Original Article

Effects of the State and Specificity of Aerobic Training on the $\%VO_2max$ versus %HRmax Ratio During Cycling

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Objective

To determine the effects of the status and specificity of exercise training in the ratio between maximum oxygen consumption ($\%VO_2max$) and the percentage of maximal heart rate (%HRmax) during incremental exercise on a cycle ergometer.

Methods

Seven runners, 9 cyclists, 11 triathletes, and 12 sedentary individuals, all male and apparently healthy, underwent exhaustive incremental exercise on cycle ergometers. Linear regressions between $\%VO_2max$ x %HRmax were determined for each individual. Based on these regressions, %HRmax was assessed corresponding to a determined $\%VO_2max$ (50, 60, 70, 80, and 90%) from each participant.

Results

Significant differences were not found between the groups in %HRmax for each of the $\%VO_2max$ assessed. Analyzing the volunteers as a single group, the average of the corresponding %HRmax to 50, 60, 70, 80, and 90% $\%VO_2max$ were 67, 73, 80, 87, and 93%, respectively.

Conclusion

The ratio between $\%VO_2max$ and %HRmax in the groups assessed during incremental exercise on the bicycle is not dependent on the status and specificity of aerobic exercise training.

Key words

oxygen consumption, heart rate, exercise prescription, training status, cycling

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A training program aiming at enhancing cardiac respiratory performance (maximum aerobic power) comprises 3 basic features: frequency (number of sessions per week), volume (duration), and exercise intensity. Duration and frequency are variables that are relatively easily monitored with consensus in the literature regarding their application. On the other hand, several ways exist to monitor exercise intensity [1-3], and a balance must be considered to regard these methods as valid, applicable, and practical. For the development of cardiorespiratory fitness in apparently healthy individuals, the regular practice of exercising (3 to 5 times a week) involving major muscle groups has been recommended, at an intensity of 60-80% of maximal oxygen consumption (VO_2max) [1].

Many studies have determined that heart rate (HR) and oxygen consumption (VO_2) are linearly related to submaximal exercise intensity [4]. Based on this relation, linear regression between VO_2max ($\%VO_2max$) percentages and maximum heart rate (%HRmax) have been proposed and can be useful for prescribing exercise intensity. The use of these equations enables the prescription of exercise intensity based on the %HRmax, instead of $\%VO_2max$, which demands complicated and expensive gas analysis.

Because of their facility, these regressions have been widely used and recommended, and their specificity is often ignored. The effort to achieve the determined goal may be extremely different from that expected. For example, Londeree and cols [5] verified that the exercise modality may influence the $\%VO_2max$ x %HRmax ratio and found that the exercises performed in an upright position and with body weight support (running, skiing) had similar regressions. However, exercises performed without body weight support (cycling, rowing) using superior limbs (rowing and arm ergometer) may require specific equations to reduce the error on prediction of exercise intensity. Likewise, Swain and cols [6] verified that aerobic endurance (assessed by VO_2max) may change the $\%VO_2max$ x %HRmax ratio during running. In this study, individuals with greater aerobic endurance had higher %HRmax than those with lower endurance during submaximal exercise (40 – 80% VO_2max) for a given $\%VO_2max$.

Another potential limitation in using the various equations found in the literature is their structure [6]. The majority of these equations, used %HRmax as an independent variable (x-axis) in the linear regression [5,7]. This is a questionable choice, because VO_2 is clearly the determining factor of the heart rate response during exercise. Additionally, if %HRmax is chosen as an independent variable, the equation obtained cannot be used to predict %HRmax for a given $\%VO_2max$, because this procedure requires a transposition of the equation. Transposition of a linear regression does not result in the same values that would have been obtained if the dependent and independent variables were inverted.

Cycling is one of the most commonly used exercises for clinical evaluation of patients and for the development of cardiorespiratory endurance. In this type of exercise, the use of major muscle groups is associated with reduced impact in the joints. These aspects are important for obese individuals who need to enhance cardiorespiratory endurance and lose fat mass, and also for athletes who need to maintain aerobic endurance (runners and players of group sports), who may be temporarily unable to perform their specific function (run). To our knowledge, no studies exist that assess the %VO_2max x %HRmax ratio during cycling in individuals with different degrees of aerobic endurance, using %VO_2max as an independent variable. Thus, our objective was to determine the effects of the status and specificity of aerobic training on the %VO_2max x %HRmax ratio during incremental exercise performed using a cycle ergometer. Knowledge of these ratios may be relevant for prescribing suitable exercise intensity for a certain population.

Methods

Seven runners (RUN) (25.8 ± 6.0 years old, 60.4 ± 4.1 kg, 172.1 ± 6.9 cm), 9 cyclists (CIC) (22.6 ± 2.1 years old, 62.8 ± 5.4 kg, 173.8 ± 5.9 cm), and 11 triathletes well trained in racing (TRI) (21.4 ± 4.1 years old; 66.2 ± 7.0 kg; 174.2 ± 8.4 cm), and 12 sedentary individuals (SED) (26.8 ± 4.1 years old, 74.9 ± 14.3 kg, 175.1 ± 5.1 cm) took part in the study. All individuals were male and apparently healthy. Athletes had at least 2 years of practice in the modality. Each volunteer was informed about the procedures and implications of the experiment, and gave their written consent. The protocol was approved by the ethics committee of the institution.

Subjects were instructed to come to the tests rested, fed, and hydrated, and to refrain from intense effort in the preceding 48 hours. Tests were performed in the same place and at the same hour of the day (± 2PM), with room temperature controlled at 21-22ºC. Cycling tests were performed on a mechanical ergometer bicycle (Monark), with speed maintained at 70 rpm throughout the test. Cardiorespiratory variables (VO_2, VCO_2, VE, and HR) were assessed using a gas analyzer (Cosmed K4b^2, Rome, Italy), collection data at each breath, and then transformed for an average of 20s. Heart rate was monitored through a heart rate monitor (Polar, Kempele, Finland) linked to the gas analyzer. This analyzer was previously validated at several exercise intensities [8]. Before each test, the analysis systems of O_2 and CO_2 were calibrated using room air and a gas with known concentrations of O_2 and CO_2, whereas the bi-directional turbine (flow meter) was calibrated using a 3-L syringe (Cosmed K4b^2, Rome, Italy).

The continuous progressive test had a 105 W initial load for cyclists and triathletes and 70 W for the remaining individuals, and 35 W increase each 3 minutes until voluntary fatigue, or when the subject could no longer maintain > 65 rpm. At the end of each stage, 25 µl of blood from the earlobe was collected to determine blood lactate concentration (YSL 2300 STAT, Ohio, USA). Lactate concentration obtained at the end of the progressive test was considered the lactate peak (peak[LAC]). The highest VO_2 and HR obtained during 20s were considered the VO_2max and HRmax, respectively. All subjects met at least 2 to 3 criteria for VO_2max: 1) respiratory exchange ratio (R) ≥ 1.1; 2) lactate concentration > 8 mM, and; 3) HRmax at least equal to 90% of the maximum predicted for the age [9].

VO_2 and heart rate obtained in the final 20 seconds of each load were expressed as the percentage of their maximum. Linear regressions were performed for each individual using the pairs of points of the end of each stage and of their maximum (100%), using %VO_2max as an independent variable. Through individual linear regression, HRmax percentage corresponding to 50%, 60%, 70%, 80%, and 90% of VO_2max were determined for each individual.

All data were expressed as mean ± SD. VO_2max and HRmax values, R and lactate were assessed using one-way variance analysis together with Scheffé's test. Comparison between the groups of %HRmax values corresponding to %VO_2max was performed using the Kruskal-Wallis' test. In all tests, a $P \leq 0.05$ significance level was adopted.

Results

Table I presents maximum VO_2, HR, R, and blood lactate values, obtained at the end of the incremental test performed on the cycle ergometer. Cyclists had VO_2max values significantly greater compared with those in the other groups ($P < 0.05$). The runners and triathletes had no differences between each other (P=0.99). As expected, sedentary individuals had the lowest VO_2max values ($P<0.0001$). HRmax of cyclists and sedentary individuals were similar (P = 0.55), however significantly greater in the groups of runners and triathletes ($P < 0.04$) that were also similar to each other (P = 0.99). Differences for peak[LAC] and R were not observed among the groups assessed ($P > 0.23$).

HRmax percentages obtained in the 4 groups of individuals in the different VO_2max percentage are in Table II. No significant differences existed among the groups regarding %HRmax for each %VO_2max assessed ($P > 0.58$). Means (± SD) of the linear regressions of groups were sedentary individuals - %HRmax = (0.68 ± 0.11)%VO_2max + (31.9 ± 11.0), with r^2 = 0.98 ± 0.1; triathletes - %HRmax = (0.65 ± 0.08)%VO_2max + (35.3 ± 8.3), with r^2 = 0.97 ± 0.2; cyclists - %HRmax = (0.66 ± 0.04) %VO_2max + (34.3 ± 3.3), with r^2 = 0.97 ± 0.1; runners - %HRmax = (0.70 ± 0.07)%VO_2max + (31.3 ± 7.5), with r^2 = 0.97 ± 0.1. Figure 1 demonstrates the mean linear regressions of the 39 individuals in the study.

Discussion

This study is the first to assess the effects of the status and specificity of aerobic training on the %VO_2max x %HRmax ratio during incremental exercise during cycling. Contrary to that previously reported by Swain and cols [6] during exercise performed in running, in our study we have verified that the %VO_2max x %HRmax ratio is independent of aerobic training status or specificity.

VO_2max values of our individuals are similar to those values reported in the literature for the profile of individuals assessed in this study [10-12]. Observing VO_2max values in our athletes, although we did not interfere with the training, we may assume that they have gone through the adaptations of a long-term aerobic training[11].

Table I - Mean values ± standard deviation of maximum oxygen consumption (VO$_2$max), maximum heart rate (HRmax), respiratory exchange ratio (R), and peak lactate (peak[LAC]) obtained during incremental testing

	VO$_2$max (ml/kg.min^{-1})	HRmax (bpm)	R	peak[LAC] (mM)
Runners (n= 7)	62.0 ± 5.0[b]	181.0 ± 14.3[b]	1.07 ± 0.05	9.5 ± 2.2
Cyclists (n= 9)	67.6 ± 7.6	191.0 ± 8.4	1.14 ± 0.04	10.1 ± 1.8
Triathletes (n= 11)	61.1 ± 5.1[b]	183.0 ± 7.0[b]	1.15 ± 0.05	9.0 ± 1.6
Sedentary individuals (n= 12)	38.0 ± 6.2[a]	187.5 ± 7.6	1.16 ± 0.05	10.3 ± 1.3

[a] $P < 0.05$ regarding all groups,[b] $P < 0.05$ regarding cyclists.

Table II – Mean values ± standard deviation of the percentage of maximum heart rate (%) corresponding to each of the percentages of the maximum oxygen consumption (%VO$_2$max) (50 – 90%)

%VO$_2$max	50%	60%	70%	80%	90%
Runners (n= 7)	66.3 ± 3.9	73.2 ± 3.2	80.2 ± 2.6	87.2 ± 1.99	94.2 ± 1.4
Cyclists (n= 9)	67.5 ± 2.9	74.1 ± 1.9	80.8 ± 1.8	87.4 ± 1.8	94.0 ± 1.8
Triathletes (n= 11)	68.0 ± 4.6	74.5 ± 4.0	81.0 ± 3.4	87.6 ± 2.9	94.1 ± 2.5
Sedentary (n= 12)	65.9 ± 6.0	72.7 ± 4.9	79.5 ± 3.9	86.3 ± 2.9	93.1 ± 2.1

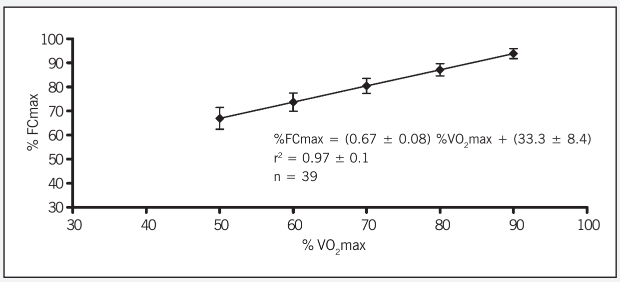

Fig. 1 - Mean linear regressions between percentage of maximum oxygen consumption (%VO$_2$max) and maximum heart rate (%HRmax) of the 39 individuals in the study.

As expected, cyclists had the highest VO$_2$max values. On the other hand, it is important to point out that the great transference of aerobic power (VO$_2$max) was demonstrated by runners, once their values were similar to those of the triathletes, and greatly superior to those of the sedentary individuals.

The %VO$_2$max and %HRmax ratio has been widely investigated, with other studies assessing the effects of the type of exercise [5], sex [6], cardiovascular disease [13], obesity [14], and level of aerobic endurance [6]. Swain and cols [6] stress that the majority of these studies used %HRmax as an independent variable to determine linear regression, which may therefore increase, mispredicting exercise intensity. In our study, we opted to use %VO$_2$max as an independent variable, enabling %HRmax prediction aiming at prescribing exercise intensity.

The influence of the status and specificity of aerobic training in predictive %HRmax for all %VO$_2$max (50 to 90) was not observed in this study. These data are different from those obtained by Swain and cols [6], who found a small (2%), however, significant, influence of aerobic endurance on the %VO$_2$max x %HRmax ratio. The individuals with greater endurance had a greater %HRmax than those with lower endurance for a given %VO$_2$max. In our study, the difference in aerobic endurance level may be considered greater (VO$_2$max - CIC = 67 mL.kg.min^{-1} vs. SED = 38 mL.kg.min ^{1}) than the difference (VO$_2$max – greater endurance = 59 mL.kg.min^{-1} vs. lower endurance = 41 mL.kg.min^{-1}) reported by Swain and cols [6], and this aspect probably cannot explain the differences between the studies. A possible explanation would be that the effect of aerobic endurance in the %VO$_2$max x %HRmax ratio, may depend on the type of exercise assessed, because in the Swain and cols' study[6] running was on a treadmill, and in the present study a cycle ergometer was used. Several studies have verified that the physiologic responses to exercise (maximum and submaximum) may depend on the interaction between the type of exercise (running x cycling) and the status and specificity of training [15]. In part confirming this hypothesis, Londeree and cols [5] verified that the %VO$_2$max x %HRmax ratio may be different between weight-bearing exercises (running) and nonweight-bearing exercises (cycling).

Use of linear regression data (VO$_2$ and HR) obtained during incremental testing for the prediction of %HRmax may introduce at least 2 biases. The first, is that the ratio between %VO$_2$max x %HRmax is not strictly linear, particularly in high effort intensities (> 90%VO$_2$max). Although the addition of a least square in the regression analysis could have been more appropriate, this procedure increases the prediction error (7%) in moderate effort intensity [5]. Because most %HRmax prediction is performed at mild to moderate intensity (40 – 80%VO$_2$max), linear regression seems to be more appropriate. Anyway, each subject (regardless of the group) had a determining coefficient between %VO$_2$max and %HRmax above 0.95, and the whole group had a 0.97 mean value. Based on the Standard Estimate Error (SEE) of the regressions of each subject, a 3 to 4% error may be expected in the %HRmax prediction. The second aspect to be considered is the presence or absence of stable phases in the VO$_2$ values and heart rate during incremental testing. To minimize this problem, we used a protocol with 3-min stages, using only mean values of the 20 final seconds of each load to derive the equation. Data from the literature demonstrate these duration approaches to the values obtained in exercise of constant load performed for a greater period [16]. Still in this regard, the %VO$_2$max x %HRmax ratio obtained during incremental exercises must be observed, and it may vary during constant load exercise. In this type of exercise, both the cardiac frequency, because of the termoregulator aspects (cardiovascular deviation) [17], and VO$_2$, due to the presence of a slow component in the exercises above the lactate threshold, that is, heavy to severe exercise [18], may not be stable over time.

Finally, special attention must be paid to the possible effects of cycling on the HRmax values. Although no difference exists in age in the groups, HRmax was significantly higher in cyclists than in runners or triathletes. Although we did not compare HRmax between running and cycling in our study, several studies have found significantly higher values in running than in cycling in sedentary [15], and active [5] individuals, and in endurance runners [15,19]. In cyclists, HRmax has not been different between running and cycling [15,19]. Thus, the use of certain regressions, eg, HRmax = 220 – age, or HRmax = 208 – 0.7 x age [20] to estimate HRmax indirectly in the cycle ergometer for individuals who are not cyclists should be carefully done. Using these equations potentially increases %HRmax prediction error, and therefore, the exercise intensity. Thus, a high-accuracy level is recommended, and if possible (clinical conditions, time available, and equipment), HRmax should be directly determined for each individual.

Based on these results, we conclude that for assessed groups, %VO_2max and %HRmax ratio during incremental exercise on the bicycle is not dependent on the status and specificity of the aerobic training. However, further studies are necessary to assess this ratio in different populations with different characteristics (age, sex, sports modality) and/or who take medication that may interfere with the cardiovascular and metabolic response during exercise.

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