

Relationship between percentages of heart rate reserve and oxygen uptake reserve during cycling and running: a validation study

Running head: %HRR-%VO₂R relationships in two exercise modes

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Acknowledgements: This research was partially supported by grants from the Carlos Chagas Filho Foundation for the Research Support in Rio de Janeiro State and Brazilian Council for the Technological and Scientific Development.

Abstract

The present study investigated the relationship between percentages of heart rate reserve (%HRR) and oxygen uptake reserve (%VO₂R) during a cardiopulmonary exercise test (CPET) and discrete bouts of isocaloric cycling and treadmill running. Thirty men visited the laboratory three times for anthropometrical and resting VO₂ assessments, and perform cycling and running CPETs. Ten men visited the laboratory twice more to investigate the validity of the %HRR-%VO₂R relationships during isocaloric bouts of cycling and running at 75% VO₂R with energy expenditures of 400 kcals. The %HRR was significantly higher than the %VO₂R during both CPETs at all exercise intensities ($P < 0.001$). During isocaloric exercise bouts, mean %HRR-%VO₂R differences of 6.5% and 7.0% were observed for cycling and running, respectively ($P = 0.007$ to $P < 0.001$). The %HRR and %VO₂R increased over time ($P < 0.001$), the rate of which was influenced by exercise modality ($P < 0.001$). On average, heart rate was 5 ($P = 0.007$) and 8 ($P < 0.001$) beats·min⁻¹ higher than predicted from the second energy expenditure quartile for cycling and running, respectively; however, observed VO₂ was lower than predicted during all quartiles for cycling, and the first quartile for running. Consequently, time to achieve the target energy expenditure was greater than predicted ($P < 0.01$). In conclusion, the %HRR-%VO₂R relationship observed during CPET data did not accurately transpose to prolonged isocaloric bouts of cycling and running. Additionally, power outputs and speeds defined by the ACSM equations for cycling and running, respectively, overestimated VO₂ and energy expenditure.

Key Words: cardiopulmonary exercise testing, isocaloric exercise, kilocalories, training intensity.

INTRODUCTION

General recommendations for aerobic exercise prescription include manipulation of training frequency, intensity, duration, and mode of activity according to the age, fitness level, and clinical condition of the exercising individual (11, 13). Intensity is arguably the most important of these variables, due to its relative efficacy in altering cardiorespiratory fitness when manipulated (25). According to the American College of Sports Medicine (ACSM), the current 'gold standard' method for prescribing aerobic exercise intensity is the application of the linear relationship between percentages of heart rate reserve (HRR) and oxygen uptake reserve (VO_2R) (2, 13). Specifically, exercise intensities between 40% and 85% HRR or VO_2R are recommended to promote health in adults (2, 13). From a practical perspective, the HRR can be used to monitor and adjust power output to achieve the target intensity, and the VO_2R can be used to determine the duration of exercise required to elicit a target energy expenditure. Accurate determination of energy expenditure associated with exercise is particularly important when prescribing exercise to promote weight loss and maintenance (10). The VO_2R also can be used in the ACSM metabolic equations to derive the required power output and speed for cycling, running, and several other exercise modalities (2).

The ACSM recommendation for using %HRR and % VO_2R is based on the assumption that there is a 1:1 relationship between these two variables (21-23). Two important issues must be considered concerning this hypothetical 1:1 ratio and the use of the ACSM metabolic equations, however. First, the use of heart rate as an indicator of relative metabolic intensity is based on validation studies that employed cardiopulmonary exercise tests (CPETs), characterized by relatively short duration maximal incremental exercise (9). Whether the change in heart rate is a valid marker of change in relative metabolic intensity during more prolonged constant power output exercise is uncertain. A question therefore arises regarding the extent to which results obtained by studies that described the hypothetical 1:1 relationship between the %HRR and % VO_2R during CPET, extrapolate to training bouts characterized by relatively long duration and constant power output. Another unanswered question is whether the power outputs and speeds defined by the ACSM metabolic equations produce target heart rate (%HRR), VO_2 (% VO_2R) and energy expenditure values during isocaloric exercise bouts. It is possible that these equations underestimate or overestimate the metabolic demand with important practical consequences for exercise prescription, especially within the context of weight control programs or experimental research where exercise volume between different bouts needs to be matched. Furthermore, exercise modality influences the magnitude of cardiorespiratory

responses at submaximal and maximal intensities (1, 8, 17), however, no study has investigated directly the extent to which different exercise modalities affect the %HRR-%VO₂R relationship.

The main aim of the present study was to investigate the validity of the hypothetical 1:1 relationship between %HRR and %VO₂R during CPET and prolonged constant power output exercise bouts using two exercise modalities (cycling and running). A second aim was to investigate whether the power outputs and speeds defined by the ACSM metabolic equations for cycling and running reproduce the predicted heart rate, VO₂ and time to achieve the target energy expenditure during the exercise bouts, when assuming a 1:1 relationship between %HRR and %VO₂R.

METHODS

Experimental Approach to the Problem

Figure 1 shows a fluxogram of the first and second parts of the study. Panel A includes procedures for investigating the hypothetical 1:1 relationship between %HRR and %VO₂R derived from cycling and running CPETs. Panel B includes procedures for establishing the validity of the %HRR-%VO₂R relationships throughout the isocaloric constant power output and constant speed cycling and running bouts, and the accuracy of the ACSM metabolic equations for determining power outputs and speeds associated with absolute values of VO₂ and associated energy expenditures.

All running tests were performed on the same motorized treadmill (InbramedTM Super ATL, Porto Alegre, RS, Brazil) and the cycling tests were performed on the same cycle ergometer (Cateye EC-1600, CateyeTM, Tokio, Japan). Ambient temperature and relative humidity throughout the study ranged from 292 to 295 K and 50 to 70%, respectively.

INSERT FIGURE

Subjects

A total of 30 apparently healthy men volunteered for the study [mean (range): age, 24 (18-34) yr; height, 1.81 (1.63-1.98) m; body mass, 84 (59-116) kg; body mass index, 25 (20-30) kg·m⁻²; percentage body fat, 18% (9%-27%); resting heart rate, 62 (44-84) beats·min⁻¹; and resting VO₂, 542.2 (326.8-971.2) mL·min⁻¹]. All subjects were involved in aerobic activities for at least the previous 3 months, 2-5 times·wk⁻¹, and 20-60 min·bout⁻¹. Among the 30 subjects involved in the first part of the study, only 10 volunteered to participate in the second part of the study that involved performing two constant power output exercise bouts. The study gained approval from the institutional ethics committee (reference 3082/2011) and subjects were informed of the benefits and risks of the study prior to signing an institutionally approved informed consent document to participate in the study.

Procedures

Resting VO₂ was determined in accordance with the recommendations of Compher et al. (4): abstention of physical exercise, alcohol, soft drinks and caffeine in the 24 h preceding the assessment, fasting at least 8 h prior to the assessment, and minimum effort when travelling to the laboratory. In the laboratory, subjects laid in a calm environment in a supine position for an acclimation period of 10 min, after which the VO₂ was determined for 40 min. The mean VO₂ between minutes 35-40 was used to calculate the %VO₂R, since this time period has previously been shown to elicit a VO₂ steady-state and high test-retest reliability (6). The resting VO₂ was always measured at the same time of the day, between 07:00-11:00 a.m.

The ramp-incremented maximal CPETs were performed as described elsewhere (5, 7). The power output and speed increments were individualized to elicit each participant's limit of tolerance in 8-12 min. The criteria for test termination followed the recommendations of the ACSM (2). The test was considered to have elicited peak capacity when at least three of the following criteria were observed (15): a) maximum voluntary exhaustion defined by attaining a 10 on the Borg CR-10 scale; b) $\geq 90\%$ predicted maximal heart rate (HR_{max}) [220 – age] or presence of a heart rate (HR) plateau (Δ HR between two consecutive power outputs or speeds ≤ 4 beats·min⁻¹); c) presence of a VO₂ plateau (Δ VO₂ between two consecutive power outputs or speeds < 2.1 mL·kg⁻¹·min⁻¹); and d) respiratory exchange ratio > 1.10 .

Based on the HR_{max} and maximal oxygen uptake (VO_{2max}) obtained in the running and cycling CPET, and on the values of resting heart rate and resting VO₂, the values corresponding to 75% of the HRR and VO₂R

were calculated to determine the intensity of the two constant power output exercise bouts. The energy expenditure was calculated individually from the net VO_2 , which is the VO_2 induced by the exercise bout (i.e. $\text{net VO}_2 = \text{gross VO}_2 - \text{resting VO}_2$) (21). The net VO_2 values expressed in $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ were converted to $\text{L}\cdot\text{min}^{-1}$ and then to $\text{kcal}\cdot\text{min}^{-1}$. The predicted time to achieve 400 kcal at 75% $\text{VO}_{2\text{R}}$ for each exercise modality also was calculated. The cycling and running bouts were preceded by a 5-min warm-up at 30 W and 65-75 $\text{revs}\cdot\text{min}^{-1}$, and 5.5 $\text{km}\cdot\text{h}^{-1}$ and 1% grade, respectively.

The absolute VO_2 values obtained from the % $\text{VO}_{2\text{R}}$ equation were used to calculate the associated running speeds and cycling power outputs by applying the ACSM metabolic equations: VO_2 running ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) = $0.2 (\text{speed m}\cdot\text{min}^{-1}) + 0.9 (\text{speed m}\cdot\text{min}^{-1}) (\text{grade } \%) + 3.5 (\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1})$; and VO_2 cycling ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) = $3.5 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1} + 12.24 \times (\text{power W}) \times (\text{body weight kg}^{-1})$ (2). The grade of the treadmill was set at 1%, and the speed converted to $\text{km}\cdot\text{h}^{-1}$. Expired gases were collected during the exercise bouts via the metabolic cart. Based on the values obtained for VO_2 and associated energy expenditure determined throughout the exercise bout, the subjects were encouraged to perform an additional amount of exercise beyond the time predicted to expend 400 kcal, until they reached an observed energy expenditure of 400 kcal. Since the exercise bouts were designed to be isocaloric, the total duration of the bouts was expected to vary between subjects with different fitness levels. In order to allow comparisons of the cardiorespiratory responses across time within exercise bouts, data for the whole exercise bout were split into energy expenditure quartiles of 100, 200, 300, and 400 kcal.

Pulmonary gas exchanges were determined using a VO2000 analyzer (Medical GraphicsTM, Saint Louis, MO, USA) and a silicone face mask (Hans RudolphTM, Kansas, MO, USA). The gas exchange variables were 30-s stationary time-averaged, which provided a good compromise between removing noise in the data while maintaining the underlying trend (16). Prior to testing, the gas analyzers were calibrated according to the manufacturer's instructions, using a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%), balanced with nitrogen (AGA[®], Rio de Janeiro, RJ, Brazil). The flows and volumes of the pneumotacograph were calibrated with a syringe graduated for a 3 L capacity (Hans RudolphTM, Kansas, MO, USA). Heart rate was measured continuously using a cardiometer (RS800cx, PolarTM, Kempele, Finland) and beat-by-beat data were 30-s stationary time-averaged.

Statistical Analyses

All statistical analyses were performed using Statistica 10 software (StatSoft™, Tulsa, OK, USA). Sample data are described using the mean \pm SD. Statistical significance was accepted as $P < 0.05$. Cohen's d effect sizes for mean differences were calculated and defined as small (0.20), moderate (0.50), and large (0.80) (3). In the first part of the study, a linear regression model was determined for each participant in order to compare the relationships between %HRR vs. %VO₂R. The heart rate and VO₂ values obtained at rest and during the CPETs were used as references to calculate %HRR and %VO₂R according to the following equations: 1) %HRR = $(HR_{\text{submax}} - HR_{\text{at rest}}) / (HR_{\text{max}} - HR_{\text{at rest}}) \times 100$; and 2) %VO₂R = $(VO_{2\text{submax}} - VO_{2\text{at rest}}) / (VO_{2\text{max}} - VO_{2\text{at rest}}) \times 100$. In these equations, HR_{max} refers to the maximal heart rate reached in the CPET; the HR_{submax} refers to the heart rate obtained throughout the CPET at 30-s intervals; VO_{2max} refers to the maximal VO₂ reached in the CPET; VO_{2submax} refers to the VO₂ obtained throughout the test at 30-s intervals. The %VO₂R was used as an independent variable in the regression model and the predicted percentages of HRR associated with 40, 50, 60, 70, 80 and 90% of the VO₂R were determined. The mean \pm SD intercepts and slopes were determined for each linear regression model and Pearson correlation for each relationship was calculated. The Student t-test for paired samples was also used to test whether the intercepts and slopes of the regression models were significantly different from 0 and 1, respectively (7, 22, 23), and to test possible differences between the regression lines, as described in detail elsewhere (24). In addition, a two-way ANOVA for repeated measures with exercise modality and intensity as factors was used for between and within group comparisons. The Tukey *post hoc* test was applied to determine pairwise differences when significant F ratios were obtained.

In the second part of the study, the differences between the predicted and observed heart rate and VO₂ were analyzed using a two-way ANOVA for repeated measures. Where effects for exercise modality and time were statistically significant, Tukey *post hoc* pairwise comparisons were performed. Mean differences between the predicted and observed times to achieve 400 kcals at 75% VO₂R were investigated using one-sample t tests, using the difference scores and a test value of zero. The distribution of these differences was graphically displayed using Bland-Altman plots, which include the associated 95% limits of agreement.

RESULTS

Table 1 shows the mean \pm SD values for cardiorespiratory variables and time to exhaustion obtained in the CPET. Mean HR_{max} and VO_{2max} were significantly higher during treadmill running compared to cycling,

whereas maximal values for minute ventilation (second part of study only) and respiratory exchange ratio were significantly higher during cycling. Mean time to exhaustion was similar between exercise modalities.

INSERT TABLE 1

Relationship between %HRR and %VO₂R

The mean \pm SD intercepts and slopes for the individual linear regression models, derived from cycling and running CPETs, are shown in Table 2. Figure 2 shows the linear regression lines representing the association between the %VO₂R and %HRR during cycling and running CPETs. Significant mean differences were observed between intercepts ($t = -6.59$; $P < 0.001$) and slopes ($t = -6.10$; $P < 0.001$) obtained for %HRR vs. %VO₂R relationships. Moreover, mean intercepts and slopes in both exercise modalities were significantly different from 0 ($P < 0.001$) and 1 ($P < 0.001$), respectively (see Table 2).

INSERT TABLE 2 AND FIGURE 2

Table 3 shows the values of %VO₂R corresponding to deciles of %HRR during the cycling and running CPETs. There were significant main effects for exercise modality ($F = 75.64$; $P < 0.001$) and intensity ($F = 9706.80$; $P < 0.001$), and a modality x intensity interaction ($F = 51.33$; $P < 0.001$). The mean %VO₂R was significantly lower than that predicted by the 1:1 relationship up to 60% HRR for cycling ($P < 0.001$) and throughout the whole range of observed speeds for running ($P < 0.001$). At all exercise intensities the %VO₂R was significantly higher in cycling compared to running ($P < 0.001$) and the %HRR was closer to the %VO₂R during cycling compared to running.

Figure 3 shows the relationships between the %HRR and %VO₂R at 100 kcal intervals during the continuous exercise bouts at 75% VO₂R. A 1:1 relationship between the %HRR and %VO₂R was not observed for either exercise modality, with an average difference of 6.5% and 7.0% between the two variables for cycling and running bouts, respectively ($P = 0.007$ to $P < 0.001$). Furthermore, the %HRR and %VO₂R increased significantly over time ($F = 2104.0$, $P < 0.001$), the rate of which was influenced by exercise modality ($F = 2659.0$, $P < 0.001$).

INSERT FIGURE 3 and TABLE 3

Predicted and observed values during submaximal exercise bouts

Table 4 shows the mean \pm SD predicted and observed heart rate and VO_2 for cycling and running bouts. There were significant differences between the predicted and observed heart rates ($F = 82.4$, $P < 0.001$) and VO_2 ($F = 35.5$, $P < 0.001$). The heart rate was significantly higher than predicted from the second energy expenditure quartile (cycling: mean difference = 5 $\text{beats}\cdot\text{min}^{-1}$, $P < 0.001$; running: mean difference = 8 $\text{beats}\cdot\text{min}^{-1}$, $P < 0.001$), with the difference progressively increasing until reaching a maximum in the fourth quartile (cycling: mean difference = 12 $\text{beats}\cdot\text{min}^{-1}$, $P < 0.001$; running: mean difference = 18 $\text{beats}\cdot\text{min}^{-1}$, $P < 0.001$). In contrast, observed VO_2 was lower than predicted during all energy expenditure quartiles for cycling, with the largest differences in the first quartile (mean difference = 359 $\text{mL}\cdot\text{min}^{-1}$; $P < 0.001$) and progressively decreasing until the fourth quartile (mean difference = 211 $\text{mL}\cdot\text{min}^{-1}$; $P = 0.005$). Unlike cycling, observed VO_2 during running was lower than predicted only in the first quartile (mean difference = 234 $\text{mL}\cdot\text{min}^{-1}$; $P = 0.001$).

Figure 4 shows the distribution of the differences between the predicted and observed times to achieve energy expenditure of 400 kcal at 75% VO_2R during cycling and running bouts. The time to achieve the target energy expenditure in each condition was significantly greater than predicted ($F = 356.2$, $P < 0.001$), with the greatest differences observed for cycling compared to running.

INSERT TABLE 4 AND FIGURE 4

DISCUSSION

The present study adds to current knowledge by investigating the %HRR-% VO_2R relationships during CPETs and isocaloric bouts of constant power output exercise with energy expenditures of 400 kcals and using two different exercise modalities (cycling and running). The main finding was that the hypothetical 1:1 relationship between the %HRR and % VO_2R was not observed in either the CPET or constant power output exercise for either exercise modality. Moreover, the ACSM equations for cycling and running overestimated the observed energy expenditure and, therefore, underestimated the time to achieved 400

kcal during exercise at 75% VO_2R . Due to the association between energy expenditure and VO_2 , similar errors were evident for VO_2 , especially for the exercise modality involving a lower muscle mass (i.e. cycling). However, the ACSM metabolic equations for cycling and running predicted heart rate during the exercise bouts with a relatively high degree of accuracy during the first energy expenditure quartile, but subsequently observed heart rates were underestimated.

Cunha et al. (7) questioned the hypothetical 1:1 relationship between %HRR and % VO_2R during running CPET. The % VO_2R was underestimated in relation to %HRR, whereas differences between the %HRR and % VO_2R were inversely proportional to exercise intensity. In other words, the difference between %HRR and % VO_2R decreased when the exercise intensity was near to maximal, at least within the context of maximal incremental exercise testing. The findings of the present study concur with those of Cunha et al. (7), since the %HRR was significantly higher than the % VO_2R until 60% HRR for cycling ($P < 0.001$) and throughout the whole range of intensities for running ($P < 0.001$) (see Table 3 and Figure 2). In any case, it is notable that %HRR was closer to % VO_2R during cycling [mean \pm SD intercept and slope: 0.08 ± 0.05 and 0.93 ± 0.06 , respectively] than during running [mean \pm SD intercept and slope: 0.22 ± 0.10 and 0.80 ± 0.11 , respectively] CPET (see Table 2). Interestingly, the effect of exercise modality on the slope of the %HRR-% VO_2R relationship also has been observed by Swain and Leutholtz (22), (23). The %HRR versus % VO_2R relationship during cycling CPET was indistinguishable from the line of identity [mean \pm SD intercept and slope: -0.1 ± 0.6 and 1.00 ± 0.01 , respectively] (22), whereas in running it was slightly different from the line of identity [mean \pm SD intercept and slope: 1.5 ± 0.6 and 1.03 ± 0.01 , respectively] (23). Comparison between results of the aforementioned studies should be viewed with caution, however, given the different exercise protocols and populations employed.

Cunha et al. (8) investigated whether there was a 1:1 relationship between the %HRR and % VO_2R at an exercise intensity corresponding to the gas exchange threshold in 16 apparently healthy men during cycling, walking, and running CPETs. The authors observed that mean values of % VO_2R at the gas exchange threshold were 7% and 11% lower than the corresponding %HRR for the cycling and running exercise modalities, respectively. The present findings concur with the hypothesis that the %HRR-% VO_2R relationship is influenced by the exercise modality used during the CPET, since the average difference between the %HRR and % VO_2R was greater during running than cycling CPET (see Figure 2). Exercise modality did not affect the average difference between the %HRR and % VO_2R during the 400 kcal exercise

bouts at 75% VO_2R (cycling: 6.5%; running: 7%; see Figure 3), however, the greatest increases in heart rate (%HRR) and VO_2 (% VO_2R) over time were observed during running compared to cycling (see Table 4 and Figure 3).

Nassis and Geladas (17) compared the physiological strain during prolonged submaximal cycling and running for 90 min at 60% $\text{VO}_{2\text{max}}$ in a thermoneutral environment ($23.8 \pm 0.3^\circ\text{C}$) in the same group of 11 healthy males [mean \pm SD: (cycling and running $\text{VO}_{2\text{max}}$: 48.5 ± 1.8 and 52.1 ± 2.2 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively)]. The authors observed a main effect for exercise modality, where VO_2 , heart rate, cardiac output, stroke volume, and rectal temperature were significantly greater during running compared to cycling ($P < 0.01$). The cardiac output declined only during cycling, however, presumably because of the greater drop in stroke volume, despite a higher degree of whole body dehydration and hyperthermia observed in running. This in turn may explain the plateau in VO_2 throughout the cycling bout compared to the progressive increase in VO_2 until minute 43 in the running bout (17). In others words, these findings suggest that active muscle mass played a role in the cardiovascular responses, which reinforce the notion that the relationships between %HRR and % VO_2R observed during CPETs are not valid in the context of aerobic training programs. In this sense, it is known that the increase in VO_2 during prolonged exercise with constant power output due to the slow component of VO_2 kinetics has been related to integrated mechanisms of kinetic control, including the activation of additional muscle groups, greater respiratory muscle activity, recruitment of type II muscle fibers, increases in muscle temperature, and higher blood lactate levels, among others (18). The progressive increase in VO_2 has been shown to be concomitant to a decrease in stroke volume and a compensatory increase in heart rate, with little variation in the cardiac output (19). Parallel to this is that the increase in body temperature and decreased hydration level may contribute to a decline in filling pressure and end-diastolic volume, promoting increased heart rate (12) and a further dissociation between %HRR and % VO_2R .

To the best of our knowledge, the present study is the first to investigate the extent to which the ACSM metabolic equations for cycling and running reproduces the prescribed heart rate (%HRR), VO_2 (% VO_2R), and time to achieve a target energy expenditure during isocaloric exercise bouts. Our findings raise doubts about the appropriateness of prescribing isocaloric exercise bouts based on a 1:1 ratio between the %HRR and % VO_2R , since the predicted VO_2 was significantly overestimated throughout the submaximal exercise protocols (see Table 4 and Figure 3). In practical terms, the subjects had to perform additional exercise in

relation to the predicted time to reach the target energy expenditure of 400 kcals for the two exercise modalities (see Figure 4). On the other hand, the predicted and observed heart rate values were quite similar across the two exercise modalities during the first energy expenditure quartile, after which the predicted heart rate was underestimated, especially for running (see Table 4 and Figure 3). In practical terms, prescribing exercise intensity based upon the VO_2 and then estimating the relative heart rate assuming a 1:1 relationship, would probably overestimate energy expenditure, especially for high intensity and long duration exercise bouts. This is important for exercise prescription, since previous studies using healthy adults (14), heart failure patients (26), and obese adults (20) have monitored heart rate to adjust the power output corresponding to the preferred exercise intensity and ensure the training bouts were isocaloric. In other words, using heart rate to ensure the intended training volume is being performed is not valid.

PRACTICAL APPLICATIONS

The hypothetical 1:1 relationship between %HRR and % VO_2R could not be reproduced, since the % VO_2R was underestimated by %HRR. Concurrently, the relationships between the %HRR and % VO_2R from maximal incremental exercise testing may not accurately transpose to prolonged constant power output exercise, regardless of exercise modality. Moreover, the present findings warrant further investigation with regards to the applicability of the ACSM metabolic equations to calculate the target power outputs and speeds based on the VO_2 obtained by calculating the target % VO_2R , since the cycling and running equations overestimated the predicted energy expenditure resulting in an underestimation of the observed time to achieve 400 kcals. This information is of paramount importance for exercise prescription to determine the predicted time to achieve a given energy expenditure during isocaloric exercise bouts ($\text{min}\cdot\text{bout}^{-1}$), as well the power output and speed (watts and $\text{m}\cdot\text{s}^{-1}$) and target heart rate ($\text{beats}\cdot\text{min}^{-1}$). Further research is required to establish the accuracy of the ACSM metabolic equations for different exercise intensities and volumes, and populations with different levels of cardiorespiratory fitness and clinical conditions.

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Figure Legends

Figure 1. Experimental design overview. VO_2 = oxygen uptake; VO_2R = oxygen uptake reserve.

Figure 2. Regression line of heart rate reserve (%HRR) and oxygen uptake reserve (% VO_2R) observed during the cycling and running cardiopulmonary exercise tests for the total sample of men ($N = 30$). The regression equation is the average of 30 individual regressions.

Figure 3. Mean \pm SD percentage of heart rate reserve (%HRR) and oxygen uptake reserve (% VO_2R) at 100 kcal intervals during the continuous cycling and running bouts at 75% VO_2R . *Significantly different from the value assessed at 100 kcal ($P < 0.01$). P values indicate significant differences between the %HRR and % VO_2R .

Figure 4. Bland-Altman plots showing individual differences between the predicted and observed times to achieve energy expenditures of 400 kcals at 75% VO_2R during cycling and running. The first and third horizontal dashed lines in each graph represent the 95% limits of agreement.

Table 1. Mean \pm SD maximal physiological responses and time to exhaustion for the running and cycling cardiopulmonary exercise tests. During the tests, all subjects satisfied at least three of the four $\text{VO}_{2\text{max}}$ test criteria stipulated in the ‘Procedures’ section.

Variable	1 st part of the study				2 nd part of the study			
	Cycling	Running	<i>P</i> value	Effect size (Cohen's <i>d</i>)	Cycling	Running	<i>P</i> value	Effect size (Cohen's <i>d</i>)
Maximal heart rate (beats·min ⁻¹)	183 \pm 10	194 \pm 8	< 0.001	1.24	184 \pm 7	192 \pm 5	< 0.001	1.39
Maximal oxygen uptake (mL·min ⁻¹)	3335 \pm 692	4068 \pm 835	< 0.001	0.97	3439 \pm 824	3979 \pm 845	< 0.001	0.68
Maximal minute ventilation (L·min ⁻¹)	101.0 \pm 21.2	95.6 \pm 11.4	NS	0.32	104.9 \pm 15.8	102.0 \pm 16.7	0.011	0.19
Maximal respiratory exchange ratio	1.13 \pm 0.05	1.07 \pm 0.04	< 0.001	1.35	1.15 \pm 0.05	1.07 \pm 0.04	< 0.001	1.86
Time to exhaustion (s)	618 \pm 102	642 \pm 102	NS	0.24	594 \pm 84	630 \pm 114	NS	0.38

NS = non-significant.

Table 2. Mean \pm SD values for the Y intercept, slope, coefficient of determination (r^2) and standard error of estimate (SEE) from individual linear regression models representing the relationships between heart rate reserve and oxygen uptake reserve obtained in the cycling and running cardiopulmonary exercise tests.

Exercise Modality	Y intercept	Slope	r^2	SEE (\pm)
Cycling	0.079 \pm 0.054*†	0.931 \pm 0.062*†	0.965 \pm 0.018	4.5%
Running	0.217 \pm 0.097*	0.799 \pm 0.106*	0.947 \pm 0.027	3.4%
Effect size (Cohen's <i>d</i>)	1.79	1.55	-	-

*Intercept and slopes significantly different from zero and one, respectively ($P < 0.001$); † Significant difference compared to running ($P < 0.001$).

Table 3. Mean \pm SD percentages of oxygen uptake reserve (%VO₂R) associated with different percentages of heart rate reserve (%HRR) determined during the cycling and running cardiopulmonary exercise tests (CPETs).

%HRR	40%	50%	60%	70%	80%	90%
%VO ₂ R Cycling	34 \pm 4%*	45 \pm 4%*	56 \pm 3%*	67 \pm 3%	77 \pm 3%	88 \pm 3%
%VO ₂ R Running	22 \pm 9%*†	35 \pm 8%*†	47 \pm 6%*†	60 \pm 5%*†	73 \pm 4%*†	86 \pm 3%*
Effect size (Cohen's <i>d</i>)	1.75	1.61	1.93	1.73	1.15	0.68

*Significant mean difference between the %HRR and %VO₂R ($P < 0.001$). † Significant mean difference for %VO₂R in cycling compared to running CPETs ($P < 0.001$).

Table 4. Mean \pm SD predicted and observed heart rate reserve (HRR) and oxygen uptake reserve (VO₂R) for the 400 kcal isocaloric exercise bouts performed at 75% VO₂R. Observed values are given for each energy expenditure quartile.

Exercise modality	Work Rate	HRR (beats·min ⁻¹)					VO ₂ R (mL·min ⁻¹)				
		<i>Predicted</i>	<i>1st</i>	<i>2nd</i>	<i>3rd</i>	<i>4th</i>	<i>Predicted</i>	<i>1st</i>	<i>2nd</i>	<i>3rd</i>	<i>4th</i>
Cycling (W)	257 \pm 55	153 \pm 7	152 \pm 6	158 \pm 5*	161 \pm 5*	165 \pm 6*	2833 \pm 607	2474 \pm 608*	2508 \pm 638*	2561 \pm 583*	2622 \pm 593*
Effect size (Cohen's <i>d</i>)	-	-	0.16	0.87	1.39	1.94	-	0.62	0.55	0.48	0.37
Running (m·s ⁻¹)	3.14 \pm 0.50	164 \pm 5	162 \pm 7	172 \pm 6*	178 \pm 7*	182 \pm 8*	3084 \pm 618	2850 \pm 640*	2978 \pm 595	3071 \pm 625	3140 \pm 641
Effect size (Cohen's <i>d</i>)	-	-	0.35	1.53	2.43	2.84	-	0.39	0.18	0.02	0.09

* Significantly different from predicted ($P = 0.005$ to $P < 0.001$). Effect size (Cohen's *d*: difference between the predicted vs. observed values.

Figure 1.

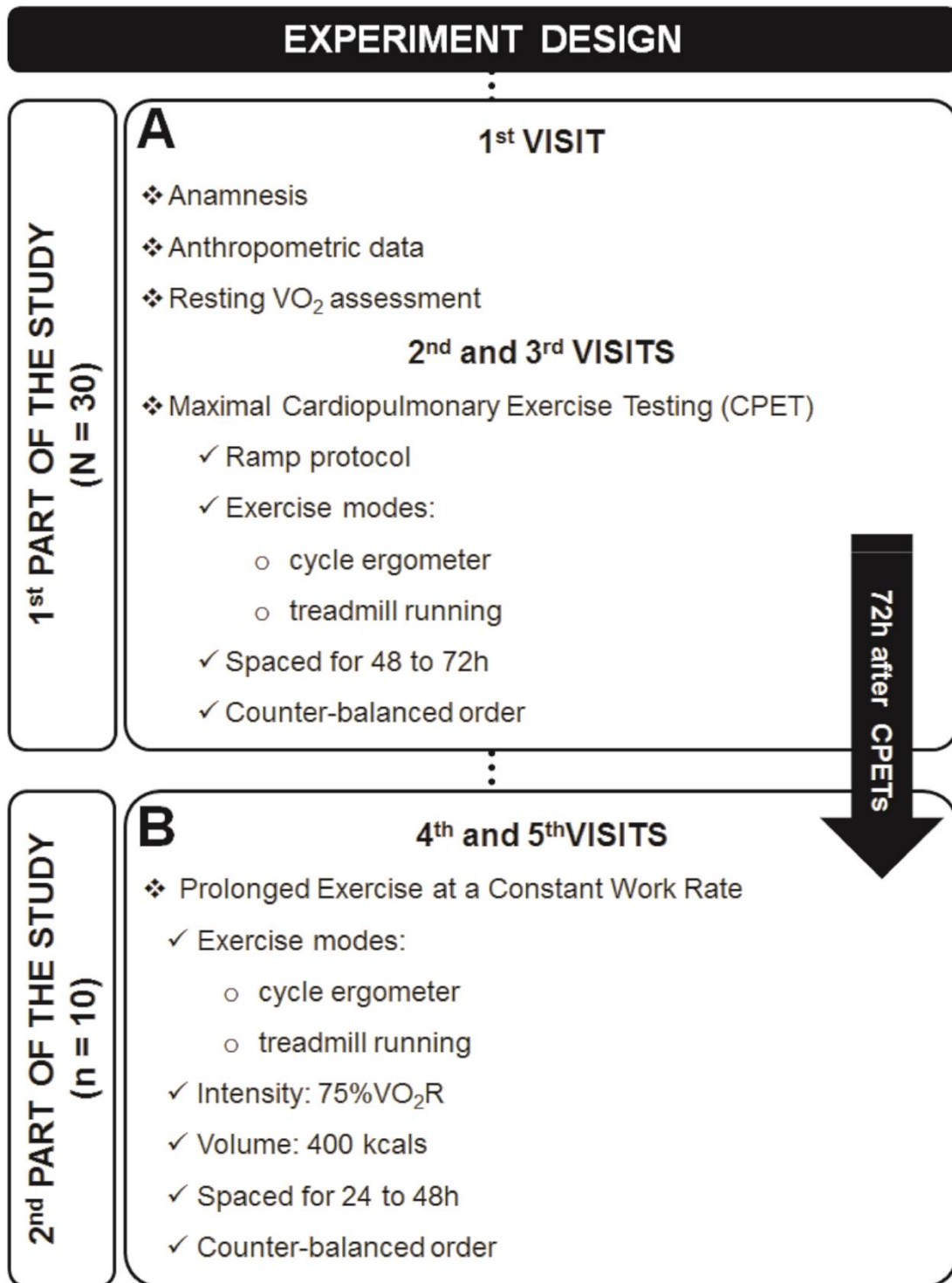


Figure 2.

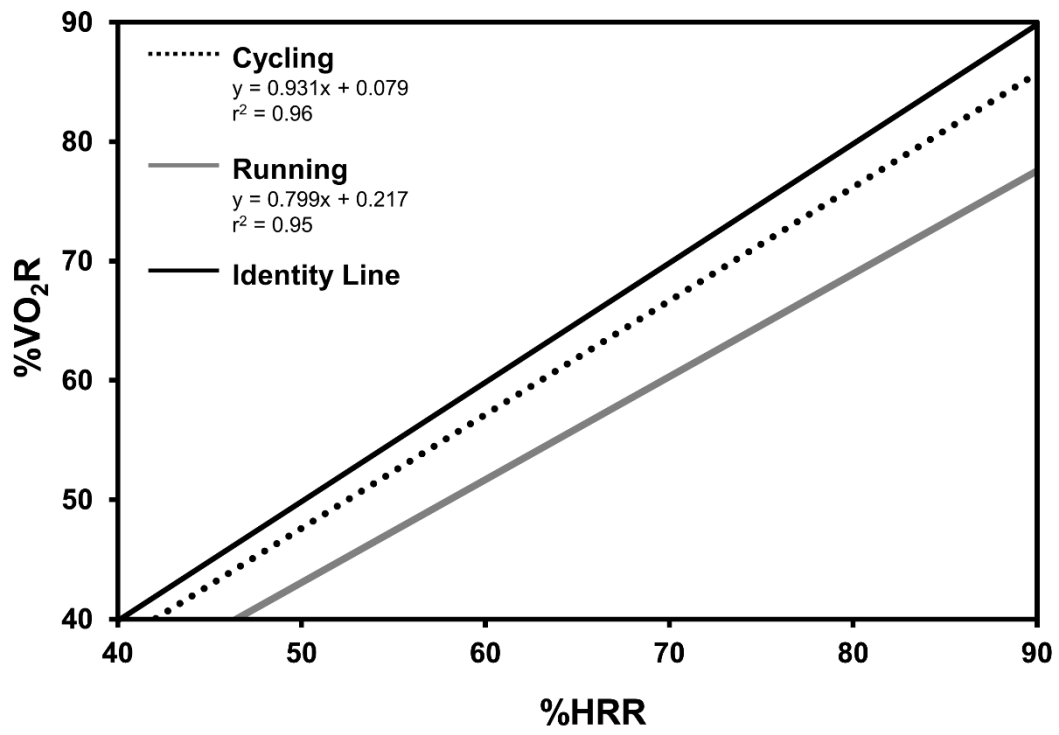


Figure 3.

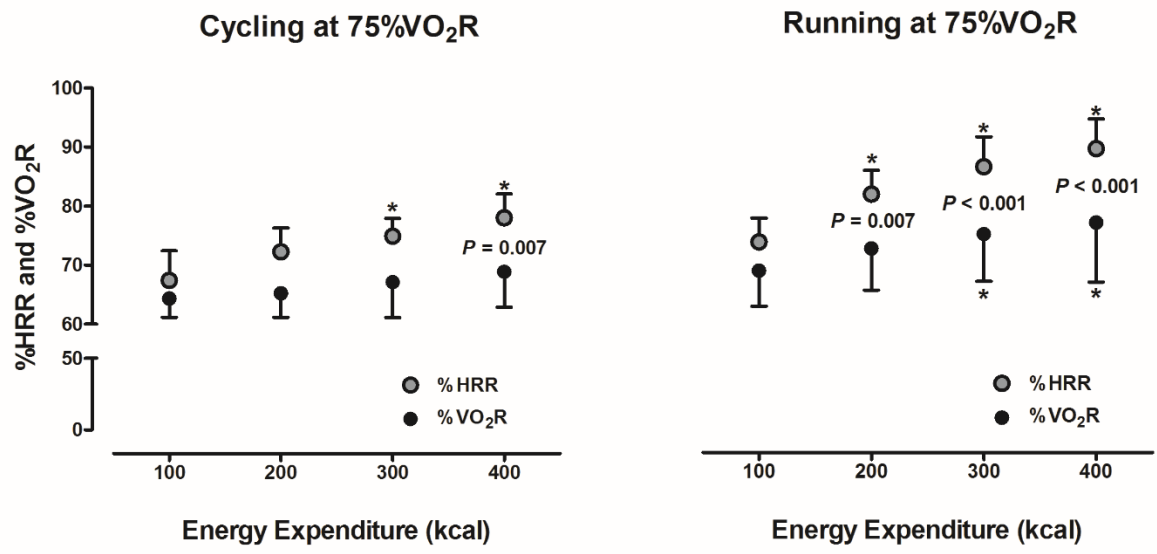


Figure 4.

