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 percentage of maximal oxygen uptake (%VO2max), percentage of maximal heart rate (%HRmax), %VO2 reserve (%VO2R), 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 estimate oxygen consumption (VO2) 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 (Pext). 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. VO2 was measured with a portable gas analyzer (COSMED K4b2) during both incremental tests. On IE and DE, %VO2R, %HRmax and %HRR at equal Pext did not differ (p > 0.05).

Results: The %HRR vs. %VO2R regression for both IE and DE did not differ from the identity line %VO2R IE = 0.99 × HRR IE (%) + 0.01 (r² = 0.91, SEE = 11%); %VO2R DE = 0.94 × HRR DE (%) + 0.01 (r² = 0.94, SEE = 8%). Similar mean values for %HRmax, %VO2R, and %HRR at equal Pext were observed on IE and DE. Predicted VO2 obtained according to rpm on IE is represented by: VO2 (L/min) = 0.000542 × rpm2 − 0.026 × rpm + 0.739 (r = 0.91, SEE = 0.319 L/min).

Conclusion: The %HRR–%VO2R relationship appears to be the most accurate for exercise training prescription on IE. This study offers new tools to better prescribe, control, and individualize exercise intensity on IE.

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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 oxygen consumption (VO2, in 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 level1 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: maximal oxygen uptake (VO2max), VO2 reserve (VO2R), maximal heart rate (HRmax), heart rate reserve (HRR), maximal metabolic equivalent of task (METsmax) and their relative expressions, %VO2max, %VO2R, %HRmax, %HRR, and %METsmax.4,4 Previous studies have shown conflicting results regarding the best approach to express %VO2 (max or reserve) as a function of HR variables (max or reserve). Several studies have shown a
better relationship between %HRR and %VO₂R in healthy adults using a treadmill or ergocycles,6,7 among athletes8 and obese subjects.9 However, another study has demonstrated a better relationship between %VO₂max and %HRR.10 The American College of Sports Medicine (ACSM) has proposed a classification of relative and absolute exercise intensity for aerobic exercise where %VO₂R and %HRR remain interchangeable, but the ACSM emphasizes that the relationship among actual energy expenditure, HRR, VO₂R, %HRmax, and %VO₂max 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.11

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.6,12 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).13,14 Giacomini et al.12 studied the relationship between revolution per minute (rpm) and VO₂–HR responses on 4 different models of immersible ergocycle (IE). They showed that for a similar pedaling rate (70 rpm) the %VO₂max varied from 45% to 90% and the %HRmax 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 (Pext) for a similar rpm. Currently, the pedaling cadence (rpm) on various IE models is the only main parameter to increase or decrease exercise intensity (Pext).13–16

Previous studies have shown that immersion can reduce VO₂ and HR during deep water running, immersed treadmill running or immersible ergocycle pedaling at maximal15,17,18 and submaximal intensities (i.e., velocity or Pext).10,17 Consequently, the VO₂–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 VO₂–HR relationship of DE could be less valid and accurate for IE exercise. The effects of immersion on the VO₂–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 (%VO₂max, %VO₂R, %HRmax, 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 VO₂max 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 Pext 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 (O₂: 16%; CO₂: 5%).21 HR was measured continuously using a HR monitor (T 61; Polar, Kempele, Finland).

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 apparent 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 (BTSP), oxygen uptake (VO₂, in L/min), standard temperature and pressure dry (STPD), and carbon dioxide production (VCO₂, in L/min). Maximal

| Parameters | Values¹ |
|------------|---------|
| Age (year) | 33 ± 10 |
| Sex (male/female) | 28/5 |
| Body mass (kg) | 72 ± 9 |
| Height (m) | 1.74 ± 0.06 |
| BMI (kg/m²) | 23.7 ± 2.5 |
| VO₂max (L/min) | 3.46 ± 0.65 |
| VO₂max (mL/min/kg) | 46.28 ± 9.18 |
| VO₂max | 33.10 ± 9.07** |
| Resting HR | 75 ± 12 |
| HRmax | 177 ± 14 |
| Maximal Pext (W) | 316 ± 12* |

¹ Values are presented as mean ± SD except sex as n.
* p < 0.005, **p < 0.001, compared with DE.

Abbreviations: BMI = body mass index; DE = dry ergocycle; HR = heart rate; HRmax = maximal heart rate; IE = immersible ergocycle; Pext = external power output; VO₂max = maximal oxygen uptake.
On the IE, the \( P_{\text{ext}} \) 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 \( P_{\text{ext}} \) expressed in watt (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:

\[
F = \frac{1}{2} \rho A v^2 C_d
\]

Eq. (5)

where \( \rho \) is the density of water (at \( 30^\circ\text{C} = 995.7 \text{ kg/m}^3 \)), \( A \) 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 \( \pm \) SD. An ANOVA with repeated measures (condition \( \times \) intensity) was performed to compare: (1) \%\( VO_2 \)R and %\( \Delta HR \) during exercise on IE and DE for the same \( P_{\text{ext}} \) and (2) the \( VO_2 \) and HR responses during maximal incremental exercise test on DE or IE. Relationships between variables (%\( \Delta HR \) and %\( VO_2 \)R) 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 11.0; Sigma, San Jose, CA, USA), StatView (Version 5.0; SAS Institute Inc., Cary, NC, USA) and SPSS (Version 15.0; SPSS, Chicago, IL, USA). The Bland and Altman analysis was performed with Excel (Microsoft, Redmond, WA, USA).

3. Results

3.1. Absolute and \%\( VO_2 \)R

Fig. 1 illustrates the absolute and relative values of \( VO_2 \) obtained on IE in relationship to DE. The data points represent \( VO_2 \) measured during the incremental test at each stage (same \( P_{\text{ext}} \)) 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) = 0.69 × \( VO_2 \) DE (L/min) + 130.09. Fig. 1B shows a significant correlation (\( r^2 = 0.89, p < 0.0001 \)) of relative \( VO_2 \)R (%) on IE as a function of relative \( VO_2 \)R (%) on DE. The regression equation obtained is \( VO_2 \)R IE (%) = 1.01 × \( VO_2 \)R DE (%) + 0.02 and indicates that the slope is equal to 1 and that the intercept goes through 0, demonstrating that both forms of expression are equal.
3.2. %HRR and %VO2R

Table 2 presents %HRR and %VO2R on IE and DE for the same Pext. As well, Table 2 proposes a classification of RPE exercise intensity for both IE and DE. The average values of %HRR and %VO2R were not significantly different for the same Pext (\(p = 0.81\) and \(p = 0.29\), respectively) during exercise on IE and DE.

![Fig. 2](image)

Fig. 2 shows the relationships between %HRR and %VO2R obtained for both IE and DE. As shown in Fig. 2A and 2B, %VO2R 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 2 expressions of exercise intensity (%VO2R and %HRR) were equal

\[ %\text{VO2R}_{IE} = 0.99 \times %\text{HRR}_{IE} + 0.01, \text{ SEE} = 11\% \]

\[ %\text{VO2R}_{DE} = 0.94 \times %\text{HRR}_{DE} + 0.01, \text{ SEE} = 8\% \]

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 (%)

\[ %\text{HRR}_{IE} = 0.97 \times %\text{HRR}_{DE} + 0.02 \]

The equation slope and intercept are near equal to 1, 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 0 (−0.08), indicating that the error in measure is nil and is constant throughout the range of 0–100%.

3.4. Estimated VO2 prediction

Predicted VO2 (L/min) obtained according to rpm on IE (data not shown) is represented by the following equation (\(r = 0.91, \text{ SEE} = 0.319\) L/min):

\[ \text{Fig. 1. Relationship of VO2 measured on IE and DE. (A) VO2 on IE relative to VO2 on DE in absolute values of VO2 (L/min); the filled black line represents the line of identity. (B) VO2 on IE relative to VO2 on DE in relative values of VO2R (VO2_{max} − VO2_{rest}). All data points represent all participants. The dashed line in both graphs represents the line of the regression equation. DE = dryland ergocycle; IE = immersible ergocycle; VO2 = oxygen uptake; VO2_{max} = maximal oxygen uptake; VO2_{rest} = oxygen uptake recorded at rest.} \]

**Table 2**

| rpm | Pext (W) | %HRR IE | %HRR DE | %VO2R IE | %VO2R DE | Intensity |
|-----|----------|---------|---------|----------|----------|-----------|
| 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. Classification of exercise intensity adapted from ACSM.1

Abbreviations: %HRR = percentage of heart rate reserve; %VO2R = percentage of oxygen uptake reserve; DE = dryland ergocycle; IE = immersible ergocycle; Pext = external power output; rpm = revolutions per minute.

![Fig. 2](image)

**Fig. 2. Relationship of %VO2R with %HRR obtained with the IE and DE. (A) %VO2R vs. %HRR obtained with IE; (B) %VO2R vs. %HRR obtained with 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 lines represent the regression equation in all graphs. %HRR = percentage of heart rate reserve; %VO2R = percentage of oxygen uptake reserve; DE = dryland ergocycle; HRR = heart rate reserve; IE = immersible ergocycle; VO2R = oxygen uptake reserve.**
VO₂ (L/min) = 0.000542 × rpm² – 0.026 × rpm + 0.739
(r = 0.91, SEE = 0.319 L/min) Eq. (6)

4. Discussion

The original findings of this study were that: 1) relative intensity was found to be similar for %VO₂R, %HRmax (data not shown) and %HRR at a similar Pext on IE and DE; 2) on IE and DE, the %HRR vs. %VO₂R 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 %VO₂R from %HRR, as shown in Fig. 2A and 2B, 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–VO₂ relationship (in % of reserve values) during incremental exercise on IE vs. DE at the same Pext in healthy subjects.

We have used the method reported in previous studies using the same IE model to calculate the Pext.¹⁵,¹⁶ This method provides a mathematical model for generalizability of calculation for IE Pext with any IE type. The model takes into account 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 Pext 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 Pext.

In the current study, the predicted values to %HRR and %VO₂R at all levels of relative intensity agreed with the most recent exercise intensity scale of the ACSM.¹ In addition, the relationship between %VO₂R 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%VO₂max or VO₂R (i.e., 92%–93%HRmax).⁷,⁸,¹⁶

Other authors, however, who criticize the “traditional” concept to prescribe exercise intensity by means of a target % of HRmax, HRR, VO₂max, or VO₂R, 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 2 different exercise devices (IE and DE) that is more accurate than the traditional %HR–%VO₂max relationship. Thus, if the following parameters, such as the absolute VO₂, HR and hemodynamic response (stroke volume, cardiac preload, cardiac output, and venous return) are affected during upright immersion exercise,¹⁴,¹⁵,¹⁹,²⁹–³¹ then, the rationale for using %VO₂R 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 VO₂max and HRmax directly in water to properly prescribe the intensity on IE.

We have previously reported that the relationship between Pext (W) and rpm during incremental exercise on the IE is non-linear and could explain why VO₂ expressed as %VO₂max for intensities >60 rpm increases exponentially as a function of rpm.¹³,¹⁶ This non-linear relationship, reported by us and others, reiterates the importance of using %HRR, as proposed herein, since as shown in Fig. 2A, the relationship between %VO₂R 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–%VO₂R 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 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 4 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–%VO₂R relationship appears to be the most accurate for exercise training prescription on IE. VO₂ (L/min) on IE can be obtained and predicted from the VO₂ measured on a DE. Similarly, VO₂ (L/min) obtained on IE can be predicted from IE pedaling cadencies (rpm) and is represented by: VO₂ (L/min) = 0.000542 × rpm² – 0.026 × rpm + 0.739 (r = 0.91, SEE = 0.319 L/min). Absolute cardiopulmonary responses (VO₂ and HR) during exercise on IE are different from that of DE, but relative intensity was found similar at a similar Pext on both IE and DE. The classification of exercise intensity from rpm on IE for relative intensity (%HRR and %VO₂R) is in agreement with the 2011 ACSM exercise intensity scale.¹

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Authors’ contributions

MGarzon conceived of the study, carried out the experiments, participated in the analysis and drafted the manuscript;
MGayda participated in the coordination and drafted the manuscript; AN helped to draft the manuscript; ASC conceived of the study, participated in the analysis, and drafted and revised the manuscript; MJ helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

That authors declare that they have no competing interests.

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