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NEW EQUATIONS TO DETERMINE EXERCISE INTENSITY USING DIFFERENT EXERCISE MODES

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ABSTRACT: The purpose of this study was to determine new equations from the relationship of $\%\dot{V}O_{2max}$ versus %HRmax, based on direct measures of oxygen uptake, in four exercise modes (leg cycling, rowing, stepping and running), in young adult females and males with low risk for cardiovascular disease. Ten adult males and ten females volunteered for the study. The participants performed an incremental test for each exercise mode until exhaustion. Regression analyses were carried out for each participant at a target % of VO2max and %HRmax was computed. At 40-90% $\dot{V}O_{2max}$, the regression equations predicted similar values of %HRmax for males and females in the four exercise modes. In contrast, estimated %HRmax for cycling was higher at 40-70% $\dot{V}O_{2max}$, when compared with stepping and running. The results support the notion that a single equation to predict target heart rate values for both males and females can be applied. Furthermore, at light and moderate intensities, leg cycling produces different $\%\dot{V}O_{2max}$-%HRmax regression equations than stepping and running.

KEY WORDS: regression equation, oxygen uptake, heart rate, exercise modes

INTRODUCTION

Percentage of maximal heart rate ($\%HR_{max}$) is useful for setting heart rate (HR) target values permitting the accurate prescription of exercise intensity for cardiorespiratory fitness in young adults. Accordingly, the classification of physical activity and training intensity based on $\%HR_{max}$ is generally supported [1,11,17,25]. Prediction of $\%HR_{max}$, from regression equations between percent of maximal oxygen uptake ($\%\dot{V}O_{2max}$) and $\%HR_{max}$, has the advantage of only requiring the measurement of maximal heart rate (HR_{max}). However, as noted by Skinner and colleagues [21], some factors, such as level of physical training, may contribute to the individual variation in the relationship between $\%HR_{max}$ and $\%\dot{V}O_{2max}$. One way to ensure greater accuracy in predicting target heart rate (HR) values is to use values of both HR and oxygen uptake ($\dot{V}O_2$), developing individual regressions for each participant in each protocol [22,23].

Previous studies with males have examined relations between $\%\dot{V}O_{2max}$ and $\%HR_{max}$, but few have analysed this relationship in women [9,22]. Given the documented sex-related differences in the physiological response to the physical exercise [8,26], there is good reason to believe that relations between the heart rate and the oxygen uptake might vary by sex. Relations between $\%\dot{V}O_{2max}$ and $\%HR_{max}$ might also vary with exercise mode. Different modes of exercise require different body positions and systolic volumes, stimulating differently the ability to utilize oxygen. At present, however, the majority of the studies that have examined the relationship between $\%\dot{V}O_{2max}$ and $\%HR_{max}$ have only used one [7,9,15,16,22,] or two exercise modes [5,10]. To our knowledge, this study is the first to focus, in both women and men, on four widely used modes of exercise in fitness facilities. Furthermore, the majority of studies have attempted to predict $\%\dot{V}O_{2max}$ rather than $\%HR_{max}$, using $\%HR_{max}$ as a predictor variable [7,9,13,14,16,19] projecting a target value for $\%HR_{max}$ at a given $\%\dot{V}O_{2max}$, and then transposing the equation. As noted by Swain and colleagues [22], this procedure could generate different values compared to those obtained from the regressions performed with $\%\dot{V}O_{2max}$ as the independent variable and $\%HR_{max}$ as the dependent variable.

In accordance with the presented ideas, we believe that there is a need to reinvestigate the relationship between $\%\dot{V}O_{2max}$ and $\%HR_{max}$, with particular emphasis on the potential moderating effects of sex and exercise mode. Thus, the purpose of the current study is to determine the relationship of %$\dot{V}O_{2max}$ versus %HR_{max}, based on direct measures of oxygen uptake, in four exercise modes (leg cycling, rowing, stepping and running), in young adult males and females with low risk for cardiovascular disease.

MATERIALS AND METHODS

Participants. Ten adult females and ten adult males (19–25 yr), with low cardiovascular risk [1], volunteered to participate in this study. All participants were recruited from within the university community through advertisements and word of mouth. Written informed consent was obtained after each participant was fully informed of the purpose and requirements of the current study. A series of clinical interviews and examinations eliminated any participants with absolute or relative contraindications to these tests [1]. All participants were familiar with the protocols and materials used for the current study, and had at least 3 hours per week of practice in these exercise modes. The participants' characteristics are presented in Table 1. The experimental work was in accordance with the Declaration of Helsinki, and was approved by the Scientific and Ethical Committees of the Faculty of Human Kinetics at the Technical University of Lisbon.

Pre-test procedures

Before testing, participants were questioned about their weekly physical activity. Each participant's height and weight (one layer of clothes, and no shoes) were measured via a stadiometer and a standard physician's scale, respectively. Percentage of body fat was estimated from the sum of skinfolds by means of a Slim Guide caliper, using the three sites (triceps, abdomen and suprailiac for women; abdomen, suprailiac and triceps for men) and equations derived by Jackson and Pollock [12]. Resting blood pressure was measured, in a sitting position, by the auscultation method.

Each participant performed an experimental session in each of the four tests: running, stepping, rowing, and leg cycling. Participants were asked to abstain from any arduous physical activities for 24 hours before testing and from the consumption of any stimulants such as caffeine, tobacco, alcohol, or any other drugs that could influence heart rate. Participants were asked to ingest the last meal at least 3 hours before the start of each test. Environmental conditions (temperature, relative humidity, and atmospheric pressure) were maintained constant during each of the four protocols.

TABLE 1. CHARACTERISTICS OF PARTICIPANTS (MEAN VALUES ± SD)

	Women	Men
Age (yr)	21 ± 2	22 ± 2
Height (cm)	163 ± 7	175 ± 4**
Body mass index ($kg \cdot m^{-2}$)	22.1 ± 1.6	23.6 ± 2.0
Body weight (kg)	58.8 ± 6.7	72.4 ± 7.6**
Body fat (%)	17 ± 2	8 ± 2**
Systolic blood pressure (mm · Hg)	119 ± 13	132 ± 15
Diastolic blood pressure (mm · Hg)	73 ± 8	71 ± 10
Physical Activity ($h \cdot week^{-1}$)	5.8 ± 1.8	6.3 ± 3.6

Note: ** Sex differences ($p<0.01$)

Maximal protocols

Each participant performed four incremental exercise tests (running, stepping, leg cycling and rowing) in 3-min stages until exhaustion. The stepper and the rower protocols were developed after extensive pilot work, and were designed to allow subjects to reach exhaustion between 8 and 17 minutes [5]. The rowing protocol used an electric rowing machine (Concept 2C, Vermont, USA), and the first stage began at 60 W, which was increased by 40 W · 3 min^{-1}, with a rowing rate of 30 strokes · min^{-1}. The stepping protocol consisted of a single stage and used a box 35 cm high, with the test requiring participants to step up and down at an initial rate of 20 cycles · min^{-1} to a four beat count, which was increased by 20 steps · min^{-1} per stage. Two digital metronomes (Seiko, model DM-10, NJ, USA) controlled step rate. The running protocol [4] used a motorized treadmill (TechnoGym RunRace HC1400, Gambettola, Italy). The test stared with 1.7 mph and the workload was increased every 3 min by changing both the percentage grade and speed, by 2% and 0.8 mph respectively. The cycling protocol [3] used an electrically braked and calibrated bicycle ergometer (Monark 829E, Varberg, Sweden), and started with an initial power output of 50 W for women and 100 W for men, at 50 rpm, increasing by 25 W (women) and 50 W (men) every 3 min from rest until exhaustion.

Participants were fitted with a mouthpiece (CORTEX Face Mask, Leipzig, Germany), and HR monitor (Sport-tester PE4000, Polar Electro, Kempele, Finland). The sequence of tests was randomly assigned, and a minimum interval of 72 hours elapsed between tests, with the participants being requested to wear "light" clothes. Selected criteria for a valid maximal test included i) heart rate within 10 beats of the age predicted value (HR_{max} = 208 – age x 0.7 [24], and/or ii) respiratory exchange ratio (RER) of at least 1.10. If the criteria were not reached, the test was repeated on a different day. Individuals were verbally encouraged to exercise until their volitional maximums. Protocols were terminated either voluntarily by the participant, or when the cadence of the test could not be maintained. This was followed by 2–3 min of active cooldown. Maximal oxygen consumption was defined as the highest $\dot{V}O_2$ obtained over any continuous 60-s time period provided that criteria mentioned above were met. Similarly, maximal heart rate was defined as the highest value recorded over any continuous 60-s period during the protocol. HR was monitored continuously and recorded every 10 seconds. Ventilation, oxygen consumption, carbon dioxide production, and respiratory exchange ratio were analysed using a computer-interfaced system and calculated for every 10-s period of exercise by a portable Cortex Metamax CBS (Leipzig, Germany) over a breath-by-breath measurement. The gas analyser was connected to a computer that used Metamax Capture and Metamax Analysis software. Each 10-s period HR and $\dot{V}O_2$ were then expressed as percentage of the highest values obtained during the protocol.

Statistical analysis

A series of repeated measure univariate analyses of variance (ANOVA) were conducted to determine the possible influence of sex or exercise mode on $\dot{V}O_{2max}$, HR_{max}, and RER_{max}. One independent factor (i.e., sex) and 4 within-subject levels (i.e., exercise modes) were considered. The same procedure was used to compare $\%HR_{max}$ values obtained by each participant, at the four designated percentages of $\dot{V}O_{2max}$, and to compare slopes and intercepts for each exercise mode. All multiple comparisons were performed with *post-hoc* Bonferroni test. Linear regressions were developed for each participant, and for each exercise mode, using paired data points above 120 beats/min of HR, with $\dot{V}O_2$ as the independent variable. The $\%HR_{max}$ values corresponding to 40%, 60%, 70%, 80%, and 90% $\dot{V}O_{2max}$ were estimated for women and men, using individual linear regressions. A level of $p<0.05$ was accepted as significant.

RESULTS

Values of $\dot{V}O_{2max}$ and HR_{max} were within the expected interval [1], for all four exercise modes, in males and females (Table 2). The males had higher $\dot{V}O_{2max}$ than the females in all four modes of exercise. Similarly, males demonstrated higher HR_{max} in leg cycling and running, and had similar RER_{max} in all modes. In females, higher values of $\dot{V}O_{2max}$ were registered in running and stepping compared to leg cycling, and in running compared to rowing. In males, $\dot{V}O_{2max}$ was higher in running compared to leg cycling and to rowing. In females, HR_{max} was highest in stepping followed by running, rowing, and cycling, respectively. In males, HR_{max} was higher only in running compared to leg cycling.

The mean values of the 20 linear regressions, performed with $\%\dot{V}O_{2max}$ as the independent variable, are presented in Table 3. There was no statistical significance for the main effect on sex between slopes. The intercepts in the males were generally higher than those observed for the females. The absence of significant interactions between exercise modes and sex, on slopes and intercepts, suggests

TABLE 2. MAXIMAL OXYGEN UPTAKE ($ml \cdot kg^{-1} \cdot min^{-1}$), HEART RATE ($beats \cdot min^{-1}$), AND RESPIRATORY EXCHANGE RATIO (RER) OF THE PARTICIPANTS, IN THE FOUR EXERCISE MODES (MEAN VALUES ± SD)

	Women			Men		
	$\dot{V}O_{2max}$	HR_{max}	RER_{max}	$\dot{V}O_{2max}$	HR_{max}	RER_{max}
Cycling	38.7 ± 2.4	176 ± 9	1.17 ± 0.03	49.9 ± 6.0╟	185 ± 9╟	1.18 ± 0.05
Rowing	40.5 ± 1.9	180 ± 8╫	1.14 ± 0.04	48.7 ± 6.6╟	184 ± 9	1.14 ± 0.03
Stepping	44.0 ± 3.8*	191 ± 6*‖	1.15 ± 0.03	52.4 ± 6.5╟	188 ± 6	1.17 ± 0.06
Running	44.8 ± 2.8‡†	185 ± 5‡†‼	1.20 ± 0.06†	56.3 ± 7.7‡†╟	192 ± 7‡╟	1.20 ± 0.06†

Note: * Stepping/leg cycling differences ($p<0.05$); ‡ running/leg cycling differences ($p<0.05$); † running/rowing differences ($p<0.05$); ‼ ╫ rowing/leg cycling differences ($p<0.05$); ‖ stepping/rowing differences ($p<0.01$); ‼ running/stepping differences ($p<0.01$); ╟ sex differences ($p<0.05$)

TABLE 3. LINEAR REGRESSION EQUATIONS $\%\dot{V}O_{2max}$-$\%HR_{max}$ FOR WOMEN (N = 10), MEN (N = 10), AND TOTAL (N = 20), FOR THE FOUR EXERCISE MODES (MEAN VALUES ± SD)

	Linear Regression Equations
CYCLING	
Women	$\%HR_{max} = 0.503 \pm 0.065 \times \%\dot{V}O_{2max} + 50.89 \pm 6.46$; $R_2=0.97 \pm 0.02$
Men	$\%HR_{max} = 0.505 \pm 0.160 \times \%\dot{V}O_{2max} + 51.57 \pm 14.25$*; $R_2=0.96 \pm 0.03$
Total	$\%HR_{max} = 0.504 \pm 0.119 \times \%\dot{V}O_{2max} + 51.23 \pm 10.78$; $R_2=0.96 \pm 0.03$
ROWING	
Women	$\%HR_{max} = 0.547 \pm 0.119 \times \%\dot{V}O_{2max} + 46.19 \pm 11.06$; $R_2=0.94 \pm 0.02$
Men	$\%HR_{max} = 0.553 \pm 0.093 \times \%\dot{V}O_{2max} + 46.35 \pm 8.90$*; $R_2=0.95 \pm 0.03$
Total	$\%HR_{max} = 0.550 \pm 0.104 \times \%\dot{V}O_{2max} + 46.27 \pm 9.77$; $R_2=0.95 \pm 0.02$
STEPPING	
Women	$\%HR_{max} = 0.649 \pm 0.075$‡ $\times \%\dot{V}O_{2max} + 37.28 \pm 7.59$†; $R_2=0.96 \pm 0.02$
Men	$\%HR_{max} = 0.572 \pm 0.163 \times \%\dot{V}O_{2max} + 44.96 \pm 15.00$*; $R_2=0.96 \pm 0.01$
Total	$\%HR_{max} = 0.610 \pm 0.129$╫ $\times \%\dot{V}O_{2max} + 41.12 \pm 12.22$┼; $R_2=0.96 \pm 0.01$
RUNNING	
Women	$\%HR_{max} = 0.589 \pm 0.083 \times \%\dot{V}O_{2max} + 42.83 \pm 7.65$╪; $R_2=0.96 \pm 0.03$
Men	$\%HR_{max} = 0.563 \pm 0.074 \times \%\dot{V}O_{2max} + 44.30 \pm 8.18$*; $R_2=0.95 \pm 0.02$
Total	$\%HR_{max} = 0.576 \pm 0.077 \times \%\dot{V}O_{2max} + 43.56 \pm 7.75$╬; $R_2=0.95 \pm 0.02$

Note: * compared with intercept of corresponding women ($p<0.05$); ‡ compared with slope of leg cycling ($p<0.05$); † compared with intercept of leg cycling ($p<0.05$); ╪ compared with intercept of stepping ($p<0.05$); ╫ compared with slope of leg cycling ($p<0.05$); ┼ compared with intercept of leg cycling ($p<0.05$); ╬ compared with intercept of leg cycling ($p<0.05$)

that the presented results are common to the four modes. In females, the slopes were different between leg cycling and stepping. As noted, only females demonstrated differences among intercepts, with stepping (37.28) being lower than leg cycling (50.89) and running (42.83). Comparing intercepts for the total participants (i.e., both sexes), leg cycling was different from stepping, while for slopes leg cycling differed from stepping and running. The net effect of these differences will be reflected in the values illustrated in Figure 1.

The regression equations predict similar values of $\%HR_{max}$ for males and females, between 40 and 90% $\dot{V}O_{2max}$, across the four modes of exercise. Estimated $\%HR_{max}$ for leg cycling was higher at all intensities of $\%\dot{V}O_{2max}$, compared with the other exercise modes (Figure 1), with significant differences from stepping and running between 40 and 70% $\dot{V}O_{2max}$. However, even considering similar $\%HR_{max}$ in women and men, differences tend (no statistical significance) to be higher in females, with the leg cycling equation at 40% $\dot{V}O_{2max}$ estimating 8% HR_{max} above the stepping equation, while in males the equivalent value is only 4% HR_{max}. Comparing leg cycling with running, the difference is similar in both women and men (5% HR_{max}). The difference in $\%HR_{max}$ among exercise modes gradually decreases with the increase of exercise intensity, disappearing above 80% $\dot{V}O_{2max}$.

DISCUSSION

The main findings of this study are that, in young adult participants with low cardiovascular risk: i) males and females can use the same equation for each mode of exercise; and ii) leg cycling has a different equation than weight-supported modes (stepping and running), predicting different $\%HR_{max}$ values until 70% $\dot{V}O_{2max}$, but not above this intensity. As previously noted, the prescription of exercise based on $\%HR_{max}$ has been consistently used for exercise prescription. To our knowledge this is the first attempt to predict $\%HR_{max}$ simultaneously in young adult women and men with low cardiovascular risk, and in four modes of exercise widely used in fitness facilities.

Participants in this study averaged between 66 and 71% HR_{max} at 40% $\dot{V}O_{2max}$ and 93-94% HR_{max} at 85% $\dot{V}O_{2max}$, which was higher than the values of 55% HR_{max} and 90% HR_{max} indicated by the American College of Sports Medicine (ACSM) [2]. The difference of 11-16% HR_{max} at 40% $\dot{V}O_{2max}$ represents an increase of 20-29% HR_{max} over the ACSM standards, while 3-4% HR_{max} at 85% $\dot{V}O_{2max}$ corresponds to an increase of 4-5% HR_{max}. The discrepancy between the ACSM standards and the values obtained by the current investigation may be due, at least in part, to the mathematical procedures as discussed earlier in this paper. Additionally, the ACSM standards are intended for the adult population in general, while in this study only young adults with low cardiovascular risk participated. Using the equations proposed by the present study, one would prescribe exercise intensity in young adults, particularly in leg cycling, rowing, stepping and treadmill running at light intensities, more accurately than using ACSM standards. As light and moderate intensities are widely used for health-fitness purposes, these findings can be considered very relevant.

Swain and colleagues [22] found, at 40% $\dot{V}O_{2max}$ in treadmill running, 64% HR_{max} in apparently healthy young women and 63% HR_{max} in men, and 92% HR_{max} at 85% $\dot{V}O_{2max}$, for both males and females. These values are 4-6% HR_{max} lower at 40% $\dot{V}O_{2max}$, and 1% HR_{max} at 85% $\dot{V}O_{2max}$, compared to the current study. Byrne and Hills [6], with obese adults, also attained slightly lower values (59% HR_{max} at 40% $\dot{V}O_{2max}$, 72% HR_{max} at 60% $\dot{V}O_{2max}$, and 86% HR_{max} at 80% $\dot{V}O_{2max}$). The current results are again slightly higher than the 76-77% HR_{peak} at 60% VO_{2peak}, and 87% HR_{peak} at 80% $\dot{V}O_{2max}$, proposed by Simmons and colleagues [20], for chronic obstructive

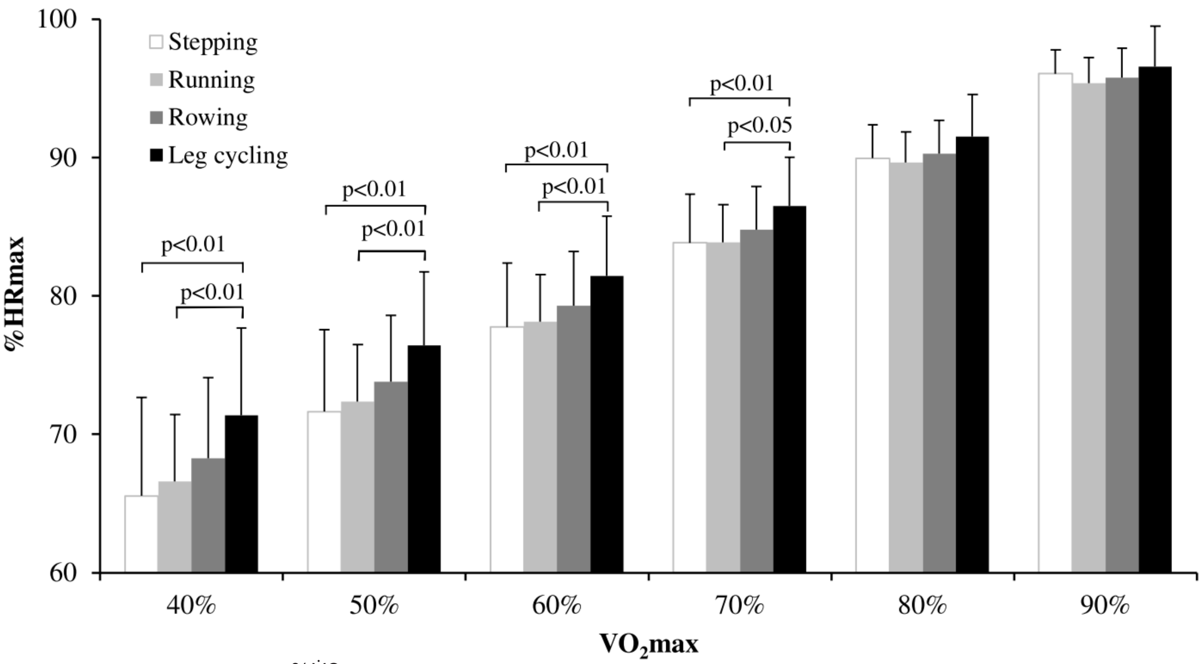

FIG. 1. ESTIMATED %HRMAX AT GIVEN $\%\dot{V}O_{2max}$ USING REGRESSION EQUATIONS FOR THE SUM OF PARTICIPANTS (N = 20), FOR THE FOUR EXERCISE MODES

pulmonary disease patients. This slight discrepancy is in agreement with Swain and colleagues [22], who attained for highly fit males about 2-3% HR_{max} higher than for less fit men, and about 1-2% HR_{max} higher for women.

The leg cycling equation (for both males and females) estimates higher values of $\%HR_{max}$ than the stepping and running equations, between 40 and 70% $\dot{V}O_{2max}$. As mentioned earlier, different body positions are related to different stroke volumes [18]. At 40%$\dot{V}O_{2max}$ the difference is 6% HR_{max} compared to stepping and 5% HR_{max} compared to running, while at 70%$\dot{V}O_{2max}$ it diminishes to 3% HR_{max} for both stepping and running. In the Londeree study [14], after transposing the equations, the maximum difference among modes (cycle versus rower) was 9% HR_{max} at 40%$\dot{V}O_{2max}$. In both studies, $\%HR_{max}$ values from the cycle equation were higher compared with the rower, stepper, and treadmill, disappearing above 85%$\dot{V}O_{2max}$ in the cited study, and above 70%$\dot{V}O_{2max}$ in the current study.

CONCLUSIONS

In conclusion, weight-supported modes, particularly leg cycling, produce significantly different $\%\dot{V}O_{2max}$-$\%HR_{max}$ regression equations than upright and weight-bearing modes (stepping and running) at light and moderate intensities. Since most prescriptions, particularly those with health-fitness purposes, recommend light to moderate intensities of exercise, it would appear better to consider the equations proposed by this paper. On the other hand, a single equation for both women and men could be used. The ACSM standards for the general population underestimate exercise intensity in leg cycling, rowing, stepping, and treadmill running, compared with the current equations. Our results can be considered relevant for populations with similar characteristics. Specific populations, such as children, pregnant women, elderly or cardiac patients, should be further examined in order to determine corresponding equations.

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