Validation of ACSM Metabolic Equations in an Anti-Gravity Environment: A Pilot Study

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Abstract

The purpose of this study was to explore whether the American College of Sports Medicine (ACSM) metabolic formulas that were developed and are used on traditional land-based treadmills would comply with the technology used in the AlterG® anti-gravity treadmill. Data were collected on 5 males and 5 females during an incremental stress test at 100%, 90% and 80% bodyweight (BW). Measured oxygen consumption (VO_2) was compared to calculated oxygen consumption using two different metabolic formulas. Significant differences were found during the last 3 stages at 100%BW, stages 2-5 at 90%BW and during all stages at 80%BW with the average measured oxygen consumption values being lower than those that were calculated. A simulated reduction in body weight would elicit training intensities below established guidelines for cardiovascular improvement and weight loss.

Kew words: simulated anti-gravity, metabolic formulas, oxygen consumption, cardiovascular exercise

1. Introduction

Aerobic exercise can be classified as activities that involve the submaximal contractions of large muscle groups for a period of time greater than 3 minutes in duration (American College of Sports Medicine (ACSM), 2010; Wilmore, Castill & Kenney, 2008). Exercise type can vary because many forms of aerobic modalities exist. Exercise prescriptions for cardiovascular conditioning are dependent on manipulating exercise frequency, intensity, time and type; otherwise known as the FITT Principle. Of the four variables, intensity is the most important because it will dictate frequency and time for training. The intensity of a cardiovascular exercise program can be represented by factors including percentages of maximal heart rate (%HRmax), heart rate reserve (%HRR) or aerobic capacity (%VO_{2max}). VO_{2max} represents the maximal amount of oxygen that the body can utilize during peak or maximal exercise or activity (ACSM, Wilmore et al.). This measure is used to determine the aerobic capacity and level of fitness for an individual. Low levels of aerobic conditioning are associated with increased prevalence of metabolic and cardiovascular disease including, but not limited to, hypertension, hyperlipidemia, hypercholesterolemia and Type II diabetes (ACSM, Wilmore et al.).

Improvements in cardiovascular fitness and weight loss from caloric expenditure can be achieved through specific programs that manipulate frequency and intensity of training. For the purpose of this article, the intensity of exercise will be represented as a percentage of VO_{2max} and VO_2reserve (VO_2R). Mathematically, VO_2R is the difference between maximal oxygen consumption and the oxygen consumption at rest which, is approximately 3.5 $ml\cdot kg^{-1}\cdot min^{-1}$, also referred to as 1 metabolic equivalent (1 MET).

$VO_2R = VO_2max - VO_2rest$ (ACSM)

Less than 40% VO_2R is considered low intensity exercise whereas 41-59% and greater than 60% are representative of moderate and vigorous intensity, respectively (ACSM, Wilmore). Current American College of Sports Medicine guidelines for improvements of aerobic capacity recommend at least 5 days of moderate, 3 days of vigorous, or 3-5 days of a combination of both moderate and vigorous intensity exercise. At least 30 minutes of activity per day is recommended for moderate intensity exercise, and 20-25 minutes for vigorous. These times can also be divided into 10-minute intervals that total the required amount of time (ACSM).

The assessment of an individual's VO_2max is required prior to development of an exercise prescription. Once determined, a proper prescription based on intensity (%VO_2R) can be designed. Metabolic formulas have been created to determine the aerobic requirements of activities such as walking, jogging, upper and lower body cycling, and bench stepping. The walking and jogging formulas will be used as the focus of this article. Speed is expressed in $meters\cdot min^{-1}$, and grade as a percent of incline.

Walking: $VO_2\ (ml\cdot kg^{-1}\cdot min^{-1}) = 3.5 + 0.1(speed) + 1.8(speed)(grade)$
Running: $VO_2\ (ml\cdot kg^{-1}\cdot min^{-1}) = 3.5 + 0.2(speed) + 0.9(speed)(grade)$ (ACSM)

Previous studies have compared the accuracy of calculated VO_2 to measured VO_2, and have resulted in either no difference between the two measures (Foster, Crowe, Saines, Sumit, Green, Lettau, Thompson, Weymier, 1996) or an error of approximately 4-5 $ml\cdot kg^{-1}\cdot min^{-1}$ (Hall, Figueroa, Fernhall, Kanaley, 2004; Marsh, 2012). Hall et al. and Marsh compared the metabolic cost of walking and running at 100% BW without the manipulation of the grade component of the equation. Each of these studies measured oxygen consumption using a traditional treadmill. Farley & McMahon (1992) used a suspension harness system to compare the metabolic cost of walking and running in a simulated reduced-gravity environment. As in the previous studies, incline was not used to increase the intensity of exercise. The authors concluded that there was a proportional decrease in metabolic cost when gravity was reduced while running, but not during walking. Teunissen, Grabowski & Kram (2007) also confirmed a reduction in metabolic work when gravity was reduced using a suspension pulley system. This study measured metabolic rate from oxygen consumption while running flat at 100%, 75%, 50% and 25% BW. Again, the grade of the treadmill was not manipulated to increase the metabolic demand of the activity. To date, no studies have compared calculated and measured oxygen consumption on an anti-gravity treadmill, which uses differential air pressure technology. Studies that have made similar comparisons did not incorporate the vertical component of the metabolic equations that is represented by the product of speed and grade (Hall et al, Marsh, Teunissen et al.).

Since the metabolic formulas were developed using traditional treadmills, the introduction of the AlterG® anti-gravity treadmill (Menlo Park, CA) may elicit exercise intensities that do not adhere to current ACSM metabolic formulas. Previous studies have demonstrated a reduction in ground reaction forces when jogging in a gravity-reduced environment (Grabowski 2010; 2008, Teunissen et al.). Recent work has shown that the reduction of gravity, down to 80% of original body weight, did not affect an individual's maximal aerobic capacity (Figueroa, Manning, Escamilla, 2011). Although there were no significant differences in the VO_2max achieved by each subject at different percentages of body weight, a trend in the data indicated that more time was required to achieve these values (Figueroa et al.).

The purpose of this study was to explore whether the ACSM formulas that have been developed and used on traditional treadmills would comply with the technology used in the AlterG® anti-gravity treadmill when body weight is altered. Accordingly, the hypothesis stated that a reduction in body weight, as represented by the manipulation of gravity, would reduce the oxygen consumption and caloric expenditure at varying intensities of exercise. As such, there would be a difference between the calculated and measured oxygen consumption.

2. Methods

Subjects were recruited from the Department of Kinesiology at William Paterson University, Wayne, NJ. Only healthy individuals, as determined by a health history and a Par-Q questionnaire, were selected for this study. All subjects gave written consent approved by the Institutional Review Board of the university.

Oxygen consumption was measured on 10 subjects (5 males, 5 females) at 100%, 90%, and 80% of their body weight with each test date separated by two weeks. The order of measurement was randomized to minimize any bias from test administration. Expired gases were collected and analyzed with the MedGraphics Ultima Series (St. Paul, MN) open exchange spirometer. Prior to data collection for each subject, the metabolic cart was calibrated for flow volume with a 3 L syringe and gas concentration using standard reference gasses. Expired gasses were collected using a facemask with a pneumotach placed over the mouth and nose. A standard 12 lead electrocardiogram (ECG) was recorded using 10 surface electrodes placed on each subject's torso (Welsh Allyn CardioPerfect, Skaneateles Falls, NY). Body fat percentage was measured using the hydrostatic method as set forth by Heyward (2006) and Miller (2012).

During test administration, each subject wore a pair of neoprene shorts that were attached to an opening in the chamber of the anti-gravity treadmill as per the manufacturer's instructions (Figures 1 & 2). Once an airtight seal was created, the pressure in the chamber was increased to produce the differential air pressure (DAP) necessary to reduce the effect of gravity. The calibration of this device requires weighing each subject under the conditions of DAP to make the necessary adjustments to allow for the manipulation of bodyweight.

A modified Bruce stress test protocol was used for metabolic data collection since the maximal grade for the treadmill was 15%. Due to the changes in speed and incline, subjects walked during the first 3 stages of data collection and jogged for the last 2 (Table 1). Each stage was 3 minutes in duration to allow for steady state oxygen consumption. The average VO_2 of the last minute of each stage was compared to the calculated VO_2 from the metabolic equations.

All data were analyzed using PASW version 19 (IBM SPSS, Chicago, IL). An ANOVA with repeated measures was used to compare the measured VO_2 to the calculated VO_2 at each stage when walking and jogging. Significance was set at $p<0.05$.

3. Results

The mean age of the males and females was 23.2 ± 1.8 years and 23.8 ± 3.7 years, respectively. Mean height and weight was 1.72 ± 0.07 m and 79.9 ± 15.7 kg for the males, 1.58 ± 0.09 m and 55.9 ± 10.3 kg for the females, respectively. Height and weight were significantly different between genders (p=0.023 and p=0.021, respectively) with the average values for men being greater than those for women. Body fat percentage, however, was not significantly different between genders (males = 16.5 ± 5.7 %, females = 23.1 ± 7.6 %, p=0.159).

Data collected during each stage and at different percentages of body weight are displayed in table 2. VO_2Calc represents oxygen consumption as calculated using the ACSM metabolic formulas for walking and jogging. Measured VO_2 was found to be significantly different from VO_2Calc during the last 3 stages at 100% BW, stages 2 through 5 at 90% BW and during all stages of 80% BW. The average oxygen consumption during these stages was lower than the calculated values using the metabolic formulas.

4. Discussion

The metabolic cost of locomotion has been shown to be significantly different when comparing walking to running with the latter requiring greater oxygen consumption (Abe, Fujuoka, Muraki, Yasukouchi, Niihat, 2011; Abe, Muraki, Yanagawa, Fujuoka, Niihata,2011; ACSM, Rubenson, Heliams, Maloney, Withers, Lloyd, Fournier, 2007; Hall et al.). The results of the present study suggest that traditional metabolic equations do not accurately estimate energy costs when body weight is altered using differential air pressure technology. As such, a new set of equations needs to be established.

Speed and grade are the only variables that can be manipulated on a traditional land-based treadmill. The AlterG® treadmill, however, allows for the added manipulation of the effects of gravity on an individual.

The differential air pressure (DAP) technology that is created in the running chamber allows for the unweighting of a person down to 20% of their original body weight. Previous work using anti-gravity and harness systems has shown to decrease ground reaction forces and metabolic responses when compared to unsupported conditions (Farley et al., Grabowski 2008; Grabowski 2010; Teunnisen et al.). These studies, however, did not manipulate the percent grade on the treadmill during testing. This eliminated the vertical component of the metabolic formulas which is represented by the product of speed and grade.

The sinusoidal movement of the center of gravity (COG) is composed of a horizontal and vertical component. Since the effect of gravity is being altered from the DAP, the vertical component of the displacement of the center of gravity is also being compromised resulting in a decrease in ground reaction forces and a concomitant decrease in metabolic work. When comparing the measured values of oxygen consumption at 100%BW to those calculated using the metabolic formulas, the differences between calculated and measured VO_2 was between 8.2 – 9.3 $ml·kg^{-1}·min^{-1}$ when walking or jogging during stages 3 – 5 (Table 2). These differences were greatest at 80% BW with the divergence between the calculated and measured VO_2 being between 3.9 – 14.5 $ml·kg^{-1}·min^{-1}$ for walking and 15.8-15.5 $ml·kg^{-1}·min^{-1}$ when jogging.

The vertical component of the COG is affected by gravity, which influences an individual's body weight but not mass. A heavier individual would require an increased amount of metabolic work to produce a similar speed of a lighter individual (Loftin, Sothern, Hoss, Tuuri, VaVrancken, Hontos, Bonis, 2007). Since VO_2 ($ml·kg^{-1}·min^{-1}$) is representative of the rate at which the body uses oxygen, two individuals with the same absolute oxygen consumption ($ml·min^{-1}$) would have different relative values once body weight (kg) is factored in to the equation. As a result, the lighter individual would have a higher relative oxygen consumption and aerobic capacity. The DAP of the AlterG® treadmill alters the effect of gravity on weight, but does not change an individual's mass. Since weight is a product of mass and gravity, a reduction in weight results in a decrease in the metabolic work required to displace the center of gravity when walking or jogging. This may be one reason for the discrepancy in the values obtained when compared to those that were calculated. These factors will affect exercise programs for cardiovascular improvement and weight loss based on exercise intensity.

5. Practical Applications

Since the use of this device is increasing in popularity in both fitness and clinical settings, it is imperative to understand its effects on the components of exercise prescription to make the desired physiological adaptations most efficient. The difference in the values of oxygen consumption is amplified during the calculation of caloric expenditure. This value can be calculated using the known constant of approximately 5 kcals per Liter of oxygen consumed (ACSM). The following calculations were used to determine caloric expenditure for 30 minutes of activity at each stage.

$\text{Total kcals}_{30min} = [((VO_2\ (ml·kg·min^{-1})\ X\ \text{bodyweight (kg)}) \div 1000)\ x\ 5\ ]\ x\ 30\ \text{min}$ (ACSM)

A net of -3500 kcals is required to decrease 1 pound (0.45 kgs) of body weight. If diet is not altered, this caloric deficit must be achieved through exercise. Using a body weight of 75 kgs, the gross and net difference in caloric expenditure between VO_2Calc and VO_2 measured at each %BW is illustrated in Table 3 and Figure 3. Gross caloric expenditure is equal to the total amount of calories expended during the exercise session. Net caloric expenditure is the difference between gross and resting caloric expenditure. Humans expend approximately 1 $kcal·min^{-1}$ at rest (ACSM). As seen in table 4, a greater number of sessions, per pound of body weight, will be required to achieve the desired caloric expenditure at 80% when compared to the methods used from the metabolic formulas. Knowing these differences is important since the appropriate modifications in program design can be implemented at the onset of training to make up for the caloric deficit at a reduced %BW.

6. Conclusion

Using the current formulas to prescribe training intensities for cardiovascular improvement at a reduced %BW would elicit metabolic intensities below the recommended level. Manipulation of time, speed and grade would be required to produce values comparable to those obtained from current metabolic formulas. Individuals will need to train longer, at a faster speed or greater incline to produce results based on established guidelines. Since the manipulation of some or all of the variables may not be feasible for some, the development of new metabolic formulas using anti-gravity technology is warranted.

Using the present formulas would be inaccurate if the AlterG® was used for obese individuals or in a cardiac rehabilitation facility. The development of metabolic formulas that factor in %BW as a method of determining VO_2, caloric expenditure and exercise intensity is necessary.

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Stage	Speed (mph)	Grade (percent)
1	1.7	10
2	2.5	12
3	3.4	14
4	4.2	15
5	5.0	15

Table 1. Testing protocol for collection of oxygen consumption.

Stage	VO_2 Calc	100% BW	p	90% BW	p	80% BW	p
1	16.3	16 .5 ± 3.6	0.99	13.3 ± 3.4	0.13	12.4 ± 2.6	0.03
2	24.7	21.4 ± 4.6	0.16	17.4 ± 4.5	<0.001	16.4 ± 2.9	$<0.001^+$
3	35.5	27.3 ± 5.9	0.001	22.3 ± 5.3	<0.001	21.0 ± 3.7	$<0.001^+$
4	41.2	32.3 ± 7.1	0.003	28.3 ± 6.3	<0.001	25.4 ± 4.3	$<0.001^+$
5	48.4	39.1 ± 7.5	0.006	36.0 ± 7.4	<0.001	33.1 ± 4.8	<0.001

Table 2. Oxygen consumption by stage. Data are represented in relative units (m□kg-1□min-1). VO2 Calc = calculated oxygen consumption. 100%, 90%, 80% represent measured oxygen consumption. P values represent significance between VO2 Calc and VO2 measured during each stage. + = significant differences ($p<0.05$) between 100%BW and 80%BW. Subjects walked during stages 1,2 &3 and jogged during stages 4&5.

Stage	VO_2Calc	KcalsCalc	100%BW	Difference	90%BW	Difference	80%BW	Difference
1	16.3	183	186	3	150	-33	140	-43
2	24.7	278	241	-37	196	-82	185	-93
3	35.5	400	307	-93	251	-149	236	-163
4	41.2	464	363	-101	318	-145	286	-178
5	48.4	545	440	-105	405	-140	372	-173

Table 1. Caloric expenditure based on a 75 kg individual exercising for 30 minutes at the intensities for each stage. VO_2Calc = calculated oxygen consumption based on ACSM metabolic formulas. KcalsCalc = calculated caloric expenditure based on VO_2Calc. 100%, 90%, 80% represent caloric expenditure calculated from collected VO_2 data. Difference = difference between KcalsCalc and calculations from measured VO_2. A negative number represents actual values below predicted values from metabolic equations.

Stage	VO_2Calc	Calckcals	100%	90%	80%
1	16.3	23	22	29	32
2	24.7	14	17	21	23
3	35.5	9	13	16	17
4	41.2	8	10	12	14
5	48.4	7	9	9	10

Table 2. Number of 30-minute exercise sessions required to expend 3500 kcals. Calckcals = number of sessions based on metabolic formulas. 100%, 90%, 80% = number of sessions based on each percent body weight

Figure 1. Setup of subject in the AlterG® anti-gravity treadmill.

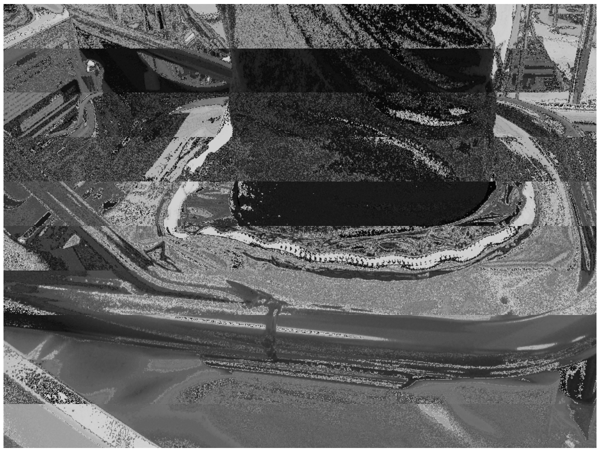

Figure 2. Attachment of neoprene shorts to opening in the AlterG® chamber.

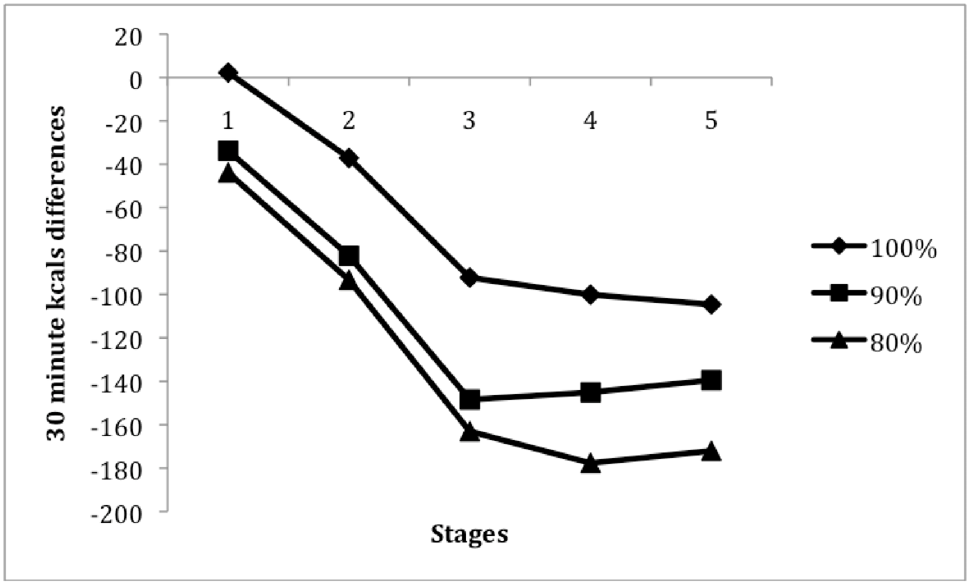

Figure 3. Differences in caloric expenditure based on a 75 kg individual exercising for 30 minutes at the intensities for each stage. 100%, 90%, 80% represent differences in caloric expenditure between measured VO_2 and values based on calculations from ACSM metabolic formulas.

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