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Original Article

Immersible ergocycle prescription as a function of relative exercise intensity

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Abstract

Purpose: The purpose of this study was to establish the relationship between various expressions of relative exercise intensity (%VO_{2max}, %HR_{max}, %VO_2 reserve (%VO_2R), and %HR reserve (%HRR)) in order to obtain the more appropriate method for exercise intensity prescription when using an immersible ergocycle (IE) and to propose a prediction equation to estimateVO_{2max} based on IE pedaling rate (rpm) for an individualized exercise training prescription.

Methods: Thirty-three healthy participants performed incremental exercise tests on IE and dryland ergocycle (DE) at equal external power output (P_{ext}). Exercise on IE began at 40 rpm and was increased by 10 rpm until exhaustion. Exercise on DE began with an initial load of 25 W and increased by 25 W/min until exhaustion. VO_2 was measured with a portable gas analyzer (COSMED K4b[2]) during both incremental tests. On IE and DE, %VO_2R, %HR_{max} and %HRR at equal P_{ext} did not differ ($p > 0.05$).

Results: The %HRR *vs.* %VO_2R regression for both IE and DE did not differ from the identity line (%VO_2R: IE = 0.988% × HRR + 0.009, $r^2 = 0.91$, SEE: 11%; %VO_2R: DE = 0.944% × HRR + 0.013, $r^2 = 0.94$, SEE: 8%). Similar mean values for %HR_{max}, %VO_2R and %HRR at equal P_{ext} were observed on IE and DE. PredictedVO_2 obtained according to rpm on IE is represented by: VO_2 (L/min) = 0.000542 × rpm^2 − 0.026 × rpm + 0.739 ($r = 0.91$, SEE = 0.319 L/min).

Conclusion: The %HRR–%VO_2R relationship appears to be the most accurate for exercise training prescription on IE. This study offers news tools to better prescribe, control and individualize exercise intensity on IE.

Keywords: Exercise prescription; Heart rate; Immersed ergocycle; Oxygen uptake; Pedaling rate

1. Introduction

Aerobic exercise training performed at an appropriate level of intensity has beneficial effects on health in the general population and improves aerobic capacity and exercise performance.[1] Prescription of exercise intensity using measured or estimated absolute values that may include either caloric expenditure (kcal/min) or absolute VO_2 (L/min) may result in misclassification of exercise intensity (e.g., moderate, vigorous) because they do not consider individual factors such as body mass, sex, and fitness level[1] or the environment in which the exercise is performed (i.e., water and land).[2,3]

Individualized exercise training prescription is more appropriate using a relative measure of intensity and the following parameters can be used: VO_{2max}, VO_2 reserve (VO_2R), maximal heart rate (HR_{max}), heart rate reserve (HRR), maximal metabolic equivalent of task ($METs_{max}$) and their relative expressions, %VO_{max}, %VO_2R, %HR_{max}, %HRR, and %$METs_{max}$.[1,4]

Previous studies have shown conflicting results regarding the best approach to express %VO_2 (max or reserve) as a function of HR variables (max or reserve). Several studies have shown a better relationship between %HRR and %VO_2R in healthy adults using a treadmill or ergocycles,[5,6] among athletes[7] and

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obese subjects.[8] However, another study has demonstrated a better relationship between $\%VO_{2max}$ and %HRR.[9] The American College of Sports Medicine (ACSM) has proposed a classification of relative and absolute exercise intensity for aerobic exercise where $\%VO_2R$ and %HRR remain interchangeable, but the ACSM emphasizes that the relationship among actual energy expenditure, HRR, VO_2R, $\%HR_{max}$, and $\%VO_{2max}$ can vary considerably depending on exercise test protocol, exercise intensity, resting HR, fitness level, age, body composition, exercise mode (i.e., water and land) and other factors.[1]

Lately, an increasing number of individuals are performing aerobic exercise training in an aquatic environment using various exercise modalities and devices. Water exercise allows participants to undergo hard workouts at intensities similar to dryland physical activities with a lower impact on joints and with different physiological responses.[2,10] Previous studies have concluded that the most accurate way to estimate exercise intensity in water is to use HR measurements and/or ratings of perceived exertion (RPE).[3,11] Giacomini et al.[12] studied the relationship between rpm and VO_2–HR responses on four different models of immersible ergocycle (IE). They showed that for a similar pedaling rate (70 rpm) the $\%VO_{2max}$ varied from 45% to 90% and the $\%HR_{max}$ varied from 60% to 90%, which could be explained by the difference between IE pedaling systems used in their study. Thus, various IE models may be responsible for producing different external power outputs (P_{ext}) for a similar rpm. Currently, the pedaling cadence (rpm) on various IE models is the only main parameter to increase or decrease exercise intensity (P_{ext}).[13–16]

Previous studies have shown that immersion can reduce VO_2 and HR during deep water running, immersed treadmill running or immersible ergocycle pedaling at maximal[15,17,18] and submaximal intensities (i.e., velocity or external power output).[10,19] Consequently, the VO_2–HR relationship (in % of max or reserve) could be modified during exercise on IE and be different from that of dryland ergocycle (DE). Therefore, exercise prescription using the VO_2–HR relationship of DE could be less valid and accurate for IE exercise. The effects of immersion on the VO_2–HR relationship during IE has not been previously studied and compared with that of DE in healthy participants. Thus, the objectives of this work were: 1) to study the relationship between various expressions of relative exercise intensity ($\%VO_{2max}$, $\% VO_2R$, $\%HR_{max}$, and %HRR) in order to obtain the more appropriate method for exercise intensity prescription when using an IE; and 2) to propose a prediction equation to estimate VO_{2max} based on IE pedaling rate (rpm) for individualized exercise training prescription.

2. Materials and methods

2.1. Experimental approach to the problem

All participants performed maximal incremental exercise tests in a random order on an IE (Hydrorider Aquabike professional; Hydrorider professional aquatic equipment®, DIESSE S.R.L, Bologna, Italy) and a DE (Ergoline 800S; Ergoline GmbH, Bitz, Germany) and at similar P_{ext} in a laboratory with air temperature maintained at 21°C and in a swimming pool at a thermoneutral exercise water temperature of 30°C.[20,21] During incremental exercise tests, cardiopulmonary responses were measured with a portable gas analyzer (Cosmed K4b²; COSMED, Rome, Italy). Gas analyzers were calibrated before each test using a standard certified commercial gas preparation (O_2: 16%; CO_2: 5%).[21] HR was measured continuously using a heart rate monitor (Polar, T 61; Kempele, Finland).

Table 1
Subjects' physical characteristics and exercise testing parameters on IE and DE.

Parameters	Mean ± SD
Age (year)	33 ± 10
Sex (n)	Men (28), women (5)
Body mass (kg)	72 ± 9
Height (m)	1.74 ± 0.06
BMI (kg/m^2)	23.7 ± 2.5
VO_{2max} (L/min)	
DE	3.46 ± 0.65
IE	2.48 ± 0.63‡
VO_{2max} (mL/min·kg)	
DE	46.28 ± 9.18
IE	33.10 ± 9.07‡
Resting HR	
DE	75 ± 12
IE	73 ± 11
HR_{max}	
DE	177 ± 14
IE	167 ± 12*
Maximal P_{ext} (W)	
DE	251 ± 55
IE	253 ± 58

* $p < 0.005$, ‡$p < 0.001$, compared with DE.
Abbreviations: BMI = body mass index; W = watts; HR = heart rate; VO_{2max} = maximal oxygen uptake; IE = immersible ergocycle; DE = dry ergocycle; HR = heart rate; P_{ext} = external power output.

2.2. Subjects

Thirty-three healthy young participants (age: 33 ± 10 years, 28 men and 5 women) were recruited at the Cardiovascular Prevention and Rehabilitation Centre of the Montreal Heart Institute. This study was approved by the Research Ethics Committee of the Montreal Heart Institute and all the subjects gave their written informed consent to participate in the study. Their baseline characteristics are presented in Table 1. Inclusion criteria were no health problems and age 18 years and above. The exclusion criteria included: 1) any documented cardiovascular, pulmonary, musculo-skeletal, or metabolic diseases; and 2) inability to perform a maximal cardiopulmonary exercise test.

2.3. Procedures

During data collection on both IE and DE, cardiopulmonary parameters were measured during: a 3 min-rest period; the exercise period; and a 5-min post exercise recovery period. Data were averaged every 15 s for minute ventilation (VE, in L/min), body temperature, pressure, and saturation (BTPS), oxygen uptake (VO_2, in L/min), standard temperature and pressure dry (STPD), and carbon dioxide production (VCO_2, in L/min STPD). Maximal exercise tests on IE and DE lasted until the attainment of one of the two primary maximal criteria: (1) a plateau of VO_2

(<150 mL) despite an increase in P_{ext} (rpm or W on IE and DE, respectively); and (2) respiratory exchange ratio (R.E.R.) > 1.1, or one of the three secondary maximal criteria: (1) measured maximal heart rate attaining 95% of age-predicted maximal heart rate; (2) inability to maintain the required workload; and (3) subject exhaustion with cessation caused by fatigue or subjects and/or other clinical symptoms (dyspnea) and/or ECG abnormalities that required exercise cessation.[15,21]

Following the 3-min rest period, the initial exercise load for incremental test on DE was 25 watts (W) and was increased by 25 W/min until exhaustion. The pedaling rate (rpm) was at a minimum cadence of 60 rpm; however, the participants were instructed to maintain a pedaling cadence of 80 rpm since previous studies have shown that in conditions simulating those seen during prolonged competitive cycling, higher cadences (i.e., 100 *vs.* 80 rpm) are less efficient, resulting in greater energy expenditure and reduced peak power output (327 ± 27 W *vs.* 362 ± 38 W, respectively) during maximal performance.[22]

The P_{ext} increases in water as a function of pedaling rate/velocity.[16,23,24] Thus, in the large number of commercially available models of IE, the only method to either increase or decrease the intensity of exercise is by varying the rpm. On the IE, the subjects were immersed up to the xiphoid process level and the exercise protocol began at a pedaling rate of 40 rpm and was increased each minute by 10 rpm until 70 rpm. Afterwards, the rpm was increased by 5 rpm until the subject was unable to follow the pace or until exhaustion.[15,16] Pedaling rate (rpm) was controlled with the use of both a metronome (Matrix MR500 Metronome, Seoul, Korea) and a pedaling rpm meter (Cateye Echowell F2, Taiwan, China) to help the participant to maintain correct rpm. Following the exercise test, the participants recovered for 5 min while seated on the IE or DE. The posture of each subject on both cycle ergometers was adjusted for the correct height of the saddle by sitting the participant on the bicycle, according to previous studies.[13,16]

The highest VO_2 and HR values reached during the exercise phase of each test were considered as the VO_{2max} and HR_{max}. The following values of HRR and VO_2R were calculated by subtracting, respectively, the value at rest from the maximal values.[7] Each test on IE and DE was separated from each other by 1 week. For each subject, HR and VO_2 values were recorded at rest, were averaged during the last 15 s of each 1 min stage and were expressed as percentages of their respective reserve (%VO_2R and %HRR) or maximum values (%VO_{2max}, %HR_{max}, data not shown).

$$\%HR_{max} = (\text{HR of each stage} / HR_{max}) \times 100 \ (\text{data not shown}) \tag{1}$$

$$\%HRR = (\text{HR of each stage} - \text{HR rest}) / (HR_{max} - \text{HR rest}) \times 100 \tag{2}$$

$$\%VO_{2max} = (VO_2 \text{ of each stage} / VO_{2max}) \times 100 \ (\text{data not shown}) \tag{3}$$

$$\%VO_2R = (VO_2 \text{ of each stage} - VO_2 \text{ rest}) / (VO_{2max} - VO_2 \text{ rest}) \times 100 \tag{4}$$

On the IE, the P_{ext} was produced by the pedaling rate that has been detailed elsewhere.[13,15,17,25] Briefly, the external forces during exercise on an IE are mainly caused by the mechanical components of the pedaling system (paddles, pedals, and rods) and by leg movement drag (calf, foot, and thigh) that is dependent on the surface area of the lower limbs and the pedaling rate (rpm).

The P_{ext} expressed in watts (W) was calculated by multiplying the total net force (F) overcoming the resistance of the system movement (pedaling system and legs) by the tangential velocity (m/s) of the pedal. Thus, the following general fluid equation was used to determine F mathematically:

$$F = \tfrac{1}{2} \rho A v^2 C_d \tag{5}$$

where ρ is the density of water (at 30°C = 995.7 kg/m^3), A is the projected frontal area (m^2) in the direction of the movement for all segments involved (lower limbs, paddles, rods and pedals), v is the velocity (m/s) ranging from 40 to 120 rpm, and C_d is the drag coefficient of shape for every element of the pedaling system and of the lower limbs.[15,16]

2.4. *Statistical analysis*

Results are presented as mean ± SD. An ANOVA with repeated measures (condition × intensity) was performed to compare: 1) %VO_2R and %HRR during exercise on IE and DE for the same P_{ext} and 2) theVO_2 and HR responses during maximal incremental exercise test on DE or IE. Relationships between variables (%HRR and %VO_2R) obtained on IE and DE were performed using linear regression analysis. The level of equivalency was evaluated with analysis of the mean slopes and intercepts (i.e., slope = 1; intercept = 0) that was determined from linear regression equations. Statistical analysis was performed with Sigma Plot (version 11; San Jose, CA, USA), StatView (version 5.0; Cary, NC, USA) and SPSS (version 15; Armonk, NY, USA). The Bland and Altman analysis was performed with Excel (Microsoft, Redmond, WA, USA).

3. Results

Baseline characteristics of the subjects (5 women and 28 men) and VO_{2max} values measured on both IE and DE are presented in Table 1.

3.1. *Absolute and relative oxygen uptake (%VO_2R)*

Fig. 1 illustrates the absolute and relative values of oxygen uptake obtained on IE in relationship to DE. The data points represent VO_2 measured during the incremental test at each stage (same P_{ext}) on IE and DE for each individual. As seen in Fig. 1A, the absolute VO_2 (L/min) obtained on IE was systematically lower and significantly correlated ($r^2 = 0.81$, $p < 0.0001$) to the VO_2 (L/min) on DE. The regression equation to predict VO_2 (L/min) on an IE from VO_2 (L/min) obtained on DE is: VO_2 IE (L/min) = 0.69VO_2DE (L/min) + 130.09. Fig. 1B shows a significant correlation ($r^2 = 0.89$, $p < 0.0001$) of relative VO_2R (%) on IE as a function of relative VO_2R (%) on DE. The regression equation obtained is VO_2R IE (%) = 1.01 VO_2R DE (%) + 0.02 and indicates that the slope is equal to one and

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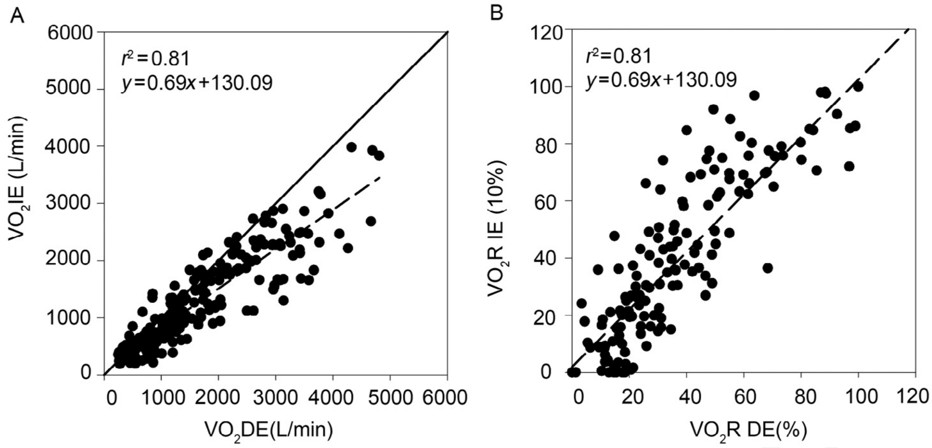

Fig. 1. Relationship of oxygen uptake (VO_2) measured on immersible ergocycle (IE) and dryland ergocycle (DE). A) VO_2 on IE relative to VO_2 on DE in absolute values of oxygen uptake (L/min); the filled black line represents the line of identity. B) VO_2 on IE relative to VO_2 on DE in relative values of maximal oxygen uptake reserve ($VO_{2max} - VO_{2rest}$). All data points represent all participants. The dashed line in both graphs represents the line of the regression equation.

that the intercept goes through zero, demonstrating that both forms of expression are equal.

3.2. %HRR and %VO_2R

Table 2 presents %HRR and %VO_2R on IE and DE for the same P_{ext}. As well, Table 2 proposes a classification of RPE exercise intensity for both IE and DE. The average values of %HRR and %VO_2R were not significantly different for the same P_{ext} ($p = 0.81$ and 0.29, respectively) during exercise on IE and DE.

Fig. 2 shows the relationships between %HRR and %VO_2R obtained for both IE and DE. As shown in Fig. 2A and B, %VO_2R was significantly correlated to %HRR for both IE and DE ($r^2 = 0.91$, $p < 0.0001$ and $r^2 = 0.94$, $p < 0.0001$, respectively), and the regression equations indicated that the two expressions of exercise intensity (%VO_2R and %HRR) were

Table 2
Relative intensity (%HRR and %VO_2R) for a similar P_{ext} (W) on IE and DE and classification of exercise intensity on IE (mean ± SD).

RPM	P_{ext} (W)	%HRR		%VO_2R		Intensity
		IE	DE	IE	DE	
40	25	12.9 ± 1.3	14.6 ± 1.5	8.0 ± 1.3	13.8 ± 0.9	Very very light
50	50	21.2 ± 1.4	21.8 ± 1.9	21.3 ± 1.7	23.1 ± 1.1	Very light
60	75	35.3 ± 1.7	38.2 ± 1.7	38.5 ± 2.5	32.0 ± 1.3	Light
70	125	56.7 ± 2.1	57.6 ± 1.8	59.4 ± 3.3	50.9 ± 1.6	Moderate
80	200	85.3 ± 2.1	81.7 ± 1.9	85.2 ± 2.3	80.2 ± 2.5	Vigorous
90	300	98.4 ± 3.4	97.5 ± 3.9	96.7 ± 6.7	97.4 ± 4.7	Near-maximal

Note: Very light < 30; light: 30–39; moderate: 40–59; vigorous: 60–89; near-maximal ≥ 90.
Abbreviations: W = watts; %HRR = percentage of heart rate reserve; %VO_2R = percentage of oxygen uptake reserve.
Classification of exercise intensity adapted from ACSM.[1]

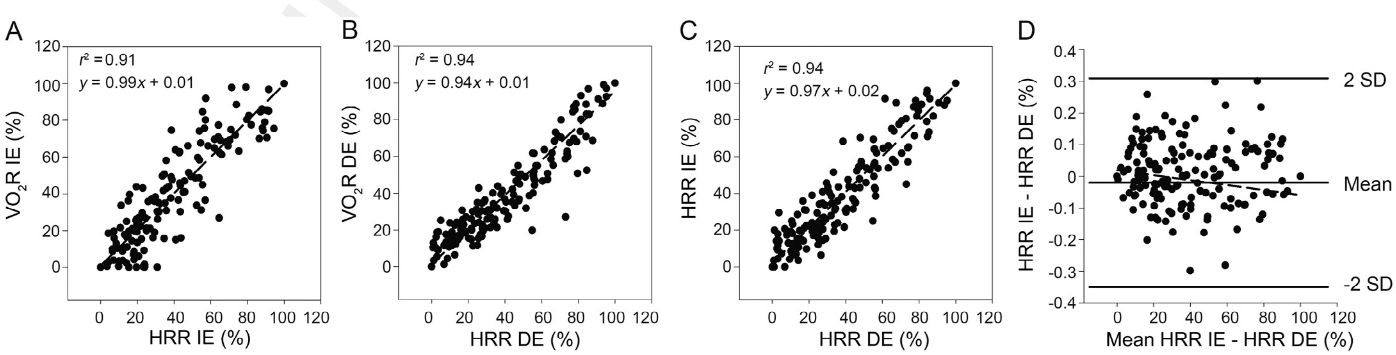

Fig. 2. Relationship of relative oxygen uptake reserve (%VO_2R) with relative heart rate reserve (%HRR) obtained with the immersible ergocycle (IE) and dryland ergocycle (DE). A) %VO_2R *vs.* %HRR obtained with the IE; B) %VO_2R *vs.* %HRR obtained with the DE; C) %HRR obtained on IE *vs.* %HRR obtained on DE; D) level of agreement between %HRR obtained on IE and %HRR obtained on DE. All data points represent all participants. Dashed line represents the regression equation in all graphs.

equal (%VO_2R IE = 0.99%HRR + 0.01, SEE 11% and %VO_2R DE = 0.94%HRR + 0.01, SEE 8%, respectively). Fig. 2C shows the significant relationship ($r^2 = 0.94$, $p < 0.0001$) between %HRR IE and %HRR DE. The regression between both variables is %HRR IE = 0.97%HRR DE + 0.02. The equation slope and intercept are near equal to one, respectively.

3.3. %HRR IE and %HRR DE level of agreement

Fig. 2D is a Bland and Altman plot illustrating the level of agreement (mean = −0.02) between the %HRR IE and %HRR DE difference. The regression line (medium hash) has a slope near equal to zero (−0.08), indicating that the error in measure is nil and is constant throughout the range of 0–100%.

3.4. Estimated oxygen uptake prediction (VO_2)

PredictedVO_2 (L/min) obtained according to rpm on IE (data not shown) is represented by the equation:

$$\begin{aligned} VO_2\ (\mathrm{L/min}) = {} & 0.000542\ \mathrm{rpm}^2 - 0.026\ \mathrm{rpm} \\ & + 0.739\ (r = 0.91, \mathrm{SEE} = 0.319\ \mathrm{L/min}) \end{aligned} \tag{6}$$

4. Discussion

The original findings of this study were that: 1) Relative intensity was found to be similar for %VO_2R, %HR_{max} (data not shown) and %HRR at a similar P_{ext} on IE and DE; 2) on IE and DE, the %HRR *vs.* %VO_2R relationship was the closest to the identity line and the most accurate for exercise prescription in immersion. Linear regressions obtained on IE and DE to predict relative VO_2 reserve (%VO_2R) from relative heart rate reserve (%HRR), as shown in Fig. 2A and B, can be considered the most accurate for exercise training prescription for either exercise modality (IE and DE). To the best of our knowledge, this is the first study to compare the HR–VO_2 relationship (in % of reserve values) during incremental exercise on IE *vs.* DE at the same external power output (P_{ext}) in healthy subjects.

We have used the method reported in previous studies using the same IE model to calculate the P_{ext}.[13,15,16] This method provides a mathematical model for generalizability of calculation for IE P_{ext} with any IE type. The model takes into account pedaling rate (rpm), IE pedaling system physical characteristics and lower limb size. Thus, from a performed incremental exercise test on IE, it is possible to obtain the relationship between rpm and P_{ext} to better prescribe relative to maximal exercise intensity on any IE. Currently, the differences between commercially available IE are in the pedaling system physical characteristics (the paddle and rod length varying between brands). The method proposed herein makes it possible to calculate P_{ext}.

In the current study, the predicted values to %HRR and %VO_2R at all levels of relative intensity agreed with the most recent exercise intensity scale of the ACSM.[1] In addition, the relationship between %VO_2R and %HRR (Fig. 2) is in agreement with the ACSM recommendations for healthy young participants despite the controversy raised by other investigators that have reported higher values at 85% VO_{2max} or VO_2R (i.e., 92%–93%HR_{max}).[7,8,26]

Other authors, however, who criticize the “traditional” concept to prescribe exercise intensity by means of a target % of HR_{max}, HRR, VO_{2max}, or VO_2R, have suggested that it might be more appropriate to consider in addition, the metabolic demand of exercise by means of determining a lactate-threshold and to tailor exercise within target training zones of intensity.[27,28] Nonetheless, our study appears to offer a method for interchanging exercise prescription intensity for two different exercise devices (IE and DE) that is more accurate than the traditional %HR–%VO_{2max} relationship. Thus, if the following parameters, such as the absolute VO_2, HR and hemodynamic response (stroke volume, cardiac preload, cardiac output, venous return) are affected during upright immersion exercise,[14,15,19,29–31] then, the rationale for using %VO_2R and %HRR for IE exercise prescription appears more appropriate. Therefore, as the theory of specificity suggests,[32,33] it is important to establish the value of VO_{2max} and HR_{max} directly in water to properly prescribe the intensity on IE.

We have previously reported that the relationship between P_{ext} (W) and rpm during incremental exercise on the IE is nonlinear and could explain why VO_2 expressed as %VO_{2max} for intensities >60 rpm increases exponentially as a function of rpm.[13,16] This nonlinear relationship, reported by us and others, reiterates the importance of using %HRR, as proposed herein, since as shown in Fig. 2A, the relationship between %VO_2R and %HRR is linear. This could have practical implications since small increases in rpm generate a more rapid increase of physiological responses. We have included a very very light category (Table 2) that corresponds to the lowest intensity on IE (≤40 rpm) and relates to the intensity recommended for warm-up.

There are some limitations in our study. This work is based on a sample of young healthy subjects; thus, our results apply only to a similar population and cannot be generalized to other groups, such as older subjects, subjects with cardiovascular risk factors or established cardiac disease.

Future studies in those populations would be necessary to see if similar results would be obtained.

Practically, however, the current study offers a new tool to better prescribe, control, and individualize exercise intensity on IE from the %HRR–%VO_2R relationship. It is possible to estimate these variables using the suggested method from IE pedaling cadencies (rpm)[13,16] for various water immersed bicycle models with a with similar pedaling systems (i.e., Hydrorider®, Archimedes®, Poolbike®) or by directly measuring cardiopulmonary and hemodynamic responses. However, for accurate prescription in different populations as quoted above, practitioners using any IE type will have to consider the following four elements when calculating the power output: (1) the pedaling rate; (2) the seat height adjustment; (3) the precise characteristics of the pedaling system (length and width of paddles, pedals, and rods); and (4) participant leg anthropometric characteristics.[16]

5. Conclusion

This study offers a new tool to better prescribe, control and individualize exercise intensity on IE. The %HRR–%VO_2R relationship appears to be the most accurate for exercise train-

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ing prescription on IE. VO_2 (L/min) on IE can be obtained and predicted from the VO_2 measured on a DE. Similarly, VO_2 (L/min) obtained on IE can be predicted from IE pedaling cadencies (rpm) and is represented by: VO_2 (L/min) = $0.000542\ \text{rpm}^2 - 0.026\ \text{rpm} + 0.739$ ($r = 0.91$, SEE = 0.319 L/min). Absolute cardiopulmonary responses (VO_2 and HR) during exercise on IE are different from that of DE, but relative intensity was found similar at a similar P_{ext} on both IE and DE. The classification of exercise intensity from rpm on IE for relative intensity (%HRR and %VO_2R) is in agreement with the 2011 ACSM exercise intensity scale.[1]

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