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Is $\dot{V}O_{2peak}$ a Valid Estimation of $\dot{V}O_{2max}$ in Swimmers with Physical Impairments?

Wellington G. Feitosa ^{a,b}, Tiago M. Barbosa ^{c,d,e}, Ricardo de A. Correia ^a, and Flávio A. de S. Castro ^a

^aUniversidade Federal do Rio Grande do Sul; ^bUniversidade Estadual do Ceará; ^cNanyang Technological University; ^dPolytechnic Institute of Bragança; ^eResearch Centre in Sports Health and Human Develop

ABSTRACT

Purpose: Peak and maximal oxygen uptake ($\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$, respectively) are used in assessing aerobic power. For swimmers with physical impairments, it is unclear whether the physiological variables obtained in 200-m and Nx200-m tests are similar. The objective of this study is to assess the validity of $\dot{V}O_{2peak}$ as an estimator of $\dot{V}O_{2max}$ and complementary physiological variables, in particular, carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), minute-ventilation (\dot{V}_E) and absolute (HR) and relative (%HRmax) heart rates—which were obtained in a time trial test (200-m) and an incremental intermittent test (Nx200-m) performed by swimmers with physical impairments. **Methods:** Eleven well-trained swimmers with physical impairments performed 200-m all-out and Nx200-m from low to all-out (controlled by a visual pacer), both with a respiratory valve system and a portable gas analyzer. **Results:** A paired Student's t-test showed no statistical difference ($p > .05$) for all comparisons. The intraclass correlation coefficient (ICC) was 0.97 and 0.98 for $\dot{V}O_2$ in l/min and ml/kg/min, respectively; ICC = 0.75 to 0.9 for $\dot{V}CO_2$ (l/min and ml/kg/min), \dot{V}_E (in l/min) and HR (beats/min); ICC = 0.5 and 0.75 for %HRmax; and ICC < 0.5 for RER. Passing-Bablok regression showed that the dispersions were acceptable, considering the proportionality, except for HR and %HRmax. Bland-Altman method showed a high level of agreement for all variables. **Conclusions:** The $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$, as well as the physiological variables $\dot{V}CO_2$ and HR obtained, respectively, by 200-m and Nx200-m tests in swimmers with physical impairment were not different.

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Oxygen uptake ($\dot{V}O_2$) is commonly monitored in sports physiology approaches (Burnley & Jones, 2018; Hale, 2008). In this way, the highest $\dot{V}O_2$ value obtained from a test is the peak oxygen uptake ($\dot{V}O_{2peak}$), and the $\dot{V}O_2$ identified in a plateau, even with increased effort, is the maximum oxygen uptake ($\dot{V}O_{2max}$), which is an indicator of aerobic power (de Souza et al., 2016; Poole & Jones, 2017). $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ can be obtained in time trials (e.g., a 200-m test) and incremental intermittent protocols (e.g., an Nx200-m test), respectively (Sousa et al., 2011; Zacca et al., 2017).

Single time trials and incremental intermittent protocols have different characteristics: incremental intermittent protocols have a longer duration, a higher rate of work and higher-intensity physiological responses compared to a single trial test (Billat et al., 1996; de Jesus et al., 2015; Lomax, Mayger, Saynor, Vine, & Massey, 2018). These characteristics impact on greater complexity during the execution of the incremental swim test to reach $\dot{V}O_{2max}$ (Poole & Jones, 2017). It is possible that swimmers with

physical impairments can benefit from $\dot{V}O_{2peak}$ results obtained in a 200-m test if these values are similar to $\dot{V}O_{2max}$ values, since some studies have shown approximations between $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ (Billat et al., 1996; Sousa et al., 2010; Zacca et al., 2017), although these studies focused on able-bodied swimmers.

For swimmers with physical impairments, the longest race is the 400-m freestyle. In swimming, both 400-m and 200-m tests provide a valid set of information on physiological variables, such as a $\dot{V}O_{2peak}$ that is similar to the $\dot{V}O_{2max}$, when compared to incremental intermittent swim tests for able-bodied swimmers (Billat et al., 1996; Sousa et al., 2010; Zacca et al., 2017). Furthermore, the duration of a time trial test (400-m) is not different to the effort time required to reach the minimal velocity at which $\dot{V}O_{2max}$ is elicited in incremental intermittent tests for able-bodied swimmers (Billat et al., 1996; Reis, Alves, Bruno, Vleck, & Millet, 2012).

The 200-m test can be used to monitor the cardiorespiratory capacity of able-bodied swimmers (de Souza

et al., 2016; Sousa et al., 2011). It also seems to be appropriate for monitoring the aerobic power of swimmers with physical impairments, since shorter swim distances are commonly used in swimmers' training. Furthermore, the duration of the 200-m test in these swimmers is dependent on large morphological variations (absence or presence of body segments), impaired muscle power and motor control (hypertonia, ataxia, athetosis, hemiplegia and paraplegias). These characteristics imply movement restrictions and increased drag during swimming (Fulton, Pyne, Hopkins, & Burkett, 2009; Oh, Burkett, Osborough, Formosa, & Payton, 2013).

However, in swimmers with physical impairments, there is a gap in the science behind the set of information that can be provided by a 200-m test, compared to an incremental intermittent test. Understanding the possible relationships between maximal effort in a time trial test (200-m, a short test) and an intermittent incremental test (Nx200-m) is useful in approaches that are applied to determine and monitor the aerobic power of physically impaired swimmers. Moreover, the technical team could formulate specific strategies in the training prescription if distance and speed are similar between time trial tests (200-m) and competitive tests (200-m race), but without starting and turning.

The standard, conventional approach to assessing cardiorespiratory response in physical tests is to monitor the $\dot{V}O_{2max}$ in incremental intermittent protocols (Poole & Jones, 2017). Swimmers with physical impairments have physiological responses, such as $\dot{V}O_2$, carbon dioxide production $\dot{V}CO_2$ and heart rate (HR), that are affected by muscle mass and the mobility restrictions involved in exercise (de Souza et al., 2016). Thus, when considering the possible uses of $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ in physiological assessments of swimmers, could a single time trial provide $\dot{V}O_{2peak}$ values similar to those achieved in incremental intermittent tests for $\dot{V}O_{2max}$ in swimmers with physical impairments? The differences between $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ are widely discussed in the literature (Azevedo et al., 2018; Zuo et al., 2018). In this sense, the incremental intermittent test, combined with breath-by-breath ventilation and gas exchange measurements, is considered the gold standard in experimental and clinical cardiopulmonary assessments (Poole & Jones, 2017) and produces a highly reproducible $\dot{V}O_2$ by forcing the rate of work to higher intensities (Cooper, Weiler-Ravell, Whipp, & Wasserman, 1984). However, incremental intermittent tests are clearly more time-consuming and present challenges in the procedures that are followed after the subject is fatigued in order to verify a "true" $\dot{V}O_{2max}$ (Pettitt & Jamnick, 2017).

Therefore, the objective of this study was to assess the validity of $\dot{V}O_{2peak}$ as a $\dot{V}O_{2max}$ estimator, as well as complementary physiological variables—in particular, carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), minute-ventilation (\dot{V}_E), heart rate absolute (HR) and relative (%HRmax)—obtained in a time trial test (200-m) and an incremental intermittent test (Nx200-m) performed by swimmers with physical impairments. We hypothesized that physiological variables collected in a time trial would be a valid proxy of data to an incremental test in swimmers with physical impairments.

Methods

Participants

Eleven well-trained swimmers (seven men and four women) with physical disabilities participated in the swimming tests, including a time trial protocol (200-m) and an intermittent incremental test (Nx200-m). G*Power 3.1 software (Düsseldorf, Germany) was used to determine the minimum sample size required to provide a statistical power of 0.8, with an alpha of 0.05 for the analysis, and a 95% confidence interval, admitting a sample error of 5% and assumed effect size of 0.56.

The swimmers' main physical characteristics and training backgrounds are outlined in Table 1. All swimmers had at least five training sessions per week and swam 20 km per week. The inclusion criterion of this study was swimmers who have participated in regional, national or international competitions, with at least two years of experience. Swimmers with any physical disability and an International Paralympic Committee (IPC) classification could participate in the study (all the swimmers were classified by an official international classifier). Participants who had any contraindications to the swimming tests, such as congenital or atherosclerotic heart disease, metabolic disease, active smoking, atlantoaxial instability, surgical procedures in the last three months, and/or any injury and/or orthopedic problems that implied an inability to complete the swimming tests did not participate in this study. The researchers collected health information from the participants before anthropometric measurements and swimming tests.

The study was approved by the local ethics committee and was performed in accordance with the Declaration of Helsinki. All swimmers signed a written consent form in which the protocol was explained in detail.

Experimental approach

The swimming test sessions (200-m and Nx200-m) were preceded by two sessions to familiarize the

Table 1. Characteristics of swimmers with impairments.

	Male (n = 7)	Female (n = 4)	Overall (n = 11)
Age (years)	28.4 ± 8.5	39.2 ± 16.3	32.3 ± 12.3
Body mass (kg)	70.3 ± 9.2	61.8 ± 9.8	67.2 ± 9.9
Height (cm)	178.1 ± 6.3	165.0 ± 3.8	173.3 ± 8.5
Training background (years)	7.2 ± 2.3	4.7 ± 5.5	6.4 ± 3.7
Classification	S5, S7, S9	S5, S8-S10	S5-S10*
Competitive level	n = 4 [♦] , n = 1 ^{♦♦} , n = 2 ^{♦♦♦}	n = 3 [♦] , n = 1 ^{♦♦♦}	n = 7 [♦] , n = 1 ^{♦♦} , n = 3 ^{♦♦♦}
200-m average speed (m/s) [□]	0.99 ± 0.19	0.84 ± 0.10	0.93 ± 0.17

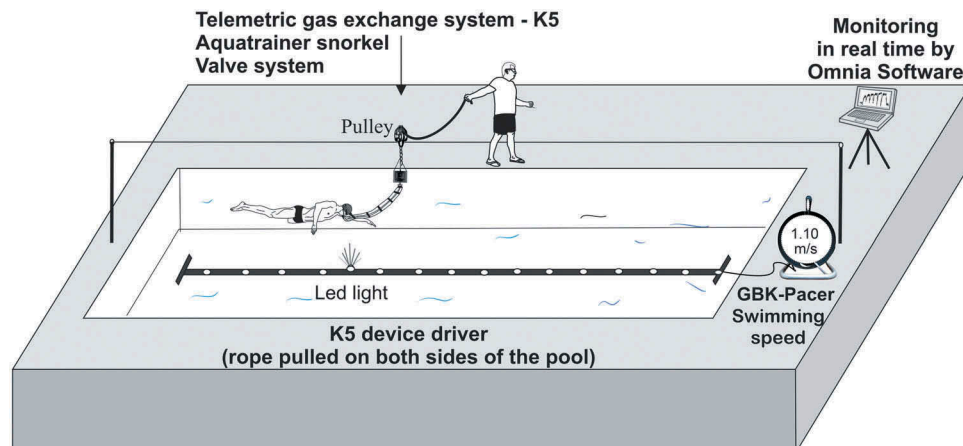
♦ Regional; ♦♦ National; ♦♦♦ International; Classification = swimmers with physical impairment (International Paralympic Committee, 2017). *Except class S6. □Swimming with Aquatrainer snorkel. Sports classes: S5—hemiplegia, S5—spinal cord injury (T11–L1); S7—spinal cord injury (T11–T12); S8—spinal cord injury (L1–L2), S8—one arm amputated near the shoulder; S9—one forearm amputation, S9—one lower limb amputation near the hip, S9—congenital crooked foot sequelae and poor ankle mobility; S10—amputation slightly below the knee.

participants with the testing procedures and equipment, and to measure their height (SANNY, Personal Caprice, resolution of 0.1 cm, Brazil) and body mass (SECA® 813, resolution of 0.1 kg, Germany). The setup of the data collection is portrayed in Figure 1. During familiarizations with the Aquatrainer snorkel (Cosmed, Italy), swimmers were encouraged to take deeper breaths compared to those used with their conventional swimming snorkels, as well as to perform different swimming speeds during 200-m tests. Simulations were also performed with the visual pacer for all moments of the incremental swimming test (outings, swimming course and 30 s interval). A wash-out period of 24 hours was set between the swimming tests. The procedures were performed during the day in an indoor swimming pool, 25 m in length, with a depth of 1.9 m, track width of 2.5 m and water temperature of 29–30°C (Intex thermometer, Brazil). The tests started in the water to avoid possible effects of the block start at swimming speed (Barbosa et al., 2013), and due to the use of a snorkel.

The warm-up was comprised of a 600 m total swim, including 200-m freestyle, 200-m with a conventional snorkel and 200-m with an Aquatrainer snorkel

(Cosmed, Italy). All of the swimmers used conventional snorkels in their training sessions on a regular basis. The warm-up intensity was adjusted according to the experience and fitness level of each swimmer and included continuous swimming at low-to-moderate intensity, technical drills and sprints. Each swimmer performed both tests using the front-crawl technique: 200-m receiving encouragement to swim their best effort, and Nx200-m with speed increases of 0.05 m/s and a 30-s interval between the 200-m stages. Swimming speed during the incremental intermittent test was controlled by an underwater visual pacer (GBK Electronics, Portugal). The use of visual pacer has been recognized as an important feature to adjust swimming speed in both experienced and inexperienced swimmers (Fernandes et al., 2008; Keskinen & Keskinen, 1999).

The incremental tests were planned so that the maximum intensity and the $\dot{V}O_{2max}$ were reached in the fifth stage of the 200-m swim. However, $\dot{V}O_{2max}$ was reached in the fourth (n = 5), fifth (n = 5) and sixth (n = 1) steps. The first speed of the intermittent incremental test was determined by calculating the average speed obtained from the time trial protocol (200-m performed at maximal effort) using the

**Figure 1.** Physiological data collection set-up over the 200-m and Nx200-m protocols.

Aquatrainer snorkel (Cosmed, Italy) and decreasing by 0.25 m/s.

Data collections of physiological variables

The $\dot{V}O_{2peak}$, $\dot{V}O_{2max}$, $\dot{V}CO_2$ in absolute (l/min) and relative (ml/kg/min) values, RER and \dot{V}_E in l/min were measured breath-by-breath using a portable gas analyzer (K5, Cosmed, Italy) and a snorkel (Aquatrainer, Cosmed, Italy) with a low hydrodynamic profile (Guidetti et al., 2018; Ribeiro et al., 2016). The K5 analyzer and Aquatrainer snorkel were moved slightly forward and above the swimmer (at a height of 2 m) on a double pulley attached to double steel ropes, minimizing any disturbance to normal swimming movements.

The $\dot{V}O_{2peak}$ was the highest value of the intervals analyzed in the gas sample (Sousa et al., 2011). $\dot{V}O_{2peak}$ was reached, on average, within the final 60 seconds. The $\dot{V}O_{2max}$ was obtained at the minimum swimming speed above which the $\dot{V}O_2$ failed to increase further (Poole & Jones, 2017). The observed primary and secondary criteria (de Jesus et al., 2015; Howley, Bassett, & Welch, 1995; Ribeiro et al., 2016; Sousa et al., 2015) included the following:

- (i) Occurrence of a plateau in $\dot{V}O_2$ with a variation smaller than 2.1 ml/kg/min, despite increased swimming speed; the $\dot{V}O_{2max}$ verification was performed with an increase in intensity of 0.05 m/s after the last 200-m (Figure 1). For more information see Poole and Jones (2017).
- (ii) Elevated blood lactate levels ≥ 8 mmol/l.
- (iii) Increased RER ($r \geq 1.0$), elevated HR (HR > 90% of [220—participant's age]) and high rate of perceived exertion (visually controlled and case-by-case).

The plateau was observed in nine swimmers (incremental test). For these nine participants it was possible to compare the $\dot{V}O_2$ reached in the last repetition of 200-m (when it was not possible to maintain the swimming speed provided by the visual pacer) with the $\dot{V}O_2$ reached in a new repetition of 200-m and increased speed (0.05 m/s), after an interval of 30 seconds. For more information see Poole and Jones (2017). For two participants the secondary criteria to define the $\dot{V}O_{2max}$ were followed (de Jesus et al., 2015; Howley et al., 1995; Ribeiro et al., 2016; Sousa et al., 2015). These two swimmers did not support an additional 200-m repetition after fatigue and presented RER ($r \geq 1.0$), blood lactate levels ≥ 8 mmol/l, HR > 90% and high rate of perceived exertion (19 points).

In order to minimize the noise arising from the gas acquisition in the breath-by-breath system, editing was performed through the ergospirometric system to exclude errant breaths (e.g., coughing or swallowing). Resulting values that fell in range of the mean \pm four standard deviations were admitted (Ozyener, Rossiter, Ward, & Whipp, 2001). The $\dot{V}O_2$ values were calculated every 10 s, on average, and smoothed using a three-breath moving average (Fernandes et al., 2008). HR (beats/min) was measured immediately after the tests, using a cardiac monitor and transmitter (Polar V800 with an H10 Bluetooth transmitter, Polar Electro Oy, Kempele, Finland). The %HRmax was calculated as $([HR_{max} - HR_{swim\ test}] / HR_{max}) * 100$ (Wilmore & Costill, 2004).

Statistical analysis

All statistical analyses were performed in software XLSTAT 2018, Data Analysis and Statistical Solution for Microsoft Excel (Addinsoft, Paris, France). Sample data are described using the mean \pm SD. The distribution of all data was verified (Shapiro-Wilk). Statistical significance was accepted as $p < .05$. The following statistical procedures were used, with the respective objectives:

- (i) The coefficient of variation (CV) is an indicator of precision and was calculated with values of the differences of the SD (SDdif) divided by the differences of the means (meandif) of the physiological variables of the Nx200-m and 200-m tests, $CV = (SDdif) / (meandif)$.
- (ii) Student's t-test for paired samples: to compare the significance between the means differences of the values, with the validity criterion set as the acceptance of the null hypothesis, that is, $p > 0.05$.
- (iii) Intraclass correlation coefficient (ICC): to establish homogeneity through the fraction or proportion of the total variability of the measurements due to variations between the results (Koo & Li, 2016).
- (iv) Simple linear regression: to quantify the coefficient of determination (R^2), identifying the percentage of the variability of the dependent variable (time trial test) in relation to the independent variable that was considered the gold standard (results of the incremental test) with validity criteria set as having at least one high association, where $R^2 \geq 0.49$ (Michaela, Štastný, Jaroslav, & Miroslav, 2016).
- (v) Passing-Bablok regression analysis: to show the dispersion of the measured variables, considering as proportional the 95% confidence interval of the slope when it includes a value

of 1 and the 95% confidence interval of intercept when it includes a value of zero. The random differences between the two methods were verified by the residual standard deviation. The Cusum linearity test was used to verify whether the data were adjusted to the linear model. A small P value (< 0.05) indicates that the relationship between the two variables is not linear and the Passing-Bablok method should not be used (Passing & Bablok, 1983).

- (vi) Bland-Altman plots: to verify the level of agreement between the tests (Bland & Altman, 1986). The Bland-Altman method included an estimation of confidence intervals for bias and limits of agreement (the 95% limits according to the mean difference of standard deviations were -1.96 and 1.96), with the validity criterion set as having at least 80% of the values within a difference ± 1.96 standard deviation.

Results

The CV between each physiological variable was 0.22 for $\dot{V}O_2$ (l/min), 0.03 for $\dot{V}O_2$ (ml/kg/min), 9.00 for $\dot{V}CO_2$ (l/min), 0.65 for $\dot{V}CO_2$ (ml/kg/min), -0.65 for RER, -6.53 for \dot{V}_E (l/min), -3.82 for HR (beats/min), -1.90 for %HRmax. The $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ curves obtained from both tests of one typical Paralympic swimmer, representative of the sample, are portrayed in Figure 2. Figure 2 shows an abrupt transition from resting (low oxygen consumption) to more intense exercise. In the transition from rest to moderate intensity, there is a short delay phase (cardiodynamic) due to increased energy demands, increased cardiorespiratory and muscle requirements, followed by an exponential profile (Reis et al., 2012).

Physiological output obtained from the 200-m and Nx200-m tests are noted in Table 2. There was no statistical difference ($p > .05$) between the values obtained from both tests (200-m and Nx200-m). Additionally, the proportion of the total variability (ICC) was equal to or greater than 72% for the vast majority of the

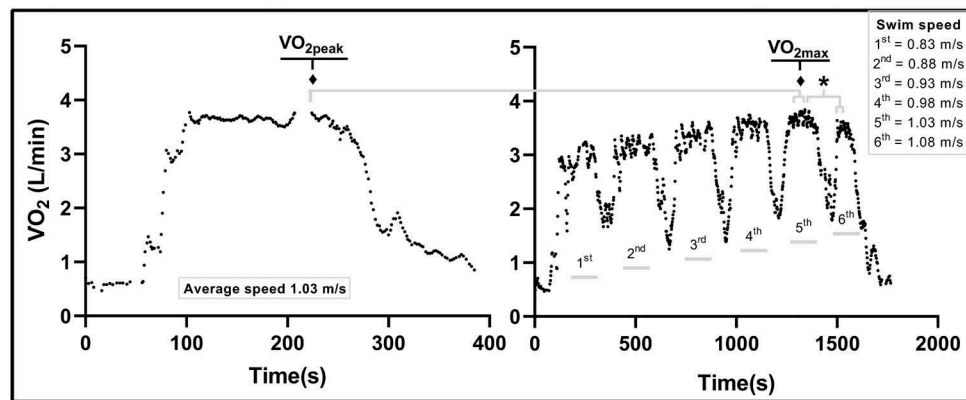


Figure 2. Individual oxygen uptake of a representative international Paralympic swimmer (Paralympics Sydney 2000, London 2012 Paralympic Games, Toronto 2015 Parapan American Games). Left: 200-m. Right: Nx200-m. ♦ Overall results: T-test: $p > 0.05$, Passing-Bablok: $p = 1.00$, Bland-Altman plots: values are close to the zero axis and within 95% of the agreement intervals. *Difference between 5th set of 200-m and test with increment of intensity for confirmation of $\dot{V}O_{2max}$.

Table 2. Physiological variables obtained in the Nx200-m and 200-m, $n = 11$ tests.

	Nx200-m ($\dot{V}O_{2max}$) mean \pm SD	200-m ($\dot{V}O_{2peak}$) mean \pm SD	Absolute mean difference (95% confidence interval of the difference)	Intraclass correlation coefficient (95% confidence interval)	Linear Regression (R^2)
$\dot{V}O_2$ (l/min)	2.58 \pm 0.74*	2.67 \pm 0.76*	-0.09 (-0.19 to 0.007)	0.97 (0.10 to 0.99)♦♦	0.96♦♦
$\dot{V}O_2$ (ml/kg/min)	38.26 \pm 8.34*	39.50 \pm 8.38*	-1.23 (-2.74 to 0.27)	0.98 (0.94 to 0.99)♦♦	0.92♦♦
$\dot{V}CO_2$ (l/min)	2.21 \pm 0.55*	2.22 \pm 0.64*	-0.01 (-0.35 to 0.33)	0.79 (0.18 to 0.94)♦	0.41♦
$\dot{V}CO_2$ (ml/kg/min)	31.03 \pm 6.82*	33.03 \pm 8.12*	-2.00 (-5.47 to 1.46)	0.85 (0.50 to 0.96)♦	0.60♦
RER	1.23 \pm 0.09*	1.20 \pm 0.11*	0.03 (-0.06 to 0.12)	0.29 (-1.78 to 0.81)	0.02
\dot{V}_E (l/min)	88.52 \pm 21.07*	87.88 \pm 25.25*	0.64 (-12.26 to 13.54)	0.80 (0.25 to 0.94)♦	0.44♦
HR (beats/min)	167.00 \pm 14.30*	164.73 \pm 22.97*	2.27 (-7.65 to 12.20)	0.83 (0.37 to 0.95)♦	0.61♦
%HRmax	88.98 \pm 6.63*	87.43 \pm 9.57*	1.54 (-3.71 to 6.80)	0.72 (-0.06 to 0.92)♦	0.34♦

Oxygen uptake ($\dot{V}O_2$); Respiratory exchange ratio (RER); Carbon dioxide production ($\dot{V}CO_2$); Minute ventilation (\dot{V}_E); Percent maximum heart rate (%HRmax); T-test: * $p > .05$; Intraclass correlation coefficient (ICC): ♦ $p < .05$; ♦♦ $p \leq .0001$; Linear regression (p -value): ♦ $p \leq .05$; ♦♦ $p \leq .0001$.

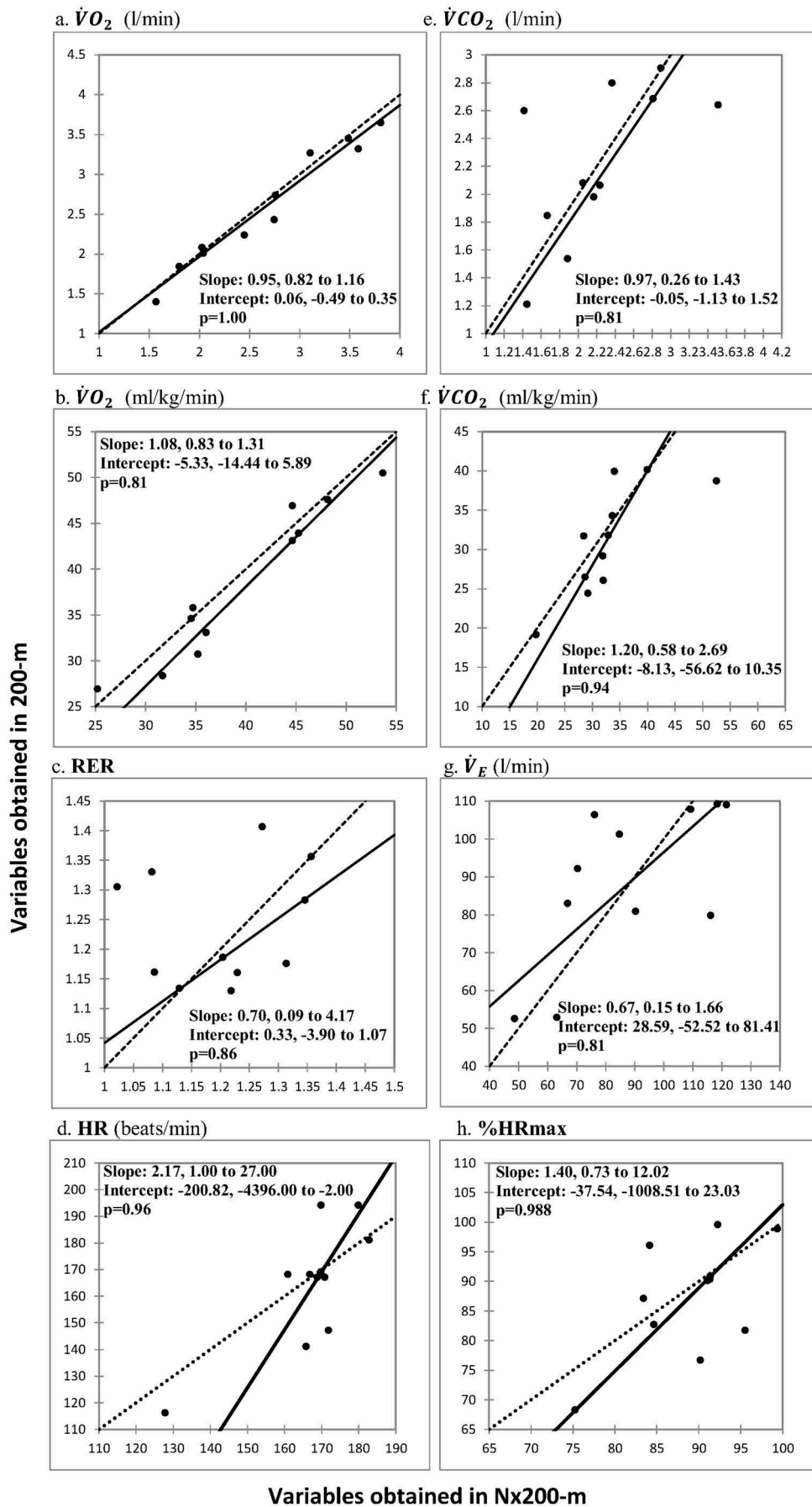


Figure 3. Passing-Bablok regression of variables obtained in Nx200 and 200-m, n = 11.

physiological variables analyzed, except for the RER (Table 2). Linear regression tests showed very high associations for $\dot{V}O_2$ (l/min and ml/kg/min), $\dot{V}CO_2$ (ml/kg/min) and HR (beats/min) (Table 2).

A Passing-Bablok regression using physiological variables obtained in the Nx200-m and 200-m is shown in Figure 3. Based on the Cusum Test, all relations between the two variables (Nx200-m and 200-m) are linear ($p > .05$) (Figure 3). The 95% confidence intervals of the slope coefficient obtained from the Passing-Bablok regression analysis include the 1-value. The 95% confidence intervals of the intercept include zero value, except for HR and %HRmax. In addition, the Bland-Altman plots using the physiological variables obtained in the Nx200-m and 200-m are portrayed in Figure 4. All of the physiological values obtained in Nx200-m and 200-m are close to zero, and at least 80% of the values fall within 95% confidence intervals (difference \pm 1.96 standard deviation). The bias and standard error are, respectively, 0.09 ± 0.15 in l/min and 1.23 ± 2.24 in ml/kg/min for $\dot{V}O_2$, 0.01 ± 0.51 l/min and 2.00 ± 5.16 in ml/kg/min for $\dot{V}CO_2$, -0.03 ± 0.13 for RER, 0.64 ± 19.20 l/min for \dot{V}_E , 2.27 ± 14.77 in beats/min for HR, and $1.54 \pm 7.83\%$ for %HRmax.

Discussion

The objective of this study was to assess the validity of $\dot{V}O_{2peak}$ as a $\dot{V}O_{2max}$ estimator and other physiological variables ($\dot{V}CO_2$, RER, \dot{V}_E , HR and %HRmax) collected in a time trial test (200-m) and an incremental intermittent test (Nx200-m) in swimmers with physical impairments. The comparisons between the physiological variables obtained demonstrate not different values on both tests. The CV for the main variable ($\dot{V}O_2$ in l/min and ml/kg/min) demonstrated precision in the results from both tests.

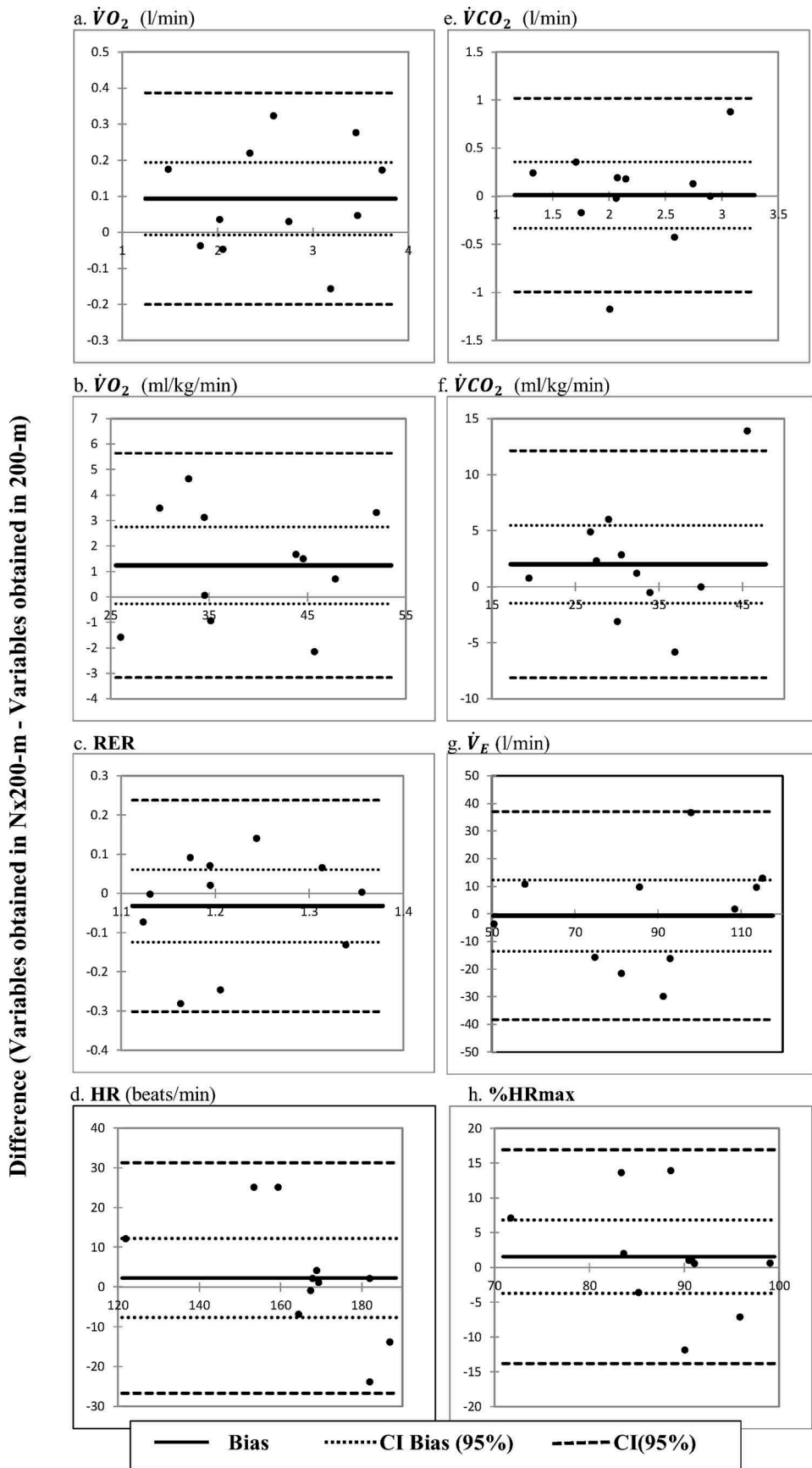
The magnitude of respiratory changes may be different over time and during the progressive increase of the work rate in intermittent tests (Cooper et al., 1984). Additionally, the proportion of total variability of measurements due to variations between $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ results was 97 and 98% in, respectively, L/min and ml/kg/min, and there was a very high coefficient of determination for $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ (both in l/min and ml/kg/min). These results are in accordance with those establishing $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ in a time trial test and incremental intermittent test (7×200 -m) for young and able-bodied swimmers (males: 15.5 ± 0.5 years of age; females: 15.0 ± 0.7 years of age) from a previous study (Zacca et al., 2017).

The ICC values were 0.79 and 0.85 for $\dot{V}CO_2$, respectively, in l/min and ml/kg/min and 0.80 for \dot{V}_E (l/min), but

were 0.29 for RER. $\dot{V}CO_2$ values were slightly lower than $\dot{V}O_2$ values during exercise in both tests. \dot{V}_E in the time trial test was slightly lower in relation to the incremental intermittent test; a possible explanation for this could be the shorter duration of the time trial test, without the cumulative effects of the previous repetitions on the tidal volume that occur in the progressive test. In the incremental intermittent test, swimmers presented slightly higher \dot{V}_E values, with less dispersion compared to the trial time test. In the incremental intermittent test, the \dot{V}_E obtained at maximal aerobic power induces a higher \dot{V}_E elevation in the incremental intermittent test than in the time trial test. At that time, a higher level of physiological function is required, including the elevation of body temperature, recruitment of type II fibers, the work of the ventilatory and cardiac muscles, and \dot{V}_E increases for the ongoing lacticacidaemia (Whipp, 1994; Whipp, Ward, & Rossiter, 2005). Swimmers used the largest static respiratory volumes differently during these exercises, reaching their \dot{V}_E in long, deep breaths (Rosser-Stanford, Backx, Lord, & Williams, 2018), and the gradual increase in intensity progressively changed the tidal volume and respiratory rate (Neder et al., 2003). Previous studies report that sharper increases in \dot{V}_E occur when swimmers approach the respiratory plateau (Aliverti, 2016). On the other hand, although the RER did not present a statistical difference, the correlation coefficient was poor, and the coefficient of determination was low. Such comparisons mean that the RER of the two tests are not associated.

The results for HR and %HR have lower validity to assume that a true $\dot{V}O_{2max}$ has been achieved (Poole, Wilkerson, & Jones, 2008). However, secondary parameters have been adopted in incremental swimming tests (de Jesus et al., 2015; Ribeiro et al., 2016; Sousa et al., 2015). In this sense, the results for HR and %HRmax showed lower precision (coefficient of variation) than $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$. However, the HR and %HRmax results were not different and were in agreement. The HR and %HRmax values in the two tests seem to be influenced by the autonomic characteristics of the participants, such as lower HR values found in swimmers with paraplegias and/or with multiple-system (e.g., motor and heart) atrophy (Fanciulli & Wenning, 2015). In this case, the variability of sympathetic and parasympathetic activation is impaired (Koenig, Jarczok, Wasner, Hillecke, & Thayer, 2014).

Immediately after the 200-m test, participants reached their absolute HR, which was close to 90% of the maximum heart rate for both tests ($87.4 \pm 9.5\%$ for the time trial test and $88.9 \pm 6.6\%$ for the incremental intermittent test), according to the secondary criteria established to assume



Average (Variables obtained in Nx200-m + Variables obtained in 200-m)

Figure 4. Bland-Altman plot of variables obtained in Nx200 and 200-m, n = 11.

the occurrence of $\dot{V}O_{2max}$ (Howley et al., 1995). Swimmers with physical impairments, such as amputations, limb malformations or paralysis, have their magnitude of respiratory volumes affected as a function of the smaller amount of active muscle mass during movement (Saltin, Radegran, Koskolou, & Roach, 1998). Muscle perfusion is directly related to the amount of active muscle mass (Saltin et al., 1998). These possible decreases in HR indicate a lower cardiac output and ventilatory volume, according to the Fick principle (cardiac output = heart rate x systolic volume) and the arteriovenous oxygen difference (arterial O_2 —venous O_2) (Narang et al., 2012).

The Bland-Altman plots displayed a good level of agreement between the physiological outputs obtained in 200-m and Nx200-m. If, on the one hand, the time trial test produces ventilatory volumes and HRs similar to those found in the intermittent incremental tests at the time of $\dot{V}O_{2max}$, it cannot be guaranteed that these values would not increase at higher intensities. The execution of work rates or locomotion speeds above which $\dot{V}O_2$ does not increase further is critical for defining $\dot{V}O_{2max}$ (Hill & Lupton, 1923). On the other hand, the 200-m test is characterized by a short duration and high intensity of effort (although swimmers may have motivational differences in official competitions and protocols for evaluation of cardiorespiratory capacity). We have not found a slow component in our time trial tests. This is in tandem with similar 200-m tests for able-bodied swimmers (Sousa et al., 2011). The slow component is characterized by an increase of $\dot{V}O_2$ to $\dot{V}O_{2max}$ in the severe domain (Poole, Ward, Gardner, & Whipp, 1988). This exercise intensity domain can be defined in the work rate range in which $\dot{V}O_{2max}$ is obtained during constant load exercise (Hill, Poole, & Smith, 2002).

However, in the Nx200-m test, there was $\dot{V}O_{2max}$ stabilization (plateau < 2.1 ml/kg/min), despite an increase in velocity to the point of exhaustion (Taylor, Buskirk, & Henschel, 1955) and an observation of the secondary criteria (Howley et al., 1995). In this way, even if the tests are in agreement, they are not interchangeable. Therefore, although the results of the present study show that the $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$, collected in the 200-m time-trial and the Nx200-m, as well as other physiological variables, in swimmers with physical impairment are not different, there are also advantages associated with each test.

A group of only 11 swimmers with different physical impairments participated in this study. This is a limitation that does not allow the results extrapolation for all populations of swimmers with physical impairments, given the great diversity of physical impairments found in Paralympic swimming. Future investigations with this population can be carried out in order to expand the data set.

Conclusion

The $\dot{V}O_{2peak}$ obtained in time trial (200-m test) compared to the $\dot{V}O_{2max}$ obtained in incremental intermittent protocols (Nx200-m test), and complementary physiological measurements ($\dot{V}CO_2$, $\dot{V}E$ and HR) were not different, homogeneous considering the proportion of variability between measurements (with the exception of HR and % HRmax) and in agreement for all variables. In view of the great diversity of impairments and number of sport classes found in Paralympics swimming, it can be concluded that the $\dot{V}O_{2peak}$, identified in a 200-m crawl test, is a valid estimate of $\dot{V}O_{2max}$ in well-trained swimmers with physical impairments similar to those found in the current study.

What does this article add?

A short trial involving a 200-m swim is less time-consuming and requires a lower work rate throughout the test and ventilatory volumes ($\dot{V}O_2$, $\dot{V}CO_2$ —both in l/min and ml/kg/min) and cardiac outcomes (HR). On the other hand, a long test involves an Nx200-m, in which $\dot{V}O_{2max}$ is reached at the point of fatigue (at the upper limit of the severe intensity domain) (Hill et al., 2002). These results make the 200-m test an acceptable one to monitor the aerobic power of a larger number of swimmers with physical impairment when compared to an incremental intermittent test (Nx200-m). Moreover, there is some advantage in the sense of task specificity when using a 200-m test, since there is a similar competitive test (i.e., the 200-m race in Paralympics competition). Thus, in order to evaluate the physiological conditions of swimmers with impairments, a 200-m test is more economical, easier to perform and requires less alternative time for running than sets at progressive swimming speeds. Thus, from the point of view of formulating quick strategies in the prescription of sport training, coaches and technical teams may find it advantageous to use a time trial test during evaluations of swimmers with physical impairments (200-m).

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ORCID

Wellington G. Feitosa  <http://orcid.org/0000-0002-8523-3940>

Tiago M. Barbosa  <http://orcid.org/0000-0001-7071-2116>
 Ricardo de A. Correia  <http://orcid.org/0000-0002-2137-2423>

Flávio A. de S. Castro  <http://orcid.org/0000-0003-0848-8226>

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