Analysis of Peak Oxygen Consumption and Heart Rate During Elliptical and Treadmill Exercise

John A. Mercer, Janet S. Dufek, and Barry T. Bates


Objective: To compare peak oxygen consumption (VO₂) and heart rate (HR) during treadmill (TM) running and exercise on an elliptical trainer (ET).

Design: A graded exercise test (GXT) during TM running and ET exercise.

Participants: Physically active college students (N = 14; 25 ± 4.6 years). Each completed a TM GXT and ET GXT on separate days.

Results: There were no differences in either VO₂peak or peak HR between TM (53.0 ± 7.7 ml · kg⁻¹ · min⁻¹, 193.4 ± 9.4 bpm) and ET (51.6 ± 10.7 ml · kg⁻¹ · min⁻¹, 191.2 ± 11.5 bpm; P > .05). Correlations between HR and VO₂ data for all stages of exercise for all subjects were similar between machines (ET: r = .88; TM: r = .95; P > .05).

Conclusion: No adjustments to the target HR used during TM running are necessary when using the ET.

Athletic training rooms and rehabilitation clinics are typically equipped with a wide variety of exercise machines that can be used for cardiovascular training, such as treadmills, bicycles, stair-steppers, cross-country skiers, and elliptical trainers. From this diverse collection, certain machines are selected for inclusion in a rehabilitation program based on the needs and goals of the patient. In many cases, the rehabilitation program involves a cardiovascular training component. Typically, the prescribed intensity of this type of exercise is based on heart-rate (HR) measures relative to a measured or estimated peak HR. In designing an effective exercise program, the practitioner and athlete would benefit by knowing how the physiological demands of exercise compare between machines.

It is well documented that the benefits of an exercise program result from manipulating frequency, duration, and intensity of exercise. The mode of exercise selected typically does not affect either frequency or duration of exercise. The mode of exercise does, however, provide a direct means of...
manipulating exercise intensity. As intensity increases, the rate of oxygen consumption (VO$_2$) and HR increase concurrently. During exercise, HR is used to quantify intensity because of the strong correlation between HR and VO$_2$. Research has demonstrated that exercising at heart rates between 55/60% to 90% of maximum HR (or 50% to 85% VO$_{2\text{max}}$) is an appropriate level of exercise intensity for improving cardiovascular fitness and reducing body fat. This target HR range corresponds to about a “somewhat hard” to “hard” perceived level of exercise intensity. The exercise machine selected to improve cardiovascular fitness or reduce percent body fat should therefore provide sufficient mechanical adjustments to allow the user to attain a range of levels of intensity within the target HR range. For example, intensity during treadmill exercise can be manipulated by changing treadmill elevation and/or belt speed.

Recently, a new exercise machine has been developed to simulate running kinematics. The machine is designed to allow for movements that result in the foot traveling in a cyclic elliptical pattern during use, so it will be referred to as an elliptical trainer (ET). The advantage of the ET is that the impact between the foot and ground is eliminated, which has been hypothesized to be related to overuse injury during running. Because the ET simulates running, there is a question of whether or not peak HR measures, which are used to establish target HR range, are similar during ET exercise and treadmill (TM) running. Therefore, the purpose of this study was to compare the peak physiological responses during maximal-effort exercise on an ET and during TM running. The intent was to determine whether or not the ET allows for a range of exercise intensities similar to TM running. This knowledge will help athletes and practitioners decide whether or not the ET is an appropriate mode of exercise to include in a rehabilitation program.

Methods

Experimental Design and Setting

A repeated-measures design was employed to compare peak metabolic responses during TM (Precor, model 9.64) and ET (Precor, model C44 Evolution) maximal-effort exercise. Dependent variables evaluated were VO$_{2\text{peak}}$, peak HR, and maximum rating of perceived exertion (RPE).

Participants

Fourteen subjects, 5 women and 9 men (N = 14; age = 25 ± 4.6 years; mass = 71.5 ± 13.3 kg; height = 1.78 ± 0.10 m), completed a graded exercise test (GXT) using each mode of exercise. Before testing, subjects signed an approved informed consent document in accordance with university policy. Subjects were recruited from a variety of recreational classes, with all subjects being
physically active at the time of testing. Because some subjects were novices to TM running and the ET, all subjects were allowed ample time to become comfortable with each mode of exercise by participating in warm-up and practice sessions. Subjects were not allowed to start the TM GXT without demonstrating that they could run on the treadmill. Likewise, they were not allowed to start the ET GXT without demonstrating that they could comfortably exercise at a range of resistance and cadence levels.

**Instrumentation**

Oxygen consumption was recorded at 20-second intervals using the TEEM 100 metabolic-analysis system (Aerosport, Inc, St Paul, Minn). The TEEM 100 was calibrated before each test per the manufacturer’s instructions. Heart rate was also recorded at 20-second intervals using a Polar HR telemetry unit. Rating of perceived exertion was recorded 20 seconds before the end of each stage using Borg’s RPE 6- to 20-point scale. VO$_2$peak and peak HR values analyzed were the highest values recorded during the GXT. Maximum RPE was the RPE recorded just before termination of the test.

**Experimental Procedures**

All subjects completed 2 GXTs, 1 using each machine. A minimum of 2 days and a maximum of 7 days rest was allowed between tests, with the order of TM and ET tests balanced among subjects. For each subject, tests were completed at about the same time of day to minimize a circadian effect. Subjects were instructed to refrain from alcohol, coffee, strenuous exercise, and smoking for 4 hours before testing.

The GXT protocols were designed to elicit, within an 8- to 15-minute range of exercise time, a maximal effort by steadily increasing intensity each minute. Before testing, subjects were allowed sufficient time to complete a self-directed warm-up.

The TM GXT consisted of 1-minute stages, with speed set to 1.3 m/s and a 3% ramp elevation. The second, third, and fourth stages required subjects to exercise with an 8% elevation and speed set at 1.6, 1.8, and 2.2 m/s, respectively. Speed for each subsequent stage was increased by 0.2 m/s (0.5 mph), until exhaustion, while elevation was maintained at 8%. The 8% elevation was selected in order to replicate the constant elevation of the ET.

Analogous to manipulating speed and elevation on the TM, the ET provides mechanical adjustments for ramp elevation and resistance level, with the user controlling cadence. Based on previous pilot work, the ramp was maintained at the midpoint of the low–high range possibilities (level 5 of a 1–10 range) because the VO$_2$ response might not be linear across low to high settings. During the GXT, exercise intensity was therefore manipulated by changing the resistance setting and by requiring subjects to change cadence. Cadence was defined as the number of right-side pedal revolutions per minute (rpm). The ET GXT began at stage 1 with a cadence of 60 rpm. Subjects were required to increase cadence by 5 rpm at each 1-minute stage
until termination of the test. In addition, after stage 4, resistance level was increased by 1 level (machine setting) concurrent with an increase in cadence. For both the ET and the TM GXT, the test endpoint occurred when the subject indicated that he or she could no longer continue to exercise at the set parameters. Near the end of the ET GXT, there was some subjects who could not initially maintain the required cadence. When this occurred, they were given about 15 seconds to increase cadence to the required level. The test terminated if they were not able to do so. In all these cases, the subjects were visibly exhausted.

**Statistical Analysis**

Paired *t* tests were used to analyze each peak variable between ET and TM. Pearson product–moment correlations for each machine were calculated between HR and VO$_2$ using all GXT data (ie, submaximal and maximal) for the ET, as well as the TM GXT. Because a wide range of subject fitness levels was tested, before calculating correlation coefficients, submaximal data were normalized to peak values. Therefore, peak HR and VO$_{2\text{peak}}$ were represented as 100%, and submaximal HR and VO$_2$ were represented as a percentage of peak. Additional analysis of submaximal HR and VO$_2$ responses was conducted by computing a linear-regression line predicting VO$_2$ from HR for each subject. Using paired *t* tests, group slopes and *y*-intercepts were compared between machines. Finally, HR–VO$_2$ correlations were compared between machines using Fisher’s *z* transformation.

**Results**

There were no differences (*P* > .05) between machines for any of the peak variables evaluated (Figures 1–3). The HR–VO$_2$ correlations during ET (*r* = .88) and TM (*r* = .95) were similar between machines (*P* > .05), with a correlation of .88 for the ET and .95 for the TM. Likewise, slopes and *y*-intercepts were not different between modes of exercise (*P* > .05). Scatterplots of all data for each machine are illustrated in Figures 4 and 5. Test times were not different between modes of exercise (TM: 8.9 ± 2.2 minutes, ET: 9.2 ± 2.3 minutes; *P* > .05). The correlation between RPE and HR was not different (*P* > .05) during ET (*r* = .81) than during TM (*r* = .85).

**Comments**

The purpose of this study was to compare select peak physiological responses during TM running and simulated running using an ET in order to determine whether or not the ET allowed for a range of exercise intensities similar to TM exercise. We observed no differences between machines for any of the peak variables evaluated (HR, VO$_2$, and RPE). Furthermore, the
Figure 1  Means and SDs for VO$_{2peak}$ during elliptical-trainer and treadmill exercise. There was no difference in VO$_{2peak}$ between machines ($P > .05$).

Figure 2  Means and SDs for peak heart rate (HR) during elliptical-trainer and treadmill exercise. There was no difference in peak HR between machines ($P > .05$).

Figure 3  Means and SDs for maximal rating of perceived exertion (RPE) during elliptical-trainer and treadmill exercise. There was no difference in peak RPE between machines ($P > .05$).
Figure 4  Heart rate (HR) vs VO\textsubscript{2} and HR vs rating of perceived exertion (RPE) relationships during elliptical-trainer (ET) exercise. Submaximal HR and VO\textsubscript{2} values were normalized to peak values for each subject. The correlation between percent HR and percent VO\textsubscript{2} during ET exercise was $r = .88$; the correlation between percent HR and RPE was $r = .81$.

Figure 5  Heart rate (HR) vs VO\textsubscript{2} and HR vs rating of perceived exertion (RPE) relationships during treadmill (TM) exercise. Submaximal HR and VO\textsubscript{2} values were normalized to peak values for each subject. The correlation between percent HR and percent VO\textsubscript{2} during TM running was $r = .95$; the correlation between percent HR and RPE was $r = .85$. 
correlations between HR and VO\textsubscript{2} (ET: \(r = .88\), TM: \(r = .95\)) were similar between machines, indicating that during TM and ET exercise, HR and VO\textsubscript{2} increased in similar fashion for different levels of intensity. The correlations between HR and VO\textsubscript{2} during TM running in our study were similar to correlations reported elsewhere: \(r = .99\) and \(r = .87\)\textsuperscript{7,8} Our observations are also similar to the results of Pecchia et al.\textsuperscript{9} who reported that when subjects exercised at a given submaximal VO\textsubscript{2} during ET and TM exercise, HR was not different between modes of exercise. These observations, combined with the results of the present study, indicate that the ET provided a range of exercise intensity similar to that of TM running.

There are no other published ET GXT protocols known to us, and it is not known whether a different GXT protocol would result in different peak values or a different HR–VO\textsubscript{2} relationship during submaximal exercise. During testing, subjects were encouraged to exercise until exhaustion; the high RPE rating (mean above 18 for both machines) provides evidence that the subjects did put forth a maximal effort for each test. Care should be taken when generalizing the results to injured populations enrolled in a rehabilitation program, because the subjects tested in this study were healthy and physically active. It is not known whether the relationships observed in this study would differ for injured populations.

It is common to include treadmill or outdoor running as a component of a rehabilitation or exercise program. Running is often included because it is relatively inexpensive, uses a large amount of muscle mass, and is a common form of locomotion in most sports. Also, a participant can run in a variety of environmental conditions, for example, indoors or outdoors, on trails or on sidewalks. There are many benefits from including running in an exercise program, but it might be contraindicated in a rehabilitation program because of the repetitive, high-impact nature of the exercise.\textsuperscript{5,6} Patients who have running-related goals but cannot participate in a running program might be directed to use an ET because of the qualitatively similar motions of the lower extremity during running and ET exercise. Whether or not the ET provides a potential benefit for a patient is for the practitioner to decide based on the patient’s needs and goals. Nevertheless, the results of our study indicate that there is no need to adjust the TM-derived target HR zone to prescribe or monitor exercise intensity during ET exercise.

The design of an appropriate exercise routine should include consideration of several parameters, 1 set being peak metabolic parameters. Meyer et al\textsuperscript{10} reported that relying only on percentage of VO\textsubscript{2peak} or peak HR results in a wide range of heart rates relative to the anaerobic threshold, indicating that prescribed exercise intensities should not be based solely on peak parameters. In a comparison of 2 modes of exercise, however, analysis of peak metabolic parameters is a logical starting point because it is common to prescribe exercise intensities based on peak parameters. The current results provide evidence that peak metabolic parameters are
similar in ET and TM exercise. This is not always the case, however, when peak metabolic responses during exercise using different modes of exercise are compared. For example, Mercer and Jensen\textsuperscript{11,12} reported that \( V\text{O}_{2}\text{peak} \) and peak HR were lower during maximal-effort deep-water running than during treadmill running. Likewise, it has been documented that \( V\text{O}_{2}\text{peak} \) and peak HR are lower during maximal effort using an arm ergometer than during treadmill exercise\textsuperscript{13} and during cross-country skiing than during treadmill running.\textsuperscript{14} Designing exercise routines based on peak HR for these exercises is complicated because peak values are different between modes of exercise. Our results indicate that no adjustments in target HR need to be made during exercise using the ET because there was no difference between machines in peak parameters, regression lines, or correlations. Research is now needed to compare the biomechanics of exercise using the ET and running on a TM.

**Conclusion**

Peak metabolic responses of \( V\text{O}_2 \) and HR were similar during maximal-effort exercise using an elliptical trainer and a treadmill. In addition, analysis of the submaximal HR–\( V\text{O}_2 \) relationship suggests that there is no need to adjust target HR during ET exercise. Based on the analysis of physiological results, we concluded that the ET is a suitable alternative to TM exercise and the ET provides a range of exercise intensities similar to that of TM running.

**Acknowledgments**

Thanks to Shing-Jye Chen and Rachael Wiley for assisting with data collection.

**References**


