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Maximal oxygen uptake, total metabolic energy expenditure, and energy cost in swimmers with physical disabilities

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ABSTRACT

The purpose of this study was to assess the maximum oxygen uptake ($\dot{V}O_{2max}$), the total metabolic energy expenditure ($\dot{E}tot$), and the energy cost (C) measured as the speed of $\dot{V}O_{2max}$ in swimmers with physical impairments. Eleven swimmers performed an Nx200-m front crawl test from a low to all-out speed and data were obtained at maximum aerobic power. The oxygen uptake was measured breath-by-breath by a telemetric gas exchange system. The $\dot{E}tot$ was calculated from the aerobic and anaerobic pathways at maximal intensity. The C was obtained by the ratio of the $\dot{E}tot$ and the mean swimming speed. The $\dot{V}O_{2max}$ was 38.2 ± 8.3 mL.kg.min^{-1}, the $\dot{E}tot$ was 191.9 ± 51.7 kJ, and the C was 0.8 ± 0.2 kJ.m^{-1}. The energy contribution of the aerobic pathway was higher ($p < 0.001$) than that of both the anaerobic pathways, which were similar ($p > 0.05$). There was no gender effect on the results of the energy contributions ($p > 0.05$). The anaerobic lactic pathway contribution was higher in male than in female swimmers ($p < 0.05$). The $\dot{V}O_{2max}$ and C were higher in swimmers who were less affected by physical impairment. The energy contribution of the aerobic pathways was similar for males and females.

1. Introduction

The physiological parameters related to performance are effectively developed as a function of each athlete's potentialities and singularities (Barbosa et al., 2010). Among the important physiological parameters related to human locomotion used in the sports performance assessment are the maximum aerobic power ($\dot{V}O_{2max}$), the total metabolic energy expenditure ($\dot{E}tot$), and the energy cost (C) (Fernandes et al., 2006; Morris, Osborne, Shephard, Jenkins, & Skinner, 2017). These physiological

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parameters might differ between swimmers with physical disabilities and those without, between male and female swimmers, and among classes. Swimmers with physical disabilities are classified into sports classes by the impact of an eligible impairment on their ability to perform the specific and fundamental tasks of the sport (classes S1 to S10 from the highest to the lowest impact) (*International Paralympic Committee [IPC]. World Para Swimming: classification rules and regulations*, International Paralympic Committee [IPC], 2017). According to different cases of disabilities and their relationship with aerobic power, expressions of energy metabolic rates and *C* can provide useful information for training strategies and performance improvement of these swimmers.

Estimates of the $\dot{E}tot$ and *C* have been calculated from oxygen uptake and blood lactate (Barbosa, Fernandes, Keskinen, & Vilas-Boas, 2008; Gonjo et al., 2018). Therefore, the $\dot{E}tot$ is the result of the sum of the energy supplied by the aerobic, anaerobic lactic and alactic pathways. In turn, the *C* is a bioenergetic predictor of the performance of human locomotion (Barbosa et al., 2010; Di Prampero, 1986) and can be described according to Equation 1:

$$C = \frac{\dot{E}tot}{v} \tag{1}$$

where *C* is the energy cost and *v* represents the speed executed in a given locomotion task. The *C* represents the amount of metabolic energy expended in transporting the body mass of the participant over a unit of distance (Capelli, Pendergast, & Termin, 1998). Thus, competitive swimmers seek to travel a given distance as quickly as possible. In this sense, the average swimming speed exercised is an important performance factor and is associated with the ability to overcome the drag (Barbosa et al., 2008). The drag is one of the main *C* determinants (Pendergast et al., 2006) and the technical level can be analysed by the swim speed (Barbosa et al., 2010). In addition, the increase in *C* is related to the increase in swimming speed and drag in the aquatic environment (Toussaint & Hollander, 1994). Among the morphological disadvantages that can increase drag and affect the speed of locomotion in swimming are, for example, deformities or amputations of limbs, hemiplegia, and paraplegia (Oh, Burkett, Osborough, Formosa, & Payton, 2013). These morphological characteristics also influence different physiological expressions whose scientific knowledge can be deepened (Bentley, Phillips, McNaughton, & Batterham, 2002; de Souza et al., 2016).

Some studies have investigated the relationship between oxygen uptake, $\dot{E}tot$, and *C* of non-disabled swimmers (Barbosa et al., 2008; Bentley et al., 2005; Capelli et al., 1998; Zamparo, Capelli, & Pendergast, 2011). However, few studies have addressed the physiological profile of swimmers with physical impairments (de Souza et al., 2016; Rodrigues Junior, De Jesus, Corredeira, Daly, & Fernandes, 2016). In one of the studies with people with physical disabilities, *C* was assessed in people who used wheelchairs (Conger & Bassett, 2011). However, we found no study reporting the $\dot{V}O_{2max}$, $\dot{E}tot$, and *C* of competitive swimmers with physical impairments. Although there are studies on the contributions of energy pathways in intermittent tests for non-disabled swimmers (Ribeiro et al., 2015; Sousa, Vilas-Boas, & Fernandes, 2014; Troup, 1991), the energy contributions in addition to the $\dot{V}O_2$, $\dot{E}tot$, and *C* measured as speed of $\dot{V}O_{2max}$

($v\dot{V}O_{2max}$) for swimmers with physical impairments are still unknown. The study of these physiological variables and $v\dot{V}O_{2max}$ can contribute to the compilation of data to aid decisions on appropriate actions before and after performance tests.

Through these evaluations it is possible to quantify the $\dot{E}tot$ and C of swimmers needed for a particular task, which enables adjustments to be made to the training programme to improve performance. In addition, such investigations explore the possible relationships between characteristics of physical disability and their possible effects on these physiological variables.

Thus, the purpose of this study was to assess the $\dot{V}O_{2max}$, the $\dot{E}tot$, and C measured as $v\dot{V}O_{2max}$ in swimmers with physical impairments, comparing: (i) swimmers grouped by sports classes and (ii) males and females. We formulated three hypotheses: (i) the highest values of $\dot{V}O_{2max}$ occur in swimmers with the lowest impact of physical disability, even though the $\dot{E}tot$ and C measured as $v\dot{V}O_{2max}$ are highest in swimmers with the highest impact of physical disability; and (ii) male swimmers have higher values of $\dot{E}tot$, C, and energy contribution (aerobic and anaerobic) than female swimmers.

2. Methods

2.1. Participants

Seven male and four female swimmers (age 32.4 ± 12.4 years; height 1.73 ± 0.85 m; body mass 67.2 ± 9.9 kg; training background 6.4 ± 3.7 years) participated in the study. The main disabilities were: hemiplegia, muscle stiffness and poor motor coordination (n = 1, sport class S5), spinal cord injury (n = 3, T11–L1, T11–T12, and L1–L2, sport classes S5, S7, and S8), one arm near the shoulder amputation (n = 1, sport class S8), one forearm amputation (n = 1, sport class S9), one lower limb amputation near the hip (n = 3, sport class S9), congenital crooked foot sequelae and low ankle mobility (n = 1, sport class S9), and amputation slightly below the knee (n = 1, sport class S10). Swimmers with at least 2 years of experience in swimming competitions at any stage (regional, national, or international) and who had any physical impairments participated in this research. All of the participants had training sessions at least five times per week and swam 20 km per week. The exclusion criterion was the presence of contraindications for physical tests at maximum intensity, e.g. mental retardation, congenital or atherosclerotic heart disease, and atlantoaxial instability or any restrictive injury for training and competition.

The study was approved by the local Ethics Committee and followed the orders of the Declaration of Helsinki. The aims and methods were thoroughly explained to the participants who gave their written consent.

2.2. Experimental approach

The swimmers had anthropometric measurements of body mass (SECA® 813, resolution of 0.1 kg, Hamburg, Germany) and height (SANNY, Personal Caprice, resolution of 0.1 cm, São Paulo, Brazil) recorded. Then, they were familiarised over two sessions with the equipment: the Aquatrainer snorkel (Cosmed, Rome, Italy) and GBK2 pacer (GBK
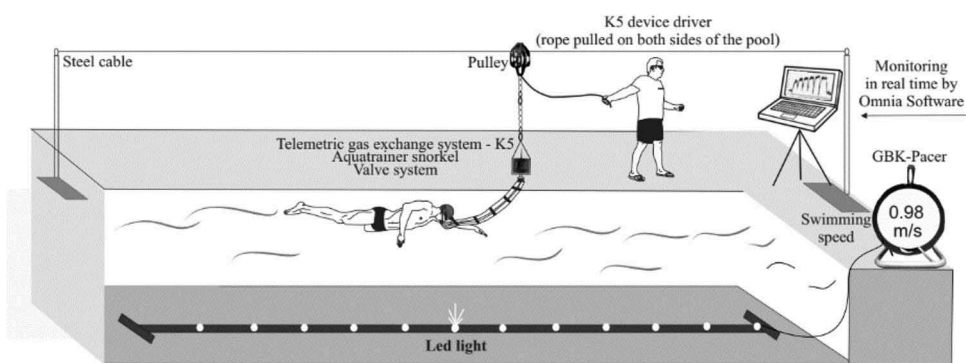
Figure 1. Physiological data collection set-up over the Nx200-m protocol.

Electronics, Aveiro, Portugal), and the procedures for physiological data collection in an intermittent incremental test, oxygen uptake ($\dot{V}O_2$), heart rate (HR), rate of perceived exertion (RPE), and blood lactate concentration (La). All swimmers had previously used snorkels in their regular training programme. A session was held to familiarised themselves with GBK2 pacer (Fernandes et al., 2008; Keskinen & Keskinen, 1999). Before the tests and measurements, the swimmers were asked not to take part in moderate to vigorous physical activity for at least 24 hours.

The tests were carried out individually in a 25-m length indoor swimming pool. The setup of the data collection is portrayed in Figure 1. A warm-up of 600-m was developed according to the experience and level of conditioning of the swimmers (swimming at low-moderate intensity in 200-m freestyle, 200-m with a conventional snorkel, and 200-m with an Aquatrainer snorkel). A time trial (200-m with encouragements for the best effort) was conducted to decide the speed of the incremental intermittent test (Nx200-m). The rest period of 24 hours occurred between the 200-m and Nx200-m tests.

The intermittent incremental test (Nx200-m) had speed increases of 0.05 $m.s^{-1}$ with 30 second rest intervals between each 200-m stage. The swimming speed during the Nx200-m was individually controlled by the GBK2 pacer (Keskinen & Keskinen, 1999). The first programmed speed on the pacer was determined by the average speed of the 200-m test decreased by 0.25 $m.s^{-1}$. However, the $\dot{V}O_{2max}$ was achieved in the 4th, 5th, and 6th stages for different swimmers.

2.3. Data collection

The concentration of gases was measured by the continuous collection of expired gases, supported by a telemetric gas exchange in a breath-by-breath system (K5; Cosmed) and respiratory valve system (Aquatrainer; Cosmed) that represent low hydrodynamic resistance (Keskinen, Rodriguez, & Keskinen, 2003; Ribeiro et al., 2016). The gas analysis system was calibrated before each collection. The device for respiratory gas capture along with the snorkel were suspended at a height of 2-m. A double pulley system and a pair of steel cords passed above the entire length of the pool. The double pulley along with the K5 and Aquatrainer snorkel were pulled on ropes by two people

(a rope on each side of the pool), minimising disruption to the movements of the swimmer (Figure 1).

In order to minimise the noise arising from the acquisition of gases by breath by breath through the ergospirometric system, errant breaths, e.g. coughing, speaking, and swallowing, that do not represent the desired breath were excluded. Values between the mean ± four standard deviations (Ozyener, Rossiter, Ward, & Whipp, 2001) were considered. The $\dot{V}O_2$ data were smoothed by using a moving average of three breaths (Fernandes et al., 2008) in average periods of five seconds (Sousa et al., 2010), which increased the validity of the estimated parameter. The $\dot{V}O_{2max}$ was obtained at the minimum swimming speed above which $\dot{V}O_2$ failed to increase further (Poole & Jones, 2017). It was in accordance with primary and secondary criteria (Howley, Bassett, & Welch, 1995): (i) the occurrence of a plateau in $\dot{V}O_2$ (variation less than 2.1 mL.kg.min^{-1}) despite increasing swimming speed; (ii) elevated La ($\geq$ 8 mmol.L); and (iii) a high respiratory exchange rate (r $\geq$ 1.0), high heart rate (HR > 90% of [220 – age in years]), and high rate of perceived exertion (visually controlled and case by case).

The La level was measured using an Accutrend Plus portable meter and reagent strips (Accutrend; Roche, Mannheim, Germany), HR was measured in beats.min^{-1} using a Polar V800 cardiac monitor with H10 Bluetooth transmitter (Polar Electro Oy; Kempele, Finland) and RPE on a scale of 15 points (Borg, 1998) was measured at rest, at 30 s intervals, immediately after the NX200-m, and at 1, 3, 5, and 7 minutes after the last swim (Sousa et al., 2014). The HR (beats.min^{-1}) was converted into a percentage of HR through the equation [(HRmax-HR swim test).(HRmax)]*100 (Wilmore & Costill, 2004). The use of %HRmax has been recommended for swimmers with different fitness levels and ages to facilitate the interpretation of the results (Pfeiffer, Pivarnik, Womack, Reeves, & Malina, 2002; Psycharakis, 2011).

The $\dot{E}_{tot}$ was calculated for the aerobic and anaerobic sources (alactic and lactic) at the $\dot{V}O_{2max}$ swim speed (at the lowest velocity at which the $\dot{V}O_{2max}$ was reached, expressed as v$\dot{V}O_{2max}$ – m.s^{-1}). The $\dot{E}_{tot}$ was calculated using the net $\dot{V}O_2$, the difference between the value measured at the end of the stage and the rest value, adjusted for body mass (Barbosa et al., 2008; Di Prampero, Pendergast, Wilson, & Rennie, 1978). The $\dot{V}O_2$ values were determined by the average of the last 60 s of each stage, except for the $\dot{V}O_{2max}$, which was calculated as already described (Howley et al., 1995). Additionally, the net blood lactate level (the difference between the value measured in each two consecutive stages) was transformed into $\dot{V}O_2$ equivalents using a 2.7 mLO$_2$.kg.mmol^{-1} constant and by Equation (2) (Di Prampero et al., 1978; Thevelein, Daly, & Persyn, 1984).

$$\dot{E}tot = VO_2net + (2.7 . La - net).t \qquad (2)$$

The $\dot{E}_{tot}$ (aerobic and anaerobic pathways) was expressed in kJ. The anaerobic contribution was calculated as the sum of the energies obtained from the blood lactate concentrations, as estimated from Lab, plus the energy derived from the maximal depletion of phosphocreatine in working muscles. The t represents the duration of the effort (Capelli et al., 1998), Equation (3):

$$\dot{E}tot \text{ anaerobic } = (0.418 \text{ KJ} * \text{Kg}^{-1} + \text{Lab}) \text{ body mass} \qquad (3)$$

where $\dot{E}tot$ anaerobic is in kilojoules, body mass of the participant is in kilograms, b is the energy equivalent of the blood lactate concentration, which was assumed to be equal to 0.0689 (kJ.kg.mmol.L^{-1}) (Di Prampero, 1981), and Lab is the peak blood lactate concentration after exercise above resting (when $\Delta Lab = 1$ mmol.L^{-1}, the net amount of metabolic energy released by lactate formation was 0.0689 (kJ.kg.mmol.L^{-1}) (Di Prampero, 1981). The value of 0.418 kJ.kg^{-1} in Equation 2 coincides with the net splitting of 18.5 mmol of phosphocreatine per kg of wet muscle in a maximally working muscle mass equal to 30% of the overall body mass (Capelli et al., 1998).

The C of locomotion was calculated by splitting the $\dot{E}_{tot}$ by swimming speed (v) (Barbosa et al., 2008; Di Prampero, 1986; Zamparo et al., 2005). The speed was obtained from the incremental swimming test at maximal aerobic power (Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes, 2011). All swimmers were exactly at the speed of the pacer. The cost values were converted into SI units where 1 mLO_2 is equivalent to 20.1 J (Minetti, 1998).

2.4. Statistical analyses

All statistical analyses were performed using the software IMB SPSS Statistics (version 25.0 for Windows, IBM Corp; Armonk, NY, USA). The Shapiro-Wilk test was used to verify the distribution of the data. Once normality was established, the sample data were described using the mean ± standard deviation (SD). The percentage difference was calculated for comparisons of the variables between genders. Individual data for sport class and $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, $\dot{E}tot$, and C were also determined. To verify if there was a difference among the energetic pathways (aerobic, anaerobic lactic, and alactic) and gender interaction, a repeated measures ANOVA with a fixed factor (gender) was used, with a Bonferroni test. The sphericity of the data was tested using a Mauchly test ($p < 0.05$) and the Epsilom Greenhouse-Geisser correction factor was applied (explained by degrees of freedom). Statistical significance was set at $p < 0.05$. The figures were produced using GraphPad Prism (version 8.00 for Windows, GraphPad Software; La Jolla, California, USA).

3. Results

The results were displayed as the mean, standard deviation, and confidence interval for the mean of swimmers with physical impairments at the speed of maximum oxygen uptake for the variables ($\dot{V}O_{2max}$, La_{peak}, C, $\dot{E}tot$, HR_{max}, and $\%HR_{max}$) obtained with $v\dot{V}O_{2max}$ (Table 1). All of the physiological variables showed low-dispersion. The physiological variables for $\dot{V}O_2$ of rest, La of rest, and RPE at the end of the test were, respectively, 4.7 ± 1.1 mL.kg.min^{-1}, 2.2 ± 0.6 mmol.L^{-1}, and 18 ± 1.9.

The individual values of $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, and C for sex and sport class are shown in Figure 2. Female swimmers showed higher values of $\dot{V}O_{2max}$ with physical impairments that had a lower impact on activity. The C of female swimmers was similar among sports classes. The male swimmers had a tendency for higher values of $\dot{V}O_{2max}$ and C with increasing $v\dot{V}O_{2max}$, except for the sport class S9 (Figure 2).

In the female group, the mean and standard deviation values of $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, and C were, respectively, 0.85 ± 0.09 m.s^{-1}, 31.0 ± 4.1 mL.kg.min^{-1}, and 0.7 ± 0.1 kJ.m^{-1}; whereas

Table 1. Overall mean, standard-deviation, and confidence interval for the mean of swimmers with physical impairments at the speed of maximum oxygen uptake (n = 11).

| Variables	Mean ± SD	95% Confidence Interval
$v\dot{V}O_{2max}$ (m.s^{-1})	0.93 ± 0.16	0.81–1.03
$\dot{V}O_{2max}$ (mL.kg.min^{-1})	38.2 ± 8.3	32.6–43.8
La$_{peak}$ mmol.L^{-1}	9.7 ± 3.9	7.0–12.3
C (kJ.m^{-1})	0.80 ± 0.21	0.66–0.95
$\dot{E}tot$ (kJ)	191.9 ± 51.7	157.1–226.7
HR$_{max}$ (beats.min^{-1})	167 ± 14.3	157.3–176.6
%HR$_{max}$	88.9 ± 6.6	84.4–93.4
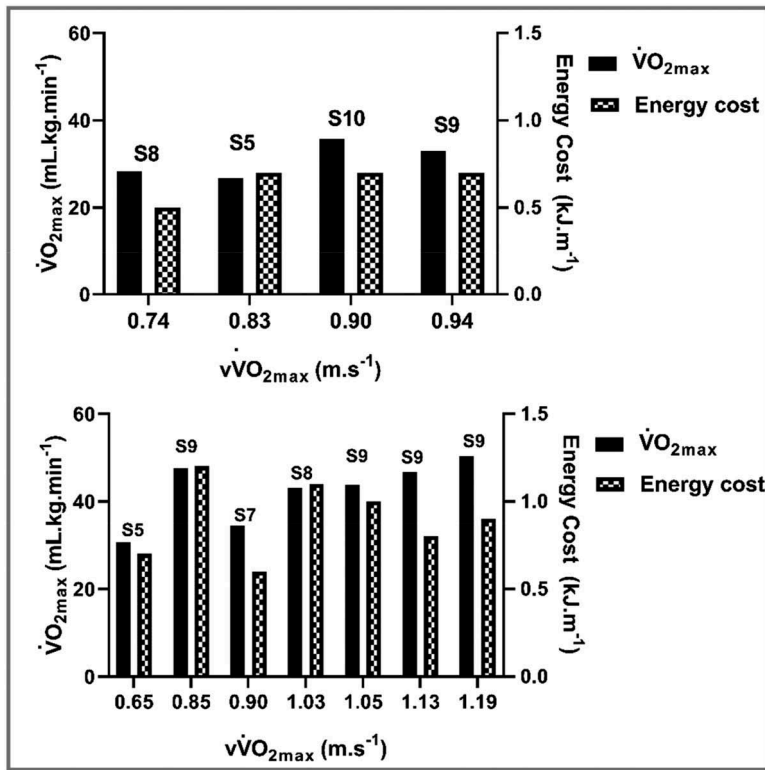
Figure 2. Individual values of $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, and C of female (top image, n = 4) and male (bottom image, n = 7) per sport class. For a description of the sport classes see (*International Paralympic Committee [IPC]. World Para Swimming: classification rules and regulations*, International Paralympic Committee [IPC], 2017).

in the male group, the $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, and C were, respectively, 0.97 ± 0.19 m.s^{-1}, 42.4 ± 7.2 mL.kg.min^{-1}, and 0.9 ± 0.2 kJ.m^{-1}. The percentage difference between the means for males and females for $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, and C was, respectively, 12.2%, 27.0%, and 22.2%.

The $\dot{E}tot$ was 214.0 ± 47.3 kJ for males and 153.4 ± 36.8 kJ for females (a 28.3% difference) (Figure 3). The aerobic and anaerobic energy contributions (lactic and alactic) to $v\dot{V}O_{2max}$ are depicted in Figure 3. The energy contribution of the aerobic
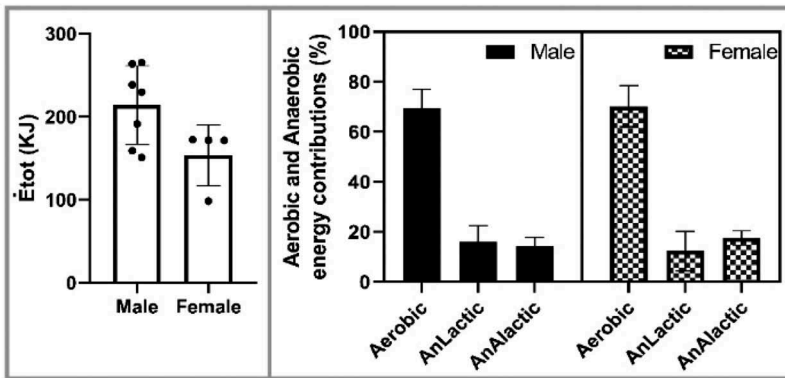
Figure 3. Mean ± SD of $\dot{E}tot$ and the percentage of aerobic and anaerobic energy (AnLactic = anaerobic lactic and AnAlactic = anaerobic alactic) contributions at $v\dot{V}O_{2max}$ (n = 11).

pathway was similar for males (69.6 ± 7.3%) and females (70.2 ± 8.1%). The energy contribution of the anaerobic lactic pathway was higher by 3.8% for males (16 ± 6.4%) than females (12.2 ± 7.8%). The anaerobic alactic energy contribution for males was 14.3 ± 3.4% and females 17.4 ± 2.8% (a 3.1% difference in the mean). The ANOVA showed that there was a distinct effect of the contribution of the energy pathways on swimmers [F (1.29–11.65) = 178.9; p < 0.001, η^2 = 0.95]. The Bonferroni post-hoc test showed that the energy contribution of the aerobic pathway was higher than that of the anaerobic lactic pathway (p < 0.001) and alactic pathway (p < 0.001), however, the anaerobic alactic and lactic pathway energy contributions did not differ to each other (p > 0.05).

4. Discussion

This study assessed the $\dot{V}O_{2max}$, $\dot{E}tot$, and C in swimmers with physical impairments. By assigning females to one group and males to another, we demonstrated that the $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, $\dot{E}tot$, and C were higher in the group of male swimmers with physical impairments than the group of females. The energy contribution of the anaerobic lactic pathway was higher for male swimmers whereas the alactic energy contribution was higher for female swimmers.

The highest values of $\dot{V}O_{2max}$ were obtained for swimmers with the lowest impacting physical impairment. Among the physical impairments present in this study were Hemiplegia, Paraplegias, amputation of the arm or forearm, and amputations of the lower limbs. The amount of activated muscle mass directly influences $\dot{V}O_2$, La, and HR (Astrand & Rodahl, 1986; Narang et al., 2012; Saltin, Radegran, Koskolou, & Roach, 1998). In our investigation, most participants with high $v\dot{V}O_{2max}$ reached the highest levels of $\dot{V}O_{2max}$ (except for the male sport class S9 swimmer, $v\dot{V}O_{2max}$ = 0.85 m.s^{-1} and $\dot{V}O_{2max}$ = 47.5 mL.kg.min^{-1}). In addition, there was also a tendency of $v\dot{V}O_{2max}$ and $\dot{V}O_{2max}$ to be higher in swimmers with physical impairments that had less of an impact. It is possible to relate higher $v\dot{V}O_{2max}$ with better aerobic performance (Di Prampero et al., 1993; Grant, Craig, Wilson, & Aitchison, 1997), even among participants with

similar $\dot{V}O_{2max}$ rates (Santos et al., 2012). However, in swimmers with physical disabilities it is necessary to take into account the ability to perform the specific and fundamental tasks of the sport (Tweedy & Vanlandewijck, 2011). Therefore, each physical disability or set of disabilities seem to directly influence the $v\dot{V}O_{2max}$.

Few studies have been carried out with swimmers with physical disabilities on incremental intermittent tests. When the peak oxygen consumption of Brazilian Paralympic swimmers at 100% of the athlete's maximum speed of the best result in official competitions (6×300 m in front crawl) was assessed, the following values were obtained for each sports class in $mL.kg.min^{-1}$ (de Souza et al., 2016): S4 (18.40, female), S5 (35.50, male), S6 (55.80, male), and S7 (37.20, female). In addition, male swimmers with a physical disability (n = 13) obtained the following sports class values for $\dot{V}O_{2max}$ in $mL.kg.min^{-1}$ (7×200 m in front crawl) (Rodrigues Junior et al., 2016): S6 (52.1), S7 (41.0), S8 (47.0 ± 4.0, n = 4), S9 (48.7 ± 6.9, n = 6), and S10 (35.10). These values are slightly higher than those reported in the present study for: (i) male swimmers presented by sport class, $\dot{V}O_{2max}$ in $mL.kg.m^{-1}$: S5 (30.6), S7 (34.5), S8 (43), and S9 (47.1 ± 2.7, n = 4); and (ii) female swimmers presented by sport class, $\dot{V}O_{2max}$ in $mL.kg.m^{-1}$: S5 (26.8), S8 (28.3), S9 (33), and S10 (35.7). Peak oxygen consumption values (31.1 ± 8.4 in $mL.kg.m^{-1}$, n = 12; 33.6 ± 7.1 $mL.kg.m^{-1}$, n = 7) were also found for handbike athletes with spinal cord injury (T2-T12 injury, paraplegia) in arm cranking maximal incremental test (arm crank ergometer out of water) (Fischer, Figueiredo, & Ardigo, 2015; Fischer, Tarperi, George, & Ardigo, 2014). The swimmers with paraplegia (n = 3, T11–L1, T11–T12, and L1–L2) of the current study reached similar values ($\dot{V}O_{2max}$ 31.1 ± 3.1 in $mL.kg.m^{-1}$).

The $\dot{E}tot$ was higher for male swimmers than female swimmers. The duration of exercise performed by male swimmers (3.63 ± 0.36 in decimal minutes) was less than of female swimmers (3.94 ± 0.54 in decimal minutes), except for two males (one swimmer with paraplegia [4.90 in decimal minutes] and one with amputation of the forearm [3.92 in decimal minutes]). In our study, $v\dot{V}O_{2max}$ ranged from 0.6 to 1.1 $m.s^{-1}$. In a study of physical disabilities (incremental intermittent test of 7×200 m) the speed reached varied similarly from 0.7 to 1.1 $m.s^{-1}$ (Rodrigues Junior et al., 2016). However, swimmers with physical disabilities are slower than non-disabled swimmers. Some studies have shown that the velocity of non-disabled swimmers (n = 8) ranged from 0.96 to 1.42 $m.s^{-1}$ (Capelli et al., 1998); 1.16 ± 0.01 $m.s^{-1}$ for low-level swimmers (n = 10) and 1.4 ± 0.06 $m.s^{-1}$ for highly trained swimmers (n = 10) (Fernandes et al., 2006). In fact, exercise duration is the major determinant of the energy source (Di Prampero, 2003).

The aerobic pathway provided approximately 70% of energy for both sexes during the repetition in which the maximum aerobic power was reached. The energy contribution of the anaerobic lactic pathway was higher in male swimmers than female swimmers. Conversely, the anaerobic alactic contribution was higher in female swimmers than in males. These energy contributions might be due to the higher muscle mass present in male swimmers than females (Ribeiro et al., 2015; Zamparo et al., 2011). Studies with non-disabled swimmers have shown that during maximal swimming trials they mainly use the aerobic energy source (61.5%), followed by energy from the anaerobic lactic (24.7%) and alactic (13.8%) pathways (Zamparo et al., 2011).

Therefore, the results of this investigation are in accordance with the energy contributions of swimmers without physical disabilities for both aerobic (65%) and the anaerobic pathways (35%) when swimming 200-m in freestyle (Troup, 1991).

Higher C values were coincided with higher values of aerobic power. The C also rose from S5 to S10 (from the highest to lowest physical impairment to perform specific sports tasks). When exploring the results, we noticed that the swimmer in class S9 reached high values of $\dot{V}O_{2max}$ and C despite having a slower swimming speed than the other swimmers. Swimmers can perform better more easily by reducing the C than by increasing $\dot{E}tot$ (in one of its components, aerobic or anaerobic) (Zamparo et al., 2011). There are a number of possible reasons for this swimmer being less energy-efficient, such as amputation of the forearm resulting in a lower swimming speed than that of other non-disabled upper limbs. However, the male swimmer in sports class S8, who had an amputation of the right arm near the shoulder, showed a higher $v\dot{V}O_{2max}$ than the male swimmer in sports class S9. The main difference between the two men is possibly their training background in years and technical level (Costa, Bragada, Marinho, Silva, & Barbosa, 2012).

The physical disability of each swimmer and their anthropometric characteristics, for example, the amount of muscle tissue and adipose tissue, might influence the hydrodynamic ability of female swimmers to perform the motor actions with a lower underwater torque (Zamparo et al., 1996). Therefore, C was higher in male swimmers with disabilities than in female swimmers. In relation to non-disabled swimmers, the literature indicates that female swimmers have a lower C than male swimmers (Chatard, Lavoie, & Lacour, 1990, 1991; Zamparo, Capelli, Cautero, & Di Nino, 2000). In freestyle, the C has been reported for elite male swimmers without disabilities to be 0.8 kJ.m^{-1} at 1.1 m.s^{-1} (Capelli et al., 1998), for low level swimmers 10.9 ± 1.80 J.kg.m^{-1} at 1.2 m.s^{-1}, for highly trained swimmers 13.1 ± 2.3 J.kg.m^{-1} at 1.2 m.s^{-1} (Fernandes et al., 2006), and 0.8 KJ.m^{-1} for male swimmers at 1.3 m.s^{-1} (Barbosa et al., 2008). In our study, the C was 0.8 ± 0.2 in kJ.m^{-1} at 0.9 ± 0.1 m.s^{-1} for the full sample, 0.7 ± 0.1 in kJ.m^{-1} at 0.9 ± 0.1 m.s^{-1} for female swimmers, and 0.9 ± 0.2 in kJ.m^{-1} at 1.0 ± 0.2 m.s^{-1} for male swimmers. Therefore, the C of swimmers with disabilities appears to be higher than that for non-disabled swimmers, taking swimming speed into account.

To our knowledge, this study is the first to investigate the $\dot{E}tot$ and C in swimmers with physical impairments. The hypotheses formulated in the introduction were partially accepted. The exception was for the second hypothesis (the $\dot{E}tot$ and C obtained in $v\dot{V}O_{2max}$ are higher in swimmers with a higher impacting physical disability). These results can be applied in training and competitions, when coaches are able to determine a swimming series' duration and intensity in an attempt to better achieve the training objectives. The monitoring of the aerobic and anaerobic power achieved along with swimming speed can be used as an important predictor of performance (Ferreira, Barbosa, Costa, Neiva, & Marinho, 2016; Lacour, Padilla-Magunacelaya, Barthelemy, & Dormois, 1990). This information can be used in training to simulate the stress levels of competition in the cardiovascular system (Ferreira et al., 2016; Lacour et al., 1990; Roy, Menear, Schmid, Hunter, & Malone, 2006; Santos et al., 2012).

A small sample of swimmers with physical impairment participated in the current study. This is a limitation that does not enable the extrapolation of the results for all

populations of swimmers with physical impairments, given the great variability in disabilities and possible interactions with physiological characteristics. Although this study provides useful information in the cases of physical impairment discussed, further investigations can be undertaken with this population in order to extend the set of data.

5. Conclusion

The values of $\dot{V}O_{2max}$ and C are higher in swimmers with physical impairments that have less of an impact on activity than those with more impact. The $v\dot{V}O_{2max}$, $\dot{V}O_{2max}$, $\dot{E}tot$, and C were higher for the male swimmers with physical impairments than their female counterparts. The aerobic energy contribution was similar for males and females. The main energy contribution was aerobic for both genders, but the anaerobic lactic and alactic pathway contributions differed between male and female swimmers.

Disclosure statement

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