Research article

RELATIONSHIP BETWEEN %HEART RATE RESERVE AND %VO$_2$ RESERVE DURING ELLIPTICAL CROSSTRAINER EXERCISE

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ABSTRACT

The primary purpose of the study was to determine the relationships between %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max during maximal elliptical crosstrainer (ECT) exercise. A secondary aim was to compare the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max relationships between maximal ECT and treadmill (TM) exercise. Adult subjects (n = 48) completed a maximal exercise test on the ECT, with a subgroup (N = 24) also performing a maximal exercise test on the TM. Continuous HR and VO$_2$ data were analyzed via linear regression to determine y-intercept and slope values for %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max. Student t-tests were used to determine whether the mean y-intercept and slope values differed from the line of identity (y-intercept = 0, slope = 1). For each group, both the y-intercept and slope for %HRR vs. %VO$_2$R fit the line of identity. Conversely, for all groups both the y-intercept and slope for %HRR vs. %VO$_2$max were significantly different (p < 0.001) from the line of identity (y-intercept ≠ 0, slope ≠ 1). In comparing the regressions of %HRR vs. %VO$_2$R between exercise modes, there were no significant differences (p > 0.05) for either y-intercept (ECT = 0.3 vs. TM = -0.3, p = 0.435) or slope (ECT = 1.01 vs. TM = 1.00, p = 0.079) values. In agreement with previous research on TM and cycle exercise, it was found that %HRR is more closely aligned with %VO$_2$R, rather than %VO$_2$max during ECT exercise. Additionally, it was found that the regressions of %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max were equivalent between the ECT and TM.

KEY WORDS: Exercise mode, regression, exercise prescription.

INTRODUCTION

The ability to accurately prescribe exercise intensity is a fundamental aspect of exercise physiology, with exercise professionals frequently relying upon multiple methods to establish target workloads, including percentages of maximal heart rate (%HR$_{max}$), heart rate reserve (%HRR), and maximal oxygen uptake (%VO$_2$max) (ACSM-American College of Sports Medicine, 1995). Traditionally, it was accepted that the %HRR was equivalent to %VO$_2$max (American College of Sports Medicine, 2006), however, more recent research has demonstrated that %HRR is more clearly aligned with percent oxygen uptake reserve (%VO$_2$R). These findings have been reported in both young, healthy populations (Swain and Leutholtz, 1997; Swain et al., 1998) and older, diseased populations (Brawner et al., 2002).

Swain and Leutholtz (1997) first reported that %HRR is equivalent to %VO$_2$R, and not %VO$_2$max, during cycling exercise in healthy, young males and females. These findings were confirmed by Swain et al. (1998) during treadmill exercise in a young,

healthy population, although the regression between %HRR and %VO$_2$R differed statistically from the line of identity. Similarly, Brawner et al. (2002) demonstrated that the relationship between %HRR and %VO$_2$R, though statistically different, is closer to the line of identity than %HRR and %VO$_2$max during treadmill exercise in cardiac patients. The authors suggested that there may be a mode effect (treadmill vs. cycle), which would explain the line of identity differences between studies. However, they added that work by Davis and Convertino (1975) argues against a mode effect, although to our knowledge, no research exists that directly compares the relationship between %HRR and %VO$_2$R in different exercise modes.

While the treadmill and cycle ergometer are among the most common forms of exercise, the elliptical crosstrainer has become increasingly popular in recent years as an alternative aerobic exercise modality in fitness centers and rehabilitation facilities (Green et al., 2004). To date, there has been limited research on this modality of exercise, however, results from one study suggest there are similar heart rate responses to elliptical crosstrainer exercise compared to treadmill exercise at equivalent rating of perceived exertion (RPE) levels (Green et al., 2004). The increasing popularity of elliptical crosstrainer exercise coupled with the need to better understand the relationships between %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max for accurate exercise prescriptions prompted the present investigation.

The primary purpose of the study was to determine the relationships between %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max during maximal elliptical crosstrainer exercise. It was hypothesized that %HRR is equivalent to %VO$_2$R, and not %VO$_2$max. Although previous research (Brawner et al., 2002; Swain and Leutholtz, 1997; Swain et al., 1998) has established that %HRR is more closely aligned to %VO$_2$R, rather than %VO$_2$max, only one study (Swain and Leutholtz, 1997) has reported that the y-intercept and slope for %HRR vs. %VO$_2$R fit the line of identity (p > 0.05). Consequently, although using %HRR vs. %VO$_2$R for exercise prescription purposes may be preferred to %HRR vs. %VO$_2$max, there still may be measurable error when

using this approach. Furthermore, it remains unclear whether the exercise mode influences the nature of the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max relationships. A secondary purpose of the study was to compare the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max relationships between maximal elliptical crosstrainer and treadmill exercise. It was hypothesized that there would be no significant differences in the relationships between the two exercise modalities.

METHODS

Subjects

A total of 48 subjects (24 males, 24 females) familiar with elliptical crosstrainer and treadmill exercise were recruited from the faculty and student population of the university as well as the surrounding community. Subjects provided informed written consent and completed a health history questionnaire prior to participating in the study. All subjects were apparently healthy as defined by the ACSM (2006). Furthermore, all subjects indicated on the health history questionnaire that they satisfied the minimum requirements for a moderate level of aerobic activity on a regular basis (at least 3 times per week) as classified by the ACSM (2006). The university's Human Subjects Institutional Review Board approved this study. Subject characteristics are presented in Table 1.

Pre-testing procedures

Subjects were instructed to avoid eating food four hours prior to testing and to refrain from strenuous exercise 12 hr prior to testing. Subjects were weighed to the nearest 0.1 kg on a medical grade scale and measured for height to the nearest 0.5 cm using a stadiometer. The average temperature throughout testing was 21.4 ± 0.5 °C. Percent fat was determined via skinfolds (Jackson and Pollock, 1985). Skinfold thickness was measured to the nearest ± 0.5 mm using a Lange caliper (Cambridge Scientific Industries, Columbia, Maryland, USA). All measurements were taken on the right side of the body using standardized anatomical sites (three-site) for both men and women. These measurements were performed until two were within 10% of each other.

Table 1. Physical characteristics of the subjects. Data are means (±SD).

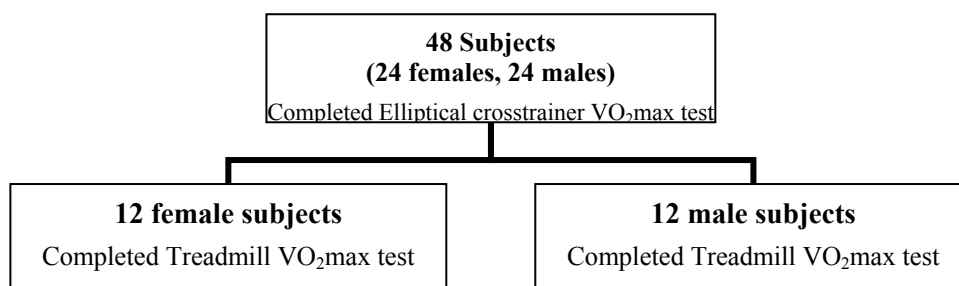| Group	n	Age (yr)	Height (m)	Weight (kg)	(%)Fat
Elliptical group	48	30.6 (7.8)	1.72 (.10)	74.3 (14.2)	19.2 (7.1)
– Females	24	32.1 (8.6)	1.64 (.07)	64.4 (9.5)	23.1 (6.4)
– Males	24	29.2 (6.8)	1.80 (.07)	84.2 (10.7)	15.2 (5.3)
Elliptical subgroup/Treadmill group	24	29.6 (7.4)	1.74 (.12)	74.1 (15.3)	18.2 (6.1)
– Females	12	31.7 (9.2)	1.65 (.08)	62.7 (8.9)	21.5 (5.1)
– Males	12	27.6 (4.6)	1.83 (.07)	85.5 (11.2)	14.9 (5.3)

Figure 1. Study flow reflecting the experimental distribution of the subjects**.**

Exercise testing protocols
Each subject (n = 48) completed an incremental, maximal exercise test in 1-min stages on the same Precor EFX 546 Elliptical Fitness Crosstrainer (Precor Inc., Woodinville, WA). The workload components of the elliptical crosstrainer include cadence, incline, and resistance, which range from 1-20 units, 1-20 units, and 0-300 strides·min^{-1}, respectively. The stride length of the Precor EFX 546 Elliptical Fitness Crosstrainer model used in the present study was 48 cm. According to a Latin Squares design, every other male (n = 12) and female subject (n = 12) from the total subject pool (Figure 1) was selected to also perform an incremental, maximal exercise test in 1-min stages (Modified Balke) on a motorized treadmill (SensorMedics 2000, Yorba Linda, CA). For the subjects who performed maximal elliptical crosstrainer and treadmill tests, testing sessions were separated by at least 24 hr to minimize subject fatigue. Additionally, testing order was randomized according to a Latin Squares design to prevent an order effect and to cancel out the potential effect of fatigue. Maximal oxygen consumption was defined as the highest VO_2 obtained over any continuous 30-s time period, provided respiratory exchange ratio (RER) was ≥ 1.10. Maximal heart rate was defined as the highest value recorded over any continuous 30-s period during exercise. The protocols for both exercise modes were designed to last approximately 8-12 min (Buchfuhrer et al., 1983).

Ellipitcal crosstrainer protocol
After pre-screening and interviewing each subject, a specific elliptical crosstrainer VO_2max protocol (Figure 2) was selected based on gender and aerobic activity participation: trained (aerobic exercise 3-5 hr/wk) and recreationally active (aerobic exercise 2-3 hr/wk). After measuring resting expired gases for 5-min, a 2-min warm-up was performed at a light workload prior to the start of the exercise protocol. Figure 2 illustrates how the intensity for each

elliptical crosstrainer VO_2max protocol was established and progressed throughout VO_2max testing by increasing either strides·min^{-1} and/or resistance·min^{-1}. The incline (slope) remained at level 6 during the entire test for all VO_2max protocols. A metronome was used to assure a consistent and correct strides·min^{-1} cadence. Incline was held constant at a setting of level 6 throughout VO_2max testing to eliminate any potential variability in the calibration of the machine that the incline parameter would have on physiological parameters. However, the calibration for the resistance workload parameter is under the proprietary control of the company and the assumption was made that this workload parameter was accurate throughout VO_2max testing protocols. The criterion for termination of the exercise test was failure of the participant to maintain within 20 strides·min^{-1} of target cadence on the elliptical crosstrainer or volitional fatigue. Following all maximal exercise tests (on both modes of exercise) each subject exercised at a self-selected intensity until heart rate recovered to less than 120 b·min^{-1}.

Treadmill protocol
On the treadmill, a modified Balke protocol was performed with subjects selecting a comfortable running speed that could be maintained for the duration of the test. After measuring resting expired gases for 5-min, subjects were gradually brought to the selected running speed for the first 2 min of the test, which was then maintained throughout the duration of the test. The first 3 min of the protocol was then performed at 0% grade, thereafter, each minute the treadmill grade was increased by 1% until volitional fatigue was reached (Figure 3).

Metabolic data collection and analysis
A nose clip and three-way valve mouthpiece (Hans Rudolph Inc., Kansas City, MO) were worn so that gas exchange data could be recorded and analyzed. During the exercise test, VO_2, VCO_2, VE, and
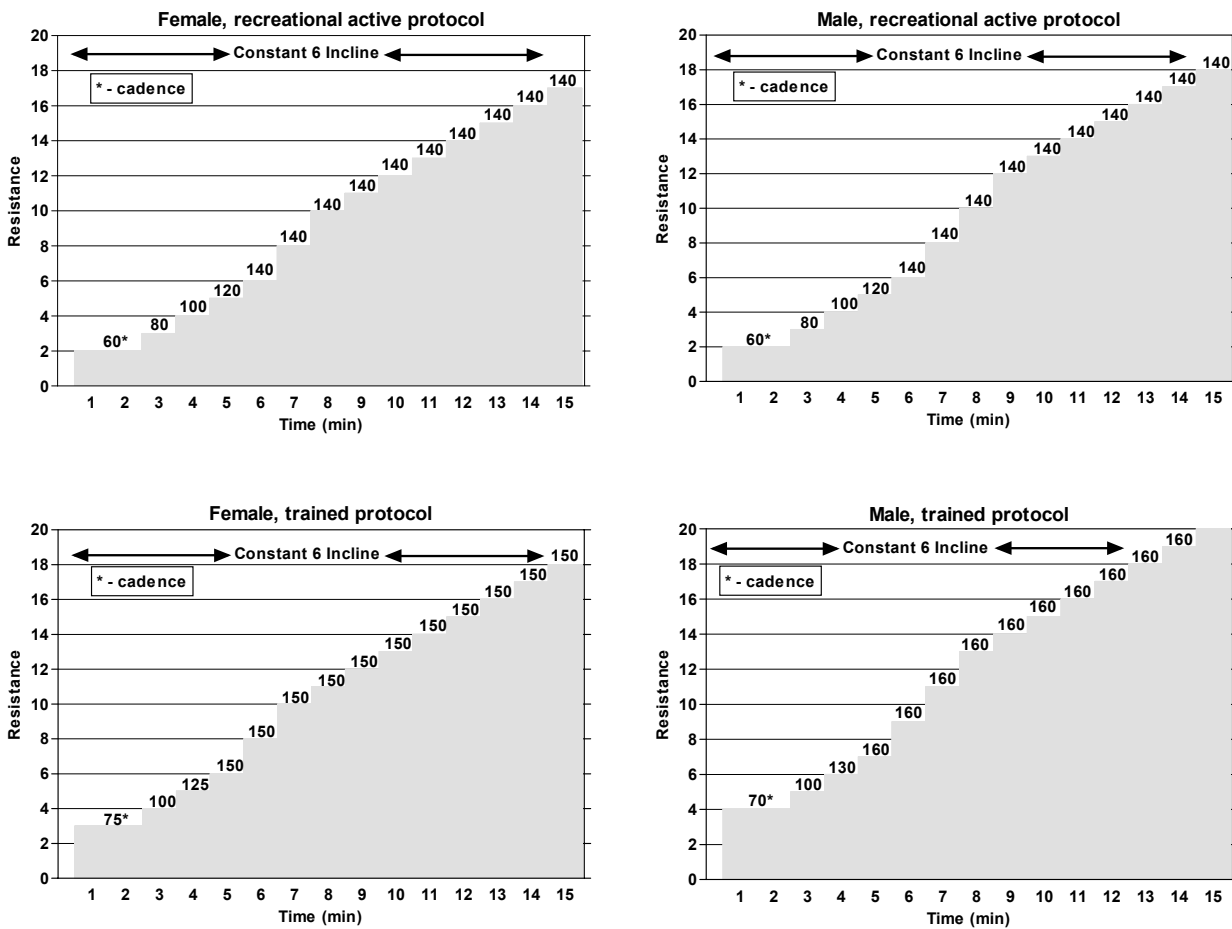
Figure 2. Elliptical crosstrainer VO$_2$max protocols.

respiratory exchange ratio (RER) were measured breath-by-breath using a fast response turbine flow transducer (K.L. Engineering Model S-430, Van Nuys, CA) and custom developed software with AEI oxygen and carbon dioxide electronic gas analyzers (AEI Technologies, Model S-3A and Model CD-3H, Pittsburgh, PA). Raw signals were acquired through a junction box via computer and integrated with a data acquisition card (National Instruments, Austin, Texas). The turbine flow transducer was calibrated prior to each testing session using a 3.0 L syringe. Oxygen and carbon dioxide analyzers were also calibrated prior to each testing session against known gas concentrations. All breath-by-breath data were smoothed using a seven-breath moving average and averaged into 30-s sampling intervals. Heart rate and electrocardiogram readings were monitored continuously (Quinton 4000, Quinton, Seattle, WA) using a 3-lead ECG configuration. Prior to the maximal exercise tests, subjects rested for 5 min while resting gas exchange and heart rate data were collected. The average values of heart rate and VO$_2$ recorded over the last 2 min of seated rest were

considered to be the resting values. For the subjects performing both exercise modes, the two sets of resting data obtained were pooled and averaged. Percentages of %HRR, %VO$_2$R, and %VO$_2$max were calculated from the heart rate and VO$_2$ values measured during the last 30 s of each stage.

Statistical analyses
All statistical procedures were completed using SPSS statistical software (Version 13.0 SPSS for Windows, SPSS Inc., Chicago, IL). The decision to use linear regression, rather than non-linear regression, was based on the statistical analyses (linear regression) performed by previous researchers to describe the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max relationships (Brawner et al., 2002; Swain and Leutholtz, 1997; Swain et al., 1998).

Prior to all data analyses, diagnostic tests were performed to check for outlying or influential observations. The normality assumption was checked using the Kolmogorov-Smirnov test and from visual inspection of the normality plot. Two
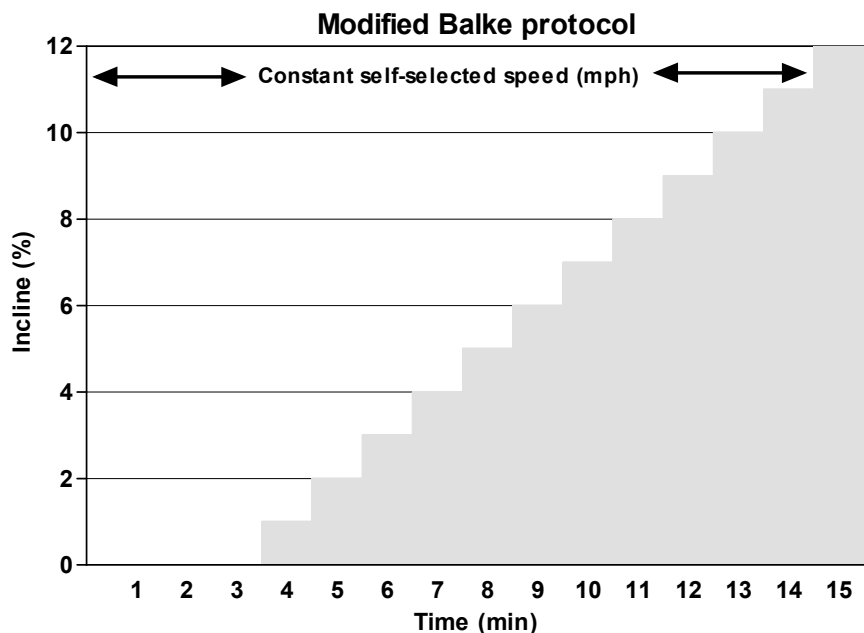
Modified Balke protocol

Figure 3. Modified Balke treadmill VO$_2$max protocol.

linear regressions were performed for each individual subject: 1) the values of %HRR vs. %VO$_2$R, and 2) the values of %HRR vs. %VO$_2$max. For each individual trial, rest period, end-of-stage, and maximal data were entered into the linear regression analysis. Mean (±SE) values for intercepts, slopes, and Pearson r correlations were determined for the two sets of regressions. Student t-tests (two-tailed) were used to determine whether the mean group y-intercept and slope differed from the line of identity (y-intercept = 0, slope = 1). To compare the two exercise modes, student t-tests (two-tailed) were also used to determine whether the slopes and intercepts were significantly different between the two regressions. In addition, paired t-tests (two-tailed) were used to determine whether there were significant differences in the maximal physiological responses between the two exercise modes. Finally, Pearson r correlations were used to determine whether there were significant inverse relationships between VO$_2$max and %HRR vs. %VO$_2$max y-intercept values for each of the groups. The probability of making a Type I error was set at $p \leq 0.05$ for all statistical analyses. In the event of multiple analyses, a Bonferroni adjustment of alpha level was performed.

Effect size and Power: The means and standard deviations of previous studies (Brawner et al., 2002; Swain and Leutholtz, 1997; Swain et al., 1998) were examined and the effect sizes of those studies were calculated. Assuming that a power of 0.80 was needed and the calculated effect sizes for %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max were 0.8, it was determined that approximately 25 subjects would be needed for each of the two exercise modality groups (Cohen, 1988).

Table 2. Physiological characteristics of the subjects. Data are means (±SD).

Group	n	Rest HR (b·min^{-1})	HR$_{max}$ (b·min^{-1})	RER$_{max}$	Rest VO$_2$ (mL·kg^{-1}·min^{-1})	VO$_2$max (mL·kg^{-1}·min^{-1})
Elliptical group	48	78 (10)	184 (9)	1.23 (.06)	3.7 (6.4)	43.2 (7.0)
– Females	24	80 (11)	184 (10)	1.21 (.06)	3.6 (.4)	39.7 (5.5)
– Males	24	77 (10)	183 (8)	1.25 (.06)	3.7 (.3)	46.7 (6.7)
Elliptical subgroup	24	78 (10)	183 (9) *	1.23 (.06) *	3.7 (.4)	44.3 (6.9) *
– Females	12	78 (9)	182 (9)	1.22 (.06)	3.6 (.4)	40.4 (6.1)
– Males	12	78 (11)	183 (9)	1.25 (.05)	3.7 (.3)	48.2 (5.5)
Treadmill group	24	78 (10)	184 (8) *	1.23 (.07) *	3.7 (.4)	44.6 (7.4) *
– Females	12	78 (9)	183 (8)	1.23 (.07)	3.6 (.4)	41.1 (7.1)
– Males	12	78 (11)	185 (8)	1.23 (.08)	3.7 (.3)	48.2 (6.1)

* $p > 0.05$ for elliptical crosstrainer subgroup vs. treadmill group.

Table 3. Regression analysis results for Ellipitcal crosstrainer group, Elliptical crosstrainer subgroup, and Treadmill group. Data are means (±SE).

	Elliptical crosstrainer group (n = 48)	Elliptical crosstrainer subgroup (n = 24)	Treadmill group (n = 24)
%HRR vs. %VO$_2$max			
y-intercept (%)	-9.3 (.6) *	-9.9 (.9) *	-10.0 (.7) *
Slope	1.11 (.01) †	1.12 (.01) †	1.10 (.01)†
%HRR vs. %VO$_2$R			
y-intercept (%)	.7 (.5)	.3 (.6)	-.3 (.5)
Slope	1.01 (.01)	1.01 (.01)	1.00 (.01)

* p < 0.001 for y-intercept = 0; † p < 0.001 for slope = 1.

RESULTS

The physiological characteristics of the subjects are presented in Table 2. A comparison of mean VO$_2$max, HR$_{max}$, and RER$_{max}$ values illustrated that there were no significantly different physiological responses to maximal exercise testing between the elliptical crosstrainer and treadmill exercise modes: VO$_2$max, t (23) = 0.431, p = 0.671; HR$_{max}$, t (23) = 1.328, p = 0.197; and RER$_{max}$, t (23) = -0.452, p = 0.656. Additionally, there was no significant difference in mean protocol duration, t (23) = -1.789, p = 0.087. Subjects required an average time of 11.3 min to complete the treadmill VO$_2$max protocol versus 11.9 min to complete the elliptical crosstrainer VO$_2$max protocol.

The regression results of %HRR vs. % VO$_2$R and %HRR vs. %VO$_2$max for the ellipitcal crosstrainer group, elliptical crosstrainer subgroup, and treadmill group are presented in Table 3. For all groups, both the y-intercept and slope for %HRR vs. %VO$_2$R fit the line of identity (y-intercept = 0, slope = 1). Conversely, for all groups both the y-intercept and slope of %HRR vs. %VO$_2$max were significantly different ($p < 0.001$) from the line of identity (y-intercept $\neq$ 0, slope $\neq$ 1). The regression lines are illustrated in Figure 4.

In comparing the regressions of %HRR vs. %VO$_2$R between exercise modes (TM vs. ECT), there were no significant differences (p > 0.05) for either y-intercept (ECT = 0.3 vs. TM = -0.3, t (23) = 0.794, p = 0.435) or slope (ECT = 1.01 vs. TM = 1.00, t (23) = -1.838, p = 0.079) values. Similarly, there were no significant differences (p > 0.05) between exercise modes (TM vs. ECT) for either y-intercept (ECT = -9.9 vs. TM = -10.0, t (23) = -0.151, p = 0.881) or slope values (ECT = 1.12 vs. TM = 1.10, t (23) = -1.888, p = 0.072) for the regressions of %HRR vs. %VO$_2$max. The regression lines for the comparison of %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max between exercise modes are illustrated in Figure 5.

Correlation analyses revealed significant inverse relationships between VO$_2$max and %HRR vs. %VO$_2$max y-intercept values for the entire elliptical crosstrainer group (r = 0.55, $p < 0.01$) and subgroup (r = 0.53, p < 0.01); and the treadmill group (r = 0.55, p < 0.01).

DISCUSSION

The main finding of the present study is that %HRR is more closely aligned with %VO$_2$R, rather than %VO$_2$max, during maximal elliptical crosstrainer exercise. Similar results have been previously reported for both treadmill and cycle exercise (Swain and Leutholtz, 1997; Swain et al., 1998). Swain and Leutholtz (1997) found that during cycle exercise there is a significant discrepancy in the line of identity between %HRR and %VO$_2$max, that was not evident between %HRR and %VO$_2$R. Likewise, Swain et al. (1998) and Brawner et al. (2002) determined that %HRR vs. %VO$_2$R fit the line of identity better than %HRR vs. %VO$_2$max during treadmill exercise in healthy and cardiac diseased populations, respectively. Our data extend this principle to elliptical crosstrainer exercise, which is a relatively new but common exercise mode.

The secondary purpose of the present study was to better understand the influence of exercise mode on the relationship between %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max during maximal elliptical crosstrainer and treadmill exercise. Swain et al. (1998) suggested the reason that the regression of %HRR vs. %VO$_2$R fit the line of identity during cycle exercise, but was significantly different during treadmill exercise, might be related to the mode of exercise. However, these authors discounted a mode effect based on earlier research findings from Davis and Convertino (1975). Findings from the current study are in agreement with this assessment. Our data showed there are no significant differences in the regressions of %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max between elliptical crosstrainer and treadmill exercise. Additionally, there were no significant differences in the line of identity (slope = 1, y-intercept = 0) for %HRR vs. %VO$_2$R during treadmill exercise. Swain et al. (1998) postulated

A. %HRR vs. %VO₂max

$$y = 1.11x - 9.3$$
$$r = 0.991, p < 0.001$$

B. %HRR vs. %VO₂R
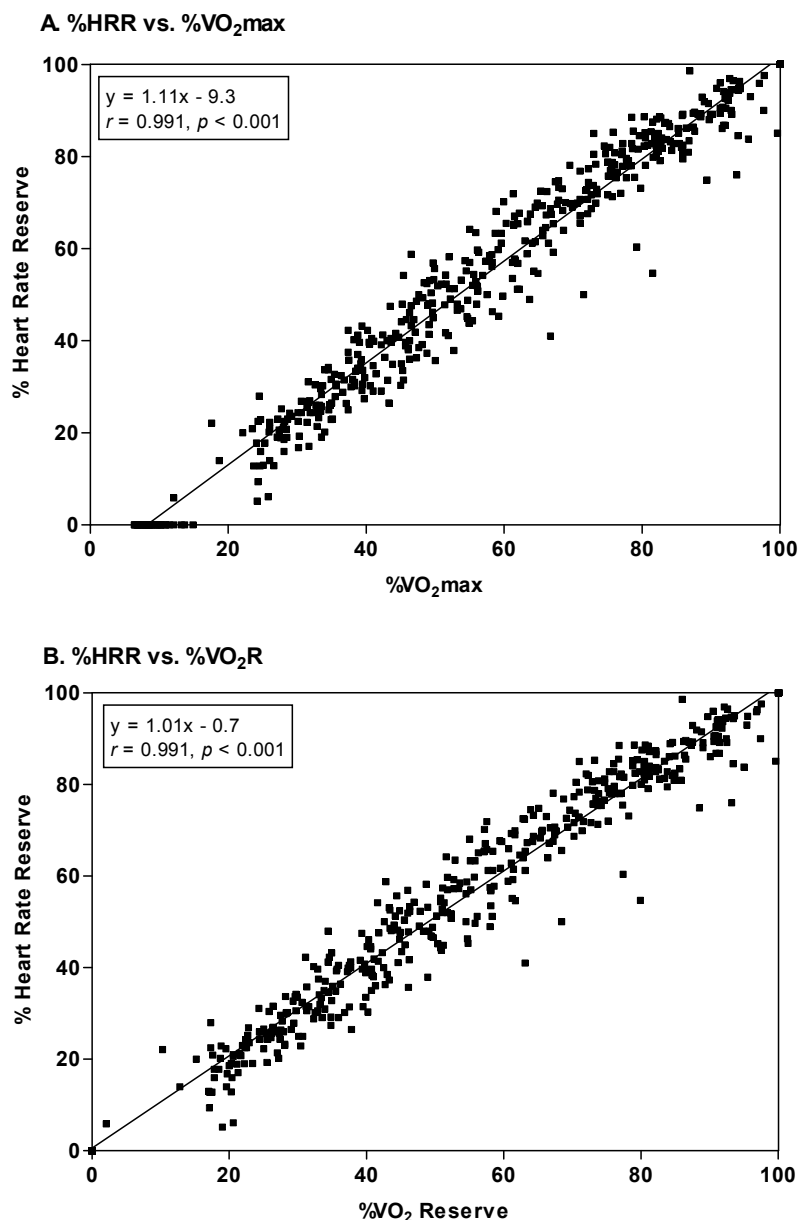

$$y = 1.01x - 0.7$$
$$r = 0.991, p < 0.001$$

Figure 4. Scatterplot and regressions of (A; N=48) %HRR vs. %VO₂max and (B; N=48) %HRR vs. %VO₂R for the elliptical crosstrainer group.

that elevated temperatures might have been responsible for the significant differences in the regression of %HRR vs. %VO₂R during treadmill exercise in their study. This interpretation may be likely as our environmental conditions for temperature (21.4 °C) were more similar to the cycle study (21.8 °C) by Swain and Leutholtz (1997) than the treadmill study (25.0 °C) by Swain et al. (1998).

Treadmill exercise is generally believed to elicit the highest VO₂max values in untrained and recreationally active individuals. Although several studies, including the present investigation, demonstrated similar VO₂max values can also be obtained from other modes of exercise. Haug et al. (1999) reported no significant differences in

VO₂max between the treadmill (42.6 mL·kg⁻¹·min⁻¹) and NordicTrack cross-country ski simulator (42.5 mL·kg⁻¹·min⁻¹) in both male and female subjects of varied fitness levels and cross-country skiing experience. Likewise, similar VO₂max values were also reported between the treadmill (52.6 mL·kg⁻¹·min⁻¹) and VersaClimber (53.9 mL·kg⁻¹·min⁻¹), a simulated arm-leg climbing device, in collegiate varsity oarswomen and coxswain (Brahler and Blank, 1995). Our findings also showed comparable HR_max and RER_max values between the treadmill and ellipitcal crosstrainer during maximal exercise testing. While data collection in the present study for the elliptical crosstrainer was conducted on the Precor EFX 546 Elliptical Fitness Crosstrainer, there
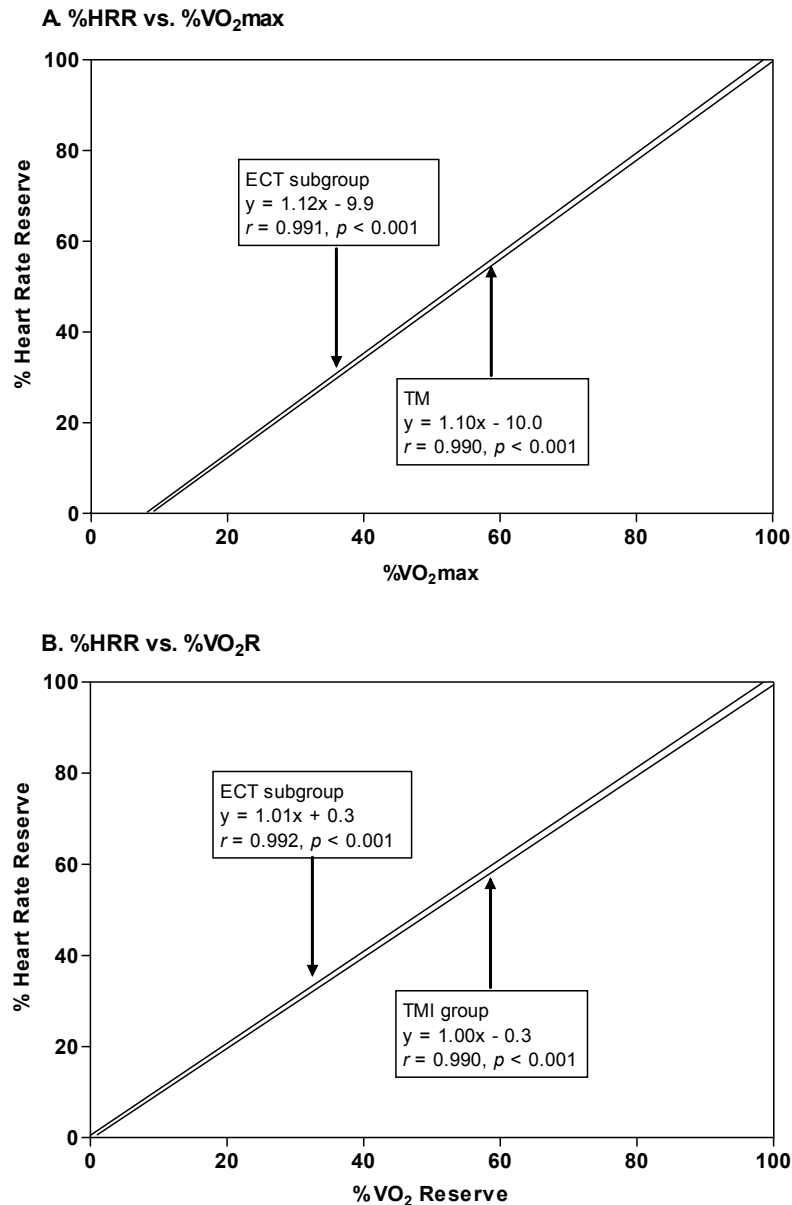
A. %HRR vs. %VO$_2$max

B. %HRR vs. %VO$_2$R

Figure 5. Regression lines and the regression equation for the comparison of the elliptical crosstrainer (ECT) subgroup and treadmill (TM) group for (A; N=24) %HRR vs. %VO$_2$max and (B; N=24) %HRR vs. %VO$_2$R.

are other elliptical crosstrainer models being utilized in fitness settings and rehabilitation facilities. As noted elsewhere (Haug et al., 1999), calibration between different models may vary considerably, limiting application of the research findings that there are similar maximal physiological responses between elliptical crosstrainer and treadmill to the specific model used in the study.

In the present investigation, the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max relationships were described using linear regression. However, the non-linear relationship between HR and VO$_2$ that has been described elsewhere in the literature merits further discussion. The HR-VO$_2$ relationship has been depicted by several investigators (Bunc et al.,

1995; Hofmann et al., 1994; Hofmann et al., 1997a) as linear at lower-intensities, and then exhibiting a threshold and change in slope at higher exercise intensities. Hofmann et al. (1997b) reported that only 6% of subjects demonstrated a linear HR response during maximal exercise testing, compared to 94% that showed a non-linear (downward or inverted deflection) HR response. Similarly, Vella and Robergs (2005) reported the HR-VO$_2$ relation during incremental cycle exercise in endurance-trained individuals was non-linear in the majority (15 out of 18) of their subjects.

The consequences of assuming a linear relationship between HR and VO$_2$ throughout the intensity spectrum is the potential for an over- or

under-estimation of training workload. As noted by Weltman et al. (1989), depending on the nature of the HR-VO$_2$ relation (downward or inverted deflection), there may be considerable disparity in the metabolic responses to exercise intensities of a given %HRR. Visual examination of the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max (Figure 4) data in the present study suggests the relationships can best be described using linear regression. Similarly, the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max data illustrated in Figures 1 and 2 of Swain and Leutholtz (1997) also support the application of linear regression. Future research is needed to determine whether the %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max relationships could better be described using non-linear regression.

As reported in previous research (Brawner et al., 2002; Swain and Leutholtz, 1997; Swain et al., 1998), we found a significant inverse relationship between fitness level and the disparity between %HRR vs. %VO$_2$max for both exercise modes. Lower fitness levels were associated with greater y-intercept values for the entire elliptical crosstrainer group (r = 0.55) and subgroup (r = 0.53), as well as the treadmill (r = 0.55). One of the major advantages of prescribing exercise according to the relationship between %HRR vs. %VO$_2$R, rather than %HRR vs. %VO$_2$max, is that it results in a more accurate target heart rate throughout the intensity spectrum (Swain et al., 1998). This approach to the exercise prescription will minimize the % error in exercise intensity, which is particularly important when working with clientele that have low fitness levels.

If the assumption is made that %HRR is aligned with %VO$_2$max when establishing exercise training workloads, the magnitude of error will be greatest at rest for low-fit clients and also throughout the lower range of intensities. For example, an individual with a VO$_2$max of 17.5 mL·kg^{-1}·min^{-1}, will be at 20% (3.5 mL·kg^{-1}·min^{-1}/17.5 mL·kg^{-1}·min^{-1}) of their VO$_2$max at rest, while an individual with a VO$_2$max of 42 mL·kg^{-1}·min^{-1}, will be at 8.3% (3.5 mL·kg^{-1}·min^{-1}/42 mL·kg^{-1}·min^{-1}) of their VO$_2$max at rest. Therefore, for the lower-fit individual there would be an error of 20 units between %HRR and %VO$_2$max at rest compared to an error of 8.3 units for the higher-fit subject. The magnitude of the error between %HRR and %VO$_2$max would lessen as exercise intensity is increased and both values reach 100%. However, as Swain and Leutholtz (1997) have noted, a relatively small disparity between %HRR and %VO$_2$max can produce a substantial error in the prescribed exercise training intensity. These errors can be avoided by prescribing training workloads in terms of %HRR being equivalent to %VO$_2$R, rather than %VO$_2$max.

Another major advantage of prescribing exercise intensity based on %VO$_2$R, rather than %VO$_2$max, is that it provides an equivalent relative intensity for individuals of different fitness levels. Consider the following example of two individuals with VO$_2$max values of 25 and 50 mL·kg^{-1}·min^{-1}, respectively. At rest, the 25 mL·kg^{-1}·min^{-1} individual is at 14% VO$_2$max, while the 50 mL·kg^{-1}·min^{-1} individual is at 7% VO$_2$max. If the intensity of the exercise prescription is set at 50% VO$_2$max, the 25 mL·kg^{-1}·min^{-1} individual increases by 36%, compared to the 50 mL·kg^{-1}·min^{-1} individual who increases by 43%, in terms of %VO$_2$max. The discrepancy in relative adjustments in training intensity in the above example may result in disparate training effects between the two individuals. Conversely, if the %VO$_2$R method were used, the individuals would both increase by identical adjustments in relative intensity (Swain and Leutholtz, 1997).

CONCLUSIONS

Based on previous research findings, the American College of Sports Medicine has changed its recommendations in recent editions; with exercise prescription guidelines now reflecting that %HRR should be based on %VO$_2$R, not %VO$_2$max (ACSM, 2006). Similar findings in the current study are in agreement with this recommendation and extend them to the elliptical crosstrainer, which is a relatively new exercise modality. Additionally, it was found that the regressions of %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max were equivalent between the ellipitcal crosstrainer and treadmill. Future studies are needed to confirm these findings among other exercise modes, and in populations differing in age and health status.

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KEY POINTS

- The present study showed that %HRR is aligned with %VO$_2$R, not %VO$_2$max, during maximal ellipitcal crosstrainer exercise.
- It was found that the relationships between %HRR vs. %VO$_2$R and %HRR vs. %VO$_2$max were equivalent between the ellipitcal crosstrainer and treadmill.
- This study revealed that the elliptical crosstrainer produced similar maximal physiological values (VO$_2$max, HR$_{max}$, RER$_{max}$) compared to treadmill running during VO$_2$max testing.

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