Comparison of Energy Expenditure on a Treadmill vs. an Elliptical Device at a Self-Selected Exercise Intensity

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Abstract

Brown, GA, Cook, CM, Krueger, RD, and Heelan, KA. Comparison of energy expenditure on a treadmill vs. an elliptical device at a self-selected exercise intensity. *J Strength Cond Res* 24(6): 1643–1649, 2010—Treadmills (TM) and elliptical devices (EL) are popular forms of exercise equipment. The differences in the training stimulus presented by TM or EL are unknown. The purpose of this investigation was to evaluate oxygen consumption, energy expenditure, and heart rate on a TM or EL when persons exercise at the same perceived level of exertion. After measuring peak oxygen uptake ($\dot{V}O_2$peak) in 9 male and 9 female untrained college-aged participants, the subjects performed 2 separate 15-minute submaximal exercise tests on the TM and EL at a rating of perceived exertion (RPE) of 12–13. $\dot{V}O_2$peak was higher ($p < 0.05$) in the males (48.6 ± 1.5 vs. 45.2 ± 1.6 ml/kg/min) than the females (41.7 ± 1.8 vs. 38.8 ± 2.2 ml/kg/min) for both TM and EL (means ± standard error of the mean; for TM vs. EL respectively), but there were no differences in the measured $\dot{V}O_2$peak between TM or EL. During submaximal exercise there were no differences in RPE between TM and EL. Total oxygen consumption was higher ($p < 0.05$) in males (30.8 ± 2.2 vs. 34.9 ± 2.2 L) than females (24.1 ± 1.8 vs. 26.9 ± 1.7 L) but did not differ between TM and EL. Energy expenditure was not different between TM (569 ± 110 J) or EL (636 ± 120 kJ). Heart rate was higher ($p < 0.05$) on the EL (164 ± 16 beats/min) compared to the TM (145 ± 15 beats/min). When subjects exercise at the same RPE on TM or EL, oxygen consumption and energy expenditure are similar in spite of a higher heart rate on the EL. These data indicate that during cross training or noncompetition-specific exercise, an elliptical device is an acceptable alternative to a treadmill.

Key Words rating of perceived exertion, oxygen consumption, heart rate, submaximal exercise, energy expenditure

Introduction

Physical inactivity is considered a major risk factor for a number of adverse health conditions including obesity, hypertension, cardiovascular disease, and diabetes mellitus (9,27,28). The current guidelines from the American College of Sports Medicine (ACSM) indicate that at least 30 minutes of moderate-intensity aerobic physical activity on most days of the week are required to promote health and prevent disease (17). The U.S. Surgeon General's report on physical activity indicates that people should engage in at least 60 minutes of moderate-intensity physical activity every day to prevent obesity, whereas the Institute of Medicine indicates that people need 90 minutes of moderate physical activity to lose weight (6).

When encouraging people to become physically active, it is important to have individuals select exercise modalities that optimize energy expenditure to prevent or treat obesity (21,26), whereas presenting a training stimulus that is perceptually preferable will enhance exercise adherence (4). Many different exercise modalities can produce beneficial cardiovascular effects (17); however, differences exist in energy expenditure among exercise devices during submaximal exercise at intensities within the perceptual preference range, which is defined as an rating of perceived exertion (RPE) of 11 (fairly light) to 15 (hard) on the Borg scale (26). By determining the efficiency of different exercise modalities, recommendations regarding the modality used for health-related physical activity can be made that may result in substantial benefits and help to promote long-term exercise adherence (15,26).

Exercising on a treadmill (TM) is very common, and this exercise modality allows people to engage in the most common form of physical activity among those persons who engage in regular physical activity–walking (2,6). Exercising on a TM has been reported to produce the greatest caloric

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expenditure for the same RPE compared to a cross-country skiing simulator, rowing ergometer, stair stepper, and cycle ergometer (29). Elliptical devices (EL) are a relatively new modality of exercise and are advertised to be superior to a treadmill because of the low joint impact and the more reasonable costs of an EL compared to a TM. Exercise on an EL has been evaluated for heart rate, RPE, and oxygen consumption during a single session of exercise (7,16). Furthermore, Egana and Donne (13) observed similar enhancements in fitness during a 12-week stair-climbing, EL, or TM training program. However, TM and EL exercise has not been compared for oxygen consumption, energy expenditure, and heart rate during a single session of exercise. Given the purported benefits of exercising on an EL compared to TM, and the utility of having several modalities of exercise available for cross training or non-competition specific exercise (20), an understanding of the physiological response to exercise on an EL compared to a TM is desirable.

The purpose of this investigation was to examine the oxygen consumption, energy expenditure, and heart rate at the same perceived intensity of exercise during a single session of exercise on a TM and EL in untrained college-aged males and females. Based on the results of Egana and Donne (13), it is hypothesized that there will be no differences in oxygen consumption, energy expenditure, and heart rate between TM and EL exercise.

Methods

Experimental Approach to the Problem

To evaluate for possible differences in oxygen consumption, energy expenditure, and heart rate between treadmill and elliptical exercise, subjects were evaluated for maximum oxygen uptake ($\dot{V}O_2max$) on a treadmill and elliptical device, then performed submaximal exercise at the same moderate-intensity RPE on both devices. Prior to any testing, subjects were given instructions regarding the proper use of the exercise equipment and were also familiarized with the 15-point (6–20) Borg RPE scale (10). Subjects were also questioned about their use of, and familiarity with, the exercise equipment and were required to demonstrate competence and correct form (e.g., not leaning on the handrails and ability to maintain balance on the devices) in the use of a TM and EL. If needed, a 10-minute practice session was performed on one or both pieces of equipment on a non-testing day before any experimental testing. Each subject then participated in 3 separate exercise sessions. The first 2 sessions involved assessment of cardiorespiratory fitness ($\dot{V}O_2peak$) on a treadmill TM and elliptical device EL. The 2 $\dot{V}O_2peak$ assessments were completed in random order at least 48 hours apart and completed within a 1-week time frame. At least 48 hours after the second $\dot{V}O_2peak$ assessment, the subjects completed a 15-minute submaximal exercise session on each device, in random order, with exercise sessions separated by 15 minutes of seated rest to allow for recovery between sessions. All aspects of this project were conducted in the same year during the months of May, June, and July in the Human Performance Laboratory at the University of Nebraska at Kearney.

Subjects

Eighteen, 19–24-year-old males ($n = 9$) and females ($n = 9$) who had no history of participation in structured aerobic or resistance training volunteered to participate in this project. Personal and immediate family health histories were obtained from each subject prior to acceptance into the program using a health and exercise history that met the suggestions provided by the American College of Sports Medicine (1) to exclude persons with known metabolic or health condition(s) such as diabetes, heart complications, and/or orthopedic limitations and to ensure that the subjects were not regularly (more than once per week) engaging in any form of exercise. In addition, subjects taking medications or supplements that could affect physical performance or metabolism (e.g., cardiac drugs, thyroid drugs, stimulants), pregnant females, and subjects who smoked or used tobacco products were excluded. Prior to beginning this project, which was approved by the University of Nebraska at Kearney Institutional Review Board, each subject read and signed a document of informed consent. The body mass of each subject was measured to the nearest 0.01 kg using a digital platform scale (PS6600, Befour Inc., Saukville, WI, USA), and body height was measured to the nearest 0.25 cm using a stadiometer (Model 115, Seca, Hamburg, Germany). Body mass index (kg/m^2) was then calculated for each subject. The male subjects were taller and had a larger body mass ($p < 0.05$) than did the females (Table 1).

Cardiorespiratory Fitness Assessment

Subjects performed a maximal graded exercise test on the TM and EL for determination of cardiorespiratory fitness ($\dot{V}O_2peak$) in a randomized, crossover pattern on 2 separate days separated by 48 hours. For measurement of $\dot{V}O_2peak$ on the TM (Model 2000, SensorMedics Inc., Yorba Linda, CA, USA), subjects performed a modified Balke protocol (1), which consisted of walking at 3.4 mph while the grade increased 2.5% every 2 minutes until volitional fatigue. There does not appear to be an established protocol for measuring $\dot{V}O_2peak$ using an elliptical device, so in the present investigation the subjects performed continuous exercise at 150 revolutions/minute with the grade crossramp set at 8% and resistance increasing 2 units every 2 minutes until volitional fatigue on the elliptical device (EFX 546, Precor USA, Woodinville, WA, USA). For a $\dot{V}O_2peak$ test to be considered valid, the subject must have met 3 out of the following 4 physiological markers: (a) maximal heart rate (HR_{max}) within 10 beats per minute (bpm) of age-predicted maximum heart rate (calculated as $220 - age$); (b) maximal respiratory exchange ratio (RER) of ≥ 1.10; (c) maximal oxygen consumption plateaued within 150 mL in the last minute of exercise; and (d) a rating of perceived exertion of ≥ 18 (1). If 3 out of the 4 criteria were not met, the subject was

TABLE 1. Subject descriptive characteristics.

	Male	Female
Number of subjects (n)	9	9
Age (years)	21.6 ± 0.3	20.6 ± 0.4
Height (cm)	184.9 ± 3.2	165.0 ± 2.0*
Body mass (kg)	91.3 ± 4.4	71.0 ± 4.0*
Body mass index (kg/m^2)	26.7 ± 3.5	26.1 ± 3.8
TM $\dot{V}O_2$peak (ml/kg/min)	48.6 ± 1.5	41.7 ± 1.8*
TM $\dot{V}O_2$peak (L/min)	4.4 ± 0.1	2.9 ± 0.1*
TM HR_{Max} (beats/min)	198.6 ± 2.8	197.9 ± 1.6
EL $\dot{V}O_2$peak (L/min) (ml/kg/min)	45.2 ± 1.6	38.8 ± 2.2*
EL $\dot{V}O_2$peak (L/min) (L/min)	4.1 ± 0.1	2.7 ± 0.2*
EL HR_{max} (beats/min)	200.8 ± 2.5	198.9 ± 1.4

TM = treadmill exercise; EL = elliptical exercise.
Data are presented as means ± standard error of the mean.
*Significant difference between genders (main effect; $p < 0.05$).

asked to repeat the test on a separate day. During both $\dot{V}O_2$peak tests and submaximal exercise tests, expired air was measured for quantity, oxygen, and carbon dioxide content at 20-second intervals using a metabolic cart (2900, Sensor-Medics. Inc., Yorba Linda, CA, USA) and heart rate was assessed with a heart rate monitor (Polar Vantage XL, Polar Electro Inc., Lake Success, NY, USA). Heart rate and RPE were collected at the end of each 2-minute stage and at the final stopping point when the subject terminated the test as a result of maximal exhaustion.

Submaximal Exercise

Each submaximal TM and EL exercise session included a 5-minute warm-up, followed by 15 minutes of exercise at an RPE of 12–13 on the Borg 15-point scale (10). The 5-minute warm-up was utilized to provide a familiarization period for the subjects to adjust the exercise intensity on each piece of equipment to attain an intensity that was perceived to be at an RPE level of 12–13 and was sustainable for the 15-minute exercise session. Prior to participation in the exercise sessions of this study, all participants were shown the Borg ratings of perceived exertion scale as illustrated by Heyward (18) and read the same description of how to rate perceived exertion during exercise as described by Birk and Birk (8). During exercise, subjects pointed to the number on the chart that corresponded to their RPE. In a review, Dishman (11) concluded that RPE is an acceptable method for regulating exercise intensity across different modalities of exercise, particularly when the RPE is between 10 and 16. Furthermore, it has been observed that using RPE provide acceptable control of exercise intensity when comparing TM and EL (16). During the submaximal exercise session, the treadmill grade was maintained at 0% and the crossramp setting on the elliptical device was maintained at 10, so the subjects only adjusted speed on the treadmill or resistance on the elliptical. After the warm-up, expired air was measured continuously for quantity, oxygen, and carbon dioxide content (as explained previously) and averaged every 20 seconds throughout the 15-minute exercise session. Heart rate was collected automatically every 15 seconds for each 15-minute submaximal exercise session using the same heart rate monitor that was used for the fitness testing. Ratings of perceived exertion were collected every 2 minutes throughout the exercise session by having the subjects point at a chart of the Borg RPE scale. Following the first exercise session, the subjects were allowed 15 minutes of seated rest to allow for heart rate recovery before beginning the subsequent exercise session.

Calculation of Energy Expenditure

Average RER was used with the total $\dot{V}O_2$ to calculate energy expenditure (EE) in kJ from nonprotein RER fat and carbohydrate oxidation using stoichiometric equations (14).

Statistical Analyses

Data were analyzed using SigmaStat 3.11 (Systat Software, Point Richmond, CA, USA) with an α level of $p \leq 0.05$. Descriptive data were analyzed for gender differences using an independent sample *t*-test. A 2-way (gender × mode) repeated-measure analysis of variance (ANOVA) was used to analyze for differences in the submaximal exercise session for $\dot{V}O_2$, HR, RPE, and EE. Specific mean differences were then identified using a Newman-Keuls post-hoc comparison. Intraclass correlation coefficients were calculated using techniques described by Bartko (5) for RPE using the RPE during submaximal exercise and the RPE measured during the fitness assessment at a corresponding oxygen consumption. Data are presented as means ± *SEM.*

RESULTS

No gender-related difference was seen in regards to body mass index, with both males and females falling in the overweight range (25–30 kg/m^2; Table 1). Absolute (L/min^{-1}) and relative (ml/kg^{-1}/min^{-1}) $\dot{V}O_2$peak were significantly higher ($p < 0.05$) in the males for both modes of exercise, but there were no mode-related differences in $\dot{V}O_2$peak. No significant differences were seen between genders or exercise modes for either predicted or measured maximum heart rate.

During EL, the resistance was 7.2 ± 1.3 for the females and 8.9 ± 0.9 for the males. During TM, the speed was

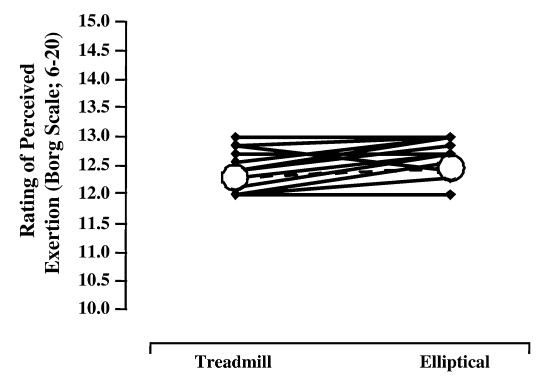

Figure 1. Rating of perceived exertion for each subject (males, $n = 9$; females, $n = 9$) while engaging in exercise on either a treadmill or elliptical device for 15 minutes when using rating of perceived exertion to achieve the same intensity of exercise on each device. Open circles connected by dashed lines represent overall means. There were no differences resulting from mode of exercise.

5.8 ± 0.3 miles/hour^{-1} for the females and 7.1 ± 0.3 miles/hour^{-1} for the males.

There were no differences in RPE between TM and EL (Figure 1). Average RPE during the submaximal exercise sessions were significantly higher (main effect; $p < 0.05$) in the females (12.6 ± 0.1 for EL and 12.4 ± 0.1 for TM) than the males (12.3 ± 0.2 for EL and 12.1 ± 0.1 for TM). There were no gender × mode differences in RPE. The intraclass correlation coefficient for RPE was 0.89.

There were no differences in total oxygen consumption between TM and EL (Figure 2). Overall, males consumed (main effect; $p < 0.05$) more total oxygen (34.9 ± 2.2 L for EL and 30.8 ± 2.2 L for TM) than females (26.9 ± 1.7 L for EL and 24.1 ± 1.8 L for TM) during the 15-minute exercise sessions. There were no gender × mode differences in total oxygen consumption, although there was a trend ($p = 0.079$) for a difference in total oxygen consumption between EL and TM. Pooling the data for males and females, and using an alpha level of 0.05 with a power of 80%, 47 total subjects would be required to detect a difference in total oxygen consumption between EL and TM. Females exercised at a higher ($p < 0.05$) percentage of $\dot{V}O_2$peak than did males, and EL elicited a higher ($p < 0.05$) percentage of $\dot{V}O_2$peak than did TM. When expressed as a percentage of the $\dot{V}O_2$peak achieved during maximal testing on the respective device, males achieved a 71 ± 3% during EL and 58 ± 3% during TM, whereas females achieved 82 ± 4% during EL and 68 ± 4% during TM.

There were no differences in EE between TM and EL (Figure 3). Overall, males experienced significantly higher total EE (main effect; $p < 0.05$) (171.9 ± 10.5 kcal for EL and 150.9 ± 11.0 kcal for TM) than females (132.3 ± 8.2 kcal for EL and 117.9 ± 9.2 kcal for TM) during the 15-minute exercise session on both TM and EL. There were no gender × mode differences for total EE, although there was a trend ($p = 0.064$) for a difference in EE between EL and TM. Pooling the data for males and females, and using an alpha level of 0.05 with a power of 80%, 42 total subjects would be required to detect a difference in total oxygen consumption between EL and TM.

The mean heart rate for both genders during EL was higher (main effect; $p < 0.05$) than TM (Figure 4). Females experienced a significantly higher (main effect; $p < 0.05$) average HR (169.2 ± 5.4 beats/min^{-1} for EL and 152.9 ± 6.1 beats/min^{-1} for TM) than the males (157.0 ± 5.1 beats/min^{-1} for

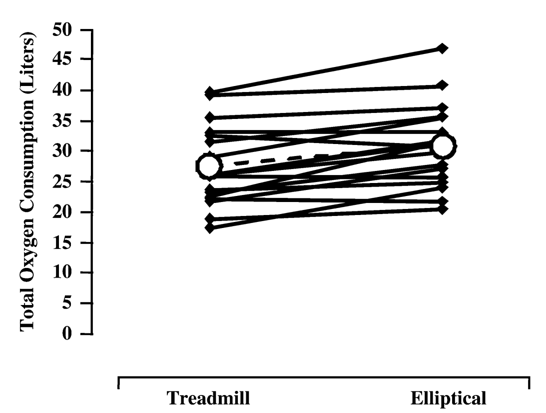

Figure 2. Total oxygen consumption for each subject (males, $n = 9$; females, $n = 9$) while engaging in exercise on either a treadmill or elliptical device for 15 minutes when using rating of perceived exertion to achieve the same intensity of exercise on each device. Open circles connected by dashed lines represent overall means. There were no differences resulting from mode of exercise.

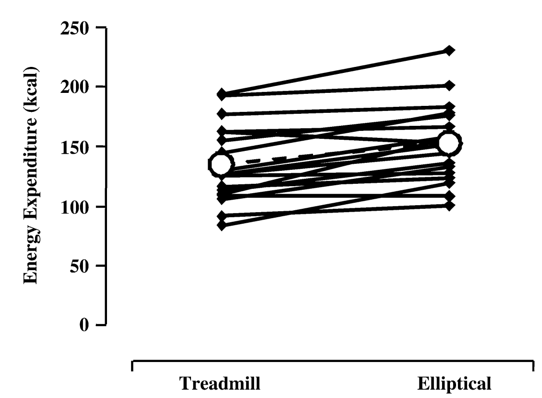

Figure 3. Total energy expenditure for each subject (males, $n = 9$; females, $n = 9$) while engaging in exercise on either a treadmill or elliptical device for 15 minutes when using rating of perceived exertion to achieve the same intensity of exercise on each device. Open circles connected by dashed lines represent overall means. There were no differences resulting from mode of exercise.

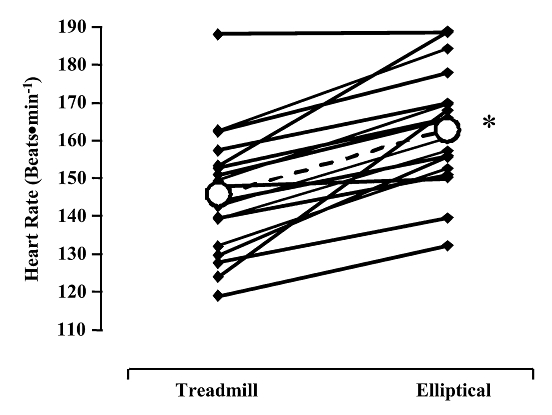

Figure 4. Mean heart rate for each subject (males, $n = 9$; females, $n = 9$) while engaging in exercise on either a treadmill or elliptical device for 15 minutes when using rating of perceived exertion to achieve the same intensity of exercise on each device. Open circles connected by dashed lines represent overall means. *Heart rate was higher (main effect; $p < 0.05$) during exercise on the elliptical device.

EL and 138.8 ± 4.8 beats/min^{-1} for TM). Females exercised at a higher (main effect; $p < 0.05$) percentage of maximum heart rate than did males, and EL elicited a higher (main effect; $p < 0.05$) percentage of maximal heart rate than did TM. When expressed as a percentage of the maximal heart rate achieved during maximal testing on the respective device, males achieved 78 ± 3% during EL and 70 ± 3% maximal heart rate during TM, whereas females achieved 85 ± 5% during EL and 77 ± 3% maximal heart rate during TM.

Mean RER for both genders during EL was higher (main effect; $p < 0.05$) than TM (Figure 5). There were no gender or gender × mode differences in RER.

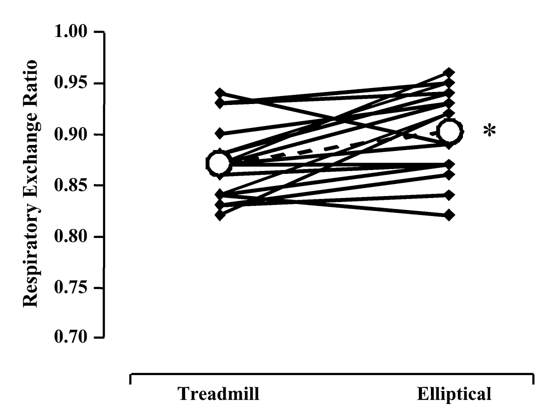

Figure 5. Mean respiratory exchange ratio for each subject (males, $n = 9$; females, $n = 9$) while engaging in exercise on either a treadmill or elliptical device for 15 minutes when using rating of perceived exertion to achieve the same intensity of exercise on each device. Open circles connected by dashed lines represent overall means. *RER was higher (main effect; $p < 0.05$) during exercise on the elliptical device.

Discussion

The primary findings of the present investigation indicate that when healthy, nonphysically active, college-aged men and women exercise at the same moderate level of perceived exertion there are no differences in total oxygen consumption or energy expenditure between exercise on a treadmill or an elliptical exercise device. However, at the same level of perceived exertion, exercise on an elliptical device results in a higher heart rate, higher percent of maximal oxygen consumption, and higher respiratory exchange ratio than does exercise on a treadmill.

The American College of Sports Medicine recommends that to improve cardiorespiratory fitness healthy adults should exercise for 20–60 minutes at a moderate intensity (17), which should correspond to an RPE of ~12–17 (10). The use of perceived exertion to select an exercise intensity is commonly used for describing exercise intensity, and correlations of 0.80–0.90 have been found between the 15-point Borg scale of perceived exertion and heart rate (24). The use of self-selected intensities of exercise has been advocated as a means to increase adherence to an exercise program (11,12). However, there is concern that by allowing self-selection of intensity, participants may not choose an intensity that is inadequate to produce health benefits (15).

There is considerable variation in the interpretation of RPE based on not only the exercise stimulus, but also the health and mode of the person exercising (10). Green et al. (16) observed no difference in overall RPE between treadmill or elliptical exercise when participants exercise at the same heart rate in both modes, but the subjects perceived that the elliptical was more difficult for their legs. Batte et al. (7) observed that when exercising on an elliptical device, heart rate and oxygen consumption were higher than what would have been expected based on the rating of perceived exertion. In agreement with Batte et al. (7), the present data indicate that individuals exercising at an RPE of 12–13 exhibit a higher heart rate and percent of maximal oxygen consumption when exercising on an elliptical device compared to a treadmill. Taken together, these finding suggest that when the intensity of exercise is prescribed based on RPE, the overall exercise stimulus from an elliptical device may be higher than would occur if a treadmill were used.

The higher heart rate response to exercise on an elliptical device compared to a treadmill could be the result of a number of reasons. Heart rates tend to be higher when an individual is exposed to an exercise stimulus to which they are not accustomed (3), and so the experience of exercising on an elliptical device may have caused increased heart rate during exercise in the subjects because of their unfamiliarity with this mode of exercise. Furthermore, when the arms are used to support one's body mass during exercise the heart rate is higher than when the arms are less active (22), and the subjects in the present investigation while exercising on the elliptical device may have used their arms to support their body more than when walking on a treadmill, despite being instructed to use their arms only to maintain balance. Heart rate is frequently used to predict oxygen consumption, and the higher heart rate in the subjects while exercising on the treadmill may have contributed to the higher percent of maximal oxygen consumption attained during elliptical exercise (3).

Oxygen consumption during exercise may be influenced by a number of factors. For instance, at the same speed of walking, increasing or decreasing the stride length or stride frequency from the usual preferred pattern will increase oxygen consumption (25). Similarly, increasing the pedaling speed while cycling can increase oxygen consumption even if the power output is not altered (23). The stride frequency in the present study was not controlled, so the higher percent of $\dot{V}O_2$peak observed during elliptical exercise may have been the result of a faster rate of foot turnover. However, there were no differences between exercise modes in terms of total oxygen consumption or energy expenditure.

In the present investigation, $\dot{V}O_2$peak, total oxygen consumption during submaximal exercise, and total energy expenditure during submaximal exercise were higher in the males than the females regardless of mode of exercise. These findings are not unexpected, given the overall larger body mass of the male subjects and the well-documented gender differences in $\dot{V}O_2$peak and absolute oxygen consumption during exercise in males (19,21). The higher heart rate exhibited by the female subjects are likely a result of the higher RPE at which the female subjects exercised.

Egana and Donne (13) observed no difference in the adaptations to exercise due to a 12-week exercise program in participants who exercised on a treadmill, stair climber, or elliptical device when heart rate and exercise duration were the same between modes. In the present investigation, there was a trend toward a significant difference in total oxygen consumption ($p = 0.079$) and energy expenditure ($p = 0.064$) between the modes of exercise. As exemplified with the sample size calculations, it would be necessary to more than double the number of subjects to detect a difference in total oxygen consumption or energy expenditure. In agreement with Egana and Donne (13), the lack of difference in the total oxygen consumption or energy expenditure between exercise on an elliptical device or a treadmill may suggest that the long-term exercise stimulus would be the same and result in the same adaptations.

Overall, the present data indicate that using an elliptical device is a viable alternative when engaging in physical activity for health enhancement. Although there are scant data, it would appear that when exercising at a self-selected rating of perceived exertion, using an elliptical device would result in similar adaptations to using a treadmill.

Practical Applications

The present data suggest that using an elliptical exercise device as a component of an aerobic training program will provide the same stimulus for developing cardiovascular fitness as a treadmill. This is of fundamental importance for novice and experienced exercisers who may desire variety in their training program to avoid staleness. Furthermore, for athletes in the many running competitions, an elliptical device may provide an alternative for cross training during an active resting phase in a periodized training program.

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References

1. *ACSM's Guidelines for Exercise Testing and Prescription.* Philadelphia: Lippincott, Williams, & Wilkins, 2000.
2. Compliance with physical activity recommendations by walking for exercise–Michigan, 1996 and 1998. *MMWR Morb Mortal Wkly Rep* 49: 560–565, 2000.
3. Achten, J and Jeukendrup, AE. Heart rate monitoring: Applications and limitations. *Sports Med* 33: 517–538, 2003.
4. Adams, TM and Brynteson, P. A comparison of attitudes and exercise habits of alumni from colleges with varying degrees of physical education activity programs. *Res Q Exerc Sport* 63: 148–152, 1992.
5. Bartko, JJ. The intraclass correlation coefficient as a measure of reliability. *Psychol Rep* 19: 3–11, 1966.
6. Bassuk, SS and Manson, JE. Physical activity and cardiovascular disease prevention in women: how much is good enough? *Exerc Sport Sci Rev* 31: 176–181, 2003.
7. Batte, AL, Darling, J, Evans, J, Lance, LM, Olson, EI, and Pincivero, DM. Physiologic response to a prescribed rating of perceived exertion on an elliptical fitness cross-trainer. *J Sports Med Phys Fitness* 43: 300–305, 2003.
8. Birk, TJ and Birk, CA. Use of ratings of perceived exertion for exercise prescription. *Sports Med* 4: 1–8, 1987.
9. Blair, SN and Brodney, S. Effects of physical inactivity and obesity on morbidity and mortality: Current evidence and research issues. *Med Sci Sports Exerc* 31: S646–S662, 1999.
10. Borg, GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 14: 377–381, 1982.
11. Dishman, RK. Prescribing exercise intensity for healthy adults using perceived exertion. *Med Sci Sports Exerc* 26: 1087–1094, 1994.
12. Dishman, RK, Farquhar, RP, and Cureton, KJ. Responses to preferred intensities of exertion in men differing in activity levels. *Med Sci Sports Exerc* 26: 783–790, 1994.
13. Egana, M and Donne, B. Physiological changes following a 12 week gym based stair-climbing, elliptical trainer and treadmill running program in females. *J Sports Med Phys Fitness* 44: 141–146, 2004.
14. Frayn, KN. Calculation of substrate oxidation rates in vivo from gaseous exchange. *J Appl Physiol* 55: 628–634, 1983.
15. Glass, SC and Chvala, AM. Preferred exertion across three common modes of exercise training. *J Strength Cond Res* 15: 474–479, 2001.
16. Green, JM, Crews, TR, Pritchett, RC, Mathfield, C, and Hall, L. Heart rate and ratings of perceived exertion during treadmill and elliptical exercise training. *Percept Mot Skills* 98: 340–348, 2004.
17. Haskell, WL, Lee, IM, Pate, RR, Powell, KE, Blair, SN, Franklin, BA, Macera, CA, Heath, GW, Thompson, PD, and Bauman, A. Physical activity and public health: Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 39: 1423–1434, 2007.

18. Heyward, VH. *Advanced Fitness Assessment and Exercise Prescription* 4th ed. Champaign, IL: Human Kinetics, 2002.
19. Jakicic, JM, Clark, K, Coleman, E, Donnelly, JE, Foreyt, J, Melanson, E, Volek, J, and Volpe, SL. American College of Sports Medicine position stand. Appropriate intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc* 33: 2145–2156, 2001.
20. Kibler, WB and Chandler, TJ. Sport-specific conditioning. *Am J Sports Med* 22: 424–432, 1994.
21. Kravitz, L, Robergs, RA, Heyward, VH, Wagner, DR, and Powers, K. Exercise mode and gender comparisons of energy expenditure at self-selected intensities. *Med Sci Sports Exerc* 29: 1028–1035, 1997.
22. Londeree, BR, Thomas, TR, Ziogas, G, Smith, TD, and Zhang, Q. %$\dot{V}O_2$max versus %HRmax regressions for six modes of exercise. *Med Sci Sports Exerc* 27: 458–461, 1995.
23. McDaniel, J, Durstine, JL, Hand, GA, and Martin, JC. Determinants of metabolic cost during submaximal cycling. *J Appl Physiol* 93: 823–828, 2002.
24. Mihevic, PM. Sensory cues for perceived exertion: a review. *Med Sci Sports Exerc* 13: 150–163, 1981.
25. Morgan, DW and Martin, PE. Effects of stride length alteration on racewalking economy. *Can J Appl Sport Sci* 11: 211–217, 1986.
26. Moyna, NM, Robertson, RJ, Meckes, CL, Peoples, JA, Millich, NB, and Thompson, PD. Intermodal comparison of energy expenditure at exercise intensities corresponding to the perceptual preference range. *Med Sci Sports Exerc* 33: 1404–1410, 2001.
27. Sundquist, J, Winkleby, MA, and Pudaric, S. Cardiovascular disease risk factors among older black, Mexican-American, and white women and men: An analysis of NHANES III, 1988–1994. Third National Health and Nutrition Examination Survey. *J Am Geriatr Soc* 49: 109–116, 2001.
28. Tudor-Locke, CE, Bell, RC, and Meyers, AM. Revisiting the role of physical activity and exercise in the treatment of type 2 diabetes. *Can J Appl Physiol* 25: 466–492, 2000.
29. Zeni, AI, Hoffman, MD, and Clifford, PS. Energy expenditure with indoor exercise machines. *JAMA* 275: 1424–1427, 1996.