Table 3). Within each gender, absolute values were not significantly different at each percent of body weight. Time to completion of VO_2max wasnot found to be significantly different between genders ($p=0.61$). Total kcals were significantly different between genders at 80% BW ($p=0.01$), but not within genders between 100%, 90% or 80% body weight. Heart rate and RPE responses were not found to be significantly different at rest or during stages 1-5 at any percent body weight (Tables 4& 5).RER values were significantly different between genders in stages 1 – 4. There were no significant differences within genders with regards to RER at any percent body weight (Table 6).

4. *DISCUSSION*

Due to the limitations in percent grade on the AlterG treadmill, a modified version of the Bruce protocol was used during data collection. Each subject was able to achieve their VO_2max as per the criteria previously described. As seen in Table 3, VO_2max (ml/kg/min) was not significantly different at any percent body weight. Although the current study did not measure GRF, previous work has demonstrated that body weight manipulation can significantly decrease GRF (Grabowski &Kram, 2008; Grabowski, 2010; Nilsson&Thorstenssen, 1989).Reducing body weight may affect the vertical impulse component of the resultant vector of the center of gravity, but not the horizontal. The support provided by the AlterG did not reduce the work required by the legs in order to maintain a given velocity on the treadmill. Klarner, Chan, Wakeling, &Lam (2010) demonstrated that body weight support up to 40% does not significantly alter EMG activity of the hip and knee, stride rate, or frequency during running. A similar study conducted by Aaslund& Moe-Nilssen(2008) revealed significant differences in the vertical component but not in the anterior or lateral components of running stride. Relative and absolute VO_2max were not significantly different since body massand the metabolically active tissueremained the same. This study, along with previous work has been able to demonstrate that a simulated change in the effect of gravity does not affect the metabolic cost of running since the mass involved is not altered (Donelan&Kram, 2000). Muscular activity may not have been affected by the differential air pressure support. Subjectively, as seen in the non-significant differences in RPE, each individual perceived to be working similarly at each percentage of body weight (Table 5).

Although the time to achieve VO_2max during each test was not found to be significantly different, an examination of the data revealed a trend that a greater amount of time was required at a lower percent body weight. An inverse trend can be seen in kcals at each percent body weight (Table 3). Normally, body mass accounts for the greatest contribution to caloric expenditure during running. An individual having a larger mass would expend a greater number of calories while jogging when compared to a person with a lower mass (Loftin, Sothern, Koss, Tuuri, VanVrancken, Kontos,&Bonis, 2007).Again, although not found to be significantly different, it appears that subjects expended fewer kcals as percent body weight decreased.

Stages 1 through 5 were used in the analysis of HR and RER since some subjects were not able to progress to stage 6 or beyond. Neither of these two variables was found to be significantly affected by the manipulation of body weight (Tables 4 & 6).

The RERs for pure fatty acid (FA) and carbohydrate (CHO) oxidation are 0.7 and 1.0, respectively. The amount of oxygen required to completely oxidize a given substrate is dependent upon the amount of carbon contained in either a fatty acid or a carbohydrate molecule (Wilmore, Costill& Kenney,2008). Tables 6 and 7 depict the RER and percent Fat and CHO, respectively. The percent substrate utilization values are based on calculations set forth by Wilmore et al. (2008). Due to the significant differences between genders, data were divided and analyzed separately. RER values did not significantly change within genders with the manipulation of body weight. Being that the calculation of substrates is dependent on RER values, it can be stated that substrate utilization also did not change between percent bodyweight.

Heart rates during each stage were not significantly different between or within genders. Although each progressive stage was able to elicit an increased HR response, a similar trend,as seen in kcals,is evident due to heart rates that appear to be lower as percent body weight decreases. Based on the guidelines of the American College of Sports Medicine (2010), moderate to vigorous intensity of exercise is described as ≥ 60 – 85% of the Heart Rate Reserve (HRR). Using the resting and maximal heart rates for these subjects, the target heart rate (THR) range for these recommended intensities was between 150 – 180 bpm.

Despite the trend towards lower heart rates, subjects were able to achieve these values by stage 4 at each percent body weight.Metabolically, it would appear that there were no differences between 100%, 90% or 80% body weight.

4. CONCLUSION

Despite changes in body weight percentage, the body mass and metabolically active tissue remained constant. Evidence for this can be seen by the non-significant differences in absolute and relative VO_2max values. Manipulation of body weight did not alter the contribution of the metabolically active muscle tissue required to maintain the forward velocity on the treadmill. Based on the results of this study, removal of up to 20% body weight does not significantly alter the metabolic responses (VO_2, HR, RER) or requirements during aerobic activity (jogging).

A decrease in body weight placed an equal cardiovascular stress on each subject while reducing the impact from ground reaction forces (Aaslund& Moe-Nilssen, 2008; Grabowski &Kram, 2008; Grabowski, 2010). From a rehabilitation perspective, knowing that similar training intensities can be achieved at different percentages of body weight can be favorable for anyone who is concerned with weight bearing injuries of the knees, lower back, plantar fasciitis or other conditions that may limit jogging as a form of exercise. Individuals who are obese would also be able to exercise at prescribed cardiovascular intensities with a concomitant reduction in musculoskeletal strain. The use of such a device may assist in the maintenance of cardiovascular fitness during rehabilitation and/or recovery after a myocardial event. Future studies should continue to examine the electromyographic (EMG) activity of trunk and lower extremity musculature in order to determine whether or not DAP significantly alters motor unit recruitment patterns. Further investigation utilizing this technology with exercise training protocols is warranted.

Treadmill Protocol		
Stage	Speed (mph)	% Grade
1	1.7	10
2	2.5	12
3	3.4	14
4	4.2	15
5	5.0	15
6	5.5	15
7	5.8	15
8	6.2	15
9	6.5	15

Table 1. Modified Bruce Protocol used during data collection on the AlterG treadmill.

	Male	Female		p
N	5	5		
Age	23 ± 2	24 ± 4		0.73
Height (m)	1.72 ± 0.07	1.58 ± 0.09	*	0.02
Weight (kg)	79.92 ± 15.7	55.92 ± 10.3	*	0.02
Body Fat %	16.5 ± 5.7	23.1 ± 7.6		0.16
BMI (kg/m^2)	27.0 ± 5.7	22.1 ± 2.0		0.11
VO_2max 100%	41 ± 9.0	44 ± 8.0		0.60
VO_2max 90%	41 ± 10.0	44 ± 9.0		0.57
VO_2max 80%	42 ± 6.0	42 ± 7.0		0.99

Table 2. Descriptive data for all subjects.VO_2max100%, 90%, 80% represent maximal aerobic capacity for subjects at 100%, 90% and 80% of bodyweight. VO_2max values are in ml/kg/min. * = Significant differences between genders.

	100%BW	90%BW	80%BW		p
VO2max (ml/kg/min)	42 ± 8	43 ± 9	42 ± 7		0.99
VO2max (L/min) [Males]	3.4 ± 1.1	3.3 ± 1.1	3.4 ± 0.9	++	0.98
VO2max (L/min) [Females]	2.4 ± 0.25	2.4 ± 0.4	2.3 ± 0.3	++	0.87
Time (min) to VO$_2$max	15.5 ± 3.7	17.8 ± 4.7	21.1 ± 6.9		0.08
kcals [Males]	150 ± 48	140 ± 60	123 ± 32*		0.67
kcals [Females]	100 ± 18	81 ± 23	70 ± 16*		0.08

Table 3. Relative VO$_2$max (ml/kg/min) and absolute VO$_2$max (L/min) at 100%, 90% and 80% of body weight. Data from both genders were combined for relative VO$_2$max and Time to VO$_2$max. P-values represent within gender differences. ++ = Significant differences (p=0.001) in absolute VO$_2$max (L/min) between genders at each percent of body weight. * = Significant differences (p=0.01) between genders at 80% BW.

HR (bpm)	100%BW	90%BW	80%BW	p
Rest	80 ± 10	83 ± 13	83 ± 13	0.77
Stage 1	104 ± 11	103 ± 11	98 ± 12	0.40
Stage 2	122 ± 17	118 ± 14	112 ± 17	0.35
Stage 3	145 ± 18	131 ± 10	127 ± 19	0.07
Stage 4	164 ± 17	153 ± 14	148 ± 18	0.09
Stage 5	174 ± 12	173 ± 14	161 ± 15	0.12

Table 4. Heart Rate (HR) response at rest and during stages 1 – 5 at each percentage of body weight.

RPE	100%BW	90%BW	80%BW	p
Stage 1	6	6	6	0.81
Stage 2	8	8	8	0.87
Stage 3	11	10	9	0.26
Stage 4	12	11	11	0.50
Stage 5	14	13	12	0.29

Table 5. RPE values during stages 1-5 at each percent body weight.

		Males			
RER	100%BW	90%BW	80%BW		p
Rest	0.83 ± 0.1	0.86 ± 0.5	0.9 ± 0.7		0.37
Stage 1	0.84 ± 0.08	0.88 ± 0.5	0.88 ± 0.4		0.67
Stage 2	0.92 ± 0.8	0.89 ± 0.04	0.91 ± 0.04		0.64
Stage 3	0.98 ± 0.12	0.95 ± 0.03	0.94 ± 0.04		0.74
Stage 4	1.05 ± 0.1	1.01 ± 0.01	1.0 ± 0.04		0.45
Stage 5	1.09 ± 0.7	1.02 ± 0.02	1.0 ± 0.02	*	0.03

		Females		
RER	100%BW	90%BW	80%BW	P
Rest	0.75 ± 0.06	0.81 ± 0.12	0.83 ± 0.05	0.26
Stage 1	0.78 ± 0.03	0.80 ± 0.08	0.80 ± 0.04	0.79
Stage 2	0.88 ± 0.05	0.85 ± 0.03	0.85 ± 0.06	0.54
Stage 3	0.94 ± 0.06	0.92 ± 0.06	0.90 ± 0.08	0.73
Stage 4	1.01 ± 0.05	0.98 ± 0.04	0.95 ± 0.05	0.19
Stage 5	1.04 ± 0.07	1.00 ± 0.04	0.96 ± 0.06	0.14

Table 6. RER values for each genders at rest and during stages 1 - 5. * RER values for males were significantly different between 100% and 80% BW in stage 5.

		% Fat			% CHO		
		100%BW	90%BW	80%BW	100%BW	90%BW	80%BW
Males	Stage 1	53	40	40	47	60	60
	Stage 2	27	37	30	73	63	70
	Stage 3	7	17	20	93	83	80
	Stage 4	0	0	0	100	100	100
	Stage 5	0	0	0	100	100	100
Females	Stage 1	73	67	67	27	33	33
	Stage 2	40	50	50	60	50	50
	Stage 3	20	27	33	80	73	67
	Stage 4	0	7	17	100	93	83
	Stage 5	0	0	13	100	100	87

Table 7. Percent substrate utilization during each stage at each percent body weight. Values are based on calculations set forth by Willmore, Costill& Kenney (2008).

REFERENCES

Aaslund, M. K., Moe-Nilssen, R. (2008). Treadmill walking with body weight support effect on treadmill, harness and body weight support systems. *Gait and Posture*, *28*, 303-308.doi:10.1016/j.gaitpost.2008.01.011

American College of Sports Medicine. (2010). ACSM's Guidelines for Exercise Testing and Prescription (8th ed.). In W. R. Thompson, N. F. Gordon, & L. S. Pescatello (Eds.), (pp. 152-182). Baltimore, MD: Lippincott Williams and Wilkins.

Donelan, J., Kram, R. (2000). Exploring dynamic similarity in human running using simulated reduced gravity. *The Journal of Experimental Biology*, *203*, 2405-2415.

Goldberg, K. F., Green, B., Moore, J., Wyatt, M., Boulanger, L., Belnap, B., Harsch, P., Donaldson, D. S. (2009). Integrated musculoskeletal rehabilitation care at a comprehensive combat and complex casualty care program. *Journal of Manipulative Physiological Therapeutics*, *32*, 781-791.doi:10.1016/j.jmpt.2009.10.010

Grabowski, A.M. (2010). Metabolic and biomechanical effects of velocity and weight support using a lower-body positive pressure device during walking. *Arch Phys Med Rehabil*, *91*, 951-957.doi:10.1016/j.apmr.2010.02.007

Grabowski, A.M., Kram, R. (2008). Effects of velocity and weight support on ground reaction forces and metabolic power during running.*Journal of Applied Biomechanics*, *24*, 288-297.

Hall, J., Grant, J., Blake, D., Taylor, G., Garbutt, G. (2004). Cardiorespiratory responses to aquatic treadmill walking in patients with rheumatoid arthritis.*Physiotherapy Research International*, *9*(2), 59-73.

Haupenthal, A., Ruschel, C., Hubert, M., de Brito Fontana, H., Roesler, H. (2010). Loading forces in shallow water running in two levels of immersion. *Journal of Rehabilitation Medicine*, *42*(7), 664-669.

Hesse, S., Uhlenbrock, D. (1999). Gait pattern of severely disabled hemiparetic subjects on a new controlled gait trainer as compared to assisted treadmill walking with partial body weight support. *Clinical Rehabilitation*, *13*, 401-410.

Heyward, V. H. (2006). Advanced Fitness Assessment and Exercise Prescription (5th ed.). In M. S. Bahrke, & A. S. Ewing (Eds.), *Assessing body composition*. (pp. 171-210). Champaign, IL: Human Kinetics.

Klarner, T., Chan. H. K., Wakeling, J.M., Lam, T. (2010). Patterns of muscle coordination vary with stride frequency during weight assisted treadmill walking. *Gait and Posture*, *31*, 360-365.doi:10.1016/j.gaitpost.2010.01.001

Loftin, M., Sothern, M., Koss, C., Tuuri, G., VanVrancken, C., Kontos, A., Bonis, M. (2007). Energy expenditure and influence of physiologic factors during marathon running.*Journal of Strength and Conditioning Research*, *21*(4), 1188-1191.

Nilsson, J., Thorstenssen, A. (1989). Ground reaction forces at different speeds of human walking and running. *ActaPhysiol Scand*, *136*(2), 217-227.

Williams, D., Kuipers, A., Mukai, C., Thirsk, R. (2009). Acclimation during space flight: effects on human physiology. *Canadian Medical Association Journal*, *180*(13), 1317-1323.doi:10.1503/cmaj.090628

Wilmore, J. H., Costill, D. L., Kenney, W. L. (2008). Physiology of Sport and Exercise (4th ed.). In M. S. Bahrke, & L. Garrett (Eds.), *Energy expenditure and fatigue*. (pp. 98-120). Champaign, IL: Human Kinetics.

Yates, B. J. (2004). The vestibular system and cardiovascular responses to altered gravity. *American Journal of Physiology Regulatory, Integrative and Comparative Physiology*, *286*(1), R22.doi:10.1152/ajpregu.00576.2003.