Validation of a New Cycle Ergometer

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Key words
- accuracy
- cycling
- calibration
- testing
- ergometry

Abstract

The purpose of this study was to test the concurrent validity of the ICBE compared to the Monark® cycle ergometer by indirect dynamic calibration. 42 men were randomly submitted to 2 maximal stress tests with increments of 50 W at 2-min intervals. One test was performed on the Monark® bicycle (834/E) and the other on the ICBE. Cardiovascular, perceived exertion and hemodynamic responses were compared between the 2 bicycles. No differences ($p > 0.05$) were observed in resting heart rate (HR), maximum HR, peak oxygen uptake (VO_{2P} $L \cdot min^{-1}$ and $VO_{2P} mL \cdot kg^{-1} \cdot min^{-1}$), and number of stages completed. High correlations ($r > 0.85$) were found between HR and VO_{2P}. Residual analysis indicated strong agreement between the 2 cycle ergometers in terms of VO_{2P} $L \cdot min^{-1}$ [−0.36–0.30] and VO_{2P} $mL \cdot kg^{-1} \cdot min^{-1}$ [−4.98–4.46]. Residual dispersion ($r = 0.25$ for both) showed that the mathematical differences in VO_{2P} $L \cdot min^{-1}$ and VO_{2P} $mL \cdot kg^{-1} \cdot min^{-1}$ between cycle ergometers were independent. The correlation coefficient (r) and coefficient of determination (R^2) between VO_{2P} $L \cdot min^{-1}$ ($r = 0.90$; $R^2 = 0.80$) and VO_{2P} $mL \cdot kg^{-1} \cdot min^{-1}$ ($r = 0.90$; $R^2 = 0.81$) obtained for the 2 cycle ergometers were high, whereas the standard error of the estimate was low (0.186 $L \cdot min^{-1}$ and 2.56 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively). The ICBE presents concurrent validity for use in submaximal and maximal cardiopulmonary tests.

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Bibliography
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Introduction

Cardiopulmonary stress tests have been used during Spinning® classes or sessions to determine differences in cardiovascular, hemodynamic and perceived exertion [5, 13, 14]. In those studies Spinning® bicycles were used as ergometers. However, most models of Spinning® bicycles do not permit a precise workload adjustment. As a consequence, the use of these bicycles in cardiopulmonary stress tests is limited since the results will not be accurate. To overcome this limitation, an indoor cycling bicycle ergometer (ICBE) was constructed and its fragmented calibration was determined [25]. The direct and indirect dynamic calibration of the ICBE has not been established.

The ICBE possesses the same characteristics as Spinning® bicycles, but permits the gradual adjustment of workload through the power produced by subject (power = force x speed) [27].

The ICBE [25] consists of a frame similar to that of Spinning® bicycles but uses the loading system from a Monark® cycle ergometer (basket of weights). The final model (▶ **Fig. 1**) measures 104 cm in length and 51 cm in width, weighs 38 kg, and has a mechanical type brake, fixed gear, seat tube angle of 72°, and a basket of 500-g and 250–1 000-g weights. It possesses fragmented calibration of the wheel and a resistive mechanical load. A Cat-Eye® bicycle computer was installed to measure speed and cadence.

It remains unknown whether the ICBE presents concurrent validity for use in cardiopulmonary tests when compared to a gold standard cycle ergometer. Therefore, the indirect dynamic calibration was used in the present study to test the concurrent validity of the ICBE compared to a Monark® cycle ergometer. The hypothesis was that subjects present similar cardiovascular, perceived exertion and hemodynamic responses to exercise on the 2 cycle ergometers.

Fig. 1 Indoor cycling bicycle ergometer (ICBE).

Material and Methods

Subjects

The sample consisted of 42 amateur male cyclists of regional level. Excluded were subjects who presented resting electrocardiogram and blood pressure anomalies, subjects who reported any problem that would impair their participation in the cardiopulmonary tests, and subjects practicing cycling <1 year. The study has been performed in accordance with the ethical standards of the IJSM [8] and was approved by the Ethics Committee of the Catholic University of Brasília.

Protocol

Pre-test assessment

The subjects were submitted to anamnesis to evaluate the presence of some type of health condition that would restrict their participation in the cardiopulmonary tests. Demographic and periodic data and training volume were collected. After a 10-min rest, blood pressure was measured with a mercury column sphygmomanometer (WanRoss®) and stethoscope (Welch-Allyn®). Next, a resting electrocardiogram was obtained (Marquette Hellige CardioSmart®).

Anthropometry

Body weight, height (Filizola Personal Line®), and the sum of 7 skinfolds (Lange caliper®) were determined to characterize the sample. Pubic symphysis height was measured (Seca) to adjust the seat to the subject [4]. Body density was estimated using the equation for 7 skinfolds [22] and converted into relative body fat percentage (%fat) by the equation of Siri [26].

Cardiopulmonary test

Before each test, the 2 cycle ergometers (Monark® and ICBE) were adjusted to each subject considering angular measurements of thigh/trunk and trunk/arm segments (Cardiomed® goniometer) and pubic symphysis height. The pedal clips of each subject were attached to the cycle ergometers.

Each subject underwent the same cardiopulmonary test twice at an interval of 48–96 h, once on a Monark® 834E cycle ergometer and once on the ICBE. The tests were randomized and performed at similar times. The room temperature was controlled at 18° to 22°C. The subjects were asked to maintain the same level of physical effort on the days preceding the 2 tests.

In view of the characteristics of the subjects studied, warm-up consisted of 1 min at the initial load. The initial load was 50 W, with increments of 50 W at intervals of 2 min (Balke protocol). Cadence was maintained at 50 rpm (Qwik Time® QT-3 metronome) to minimize the variability in power produced at each stage. Low pedaling rates (50–60 rpm) are more economical and efficient than the high pedaling rate (>90 rpm) [15]. There are no differences in delta efficiency for different cadences ranging from 50 to 100 rpm for runners, less trained non-cyclists or trained cyclists [18]. The tests were performed until voluntary exhaustion. The last stage was considered to be completed after a minimum exercise period of 1 min 40 s. The subjects remained seated on the saddle during the tests.

Absolute and relative oxygen uptake (VO_2 $L \cdot min^{-1}$; VO_2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) were obtained breath-by-breath and were expressed as the mean value of the last 20 s of each stage and after 2 min of recovery. Peak oxygen uptake (VO_{2P}) was defined as the highest value obtained in the last stage completed and these were also computed (n stage). The gases were analyzed with an open-circuit gas analysis system (Metalyzer 3B®, Cortex Biophysics) using the Metasoft 3.3 and Ergo PC Elite 3.3 dedicated softwares (Micromed) [16]. The analyzer was calibrated before each test using gases of known concentration (17% O_2 and 5% CO_2) and a 3-liter syringe.

Were also obtained resting heart rate (RHR), heart rate (HR) measured at the end of each stage and 2 min after recovery and maximum HR (HR_{max}) measured at the end of the last stage completed were also obtained (CM5, Micromed® Digital Electrocardiograph).

Perceived exertion

Perceived exertion (PE) was rated on a 6–20 point Borg scale at the end of each stage and 2 min after recovery.

VO_2 cut-off

There is a lack of consistency between studies as to the level of error that is deemed to be acceptable [12]. The variation in VO_{2max} between different gas analysis systems should not exceed 4% or 2–3 $mL \cdot kg^{-1} \cdot min^{-1}$ [1]. This affirmation is not clear: 3 $mL.kg^{-1}.min^{-1}$ corresponds to 4.28% for VO_{2max} = 70 $mL.kg^{-1}.min^{-1}$, but to 7.5% for VO_{2max} = 40 $mL.kg^{-1}.min^{-1}$. Differences in VO_2 and VO_{2max} of 5–10 $mL \cdot kg^{-1} \cdot min^{-1}$ (10–15%) between 3 gas analysis systems have been reported for submaximal and maximal workloads [1]. Analysis of the repeatability of VO_2 measurement showed a difference of up to 15% between the same 3 analyzers and between different laboratories [29]. Differences of 22% have been reported when comparing 3 gas analysis systems [11]. These results show that a measurement error of <5% is not an easily achievable goal and acceptable limits in predictive validity for measurements of VO_2 is poorly defined [12]. Using the findings of these studies as a parameter, an acceptable error ≤8% was established for VO_2, corresponding to approximately half the difference observed when comparing the same 3 analyzers [29]. This value is also lower than the tolerable error for the same gas analysis system [12] and lower than the difference in VO_{2max} obtained for the same cycle ergometer. Thus, 8% of VO_2 (50.25 $mL.kg^{-1}.min^{-1}$ and 3.66 $L.min^{-1}$) obtained (Monark®) for the sample of the present study, respectively, correspond to 4 $mL.kg^{-1}.min^{-1}$ and 0.291 $L.min^{-1}$. A cut-off value ≤8% (4 $mL.kg^{-1}.min^{-1}$; 0.291 $L.min^{-1}$) was used for analysis of individual variations (residue analysis), whereas a cut-off ≤5% (2.51 $mL.kg^{-1}.min^{-1}$; 0.183 $L.min^{-1}$) was used for mean random error and standard error of the estimate.

Statistical analysis

The data showed a normal distribution (Shapiro-Wilk test) and are reported as means ± standard deviation. To determine

Variables	Monark®	ICBE	t	p	r
$RHR_{b.min^{-1}}$	56.8 ± 12.3	57.6 ± 11.9	0.751	0.457	0.853
$HR_{max\ b.min^{-1}}$	182.1 ± 12.4	180.6 ± 12.6	−1.558	0.127	0.879
$VO_{2P\ L \cdot min^{-1}}$	3.66 ± 0.41	3.68 ± 0.41	0.550	0.585	0.896
$VO_{2P\ mL \cdot kg^{-1} \cdot min^{-1}}$	50.3 ± 5.8	50.5 ± 5.7	0.568	0.573	0.899

Note: t = paired t-test, p = level of significance (t-test), r = Pearson's correlation coefficient, RHR = resting heart rate, HR_{max} = maximum heart rate

Table 1 Comparison of heart rate (HR) and maximal oxygen uptake (VO_{2P}) between the 2 cycle ergometers.

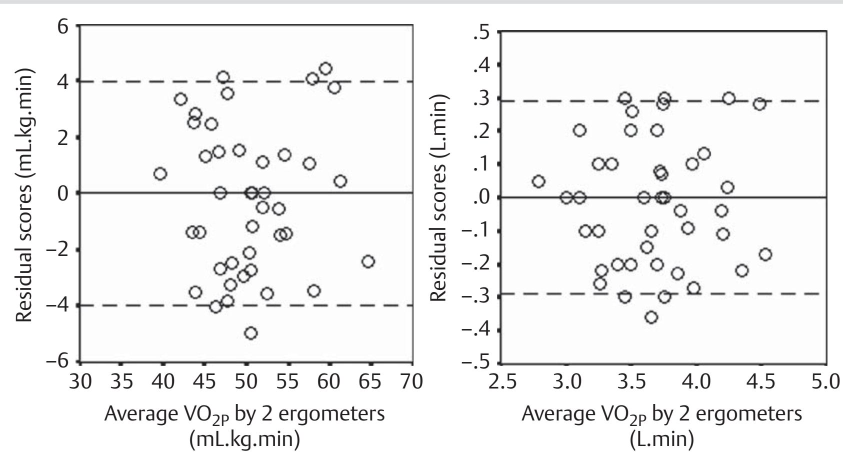

Fig. 2 Analysis of residual scores of peak oxygen consumption obtained for the Monark® cycle ergometer and ICBE. The upper and lower dashed lines represent the validation limits of the ICBE (VO_{2P} = 0.291 L.min^{-1} and 4.0 mL·kg^{-1}·min^{-1}).

whether the ICBE presented indirect dynamic calibration compared to the Monark® cycle ergometer, the cardiopulmonary, hemodynamic and perceived exertion variables obtained in the tests performed on the 2 cycle ergometers were compared using the paired t-test ($p > 0.05$), Pearson's correlation coefficient (r), standard error of the estimate (SEE), coefficient of determination (R^2) ($p \leq 0.05$), and analysis of residual scores [3]. The mean random error of VO_2 ($\Delta\% = [\Sigma(VO_{2\ Monark} – VO_{2\ ICBE})/10]$ was also determined. Statistical analysis was performed using the Statistical Package for the Social Sciences, v. 14.0, licensed for use to the Catholic University of Brasília.

Results

The sample presented the following characteristics (mean ± standard deviation): age = 34 ± 8 years; height = 175 ± 6 cm; body weight = 73 ± 6 kg; %fat = 16 ± 4; systolic blood pressure = 117 ± 13 mmHg; diastolic blood pressure = 74 ± 10 mmHg; cycling experience = 10 ± 8 years; weekly training volume = 332 ± 160 km, and annual training volume = 10 309 ± 7 792 km.

No significant differences ($p > 0.05$) in RHR, HR_{max}, VO_{2P} L·min^{-1}, or VO_{2P} mL·kg^{-1}·min^{-1} were observed. The correlations between HR and VO_{2P} were high ($r > 0.85$) (**Table 1**). Mean n stage did not differ between the 2 ergometers [t (41) = 0.000; 1.0].

Residual analysis, illustrated in **Fig. 2**, indicates strong agreement between the 2 cycle ergometers in terms of VO_{2P} L·min^{-1} [−0.36–0.30] and VO_{2P} mL·kg^{-1}·min^{-1} [−4.98–4.46], taking the cut-off points established as parameter. Interestingly, VO_{2P} L·min^{-1} and VO_{2P} mL·kg^{-1}·min^{-1} obtained for the ICBE differed more than 0.219 L·min^{-1} and 4 mL·kg^{-1}·min^{-1} from the Monark® bicycle in 6 of 42 (15%) and 4 of 42 (10%) subjects, respectively. Residual dispersion (r = 0.25 for both) showed that the mathematical differences in VO_{2P} L·min^{-1} and VO_{2P} mL·kg^{-1}·min^{-1} between cycle ergometers were independent. The correlation and coefficient of determination between VO_{2P} L·min^{-1} (r = 0.90; R^2 = 0.80) and VO_{2P} mL·kg^{-1}·min^{-1} (r = 0.90; R^2 = 0.81) obtained for the 2 cycle ergometers were high, whereas the SEE was similar to the cut-off points (0.186 L·min^{-1} and 2.56 mL·kg^{-1}.min^{-1}, respectively).

The comparison of cardiopulmonary, hemodynamic and perceived exertion variables (ICBE *vs.* Monark®) is shown in **Table 2**. 37 of the 42 subjects reached exhaustion by stage 10. Four reached stage 11 and 1 stage 13. Results past stage 10 were excluded in accordance to a similar study by Basset et al. [2]. Differences ($p \leq 0.05$) in VO_2 L·min^{-1} and VO_2 mL·kg^{-1}·min^{-1} were observed in the 2nd, 9th and 10th stages, with Δ% of 3.5 ± 1.8% [1.32–6.66] for VO_2 L·min^{-1} and of 3.5 ± 1.7% [1.44–6.9] for VO_2 mL·kg^{-1}·min^{-1}. Differences ($p \leq 0.05$) in HR were observed in the 10th stage and differences in PE in the 10th stage and during recovery.

Discussion

The objective of this study was to determine the concurrent validity of the ICBE using indirect dynamic calibration. The RHR results suggested that the subjects started the 2 tests (Monark® and ICBE) under the same fisiological conditions. HR_{max} and the HR determined at each stage indicate that cardiovascular stress was similar in the 2 tests. These results are confirmed by lactatemia (data not shown). The same n stage necessary to complete the tests supports this finding and demonstrates that the power produced by the subjects was similar in ICBE and Monark® cycle ergometer. However, direct dynamic calibration may support these findings.

VO_{2P} L·min^{-1} and VO_{2P} mL·kg^{-1}·min^{-1} obtained with the ICBE were accurate when compared to those obtained with the Monark® cycle ergometer. This was supported by analysis residual scores, with the observation of strong agreement using a rigorous cut-off point. More than 80% of the variation in VO_{2P} L·min^{-1} and VO_{2P} mL·kg^{-1}·min^{-1} observed for the ICBE was explained by the respective results obtained with the Monark® cycle

Table 2 Comparison of oxygen uptake (VO_2), perceived exertion and heart rate between the 2 cycle ergometer according to stage.

St.	n	$VO_{2\ L/min^{-1}}$		$VO_{2\ mL \cdot kg^{-1} \cdot min^{-1}}$		Perceived exertion		Heart rate $_{b.min^{-1}}$	
		Monark®	ICBE	Monark®	ICBE	Monark®	ICBE	Monark®	ICBE
1°	42	0.85±0.10	0.83±0.16	11.7±1.5	11.3±2.2	6.6±0.9	6.5±1.1	83.9±11.1	83.6±14.9
2°	42	1.20±0.17	1.12±0.21*	16.5±2.4	15.4±3.0*	7.5±1.5	7.2±1.5	96.3±13.4	94.0±14.7
3°	42	1.54±0.17	1.46±0.28	21.1±2.7	20.1±4.0	8.9±1.7	8.5±1.7	108.5±14.0	106.1±15.8
4°	42	1.91±0.22	1.83±0.36	26.2±3.7	25.2±5.2	10.4±2.0	10.0±2.0	121.7±16.2	119.1±16.9
5°	42	2.26±0.21	2.23±0.40	31.2±4.2	30.7±5.9	12.0±2.1	11.5±2.4	133.8±16.3	132.1±18.5
6°	42	2.66±0.22	2.62±0.43	36.7±4.5	36.1±6.5	13.4±2.2	13.1±2.6	146.4±17.0	144.6±18.9
7°	42	3.02±0.22	2.96±0.39	41.5±4.7	40.8±6.5	14.6±2.3	14.7±2.7	158.0±16.5	156.9±18.3
8°	36	3.30±0.34	3.22±0.33	45.3±6.1	44.1±5.6	15.6±2.5	15.5±2.9	168.0±14.9	164.5±16.2
9°	25	3.67±0.26	3.46±0.22*	49.5±4.7	46.8±5.4*	16.9±2.1	16.2±2.8	174.2±15.7	169.7±16.2
10°	15	3.92±0.28	3.73±0.22*	51.6±6.6	49.2±5.9*	17.6±2.1	15.8±2.8*	177.4±8.9	172.0±12.4*
Rest	42	1.29±0.25	1.27±0.25	17.7±3.5	17.4±3.6	9.0±2.4	8.2±2.2*	131.2±14.5	130.5±13.5

Note: St = stage, n = number of subjects who completed the stage
* = $p \leq 0.05$

ergometer and was supported by the high consistency of the data ($r > 0.89$). The SEE were similar to the cut-off points established, indicating that VO_{2P} estimated in the cardiopulmonary test performed on the ICBE is accurate when compared to that obtained with the Monark® cycle ergometer.

The kinetics of VO_2 $L \cdot min^{-1}$ and VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ were linear over the load increments for all stages and during recovery. The differences ($p \leq 0.05$; $\Delta\%$ 4.7–6.9) in the 3 stages (2nd, 9th, 10th) were lower than the cut-off points established. These differences are not important if the prescription of aerobic resistance training, graded from 10 to 20% VO_{2P} [6], is considered.

Variations in VO_2 of 209 $mL.min^{-1}$ and 332 $mL.min^{-1}$ for submaximal and maximal loads, respectively, have been observed in repetitive tests on the same cycle ergometer [28]. The difference in VO_2 between the ICBE and Monark® bicycle was 80, 210 and 190 $mL.min^{-1}$ in the 2nd (submaximal load), 9th and 10th (maximal load) stages, respectively. Thus, the variations in VO_2 observed in the present study were markedly lower. This finding is supported by the low mean random error ($\Delta = 3.6\%$) between the 10 stages.

The lower VO_2 observed for the ICBE might be explained by the difference in seat tube angle (ICBE: 72°; Monark®: 80°). Larger angles increase power production, alter the posture of the cyclist and reduce activation of the biceps femoralis muscle [24]. The Monark® cycle ergometer probably required greater energy expenditure of the lower limbs, causing a higher VO_2 of the accessory muscles and lower economy [9,23]. The subjects reported (qualitatively) better pedaling comfort on the ICBE because it is similar to their usual bicycles. In addition, experienced cyclists reduce VO_2 when using cycle ergometers with a geometry similar to that of their training bicycles [9,23].

In view of the above considerations and since the differences ($\Delta\%$) obtained were below the cut-off point established, the ICBE presents concurrent validity for the use in tests quantifying VO_2 at submaximal and maximal loads.

HR and PE accompanied VO_2 kinetics as previously reported [20,28]. The difference in HR was 5 bpm ($\Delta = 5\%$), a difference considered to be poorly relevant [19] and lower than that found in test-retest situations on the same cycle ergometer (10 bpm, $\Delta = 10\%$) [28]. The small sample size ($n = 15$) might have influenced the differences observed in the 10th stage. The difference of 1.8 points ($\Delta = 10\%$) in PE is close to the 1.3 ($\Delta = 7\%$) reported for maximal loads [28]. HR and PE per se permit to precisely regulate the workload intensity.

Among the 40 comparisons made (1st to 10th stage), differences were observed in 8 subjects (20%), 6 of them (15%) in the final stages. In clinical practice, this finding does not exclude the use of the ICBE in submaximal and maximal ergometric tests since the physiological, hemodynamic and perceived exertion magnitude ($\Delta\%$) of these differences is small.

In addition to the factors cited, other factors not analyzed here may contribute to differences between cycle ergometers, such as lack of reliability of the gas analysis system [29]. Cycle ergometer errors and biological variations substantially contribute to common measurement errors [21]. Biological variability accounts for about 90% of the total variability with 10% of the remaining variability caused by technical problems [16]. Variations in cadence, incomplete transmission of the load to the wheel [17], internal resistance, chain deformation, and vibration of the load system [10] are some possible sources of cycle ergometer errors. The design and instruments used did not permit to establish the magnitude of these sources of error. This opens the possibility of further studies for the measurement of the power of the ICBE (e.g. direct dynamic calibration) since improvement of the equipment is the most important factor to obtain accurate measures. However, it should be noted that an ergometer presenting validity determined by direct dynamic calibration may not present concurrent validity in relation to a gold standard ergometer because of errors [29] between the same gas analysis systems. However, 5 brands of cycle ergometers were evaluated [7] by comparing the VO_2 requirements at different displayed power. Large differences (5–10 $mL \cdot kg^{-1} \cdot min^{-1}$) at the same displayed power indicate inaccuracy of displayed power output. Using corrected power values from the standard dynamometer revealed that for the same VO_2 the power output was underestimated by 15 W for the Monark. The researchers [7] did not consider the error of gas analysis systems.

Thus, the results of this study derived from the different statistical analyses permit to infer that the gas analysis system was reliable for the 2 ergometers. Therefore, the ICBE can be used as an ergometer to obtain accurate data.

In conclusion, the hypothesis raised in this study was confirmed, i.e., the subjects presented similar cardiovascular, perceived exertion and hemodynamic responses to exercise on the 2 cycle ergometers. The loads imposed by the ICBE were accurate when compared to the Monark® cycle ergometer. Thus, the ICBE presents concurrent validity for use in submaximal and maximal cardiovascular tests when compared to the Monark® ergometer.

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