Heart Rate Reserve and VO_2 Reserve Are Not Interchangeable During Prolonged Exercise

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ABSTRACT

Background: Percentages of heart rate reserve (%HRR) and oxygen consumption reserve (%VO_2R) provide equivalent intensities during incremental exercise. These percentages increase during prolonged exercise at a constant workload, and it is unclear if they increase to a similar degree. In this study, we tested whether %HRR and %VO_2R maintain equivalency during prolonged exercise at a constant workload.

Methods: Fifteen males and 12 females participated in an incremental cycle ergometer test to determine maximum VO_2. They then performed 2 prolonged exercise trials, 1 for 30 min at a vigorous-intensity workload corresponding with 60% VO_2R, and 1 for 60 min at a moderate-intensity workload of 40% VO_2R. HR and VO_2 were measured continuously, and %HRR and %VO_2R were reported every 5 min. A fan and consumption of cold water were used to minimize heat stress.

Results: Both %HRR and %VO_2R increased during constant-workload exercise ($P < 0.001$), and %HRR increased significantly more than %VO_2R ($P < 0.001$). Females exhibited greater %HRR than %VO_2R beginning at 10 min into both trials ($P < 0.05$), while %HRR exceeded %VO_2R for males beginning at 15 min of the 30-min trial ($P < 0.05$) and at 30 min of the 60-min trial ($P < 0.05$). HRR values for females were significantly greater than those for males at most time points ($P < 0.05$).

Conclusion: During prolonged, constant-workload exercise, cardiovascular drift results in a greater increase in %HRR than %VO_2R, and this is more pronounced in females than males.

Keywords: exercise prescription, cardiovascular drift, sex differences

INTRODUCTION

Authors of studies conducted in 1997 and 1998 found that percent of heart rate reserve (%HRR) was equivalent to percent of oxygen consumption reserve (%VO_2R) during incremental exercise with 3-min stages (1,2). Over 20 years earlier, Davis and Convertino (3) also determined an equivalency between %HRR and %VO_2R (which they called % net VO_{2max}), but their finding had not been widely recognized. In 1998, the American College of Sports Medicine (ACSM) position stand stated that %HRR and %VO_2R provide equivalent intensities and are the preferred measures for cardiorespiratory prescription, eliminating errors of exercise intensity when using %VO_{2max} or %HR_{max}, especially among individuals with low fitness at low exercise intensities (4). Authors of most studies since that position stand have supported the equivalency or near equivalency of %HRR and %VO_2R, during incremental exercise (5). However, the relationship between these 2 variables during prolonged exercise at set intensities is not well known. Authors of only 1 study have examined this relationship during aerobic exercise at a constant workload; it measured %VO_2R and %HRR during 40-min exercise sessions at 60%, 70%, and 80% of VO_2R (6). Both HR and VO_2 increased as exercise proceeded, and %HRR values exceeded %VO_2R values (6). However, the authors of that study did not use protocols to minimize the cardiovascular drift that occurs during prolonged exercise (7,8). Cardiovascular drift is observed during prolonged exercise in a thermoneutral environment and involves increasing

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Conflicts of Interest and Source of Funding: None

TABLE 1. Physical characteristics of 15 male and 12 female participants (mean ± SE).

	Age (y)	Height (cm)	Mass (kg)	% Fat
Males	23.7 ± 1.2	180.2 ± 1.5	78.6 ± 3.4	12.5 ± 1.4
Females	22.4 ± 1.2	166.3 ± 1.5	64.2 ± 2.9	24.8 ± 2.4
P	0.444	<0.001	0.004	<0.001

heart rate and decreasing stroke volume, while cardiac output is maintained (9). Rising core body temperature and dehydration heighten cardiovascular drift (10), especially during exercise in warm environments (11). Ingestion of cold fluids and the use of a fan during exercise diminish increases in both cardiovascular drift and core temperature (7).

A separate but crucial point is that Cunha et al. (6) did not study females. Authors of a recent review concluded that women may experience more rapid core temperature increases than men at exercise onset, which the authors suggested could translate to greater cardiovascular strain (12). Since the publication of the Cunha et al. (6) article, many scientific journals require researchers to study both sexes in accordance with Sex and Gender Equity in Research guidelines (13).

Therefore, the purpose of this study was to test whether, in both men and women, the %HRR and %VO_2R equivalency observed during incremental exercise is maintained over moderate-intensity and vigorous-intensity constant-workload exercise when procedures are used to minimize cardiovascular drift. Given that the ACSM defines moderate intensity as 40%–59% of VO_2R or HRR and defines vigorous intensity as 60%–89% of these parameters (14), we chose intensities of 40% and 60% of VO_2R. Further, since both the ACSM and the Department of Health and Human Services recommend that individuals perform 150–300 min of moderate-intensity physical activity or 75–150 min of vigorous-intensity physical activity per week to enhance health (14,15), we chose a duration for moderate-intensity exercise twice as long as for vigorous. We hypothesized that HR and VO_2 (and thus %HRR and %VO_2R) would nonetheless increase during exercise, but the percent reserve values would remain similar between these 2 variables.

METHODS

Participants

Participants were between 18 and 35 years old, physically active (≥30 min of moderate-intensity physical activity at least 3 times weekly for the past 3 months), reported no cardiovascular or metabolic disease, showed no signs or symptoms of such diseases, and were free of injuries interfering with leg cycling. Each participant provided informed consent in accordance with the university's Institutional Review Board guidelines. While 28 participants were enrolled (15 males, 13 females), 1 female discovered she was pregnant after initial testing and did not perform the remainder of the protocol. Characteristics of the remaining 27 participants are displayed in Tables 1 and 2.

Visit Protocol, Data Collection, and Analysis

Pretesting

For 3 h prior to testing, participants were asked to refrain from food, beverages other than water, and tobacco or other drugs. A 3-h fast was selected, as that has commonly been used in previous studies of VO_2R (16–18). Participants were asked to refrain from strenuous exercise for 24 h prior to testing and consume 400–500 mL of water 3 h before arrival. Upon arrival at the laboratory, participants voided their bladder, if needed. Participants' height and body mass were measured, followed by a body composition assessment using an InBody 770 (Cerritos, California).

Each participant was then fitted to a Lode cycle ergometer (Excalibur Sport, Groningen, Netherlands), with seat and handlebar height adjusted for comfort. Participants were fitted with a HR chest monitor (H10, Polar; Kempele, Finland) as well as Hans Rudolph facemask (Shawnee, Kansas) to collect expired air for the measurement of VO_2 by a Parvo TrueOne 2400 (Salt Lake City, Utah). The metabolic cart's flow sensor and gas analyzers were calibrated with a 3-L syringe and known concentrations of O_2 and CO_2 standard gas, 16% and 4%, respectively. All tests occurred in an environmentally controlled laboratory with a temperature range of 20.6–22.0°C (mean of all tests was 21.5 ± 0.1°C, which did not differ between the 3 test sessions).

TABLE 2. Physiological characteristics of 15 male and 12 female participants (mean ± SE).

	HR_{rest} (b·min^{-1})	HR_{max} (b·min^{-1})	VO_{2rest} (mL·min^{-1}·kg^{-1})	VO_{2max} (mL·min^{-1}·kg^{-1})	P_{max}/mass (W/kg)	RER_{max}
Males	71 ± 4	177 ± 5	3.4 ± 0.2	40.5 ± 2.6	2.92 ± 0.17	1.19 ± 0.02
Females	73 ± 2	180 ± 3	3.5 ± 0.1	35.9 ± 2.9	2.75 ± 0.21	1.19 ± 0.03
P	0.252	0.217	0.576	0.250	0.535	0.899

HR = heart rate; P_{max} = maximum power; RER = respiratory exchange ratio; VO_2 = oxygen consumption; b·min^{-1} = beats per minute; W = watts; kg = kilograms

Incremental Exercise Test

Each participant sat for 10 min to allow for the measurement of resting VO_2. Throughout the 10-min rest, HR and VO_2 were continuously sampled. For the determination of resting HR and VO_2, minutes 5–10 were averaged. Participants returned to the Lode ergometer, and the following incremental exercise protocol was used: 3-min stages starting at and increasing by 40 Watts until voluntary exhaustion. Throughout testing, participants maintained a cadence of 60–80 revolutions per minute (rpm). If cadence fell below 60 rpm, despite verbal encouragement, the test was terminated. During testing, a large fan was directed at the participant to enhance evaporative cooling. Heart rate and VO_2 were collected from the final 60 seconds of each stage, allowing for the determination of %HRR, %VO_2R, and %VO_{2max}. VO_{2max} and maximal HR were defined as the highest values obtained over a continuous 60-second period. Maximum respiratory exchange ratio (RER_{max}) was defined as the highest value obtained over 15–20 seconds during the exercise (i.e., postexercise was excluded). As in previous studies from this laboratory, criteria for attainment of maximal VO_2 were volitional fatigue despite strong verbal encouragement to continue and an $RER_{max} \geq 1.10$ (1,2). All subjects met the volitional fatigue criterion, and 25 of 27 subjects met the RER criterion. The 2 subjects not achieving an RER_{max} of 1.10 had values of 1.04 and 1.09. Maximum power output on the Lode ergometer was determined by the following equation if participants did not conclude exercise at the end of a stage: max power = (total seconds completed during final stage/180 seconds) × (40 watts) + wattage of last completed stage. From the incremental test data, workloads corresponding to 20%, 40%, and 60% VO_2R were calculated for use during visits 2 and 3.

Participants subsequently returned to the laboratory for 2 separate sessions to perform 30-min and 60-min exercise bouts, in a randomized counterbalanced order. Each session occurred no closer together than once every 3 d. For each participant, the times of day for the sessions were similar.

60-Min Moderate-Intensity Exercise Trial

Each participant was asked to arrive following the same pretesting instructions as stated above. A fan was used as noted during the incremental test, and participants were asked every 5 min if they wished to have the fan speed increased. After attachment to equipment as for the maximal test, participants rested for 2 min, then performed a 5-min warmup at 20% VO_2R workload, and then exercised at 40% VO_2R workload for 60 min. The facemask remained in place throughout, except for 2-min periods at minutes 15, 30, and 45 of the 60-min exercise trial to allow for cold water consumption ad libitum. Throughout the trial, water bottles were submerged within an ice bath at 0.5°C. The quantity of water consumed was recorded in grams. HR and VO_2 were recorded continuously (when the facemask was in place) and averaged over the last minute of each 5-min period for analysis. One female did not complete this 60-min trial, and none of her data during the trial were used in analysis. For this trial and for the 30-min vigorous trial, percentages of HRR and VO_2R were based on resting and maximal HRs and VO_2's obtained during the incremental exercise test. The equation for determining %HRR was: %HRR = $(HR_{max} - HR_i)/(HR_{max} - HR_{rest})$, where HR_i is the average HR over the last minute of each 5-min portion of the trial. The equation for determining %VO_2R was identical, with replacement of VO_2 values for HR values.

30-Min Vigorous-Intensity Exercise Trial

Procedures were similar to the 60-min trial, except that the warmup consisted of 2.5 min at 20% VO_2R workload and 2.5 min at the 40% VO_2R workload, then 30 min of exercise were performed at the 60% VO_2R workload; a single water break was given at minute 15. All participants completed this 30-min trial.

Statistics

Values in tables are expressed as mean ± standard error. Characteristics of males and females were compared using unpaired *t*-tests. As in previous research (1,2), linear regressions were performed for each participant on the %HRR versus %VO_2R values from rest to maximum during the incremental exercise tests, with %VO_2R as the independent variable, as well as on %HRR versus %VO_{2max} values, with %VO_{2max} as the independent variable; the mean slopes and intercepts of these regressions were compared with 1 and 0, respectively (i.e., the line of identity), using *t*-tests.

Three-way analyses of variance (ANOVAs; time × variable × sex) were used to examine the responses of %HRR and %VO_2R during prolonged exercise. Separate ANOVAs were performed for the moderate-intensity trial and the vigorous-intensity trial. Repeated measures were used on time (6 time periods for the vigorous trial and 12 for the moderate trial) and variable (%HRR and %VO_2R). Following significant F ratios, post hoc pairwise differences were tested using the estimated marginal means option in SPSS General Linear Model Repeated Measures. The least significant difference method (equivalent to no adjustments) was used for these comparisons. A P of ≤ 0.05 was set for significance. All analyses were done in SPSS (version 28, IBM Corp, Armonk, NY, USA).

RESULTS

As shown in Table 1, males had greater height and mass than females, while females had greater percentage of body fat. Resting HR and VO_2 were similar between sexes, as were maximal responses during incremental exercise (Table 2). Males had a greater absolute maximal power (P_{max}), measured in Watts, than females (P_{max} = 226 ± 13 versus 172 ± 11 W, respectively, P = 0.005), but no difference was found when expressed relative to body mass. Mean power during the moderate-intensity 60-min trial was 64.7 ± 4.9 W for females and 85.9 ± 4.8 W for males. For the vigorous-intensity 30-min trials, the mean powers were 99.5 ± 7.2 W for females and 116.5 ± 6.3 W for males.

Males and females did not differ in their linear regressions of %HRR versus %VO_2R or of %HRR versus %VO_{2max},

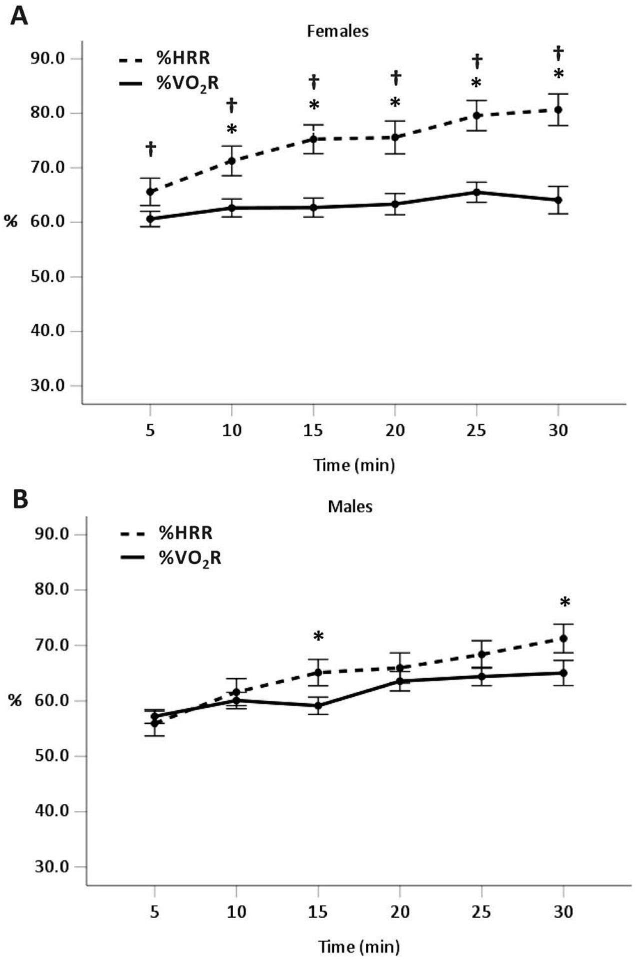

FIGURE 1. Changes in %VO_2R and %HRR over the 30-min vigorous-intensity trial in (A) females and (B) males. * represents differences between %VO_2R and %HRR at individual time points ($P \le 0.05$); specific P values are as follows; for women, minute 10: 0.017; minute 15: 0.003; minute 20: 0.012; minute 25: 0.001; and minute 30: 0.004; for men, minute 15: 0.032; and minute 30: 0.042. † represents differences between females and males for %HRR at individual time points ($P \le 0.05$); specific P values are as follows; minute 5: 0.008; minute 10: 0.014; minute 15; 0.008; minute 20: 0.025; minute 25: 0.006; and minute 30: 0.023. No differences were found between females and males for %VO_2R at individual time points.

and results have been combined across sexes. The %HRR versus %VO_2R regression had a mean slope of 1.016 ± 0.008 and a mean intercept of −0.7 ± 0.9. The mean slope was significantly different than the theoretically assumed slope of 1.0 ($P = 0.048$), while the mean intercept was indistinguishable from the theoretically assumed intercept of 0 ($P = 0.417$). The %HRR versus %VO_{2max} regression had a mean slope of 1.123 ± 0.011 and a mean intercept of −11.4 ± 1.2. These values were different from 1 and 0, respectively, with $P < 0.001$ for both.

The 3-way ANOVA for the 30-min vigorous-intensity trial revealed a time effect ($P < 0.001$), indicating the 2 variables (%HRR and %VO_2R) taken together increased across the 5-min periods. A variable effect ($P = 0.002$) indicated that %HRR values were globally greater than %VO_2R values. A time × variable interaction ($P < 0.001$) indicated that %HRR values increased more than %VO_2R variables as time proceeded. A sex effect ($P = 0.010$) indicated that females globally had greater responses than males. The variable × sex interaction was not significant, but a trend ($P = 0.057$) suggested that the greater response by females than males was more pronounced in %HRR than in %VO_2R. The time × variable × sex interaction was not significant ($P = 0.213$). To illustrate the increase in variables over time and their difference from each other, the sex-specific data are shown in Figure 1. Post hoc tests revealed that, for women, %HRR values exceeded %VO_2R values at 10 min and thereafter. For men, %HRR exceeded %VO_2R only at the 15-min and 30-min time points. When participants were pooled as a single group, a significant difference was found between these 2 variables at every time point from 10 min onward. Post hoc testing between sexes revealed that %HRR was higher among women than men at every time point during the 30-min trial, but no time point differences were found in %VO_2R between women and men.

Results from the 3-way ANOVA for the 60-min trial were similar to those from the vigorous trial. A time effect ($P < 0.001$), variable effect ($P = 0.002$), and time × variable interaction ($P < 0.001$) were found, but unlike in the vigorous trial, the sex effect ($P = 0.112$) was not significant, and the variable × sex interaction ($P = 0.127$) did not approach significance. Results for males and females are displayed in Figure 2. For women, %HRR exceeded %VO_2R at most time points beginning with 10 min. For men, %HRR was significantly greater than %VO_2R only at 30, 55, and 60 min. When data for males and females were combined, %HRR was greater than %VO_2R at all time points except 5 min and 35 min. Post hoc testing between the sexes revealed that %HRR was higher among women than men at 15, 20, and 35 min, but as with the 30-min trial, no sex differences were found in %VO_2R.

DISCUSSION

In this study, we demonstrate that both %HRR and %VO_2R increase during prolonged exercise at a constant workload and that %HRR values exceed %VO_2R values at 10 min or more. Our hypothesis—if measures are used to moderate the thermoregulatory challenge during constant-load exercise, %HRR will not exceed %VO_2R—is rejected. A crucial finding is that females exceed males in their %HRR response during prolonged exercise. Additionally, in this study, we confirm that %HRR and %VO_2R yield nearly equivalent values during incremental exercise in men and women.

Incremental Exercise Findings

The equivalence of %HRR and %VO_2R during incremental exercise was first reported in 1975 (3). However, the ACSM in its 1990 position stand stated that %HRR values were equivalent to %VO_{2max} values (19). In 1997, Swain and Leutholtz (1) demonstrated that the regression of %HRR to %VO_2R during incremental cycling exercise fell on the line of identity, while %HRR differed from %VO_{2max}. Authors of a 1998 study found similar results with incremental treadmill exercise; while the regression of %HRR versus %VO_2R was not coincident with the line of identity, it was closer than the regression of %HRR versus %VO_{2max} (2). In 1998, the ACSM published an updated position stand recommending that %HRR and %VO_2R values be used to provide equivalent cardiorespiratory exercise intensities (4). A recent review examined 13 studies that performed regressions of %HRR versus %VO_2R with %VO_2R as the independent variable (5). Authors of all but 2 studies found that the %HRR versus %VO_2R regression was either coincident with the line of identity or closer to the line of identity than %HRR versus %VO_{2max} (5). Authors of both studies that found conflicting results measured HR over a few seconds at the end of each stage, when the highest HR of each stage was reached, while measuring VO_2 over a longer timeframe, thus biasing the results to higher %HRR values than %VO_2R values (17,20). Authors of most studies, including the current one, measured HR and VO_2 over the same period within each stage of exercise (5).

A well-established finding is that the discrepancy between %HRR and %VO_{2max} in incremental exercise is larger in population groups with lower aerobic fitness (4,5). For example, while the regression in this study of young adults with an average VO_{2max} of 39.5 $mL \cdot min^{-1} \cdot kg^{-1}$ was %HRR = 1.12(%VO_{2max}) − 11.4, the regression for heart failure patients with a VO_{2max} of 16.5 $mL \cdot min^{-1} \cdot kg^{-1}$ was %HRR = 1.26(%VO_{2max}) − 34.9 (21). If intensity were set using a percentage of VO_{2max}, a very large error with %HRR values would be prescribed for such low-fit clients.

Prolonged, Constant-Load Exercise Findings

The most important finding of this study is that %HRR values during prolonged, constant-load exercise are greater than %VO_2R values despite measures (airflow and cold-water ingestion) being used to reduce cardiovascular drift. Authors of 1 other study reported a similar finding in 2011 (6). Cunha et al. (6) had 28 young men perform three 40-min bouts of constant-speed running using workloads calculated to provide 60%, 70%, and 80% of VO_2R. Both %HRR and %VO_2R increased over time, and the mean value of %HRR during each bout was greater than the mean for %VO_2R, with no significant variability over the 40 min of exercise or between the bouts. Authors of a small study that did not employ a constant-load protocol also support the finding of a disparity between %HRR and %VO_2R during prolonged exercise (22). Eight young men ran at 60% and 80% of HRR in separate bouts of 15-min and 45-min duration. Rather than running at a constant speed, the speed was reduced as time proceeded to maintain a constant HR. %HRR and %VO_2R values were assessed only during the last 5 min of each trial. The authors found that %VO_2R decreased as workload decreased and was less than %HRR at the end of the 45-min bouts; however, the 2 variables did not differ at the end of the 15-min bouts (22).

While the results of the current study agree with the findings of Cunha et al. (6) that %HRR exceeds %VO_2R during constant-load exercise, our findings differ in that the delta between %HRR and %VO_2R was time dependent among our participants. These 2 variables were not different until 10 min of exercise at the prescribed intensity. In this regard, our results are similar to those of Ferri Marini et al. (22), who found no difference between %HRR and %VO_2R at the conclusion of 15-min bouts of exercise but did at the end of 45-min bouts of exercise. Since Cunha et al. (6) and Ferri Marini et al. (22) studied only men, results from our male participants are particularly relevant. Men in our study did not show a significant difference between %HRR and %VO_2R until 15 min of the vigorous-intensity trial and 30 min of the moderate-intensity trial, bearing a close comparison to the findings of Ferri Marini et al. (22).

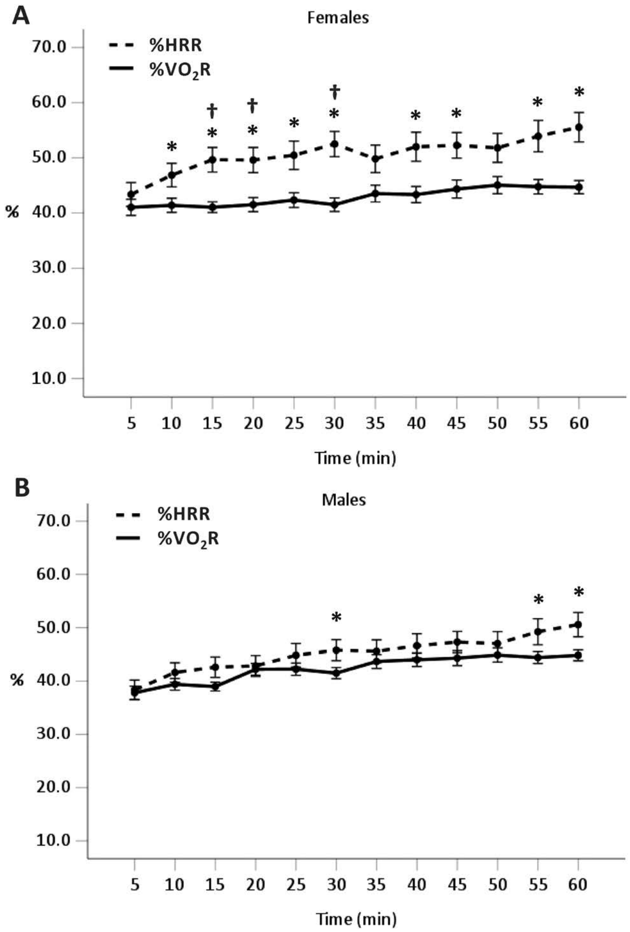

FIGURE 2. Changes in %VO_2R and %HRR over the 60-min moderate-intensity trial in (A) females and (B) males. * represents differences between %VO_2R and %HRR at individual time points ($P \leq 0.05$); specific P values are as follows; for women, minute 10: 0.050; minute 15: 0.004; minute 20: 0.050; minute 25: 0.010; minute 30: 0.004; minute 40: 0.024; minute 45: 0.026; minute 55: 0.029; and minute 60: 0.008; for men, minute 30: 0.022; minute 55: 0.023; and minute 60: 0.013. † represents differences between females and males for %HRR at individual time points ($P \leq 0.05$); specific P values are as follows: minute 15: 0.024; minute 20: 0.034; and minute 30: 0.036. No differences were found between females and males in %VO_2R at individual time points.

Cunha et al. (6) and Ferri Marini et al. (22) found that the discrepancy between %HRR and %VO_2R did not increase with exercise intensity. Cunha et al. (6) found that the delta was approximately 8% regardless of intensity. Ferri Marini et al. (22) found a delta of 4.8% in the 60% HRR trial and 8.6% in the 80% HRR trial, but these did not significantly differ. Our results were similar in that the mean delta for all subjects was 7.9 ± 1.8% and 9.2 ± 2.2% at the conclusion of the 40% and 60% VO_2R trials, respectively, but these did not differ (post hoc *t*-test, $P = 0.413$). Since the authors of the previous 2 studies did not moderate participants' heat load, while we did, we can conclude that such techniques are insufficient to reduce cardiovascular drift under the conditions present in these studies.

Sex Differences

The current study was the first to measure the %HRR and %VO_2R of females during prolonged, constant-load exercise. Females exhibited a greater discrepancy between these 2 variables than males, which was because females had larger %HRR values, exceeding males by 10.0% and 5.4% on average during the vigorous- and moderate-intensity trials, respectively. The reasons that females have a larger and more rapid increase in HR than males during exercise are not known. Possibilities include a greater thermoregulatory strain due to greater body fat and lesser sweating (12). Females have a lower sweating rate during exercise than males (23), which could be advantageous in lessening dehydration. However, less sweating translates to less evaporative cooling and could exacerbate increases in core temperature. Moreover, females have a greater body fat percentage than males and thus less body water for a given total body mass (12). Therefore, a given level of dehydration represents a greater portion of females' total body water and can be expected to produce greater cardiovascular strain. Females have an earlier onset of increased core temperature, and at a lower level of dehydration, than men during exercise (24,25). These points are based primarily on comparisons of single-sex-design studies. More work is needed that directly compares men and women in exercise-induced dehydration trials. Moreover, heat balance in women can be affected by menstrual cycle phase and contraceptives (26), factors not controlled in our study. Since we are the first to examine a sex effect on %HRR during prolonged exercise, more research using a greater number of females and with a wider range of age, fitness, and health status is needed.

Limitations

The current findings apply to young, apparently healthy adults. While studies of the relationship between %HRR and %VO_2R during incremental exercise in clinical populations exist (16,21,29), none have examined the increase of %HRR and %VO_2R during prolonged constant-workload exercise. It is reasonable to assume that both HR and VO_2 will rise in any population, but the extent to which they rise may be different in older or clinical populations than what was observed in this study. Our results are also limited by the modest number of subjects. In our study, we examined 27 participants, and the authors of the only previous study of HRR and VO_2R during constant-load exercise examined 28 participants (6). The findings of both studies showed statistically significant differences between %HRR and %VO_2R. As well, we found significant differences between males and females in our study, yet the possibility of type I errors exists, and confirmatory studies would be helpful. A possible limitation arises from the methodology for measuring resting HR and resting VO_2, which were measured during minutes 5–10 in a sitting position following a fast of at least 3 h. For the lowest possible measurement of resting VO_2, a fast of at least 6 h and measurement in the supine position has been recommended (30). For practical reasons, we feel that sitting is better than supine when determining the resting HR for exercise prescriptions, particularly in the current study when the exercise itself was performed sitting. Further, while a 6-h fast is likely to minimize the thermic effect of the last meal more than a 3-h fast, it is not practical to expect clients and patients to fast 6 h prior to exercise training sessions. Thus, the shorter fast provides a closer comparison with real-world application. Nonetheless, differences in these procedures should be recognized when comparing studies. Finally, our study is limited because we did not measure core body temperature or dehydration during the prolonged exercise trials. We used procedures to minimize heat load during exercise that were effective in prior research (7), but we cannot assume these procedures were fully effective in the current study. Authors of future studies should measure core temperature and hydration status (body weight change) to determine if homeostatic control of these factors prevents %HRR increasing more than %VO_2R during prolonged constant-load exercise.

Clinical Implications

The equivalency of %HRR and %VO_2R during incremental exercise testing has been promoted by the ACSM for prescribing the intensity of cardiorespiratory exercise (4,14). Should the finding that this equivalency is lost during prolonged exercise alter this recommendation? Exercise intensity for clients in a practical setting is not monitored via a metabolic cart. While knowledge of VO_{2max} and %VO_2R is helpful in establishing an intensity, the intensity is transcribed into a HR, workload, or rating of perceived exertion (RPE) in practical use. Moreover, as stated by the ACSM in its current guidelines text: "Intensity of exercise training is usually determined as a range" (27). In the 2006 edition, the ACSM illustrated a typical exercise session with HR starting at the low end of a prescribed range and then increasing, stating that this increase is due to cardiovascular drift, and the workload may need to be reduced to keep the client's HR within the prescribed range (28). In our study, workloads at the low end of the moderate and vigorous ranges as defined by the ACSM (40%–59% and 60%–89% of VO_2R, respectively) were used (14), and participants were observed as HR increased. The findings that %HRR increased more than %VO_2R and that %HRR increased more among women than men do not alter the fact that the desired workload was appropriately set at the beginning. We do not see a rationale for changing this method of prescription. Rather, our results confirm that an intensity range is used during exercise and that clients and patients should be monitored to see that they remain within the desired range. For clinical populations in particular, such monitoring would minimize the possibility of adverse events associated with increasing HR.

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