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A Comparison of Physiological Demand between Self-Propelled and Motorized Treadmill Exercise

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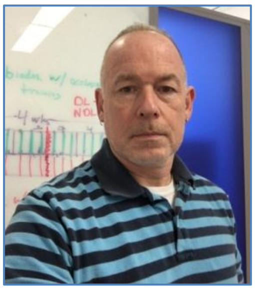
Abstract: There are a wide range of options for individuals to choose from in order to engage in aerobic exercise; from outdoor running to computer controlled and self-propelled treadmills. Recently, self-propelled treadmills have increased in popularity and provide an alternative to a motorized treadmill. Twenty subjects (10 men, 10 women) ranging in age from 19-23 with a mean of 20.4 ± 0.8 SD were participants in this study. The subjects visited the laboratory on three occasions. The purpose of the first visit was to familiarize the subject with the self-propelled treadmill (Woodway Curve 3.0). The second visit, subjects were instructed to run on the self-propelled treadmill for 3km at a self-determined pace. Speed data were collected directly from the self-propelled treadmill. The third visit used speed data collected during the self-propelled treadmill run to create an identically paced 3km run for the subjects to perform on a motorized treadmill (COSMED T150). During both the second and third visit, oxygen consumption (VO_2) and respiratory exchange ratio (R) data were collected with COSMED's Quark cardiopulmonary exercise testing (CPET) metabolic mixing chamber system. The VO_2 mean value for the self-propelled treadmill (44.90 ± 1.65 SE ml/kg/min) was significantly greater than the motorized treadmill (34.38 ± 1.39 SE ml/kg/min). The mean R value for the self-propelled treadmill (0.91 ± 0.01 SE) was significantly greater than the motorized treadmill (0.86 ± 0.01 SE). Our study demonstrated that a 3km run on a self-propelled treadmill does elicit a greater physiological response than a 3km run at on a standard motorized treadmill. Self-propelled treadmills provide a mode of exercise that offers increased training loads and should be considered as an alternative to motorized treadmills.

Key Words: Treadmills, Metabolic, Motorized Treadmills.



Dr. Todd Backes *joined the Biology department at SUNY Fredonia in 2013, after starting the Exercise Science program in the Athletic department at SUNY Fredonia in 2009. Previously he completed his PhD (2009) at the University at Buffalo, preceded by an undergraduate degree in Exercise Physiology (2001) at The Ohio State University. He has 17 years of teaching experience and he founded and developed the Exercise Science major at SUNY Fredonia along with all core courses. He established an active student centered research lab that conducts various projects on human physiology, human performance and health. His main research is in the area of how hydration and drinking behavior can impact exercise performance as well as cognition. His hypotheses run counter to prevailing beliefs in hydration research and, in contrast, have an evolutionary basis. Another focus in his lab has been to examine how acute bouts of physiological stress alter working memory and executive functions.*

1. Introduction

Runners, active individuals, and athletes require modes of exercise and equipment to provide predictable and consistent training intensities [1, 2]. There are a wide range of exercise modalities for individuals to choose from in order to maintain or improve aerobic fitness. Among these options, running is a common modality of exercise which can be done outdoors or indoors on treadmill.

Individuals engaging in treadmill running have a range of equipment options from standard motorized treadmills, to sophisticated computer-controlled machines, or self-propelled models. An o answer is the predictability of training intensity for individuals engaging in treadmill running.

Indoor treadmill running differs from level outdoor running primarily because of the removal of wind resistance; thus lowering the metabolic cost and training load of the exercise bout. Researchers have investigated the differences in metabolic activity between standard motorized treadmill running and outdoor running [3, 4, 5, and 6]. The data from these investigations have yielded equivocal results. Bassett et al. (1985) found no significant difference in oxygen consumption between level outdoor and level treadmill running and between inclined outdoor and inclined treadmill running [7]. McMiken and Daniels (1976) concluded that oxygen consumption measured during treadmill running is a valid predictor of oxygen consumption of level outdoor running in calm conditions [8]. Pugh (1970) found that treadmill running resulted in similar oxygen consumption values when compared to outdoor running in calm conditions [9]. However, treadmill running resulted in lower oxygen consumption values when compared to outdoor running with increasing wind speeds. Jones and Doust (1996) demonstrated that treadmill running elicits lower metabolic equivalents (METs) and lower rating of perceived exertion (RPE) when compared to outdoor level ground running at similar intensities [10].

This possible diminished physiological demand of treadmill running compared to outdoor running may make treadmill running a non-desirable training option for individuals wishing to the mimic the training load of outdoor running. The utilization of a grade/incline component of motorized treadmills better approximates the intensity of outdoor running but such changes can alter the biomechanics of running [10, 11].

Recently, commercially available self-propelled treadmills have increased in popularity and provide an alternative to traditional indoor motorized treadmill running. Previous work has demonstrated walking on a self-propelled treadmill can elicit higher heart rates and higher oxygen consumption values when compared to walking on a standard motorized treadmill [12]. Smoliga et al. (2015) found increased metabolic demand and rating of perceived exertion when walking or running on a self-propelled treadmill compared to a traditional motorized treadmill [13]. Additionally, the subjects self-selected slower walking and running speeds on the self-propelled treadmill. Stevens et al. (2015) reported that self-propelled treadmills can be used as an evaluation tool for endurance running performance [14].

Given the increasing availability of consumer-friendly self-propelled treadmills and the paucity of data evaluating exercise on self-propelled treadmills versus standard motorized treadmills, there is a need for further study. The purpose of this study was to evaluate metabolic demand including oxygen consumption and substrate utilization via respiratory exchange ratio of a 3km run at matched speed on a self-propelled treadmill and a standard motorized treadmill.

2. Methods

2.1 Participants

Twenty subjects (10 men, 10 women) ranging in age from 19-23 with a mean of 20.4 ± 0.8 SD were participants for this study. The research protocol was approved by the Fredonia's Human Subjects Institutional Review Board. All data collection procedures were performed in the Exercise Physiology Laboratory at SUNY Fredonia. All subjects gave his or her written consent and were deemed "apparently healthy" when it was determined that they were free of signs and symptoms of cardiovascular and pulmonary disease and met the criteria for the American College of Sports Medicine (ACSM) low risk stratification for coronary artery disease [15]. Additional exclusionary criteria included recent lower limb skeletal muscle injuries that could prevent subjects from completing the treadmill protocol. All subjects were members of SUNY Fredonia's athletic teams and familiar with treadmill running. Subjects were asked to report to the lab on three separate occasions. This project was conducted as part of a larger study which included lower limb electromyography data collected at the second and third laboratory visits.

2.2 First Visit

The purpose of the first visit was to conduct a familiarization trial on the self-propelled treadmill (Woodway Curve 3.0 Waukesha, WI) and collect informed consent information from the subjects. After instruction on how to use the treadmill, the subject ran for 1km at a self-selected pace. No oxygen consumption or treadmill speed data were collected at this time.

2.3 Second Visit: Self-propelled treadmill

During the second lab visit oxygen consumption and respiratory exchange ratio were determined with COSMED's Quark cardiopulmonary exercise testing (CPET Rome, Italy) metabolic mixing chamber system. Subjects were fitted with Hans-Rudolph head gear and mask. The fitted mask was connected to a two-way breathing valve and turbine flow meter with attached gas sampling line leading to the CPET gas analyzers. Subjects were instructed to run on the self-propelled treadmill for 3km at a self-selected pace. During the run, oxygen consumption and respiratory exchange ratio data were collected continuously. Speed data were collected directly from the self-propelled treadmill via the manufacturer's Pacer software.

2.4 Third Visit: Motorized treadmill

The speed data collected during the self-propelled treadmill run were used to create a 3km motorized treadmill protocol. The third visit consisted of the subject again being fitted with Hans-Rudolph head gear and mask. The fitted mask was connected to a two-way breathing valve and turbine flow meter with attached gas sampling line leading to the CPET gas analyzers. The subjects were then instructed to run on the motorized treadmill (COSMED T150, Rome,Italy)). The speed and speed changes were controlled by a research assistant that duplicated their self-propelled treadmill run. The motorized treadmill sessions for all subjects were conducted with a 1% incline. The 1% incline was used because the self-propelled treadmill has a slight upwards curve to the running deck.

3. Analysis

The CPET software allowed continuous oxygen consumption (VO_2) and respiratory exchange ratio (R) data to be obtained every second. These data were averaged over the first quarter of the distance run, the second quarter of the distance run, the third quarter of the distance run, and the last quarter of the distance run. For statistical analysis of the VO_2 and R average data we ran a general linear model repeated measures ANOVA in SPSS (IBM SPSS Statistics 24). Within-subjects factors were quarter of distance run (quarters indicated as 25, 50, 75, and 100) and treadmill (self-propelled and motorized). All interaction effects were evaluated by the model. If significant in the repeated measures general linear model, tests were evaluated for quarter and treadmill and adjusted for multiple testing. Values are expressed as means and ± SE. Significance of tests was compared with a significance level of 0.05 except for correction for multiple testing. Mauchly's test indicated a lack of sphericity for our analysis therefore Greenhouse-Geisser adjusted P-values are used. All comparisons were evaluated using Shapiro-Wilk tests of normality and found to not differ from a normal distribution ($P > 0.05$).

4. Results

4.1 Oxygen consumption

The quarter factor ($P < 0.0005$) was significant for VO_2 (Table 1, Fig. 1). A post-hoc examination of the quarter factor revealed all quarters to be significantly different from each other except for 75 and 100 (Fig. 1). The VO_2 mean value for quarter 25 was 36.79 ± 1.29 ml/kg/min, for 50 was 39.45 ± 1.47 ml/kg/min, for 75 was 40.97 ± 1.65 ml/kg/min, and 100 was 41.35 ± 1.80 ml/kg/min.

Table 1. Significant results from repeated measures general linear models for oxygen consumption (VO2) and respiratory exchange ratio (R). Within-subject factors were quarter (25, 50, 75, 100) and treadmill (self-propelled and motorized).

Physiological Variable	F	Df	Sig*
VO_2			
Quarter	19.03	1.79	< 0.0005
Treadmill	485.92	1.00	< 0.0005
Quarter*Treadmill	4.30	1.91	0.023
R			
Quarter	24.20	1.80	< 0.0005
Treadmill	28.94	1.00	< 0.0005

*Greenhouse-Geisser adjusted P-values

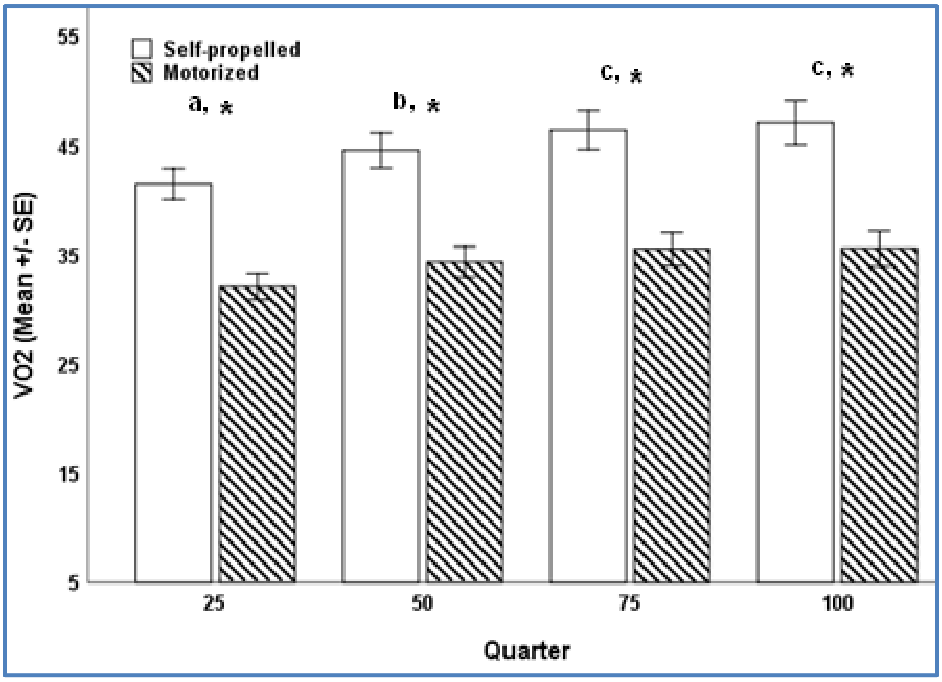


Figure 1. VO2 mean values (ml/kg/min) at the first quarter (25), second quarter (50), third quarter (75), and fourth quarter (100) of the distance run on self-propelled and motorized treadmills.

Quarters not sharing a common letter are different (P < 0.05)

* Indicates significance (P < 0.05) for treadmill type at each quarter

P-values were adjusted for multiple testing.

The treadmill factor (P < 0.0005) was significant for VO_2 (Table 1, Fig. 1). The VO_2 mean value for the self-propelled treadmill was 44.90 ± 1.65 ml/kg/min and for the motorized treadmill was 34.38 ± 1.39 ml/kg/min. A post-hoc examination of the treadmill factor revealed the treadmill types to be significantly different from each other at every quarter (Fig. 1).

There was a significant interaction effect between quarter and treadmill for VO_2 (P = 0.023, Table 1). For quarter 25 the VO_2 mean value for the self-propelled treadmill was 41.48 ± 1.48 ml/kg/min and for the motorized treadmill were 32.09 ± 1.24 ml/kg/min. For quarter 50 the VO_2 mean value for the self-propelled treadmill was 44.56 ± 1.79 ml/kg/min and for the motorized treadmill were 34.34 ± 1.53 ml/kg/min. For quarter 75 the VO_2 mean value for the self-propelled treadmill was 46.42 ± 1.92 ml/kg/min and for the motorized treadmill were 35.52 ± 1.62 ml/kg/min. For quarter 100 the VO_2 mean value for the self-propelled treadmill was 47.13 ± 2.16 ml/kg/min and for the motorized treadmill was 35.58 ± 1.71 ml/kg/min.

4.2 Respiratory exchange ratio

The quarter factor ($P < 0.0005$) was significant for R (Table 1, Fig. 2). A post-hoc examination of the quarter factor revealed quarter 25 to be significantly different from the other quarters (Fig. 2). The R mean value for quarter 25 was 0.83 ± 0.01, for 50 was 0.90 ± 0.02, for 75 was 0.90 ± 0.01, and 100 was 0.90 ± 0.01.

The treadmill factor ($P<0.0005$) was significant for R (Table 1, Fig. 2). The R mean value for the self-propelled treadmill was 0.91 ± 0.01 and for the motorized treadmill was 0.86 ± 0.01. A post-hoc examination of the treadmill factor revealed the treadmill types to be significantly different from each other at every quarter (Fig.2). At quarter 25 the R mean value for the self-propelled treadmill was 0.85 ± 0.01 and for the motorized treadmill was 0.81 ± 0.01.

At quarter 50 the R mean value for the self-propelled treadmill was 0.93 ± 0.02 and for the motorized treadmill was 0.88 ± 0.02. At quarter 75 the R mean value for the self-propelled treadmill was 0.92 ± 0.02 and for the motorized treadmill was 0.87 ± 0.02. At quarter 100 the R mean value for the self-propelled treadmill was 0.92 ± 0.01 and for the motorized treadmill was 0.88 ± 0.02.

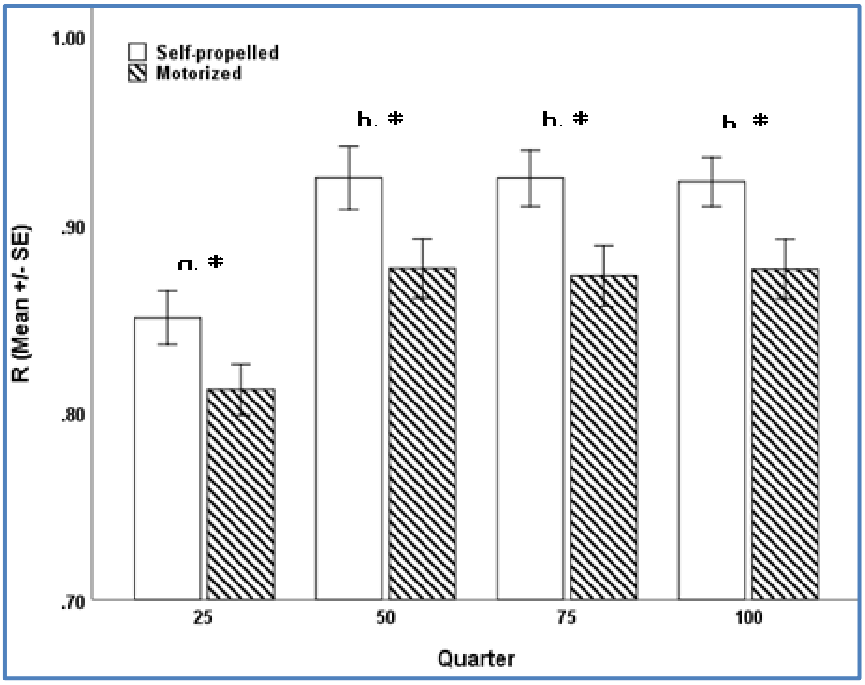


Figure 2. R mean values at the first quarter (25), second quarter (50), third quarter (75), and fourth quarter (100) of the distance run on self-propelled and motorized treadmills.

Quarters not sharing a common letter are different ($P < 0.05$)

* Indicates significance ($P < 0.05$) for treadmill type at each quarter P-values were adjusted for multiple testing.

5. Discussion

Self-propelled treadmills have been marketed as an alternative to traditional motorized treadmills. The advertised benefit of a self-propelled treadmill is that it can elicit higher training intensities, recruit greater muscle mass and burn more calories than traditional motorized treadmills [16]. The purpose of our study was to evaluate oxygen consumption and substrate utilization via respiratory exchange ratio a 3km run on both a self-propelled treadmill and a standard motorized treadmill.

Aerobic exercise such as running requires increased oxygen delivery to working skeletal muscle [6, 7, 17, and 18]. Measurement of oxygen consumption is used to determine the contribution of oxidative phosphorylation to ATP production at rest or exercise. Oxygen consumption is used by athletes, trainers, clinicians and physicians as a universally recognized standard of aerobic fitness [19, 20]. At the onset of exercise there is a fall in intramuscular partial pressure of oxygen, concomitantly there is in an increase in oxygen uptake (measured at the lungs) [21, 22, and 23]. This change in oxygen consumption above resting values reflects the ability to not only take up oxygen at the lungs but also to deliver oxygen to active skeletal muscle. Therefore, the measurement of oxygen consumption is a useful tool for exercise physiologists, clinicians, coaches, and trainers to evaluate the aerobic contribution to meeting ATP demands of exercise [19,20, and 24].

Oxygen consumption across all quarters was significantly higher for the self-propelled treadmill. The self-propelled treadmill belt must be moved backwards by the subject in order to "move forward" requiring greater effort and possibly introducing a new source of friction from the belt and the internal mechanism of the treadmill (compared to a motorized treadmill that moves the belt). The belt and the friction adds to the intensity of the run, likely requiring greater muscle recruitment and therefore greater oxygen consumption. Additionally, early self-propelled treadmills required the subject to use a harness to help with balance and stability. The self-propelled treadmill used in our study does not require the use of a harness, however, it is also possible that a greater amount of upper body muscle mass was recruited in the self-propelled treadmill in order to help with stability. The recruitment of this additional mass would elicit greater oxygen consumption values.

The pattern of oxygen consumption across all quarters for both treadmill types was similar. Each treadmill type demonstrated a significant increase in oxygen consumption between the first quarter (25) and each subsequent quarter (50, 75, &100). The self-propelled treadmill was also significantly different between the second (50) and each of the final two quarters (75 &100), however, a plateau of oxygen consumption was reached between 75 and 100. With the overall consumption of oxygen higher for the self-propelled compared to the motorized treadmill the pattern of oxygen consumption between quarters is expected. The increased metabolic stress (measured as oxygen consumption) and larger muscle mass recruitment incurred when running on the self-propelled treadmill represents a larger magnitude change from non-exercise oxygen consumption values resulting in a non-significant difference in oxygen consumption occurring later in the exercise bout. Therefore the observed pattern of oxygen consumption further supports the explanation for the increased VO_2 between treadmills as being a result of increased muscle recruitment.

The respiratory exchange ratio is an expression of the volume of carbon dioxide produced to the volume of oxygen consumed during metabolism. The numerical expression of this ratio indicates the percentage of carbohydrate and fat contribution as substrate utilized for ATP generation [25]. Respiratory exchange ratio values range from 0.70 to 1.00. A value of 0.70 indicates the greatest contribution of fat as substrate. As the value increases towards 1.00 the contribution of fat as substrate decreases and the contribution of carbohydrate increases [26]. An increase in exercise intensity necessitates a demand for an increase in the rate of ATP production. Carbohydrate utilization as a fuel substrate is quicker than fat. Therefore, at the beginning of the bout of exercise the increase in intensity from rest requires a greater rate of ATP production reflected in the significant increase in the respiratory exchange ratio (comparing 25 to 50) then a plateau for both treadmills. The self-propelled treadmill resulted in greater oxygen consumption and as would be expected there was a significantly higher respiratory exchange ratio.

Our study incorporated only one familiarization trial which could influence a subject's balance and stability on the self-propelled treadmill. The lack of familiarity with the self-propelled treadmill could cause a subject to recruit more muscle mass to maintain balance and stability. As stated previously this increase in muscle mass recruitment could explain the measured increase in oxygen consumption in the self-propelled treadmill condition. It is possible that becoming more familiar with the self-propelled treadmill would reduce the subject's need to recruit stabilization muscles thus eventually reducing the amount of oxygen consumed in the self-propelled condition. However, Tofari et al. (2015) demonstrated that a single self–propelled self-paced session provided adequate test-retest reliability on a self-propelled treadmill [27]. Therefore, it seems unlikely that increased familiarization with the self-propelled treadmill would result in a decrease in oxygen consumption to motorized treadmill levels. It is possible that there was an order effect since all subjects performed the self-propelled treadmill portion first. The study design, however, requires the self-propelled treadmill portion to be completed first. In order to be able to have the subjects run the 3km on both treadmills at matched speeds the speed must be recorded from the self-propelled run and then be used to create the motorized treadmill protocol.

Our study demonstrated that a 3km run on a self-propelled treadmill can elicit a greater physiological response than a 3km run at matched speeds on a standard motorized treadmill. The results of this study are supported by previous work that also found walking or running on a self-propelled treadmill elicited higher oxygen consumption values, higher heart rates, and higher rating of perceived exertion. To our knowledge, this study was the first to directly compare the physiological responses to identical subject-paced runs on self -propelled and motorized treadmills.

6. Conclusions

Athletes and active individuals use treadmills for additional training, injury rehabilitation, and maintaining fitness during the offseason. Our study demonstrated that self-propelled treadmills can provide a mode of exercise that offers increase training loads and should be considered as an alternative to motorized treadmills when available. Additionally, in clinical settings it should be noted that patients, such as in a cardiac rehabilitation situation, should be instructed to walk at a slower pace than they are accustomed to on a motorized treadmill because of the increased physiological response. Future studies should further evaluate exercise on self-propelled treadmills compared to outdoor running.

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Competing Interests

The authors declare that they have no competing interests.