TITLE PAGE

Influence of cardiopulmonary exercise testing protocol and resting VO_2 assessment on $\%HR_{max}$, %HRR, $\%VO_{2max}$ and $\%VO_2R$ relationships

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Abstract

The findings of previous studies that investigated the strength of the relationships between the percentages of maximal heart rate (%HR_{max}), heart rate reserve (%HRR), maximal oxygen uptake (%VO_{2max}), and oxygen uptake reserve (%VO_2R) have been equivocal. This inconsistency between studies could largely be due to differences in methodology. The purpose of this study was therefore to determine whether different VO_{2max} test protocols and resting VO_2 assessment influence the relationships between the %HR_{max}, %HRR, %VO_{2max}, and %VO_2R. Thirty-three young men performed maximal treadmill protocols [ramp, Bruce] to assess HR_{max} and VO_{2max}. Resting VO_2 was assessed as follows: a) resting $VO_{2standard}$, using strict criteria [24h exercise abstention, alcohol, soft drinks, or caffeine; 8h fasting; 30min assessment]; b) resting $VO_{2sitting}$ and; c) resting $VO_{2standing}$ [both 5min before exercise testing]. The %HRR was closer to %VO_{2max} than to %VO_2R, especially in the ramp protocol ($p<.05$). In the Bruce protocol relationships were closer to the identity line, and there was no significant difference between %HRR and %VO_{2max} or %VO_2R. The VO_{2max} was significantly higher in the ramp protocol compared to the Bruce protocol ($p<.001$). In both protocols resting VO_2 assessment produced no significant differences in intercepts and slopes of %HRR-%VO_2R relationships obtained from individual regression models. The %VO_2R calculated using resting $VO_{2standard}$ was closer to %HRR compared to $VO_{2sitting}$ and $VO_{2standing}$. The premise that %HRR is more strongly related to %VO_2R than to %VO_{2max} was not confirmed. The %VO_{2max} should be used to prescribe aerobic exercise intensity since its association with %HRR was stronger than the %VO_2R-%HRR relationship.

Key words: aerobic training, physical fitness, health, linear regression, Bruce protocol, ramp protocol.

Introduction

Exercise that is performed at an inadequately low relative intensity results in a level of physiological strain that is insufficient to stimulate favorable adaptation and enhanced fitness [27]. In the early stages of a training program, for example, previously sedentary individuals have been shown to enhance cardiorespiratory fitness by training at exercise intensities as low as 40% VO_{2max} [5]. However, the minimal intensity that enhances cardiorespiratory fitness is positively related to the cardiorespiratory fitness of the individual [39]. The importance of exercise intensity in relation to enhancing cardiorespiratory fitness has been eloquently summarized in a review of the literature that concluded that exercise intensity, rather than training volume and frequency, was the most important factor in enhancing cardiorespiratory fitness [45]. However, relative high exercise intensities have been found to significantly reduce adherence to physical training programs [20]. Accurate exercise intensity prescription is therefore important to ensure that exercise is effective in improving fitness whilst simultaneously promoting adherence to training programs. These two issues are fundamental in employing physical exercise for improving public health.

One of the most well established methods for prescribing exercise intensity relies on the relationship between the percentage of maximal heart rate (%HR_{max}) and the percentage of maximal oxygen uptake (%VO_{2max}). According to the American College of Sports Medicine [3], 40, 50, 60, 80, and 85% VO_{2max} corresponds, respectively, to 55, 62, 70, 85, and 90% HR_{max} [15,20,22,33,36]. However, some studies have suggested that the relationship proposed by the ACSM overestimates the %HR_{max} associated with any given %VO_{2max}, especially at intensities lower than 80-85% VO_{2max} [10,18,23,30,35,38]. Exercise prescription based only on the %HR_{max} has therefore been criticized because it is likely to underestimate the desired exercise intensity, especially during low-intensity exercise and in individuals with poor exercise tolerance [2].

Nevertheless and in spite of these limitations, the utilization of heart rate to control training intensity is still of great value: it is undeniable that heart rate is a physiological variable which, apart from maintaining a linear relationship with increasing oxygen uptake (VO_2), is easily measured. Moreover, exercise prescription based on VO_2 allows for the determination and control of work rate, training volume, and caloric expenditure [2]. Therefore another strategy for exercise prescription has been proposed based upon the relationship between the heart rate reserve (HRR) and VO_2 reserve (VO_2R) [1,2]. The HRR and VO_2R are a measure of the difference between the resting and maximal values for heart rate and VO_2, respectively [2]. Several studies reported that the %HRR and %VO_2R were more strongly related than the %HR_{max} and %VO_{2max}, and therefore, should provide more accurate exercise prescription [40,41]. The ACSM [1] subsequently published an official stand recommending the %HRR-%VO_2R method.

Although the %HRR-%VO_2R method of exercise prescription appears to have gained widespread acceptance, there are several methodological issues related to previous research on this topic that likely limits its utility. These limitations are mainly related to the assessment of resting VO_2 and VO_{2max}, as well as to the analysis of the relationship between the %HRR and %VO_2R in different populations and using different incremental test protocols. Among 12 studies dedicated specifically to analyzing the %HRR-%VO_2R relationship, only four [10,18,23,30] conformed to the minimal methodological criteria suggested to be necessary for accurate and reproducible determination of resting VO_2 [12]. Six studies respected none [13,25] or only some [11,32,40,41] of the five recommended criteria for resting VO_2 assessment. The two remaining studies did not measure the resting VO_2, but instead, adopted an inappropriate metabolic equivalent (MET) reference value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ [6,16]. Byrne et al. [9] reported that the mean ± SD resting VO_2 of 2.6 ± 0.4 $mL \cdot kg^{-1} \cdot min^{-1}$, for 769 men and women, was significantly lower than the widely accepted 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ reference value.

The test protocols used to determine VO_{2max} also have differed between studies. With the exception of two studies [25,30], the relationship between the %HRR and %VO_2R has been determined using intermittent [10,18] or continuous step-incremented test protocols [6,11,13,16,23,32,40,41]. These test protocols possess characteristics that can reduce the VO_{2max} value when compared to that derived from ramp protocols [8,28,29,46]. Prolonged step-incremented tests, and those that incorporate high treadmill grades, have been particularly implicated in being inappropriate for eliciting true VO_{2max} [26].

It is presently not known how methodological differences in the determination of resting VO_2 and VO_{2max}, used in previous studies, affect the relationships between the %HR_{max}, %HRR, %VO_{2max} and %VO_2R. Therefore, the aim of this study was to investigate the influence of different approaches to assessing resting VO_2 and VO_{2max} (using ramp and Bruce protocols) in order to establish how these methodological differences affect the accuracy of exercise prescription. We hypothesized that different exercise testing protocols and the different resting VO_2 assessment strategies would affect exercise prescription based on the relationships between %VO_2 (maximal or reserve) and %HR (maximal or reserve).

Methods

Participants

A sample size estimation was previously calculated for the correlation (point serial model) considering: effect-size = 0.5, alpha error probability = 0.05, statistical power = 0.80 (G*Power version 3.0.10). The estimated N was 20. Thirty-three healthy male participants volunteered for the study [mean ± SD, age: 21.0 ± 4.0 years; height: 175.6 ± 6.8 cm; body mass: 70.8 ± 7.7 kg; BMI: 22.9 ± 1.8 kg·m^2; body fat: 11.5 ± 3.4%]. All participants_were involved in aerobic activities 20-60 min/session, 3-5 times/wk, for at least six months prior to the study. The study gained approval from the institutional ethics committee and prior to the commencement of the study, participants were informed of the potential risks and discomforts, and subsequently gave written informed consent.

Procedures

Each subject visited the laboratory three times on three separate days. On the first visit resting VO_2 was determined, the anthropometric measurements were taken, and the participants_were habituated to the equipment and test protocols. No subject presented difficulty or limitation of movement while carrying out the procedure, as all had previous experience with treadmill exercise. The second and third visits were separated by 72 h and involved determination of resting VO_2 using an additional two methods in a counterbalanced crossover design, after which, participants_performed either a ramp or Bruce incremental exercise test protocol. The order of the tests was counter-balanced. Both of the incremental tests were performed on the same motorized treadmill (Q65, Quinton Instruments, Seattle, WA, USA). Mean±SD ambient temperature and relative humidity during testing were 21.6±1.0°C (range 19-22°C) and 62.5±4. 1% (range 50-70%), respectively.

Three approaches were adopted to assess the resting VO_2 for the later calculation of %VO_2R (see Table 1). The resting $VO_{2standard}$ assessment, performed on the first visit, conformed to the guidelines of Compher et al. [12]. These were abstention from physical exercise, alcohol, soft drinks and caffeine in the 24 h preceding the assessment, fasting for 8 h prior to the assessment, and minimum effort when travelling to the laboratory. In the laboratory, participants_laid in a calm environment for 20 min, after which, VO_2 (mL·kg^{-1}·min^{-1}) was measured for 30 min. The resting VO_2 was taken as the average of the last 10 min of (steady-state) data. The other two approaches (resting $VO_{2sitting}$ and resting $VO_{2standing}$) were carried out before the cardiopulmonary exercise tests, using similar criteria adopted by previous studies that aimed to investigate the relationship between the $\%HR_{max}$, %HRR, $\%VO_2R$ and $\%VO_{2max}$ [10,11,13,18,23,25,30,32,40,41]. Participants_were instructed not to engage in any form of physical exercise in the previous 24 h, to abstain from alcohol, soft drinks and caffeine in the 8 h preceding the test and to fast for 3 h. In the laboratory, participants_laid quietly for 10 min. After this rest period, the VO_2 was measured for 5 min either in the sitting or standing position, and the average of the last 2 min was regarded as resting VO_2. All resting VO_2 measurements were made at the same time of the day, between 09:00-11:00 a.m.

The RMR assessment is an important methodological limitation of the studies which investigated the VO_2-HR relationships. The fasting period can influence the RMR reproducibility due to the thermic effect of food, and a minimum of 4 to 6h has been suggested [12]. With the exception of two studies [11,30], the available research adopted fasting periods of 1h [40,41] or 3h [10,18,23,32]. Two others did not report the fasting period [13,25]. The adoption of very different fasting periods [8h - resting $VO_{2standard}$ and 3 h – resting $VO_{2sitting}$ and resting $VO_{2standing}$] is justified considering one of the aims of the study: that is, to observe the influence of this issue on the RMR determination, and therefore, the VO_2R calculation. If significant differences were observed in the RMR value, the relationship between VO_2R and HRR would be affected. The choice of the two fasting periods was based on extensive methodological criteria previously proposed (in the case of the 8 h fasting) [12] and to the fasting period usually adopted by the studies comparing VO_2R-HR relationships (in the case of the 3 h period).

INSERT TABLE 1

Two incremental test protocols were used to determine maximal values of heart rate and VO_2. The ramp protocol incorporated workload increments that were individualized to elicit the subject's limit of tolerance within the test duration. A previous test used five participants_to determine the initial and final workloads in the ramp protocol, the purpose of which was to confirm that the duration of the exercise testing protocols fell within the range of 8-12 minutes [8]. Initially a non-exercise model developed to estimate the VO_{2max} of a healthy population aged 19 to 80 years was applied [24]. Based upon the predicted VO_{2max}, the final speed was calculated using the ACSM [2] equation [mean ± SD: 14.3±0.8 $km.h^{-1}$ for the five participants]. The workloads of 40 and 60% of the predicted VO_{2max} were then calculated, respectively, for the 3-minute warm-up period [mean ± SD: 5.6±0.3 $km.h^{-1}$ for the five participants] and for the initial test workload [mean ± SD: 8.5±0.5 $km.h^{-1}$ for the five participants]. The treadmill inclination was set at 1% as proposed elsewhere [19]. The results showed that the VO_{2max} estimated by the Mathews model [mean ± SD: 53.1±2.8 ml.kg^{-1}.min^{-1} for the five participants] was closer to the VO_{2max} obtained in the ramp protocol designed in this manner [mean ± SD: 52.6±4.6 ml.kg^{-1}.min^{-1} for the five participants]. The test duration test was also very close to the targeted range [mean ± SD: 11.0±1.0 min for the five participants], as expected with participants with similar characteristics to our sample.

Therefore the non-exercise model proposed by Mathews et al. [24] was considered appropriate to estimate the VO_{2max} and help design the ramp protocol. The workload increment for each subject was 0.8 km·h^{-1}/ 1 min. The predicted final speed for the whole sample was [mean ± SD] 14.0 ± 0.6 km·h^{-1}. When considering the whole sample, the mean ± SD workloads associated with 40% (warm-up period) and 60% (initial speed test) of the VO_{2max} were, respectively, 5.6 ± 0.2 km·h^{-1} and 8.0 ± 0.3 km·h^{-1}. The treadmill inclination was set at 1% throughout the tests [19]. Table 2 presents the actual values obtained for the peak treadmill speed and exercise test duration produced by the ramp protocols.

The Bruce protocol incorporated 3-min stages and workload increments of approximately 2 METs per stage, achieved by increasing both the speed and inclination of the treadmill until the subject reached the limit of his exercise tolerance [7].

Oxygen uptake (VO_2), pulmonary ventilation (V_E), carbon dioxide output (VCO_2), respiratory exchange rate (RER), heart rate (HR), and oxygen pulse (VO_2/HR) data were calculated, averaged, and recorded every 30 seconds. The 30-s time average provided a good compromise between removing noise from the VO_2 data while maintaining the underlying trend. Gas exchanges were assessed using a VO2000 analyzer (Medical Graphics, Saint Louis, MO, USA) and the heart rate using a cardiotachometer (Polar S-810, Kempele, Finland). The gas analyzers were calibrated with a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%), balanced with nitrogen. The flows and volumes of the pneumotachograph were calibrated with a syringe graduated for a 3 L capacity (Hans Rudolph, Kansas, MO, USA). The tests were considered as maximal if the participants satisfied at least three of the four following criteria: a) maximum voluntary exhaustion as measured by the Borg CR-10 scale; b) ≥ 90% predicted HR_{max} [220 – age] or presence of a HR plateau (ΔHR between two consecutive work rates ≤ 4 beats·min^{-1}); c) presence of a VO_2 plateau (ΔVO_2 between two consecutive work rates < 2.1 mL·kg^{-1}·min^{-1}); and d) a maximal respiratory exchange ratio (RER_{max}) > 1.1 [17]. The participants were verbally encouraged to provide a maximal effort [4]. Holding onto the side or front bars of the treadmill was not permitted.

Data analysis

Mean differences in resting VO_2 for the three methods of assessment (resting $VO_{2standard}$, resting $VO_{2sitting}$, and resting $VO_{2standing}$) were tested using a repeated measures one-way analysis of variance (ANOVA), followed by Tukey *post hoc* tests. The homogeneity of variance and normality assumptions were assessed using the Levene's test and Shapiro-Wilk's test, respectively. The VO_{2max} and HR_{max} obtained in the ramp and Bruce protocols were compared using the Student t-test for paired samples.

Five linear regression models per incremental test protocol (ramp and Bruce) were determined for each subject in order to compare the relationships between heart rate and VO_2: a) *%HR_{max} vs %VO_{2max}*; b) *%HRR vs %VO_{2max}; c) %HRR vs %$VO_2R_{standard}$; d)%HRR vs %$VO_2R_{sitting}$; e)%HRR vs %$VO_2R_{standing}$*. The values obtained at rest, and during maximal and submaximal exercise, were used as references to calculate %HR_{max}, %HRR, %VO_{2max} and %VO_2R according to the following equations: 1) %HR_{max} = HR_{submax}/HR_{max} x 100; 2) %HRR = (HR_{submax} – HR at rest) / (HR_{max} – HR at rest) x 100; 3) %VO_{2max} = $VO_{2submax}$/ VO_{2max} x 100; and 4) %VO_2R = ($VO_{2submax}$ – VO_2 at rest) / (VO_{2max} – VO_2 at rest) x 100. In these equations, HR_{max} refers to the maximal heart rate reached in the incremental test; the HR_{submax} refers to the heart rate obtained during the test at 30-s intervals (ramp protocol) and at the end of each stage (Bruce protocol); VO_{2max} refers to the maximal VO_2 reached in the incremental test; $VO_{2submax}$ refers to the VO_2 obtained during the test at 30-s intervals (ramp protocol) and at the end of each stage (Bruce protocol). The %VO_{2max} and %VO_2R were used as independent variables in the regression models.

The influence of the three assessment methods for resting VO_2 on the relationship between HRR and VO_2R was tested by comparing the values of the intercepts and slopes of the individual linear regressions for the %HRR *vs* %$VO_2R_{standard}$, %HRR *vs* %$VO_2R_{sitting}$, and %HRR *vs* %$VO_2R_{standing}$ relationships, using a repeated measures ANOVA followed by Tukey *post hoc* tests. The influence of the maximal exercise test protocol on the intercepts and slopes was tested using Student t-test for paired samples.

The individual linear regression models also were used to analyze the relationship between the percentages of HR_{max} corresponding to 40, 50, 60, 80 and 85% VO_{2max}. The Student t-test was used to compare the observed values with those proposed by the ACSM. Additionally, the percentages of HRR, corresponding to 30, 40, 50, 60, 70, 80 and 90% of the VO_2R and of the VO_{2max} were determined. The mean ± SD values of the intercepts and slopes were determined for each linear regression model and the Pearson correlation for each relationship was determined. 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 [40,41], and to test possible differences between the regression lines, as described in detail elsewhere [47]. Two-tailed statistical significance for all hypothesis tests was accepted as $p < 0.05$. All statistical analyses were performed using Statistica 6.0 for Windows software (Statsoft, Tulsa, OK, EUA).

Results

Cohen's d and the associated effect-size r were calculated considering the N = 33 and the conditions previously established for the sample estimation, (t-value = 1.696 and df = 31). Cohen's d was 0.61 and the effect-size r was 0.29 for a statistical power of 0.95 (1-beta). The mean ± SD (range) obtained for resting VO_2 standard, sitting and standing, were significantly different from each other ($p<0.001$) (Table 1). Table 2 shows the mean±SD values for cardiorespiratory variables (HR_{max}, VO_{2max}, V_E, VO_2/HR and RER) and time to exhaustion obtained in the ramp and Bruce incremental exercise test protocols. No significant difference was observed for the resting HR, HR_{max}, V_E, and RER. Statistical significance between test protocols was observed only for the difference in VO_{2max}, VO_2/HR and time to exhaustion ($p=0.002$).

Prediction of the %HR_{max} from the %VO_{2max}

The mean ± SD intercepts and slopes for the relationship between %HR_{max} and %VO_{2max} were: ramp protocol intercept 0.432 ± 0.090%, slope 0.583 ± 0.100%; Bruce protocol intercept 0.339 ± 0.090%, slope 0.667 ± 0.090%. The following prediction equations, r, r^2 and standard error of the estimate (SEE) were determined:

A. %HR_{max} = 0.583 (%VO_{2max}) + 0.432 (r = 0.972 ± 0.019; r^2 = 0.946 ± 0.037; SEE = 2%) [ramp protocol]

B. %HR_{max} = 0.667 (%VO_{2max}) + 0.339 (r = 0.986 ± 0.009; r^2 = 0.972 ± 0.019; SEE = 3%) [Bruce protocol]

The results for the estimation of the %HR_{max} from the %VO_{2max} are presented in Table 3. The values of the %HR_{max} obtained in the ramp and Bruce protocols for 40, 50, 60, 80 and 85% of the VO_{2max} were significantly different ($p<0.001$) from those recommended by the ACSM (except for 85% VO_{2max} for the Bruce protocol). From 40 to 85% VO_{2max}, significant differences ($p<0.001$) were observed between test protocols.

Prediction of %VO_{2max} and %VO_2R from %HRR

The mean ± SD for the intercepts and slopes from the individual linear regression models, calculated for the ramp and Bruce protocols, are shown in Table 4. No significant differences were observed between the mean values of the intercepts and slopes obtained from the two protocols, for the relationships between %HRR versus %$VO_2R_{standard}$, %HRR versus %$VO_2R_{sitting}$, and %HRR versus %$VO_2R_{standing}$. However, the mean values of the intercept and slope obtained from the individual linear regression models for the relationship between %HRR versus %VO_{2max} differed significantly ($p<0.001$).

In the ramp protocol, the mean values of the intercepts and slopes in all the studied relationships (except the slope for the relationship between %HRR versus %VO_{2max}) were significantly different from 0 ($p<0.01$) and 1 ($p<0.001$), respectively. In the Bruce protocol, no significant differences were observed for the mean values of the intercept (0) and slope (1) obtained from the individual linear regressions. However, the comparison between the ramp and Bruce protocols revealed significant differences for the intercepts and slopes from all the observed relationships ($p<0.001$).

Figure 1 presents the predicted values for the %VO_{2max} and %VO_2R in the ramp protocol, derived using the three approaches for assessing the resting VO_2. Both %VO_{2max} and %VO_2R were underestimated by the %HRR in all the assessment approaches. In fact, the relationships between %VO_{2max}, %$VO_2R_{standard}$, %$VO_2R_{sitting}$ and %$VO_2R_{standing}$ and %HRR were lower than the identity line throughout the full range of observed work rates ($p<0.001$). In any case, it is notable that the %HRR was closer to the %VO_{2max} than the %VO_2R, regardless of the assessment method for determining resting VO_2 (Figure 1). Significant differences between %VO_{2max} and the different VO_2R values were observed up to 80% HRR.

Figure 2 presents the predicted values for the %VO_{2max} and %VO_2R for the Bruce protocol. All the calculated relationships were very close to the identity line. Significant differences were found only between the methods of determining the intensity of effort by the VO_2. For example, up to 60% HRR, the %VO_{2max} and the %VO_2R [considering all resting VO_2 assessment methods] differed significantly from each other ($p<0.001$) (Figure 2). From 60-70% HRR significant differences between the methods were evident only for the %$VO_2R_{standing}$ ($p=0.008$). Above 70% HRR significant differences were no longer observed. Notably, the regression curves suggested that for the establishment of the investigated relationships, the Bruce protocol was better than the ramp protocol.

In Table 5, the values corresponding to the deciles of the HRR are presented as the percentage error (PE) associated with the $\%VO_{2max}$ and $\%VO_2R$ (standard, sitting and standing), respectively, for the ramp [A] and Bruce [B] protocols. The PE obtained in the ramp protocol was much larger than in the Bruce protocol. Regarding the influence of the different assessment methods for resting VO_2, the $\%VO_2R$ calculated based upon the resting $VO_{2sitting}$ and resting $VO_{2standing}$ resulted in a greater PE in comparison to the $\%VO_{2max}$ and $\%VO_2R_{standard}$, especially for exercise intensities below 50% HRR.

Discussion

The present study aimed to investigate the influence of different approaches to the assessment of the resting VO_2 and VO_{2max} on the relationship between the percentages of absolute and reserve HR and VO_2. The most important aspect of the study was to establish the extent of the errors in prescribing exercise intensity using the different methods in order to make a recommendation as to which methods should be used. The main findings were that the relationships between $\%HR_{max}$, %HRR, $\%VO_{2max}$ and $\%VO_2R$ were significantly influenced by the type of incremental test protocol (ramp or Bruce) used to explore these relationships.

Swain [42] stated that the %HRR is not equivalent to the $\%VO_{2max}$ because it does not take into consideration the resting VO_2, thereby resulting in an overestimation of the predicted exercise intensity. This would be especially true in participants_with poor physical fitness and at low exercise intensities. For instance, Swain and Leutholtz [41] described a simple mathematical transposition in which an average subject with a 10 MET capacity would be at 1 MET/10 MET or 10% of $\dot{V}O_{2max}$ at rest. Thus, there would be an error of 10 units between %HRR and $\%VO_{2max}$ at rest. A subject with a 20 MET capacity would have a 5% error while a subject with a 5 MET capacity would have a 20% error.

Our results disagreed with such a premise, at least for young, male, physically active participants. In our study, the %HRR was closer to the $\%VO_{2max}$, especially for the ramp protocol (as indicated by the PE). In the Bruce protocol, all the studied relationships were very close to the identity line, and there was no significant difference between the various methods of exercise intensity prescription by the VO_2 in relation to the %HRR. Therefore, the present study suggests that the $\%VO_{2max}$ should be used for aerobic exercise prescription instead of the $\%VO_2R$.

Compared to the ramp protocol, the Bruce protocol produced stronger VO_2-HR relationships. A possible explanation is that the 3-min stage duration in the Bruce protocol may have favored the stabilization of heart rate and VO_2, especially in the initial stages of the test, allowing a better approximation of these variables [14]. On the other hand, the VO_{2max} obtained in the Bruce protocol was significantly lower than for the ramp protocol. High treadmill inclinations and prolonged stage durations are associated with reduced VO_{2max} values, compared with shorter tests with low or moderate treadmill inclinations [26]. Therefore, a question arises: which of the results should be taken into account for more accurate exercise prescription? Would it be better to use the test protocol which produced the stronger relationship between heart rate and VO_2, or the protocol which obtained the highest VO_{2max}? Two issues may be considered to answer this question: a) the difference between the mean VO_{2max} values; and b) the standard error of the estimate (SEE) associated with the linear regression models. The Bruce protocol produced a lower VO_{2max} than the ramp protocol [4.2 $mL \cdot kg^{-1} \cdot min^{-1}$ difference], which corresponded to a relative error of 8%. However, the Bruce protocol had a higher SEE [5-6% vs 3% in the ramp test], corresponding to an absolute difference of 1.0 $mL \cdot kg^{-1} \cdot min^{-1}$ (Table 4). When these two values [difference between the values of VO_{2max} plus SEE] are considered together, the absolute total difference between the Bruce and ramp protocols was 5.2 $mL \cdot kg^{-1} \cdot min^{-1}$. For example, at 70% HRR a given participant would have a target HR of 167 $b.min^{-1}$ and a target VO_2 of 37.7 $mL \cdot kg^{-1} \cdot min^{-1}$ and 34.8 $mL \cdot kg^{-1} \cdot min^{-1}$ considering respectively the $\%VO_2R$ and $\%VO_{2max}$ methods. According to the ACSM equation [2] this would represent a running speed of 10.3 $km.h^{-1}$ and 9.4 $km.h^{-1}$ respectively. In other words, the exercise prescription based on the VO_{2max} obtained in the Bruce protocol may underestimate the workload for a given %HRR by 1 to 3 METs. It is notable that in the present example the resting VO_2 was directly assessed [resting $VO_{2standard}$] (Table 1). Thus, despite the stronger relationship between VO_2 and HR obtained from the Bruce protocol, the ramp protocol produced higher and more precise VO_{2max} values. Based on these findings the ramp protocol may be considered more accurate than the Bruce protocol for aerobic exercise prescription.

The influence of the resting VO_2 assessment was less marked. Although the mean resting VO_2 determined for each of the three methods (standard, sitting and standing) were all significantly different, these differences did not significantly affect the mean intercepts and slopes obtained from the individual linear regression models for the relationships between %HRR *vs.* $\%VO_2R_{standard}$, %HRR *vs.* $\%VO_2R_{sitting}$, and %HRR *vs.* $\%VO_2R_{standing}$, in either the ramp or Bruce protocol. However the %VO_2R calculated using the resting $VO_{2standard}$ data was closer to the %HRR than the %VO_2R determined using the resting $VO_{2sitting}$ and resting $VO_{2standing}$. These findings suggest that attending to the recommended methodological criteria for assessing resting VO_2 results in improved accuracy in the VO_2 reserve calculation. Such concern may be particularly important for sedentary or elderly populations, since previous research has shown that the resting VO_2 tends to be lower in participants_with low physical fitness [31,37] and probably declines with age [9,43,44]. Only a few studies observed the relationships between %HRR and %VO_2R in populations with low fitness and only two studies (using obese participants) satisfied the suggested minimum methodological criteria for the resting VO_2 determination [10,30]. The study by Mezzani et al. [25], which used chronic heart failure patients, did not satisfy any of the suggested minimum methodological criteria for resting VO_2 assessment, while Brawner et al. [6] did not measure the resting VO_2 of heart disease patients, but instead, adopted the reference value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$. However, the adoption of this reference value is not recommended. Previous studies have shown that the resting VO_2 may be overestimated by an average of 35%, and introduce errors of almost 2 $mL \cdot kg^{-1} \cdot min^{-1}$ for some individuals [9]. Savage et al. [34] assessed directly the resting VO_2 in a group of 109 (60 men and 49 women) overweight individuals with coronary heart disease. The mean VO_2 at rest was 2.6 ± 0.4 $mL \cdot kg^{-1} \cdot min^{-1}$. This value was 36% lower than the widely accepted value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (1MET) and was similar to that reported by Byrne et al. [9]. In the present study, which used physically active participants, the mean resting VO_2 was 3.0 ± 0.4 $mL \cdot kg^{-1} \cdot min^{-1}$ for the standard assessment. This equated to a difference of approximately 14% when compared to the widely accepted reference value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$, and introduced errors of up to 1.5 $mL \cdot kg^{-1} \cdot min^{-1}$.

The present study suggests that prescribing exercise intensity based on the relationships between heart rate and VO_2 is significantly influenced by the test methodology that was used. Another related issue concerns the stability of such relationships within the context of actual training. Most of the available studies calculated individual linear regressions from heart rate and VO_2 data derived from maximal incremental exercise testing protocols. In reality, aerobic training often involves, among other factors, relatively constant exercise intensity lasting between 20 to 60 min [2], or even longer, depending on the aim of the training. An important question is therefore: up to what point do the results obtained from linear regression analysis in different maximal incremental test protocols, reflect the results that would be observed during exercise conducive to effective exercise prescription? Would the relationships between the %HR_{max}, %HRR, %VO_{2max} and %VO_2R be similar in submaximal training protocols with different intensities and durations? In an attempt to address these questions, research concerned with the internal and external validity of the relationships between $\%HR_{max}$, %HRR, $\%VO_{2max}$ and $\%VO_2R$ is needed. First, the quality of the data used to calculate the regression equations, that is, HR_{max}, VO_{2max} and resting VO_2, should be more carefully considered. The influence of the exercise testing protocols should be further investigated for their sensitivity and accuracy to assess the VO_{2max} and HR_{max}. Moreover, minimum methodological criteria to assess resting VO_2 should be respected. Second, it seems necessary to evaluate the applicability of these relationships on actual training situations, which are characterized by different intensities and durations. It would be interesting to use the ACSM equations to prescribe walking or running speeds, or cycling power based on values of VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$) for a particular $\%VO_2R$, or using a $\%VO_2$ associated with a given HRR (bpm). It is not known how much the speeds or the power defined by the ACSM equations actually reproduce the $\%VO_2R$ or the $\%VO_{2max}$ intended for training. It is possible that these equations underestimate or overestimate the intensity which served as a basis for the exercise prescription. By assessing the respiratory gas exchanges during aerobic training it would be possible to check the extent to which the ACSM equations reproduce the targeted $\%VO_2R$ or $\%VO_{2max}$. One practical application of this information would be to compare the observed and estimated caloric expenditure during the training sessions.

Conclusion

In conclusion, the relationships between the $\%HR_{max}$, %HRR, $\%VO_{2max}$ and $\%VO_2R$ were affected by the type of exercise testing protocol. While the Bruce protocol produced stronger interclass relationships, the ramp protocol produced higher VO_{2max} values and smaller prediction errors. From a practical perspective, this latter issue seems to be more important and therefore the ramp protocol should be used to determine the VO_{2max} in the context of aerobic training. On the other hand, the present findings did not confirm the existing premise that the %HRR is equivalent to the $\%VO_2R$ and not to the $\%VO_{2max}$. The %HRR values were closer to the $\%VO_{2max}$ than to the $\%VO_2R$, irrespective of the VO_{2max} test protocol and resting VO_2 assessment strategy . Therefore aerobic exercise prescription should rely on the $\%VO_{2max}$-%HRR relationship rather than on $\%VO_2R$-%HRR relationship. As for the influence of the resting VO_2 on the relationship between %HRR and $\%VO_2R$, although no differences were observed between the VO_2R calculated using the different assessment approaches, the error between the %HRR and $\%VO_2R$ was reduced when the suggested minimum methodological criteria were applied [resting $VO_{2standard}$]. However, this latter point has little practical value within the context of the present paper, since %HRR values were closer to $\%VO_{2max}$ than to $\%VO_2R$. Our findings suggest that inappropriate methodology can cause errors in exercise prescription of up to 1-3 METs. Over the long term this amount of error could reduce the effectiveness of training programs in improving health and fitness, and certainly will reduce the accuracy of guidelines on employing exercise for improving public health. Additional research is needed to verify the applicability of the $\%HR_{max}$, %HRR, $\%VO_{2max}$ and $\%VO_2R$ relationships within the context of actual aerobic training, in different populations and for sub-maximal continuous exercise of different intensities and durations.

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Table 1. Resting VO_2 obtained by three different assessment strategies (standard, sitting and standing).

resting VO_2 assessment	**Mean ± SD (range)**
$VO_{2standard}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	3.0 ± 0.4 (2.0-3.8)*
$VO_{2sitting}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	3.7 ± 0.4 (2.7-4.7)*
$VO_{2standing}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	4.1 ± 0.4 (3.0-5.0)*

*Significant difference between the three assessment methods ($p<0.001$).

Table 2 Mean ± SD values for cardiorespiratory variables and time to exhaustion determined during ramp and Bruce incremental exercise test protocols.

Variables	**Ramp Protocol**	**Bruce Protocol**
Resting heart rate (beats·min^{-1})	67 ± 10	70 ± 9
Peak heart rate (beats·min^{-1})	191 ± 6	189 ± 5
VO_{2peak} (mL·kg^{-1}·min^{-1})	52.6 ± 4.1*	48.4 ± 4.0*
Minute ventilation (L·min^{-1})	94.3 ± 9.6	97.4 ± 11.0
Respiratory exchange ratio	1.05 ± 0.06	1.10 ± 0.10
VO_2/HR (mL·beats·min^{-1})	19.7 ± 2.3†	18.7 ± 2.2†
Peak treadmill velocity (km·h^{-1})	16.0 ± 1.0*	7.9 ± 0.7*
Time to exhaustion (min)	10.8 ± 1.5 *	15.1 ± 1.6 *

***** Significant difference between test protocols ($p<0.001$).
† Significant difference between test protocols ($p=0.002$).
HR = heart rate; VO_2 = oxygen uptake.

Table 3 A comparison of the percentages of maximal heart rate (%HR_{max}) associated with various percentages of maximal VO_2 (%VO_{2max}) reported by the American College of Sports Medicine (ACSM, 1990) and those obtained from the ramp and Bruce incremental exercise test protocols.

%VO_{2max}	**%HR_{max}**		
	ACSM's guidelines	**Ramp protocol**	**Bruce protocol**
40%	55%	66.5 ± 0.05*	60.6 ± 0.06*#
50%	62%	72.3 ± 0.04*	67.3 ± 0.05*#
60%	70%	78.2 ± 0.04*	74.0 ± 0.04*#
80%	85%	89.8 ± 0.02*	87.3 ± 0.03*#
85%	90%	92.7 ± 0.02*	90.6 ± 0.02#

***** Significant difference compared to the values reported by the ACSM ($p<0.001$).
# Significant difference compared to the values from the ramp protocol ($p<0.001$).

Table 4 Mean ± SD values for the Y intercept, slope, coefficient of determination (r^2) and standard error of the estimate (SEE) of the individual linear regression models obtained in the ramp and Bruce protocols for the %HRR and %VO_{2max}, %HRR and %$VO_2R_{standard}$, %HRR and %$VO_2R_{sitting}$, %HRR and %$VO_2R_{standing}$.

Relationship	Protocol	Y intercept	Slope	r^2	SEE (±)	
					%	$ml \cdot kg^{-1} \cdot min^{-1}$
%HRR vs. %VO_{2max}	Ramp	0.083 ± 0.122*	0.941 ± 0.136	0.946 ± 0.037	3%	1.6
	Bruce	-0.056 ± 0.118 †	1.066 ± 0.116 †	0.972 ± 0.019	5%	2.6
%HRR vs. %$VO_2R_{standard}$	Ramp	0.137 ± 0.111* #	0.887 ± 0.125‡	0.946 ± 0.037	3%	1.6
	Bruce	0.009 ± 0.112 †	0.999 ± 0.108 † #	0.972 ± 0.019	6%	2.7
%HRR vs. %$VO_2R_{sitting}$	Ramp	0.149 ± 0.110* #	0.875 ± 0.125‡	0.946 ± 0.037	3%	1.6
	Bruce	0.017 ± 0.105 †	0.988 ± 0.103 † #	0.975 ± 0.037	5%	2.6
%HRR vs. %$VO_2R_{standing}$	Ramp	0.156 ± 0.109* #	0.868 ± 0.124‡	0.946 ± 0.037	3%	1.6
	Bruce	0.027 ± 0.106 †	0.978 ± 0.103 † #	0.975 ± 0.018	5%	2.6

***** Intercept significantly different from zero (p=0.003).
‡ Slope significantly different from one (p<0.001).
† Significant difference (p<0.001) compared to ramp protocol.
# Significant difference compared to the value obtained from the relationship between %HRR vs. %VO_{2max} (p<0.001).
HRR = heart rate reserve; VO_2R = oxygen uptake reserve.

Table 5 Mean ±SD percentages of VO_{2max} and VO_2 reserve (%VO_2R) associated with different percentages of heart rate reserve (%HRR) determined during the [A] ramp protocol and [B] Bruce protocol. The $VO_2R_{standard}$, $VO_2R_{sitting}$ and $VO_2R_{standing}$ refer to VO_2 reserve calculated with three different methods of determining resting VO_2.

Relationship	**%HRR**						
	30%	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
[A] Ramp protocol							
%VO_{2max}	21.9 ± 0.09	32.7 ± 0.08	43.5 ± 0.06	54.4 ± 0.05	65.2 ± 0.04	76.0 ± 0.04	86.8 ± 0.03
PE	*-27%*	*-18%*	*-13%*	*-9%*	*-7%*	*-5%*	*-4%*
%$VO_2R_{standard}$	17.3 ± 0.09	28.8 ± 0.08	40.2 ± 0.07	51.7 ± 0.05	63.2 ± 0.04	74.6 ± 0.04	86.1 ± 0.03
PE	*-42%*	*-28%*	*-20%*	*-14%*	*-10%*	*-7%*	*-4%*
%$VO_2R_{sitting}$	16.2 ± 0.09	27.8 ± 0.08	39.4 ± 0.07	51.0 ± 0.05	62.7 ± 0.04	74.3 ± 0.04	85.9 ± 0.03
PE	*-46%*	*-31%*	*-21%*	*-15%*	*-10%*	*-7%*	*-5%*
%$VO_2R_{standing}$	15.4 ± 0.09	27.1 ± 0.08	38.9 ± 0.07	50.6 ± 0.05	62.3 ± 0.04	74.0 ± 0.04	85.7 ± 0.03
PE	*-49%*	*-32%*	*-22%*	*-16%*	*-11%*	*-7%*	*-5%*
[B] Bruce protocol							
%VO_{2max}	32.6 ± 0.08	42.1 ± 0.07	51.6 ± 0.06	61.1± 0.05	70.6 ± 0.04	80.1 ± 0.04	89.6 ± 0.03
PE	*9%*	*5%*	*3%*	*2%*	*1%*	*0%*	*0%*
%$VO_2R_{standard}$	28.3 ± 0.06	38.4 ± 0.08	48.5 ± 0.07	58.6 ± 0.06	68.8 ± 0.05	78.9 ± 0.04	89.0 ± 0.03
PE	*-6%*	*-4%*	*-3%*	*-2%*	*-2%*	*-1%*	*-1%*
%$VO_2R_{sitting}$	27.9 ± 0.08	38.1 ± 0.07	48.4 ± 0.06	58.6 ± 0.05	68.8 ± 0.04	79.0 ± 0.04	89.3 ± 0.03
PE	*-7%*	*-5%*	*-3%*	*-2%*	*-2%*	*-1%*	*-1%*
%$VO_2R_{standing}$	27.1 ± 0.08	37.5 ± 0.07	47.8 ± 0.06	58.2 ± 0.05	68.5 ± 0.05	78.8 ± 0.04	89.2 ± 0.03
PE	*-10%*	*-6%*	*-4%*	*-3%*	*-2%*	*-1%*	*-1%*

PE = percentage error.

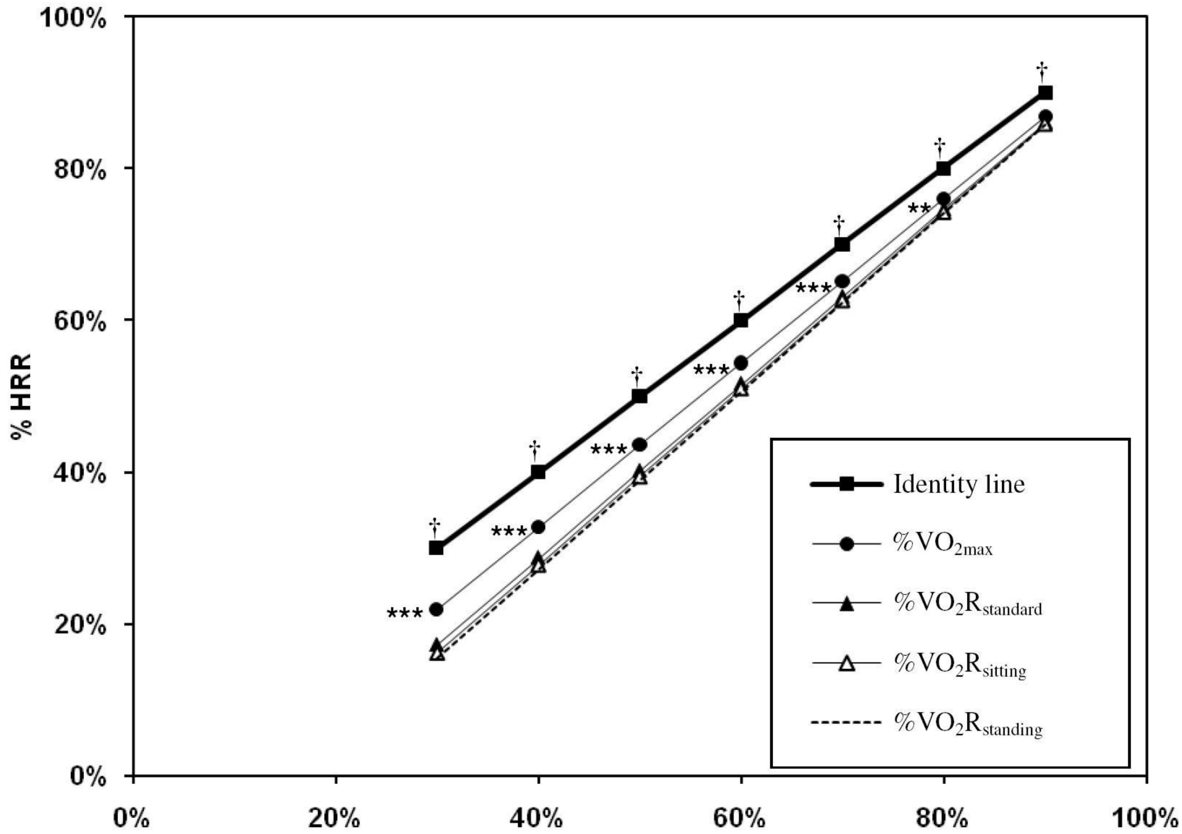

Fig. 1 Linear regression curves between the predicted values of $\%VO_{2max}$ and $\%VO_2R$ (standard, sitting and standing) at a given value of %HRR obtained in the ramp protocol. **†** Significant difference between %HRR and $\%VO_{2max}$ - $\%VO_2R$ (standard, sitting and standing) ($p<0.001$). ***** Significant difference between $\%VO_{2max}$ and $\%VO_2R$ (standard, sitting and standing) ($p<0.001$). **** Significant difference between $\%VO_{2max}$ and $\%VO_2R_{standing}$ ($p=0.01$).

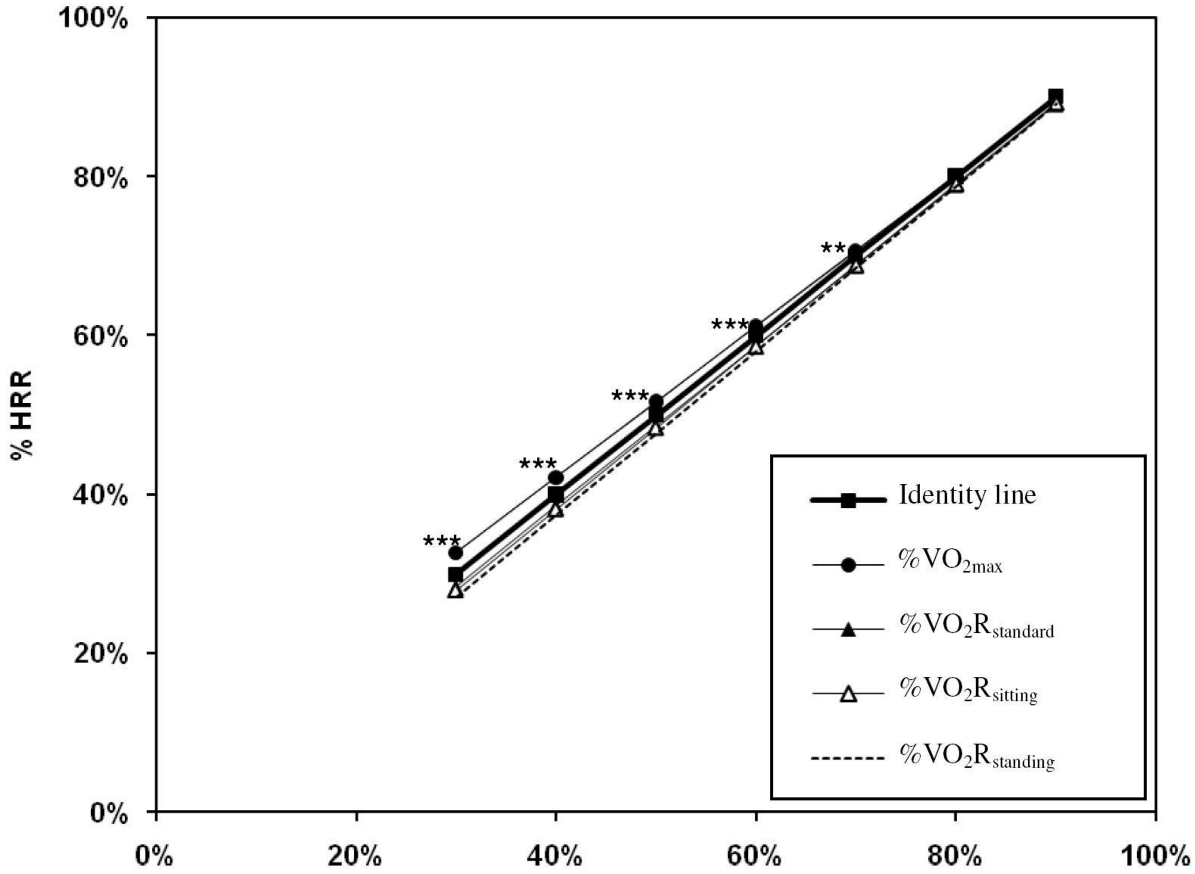

Fig. 2 Linear regression curves between the predicted values of $\%VO_{2max}$ and $\%VO_2R$ (standard, sitting and standing) at a given value of %HRR obtained by means of the Bruce protocol. ******* Significant difference between $\%VO_{2max}$ and $\%VO_2R$ (standard, sitting and standing) ($p<0.001$).******Significant difference between $\%VO_{2max}$ and $\%VO_2R_{standing}$ ($p=0.008$).