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Research Notes

Metabolic, kinematic and coordinative behavior of a para swimmer with cerebral palsy

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HIGHLIGHTS

- A trained para swimmer was assessed for metabolic, kinematic, and coordination variables during an incremental test.
- The anaerobic threshold occurred at (or closer to) the fourth 200-m step, followed by an increase in heart rate and blood pressure.
- Changes in general kinematic parameters occurred and stability in IVV and IdC were observed.
- Swimming intensity seems to influence the para swimmers' metabolic, kinematic, and coordinative behavior.

ABBREVIATIONS

HR	Heart rate
ICC	Intraclass correlation coefficient
IdC	Index of interlimb coordination
IVV	Intracyclic velocity variations
[La-]	Lactate concentrations
Pa	Blood pressure
SF	Stroke frequency
SL	Stroke length
SI	Stroke index

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BACKGROUND: It has been increasingly necessary to assess and monitor the physiological and biomechanics variables of para swimmers to enlarge the current knowledge on how different impairments limit swimming performance and explain each competition class variability in metabolic and technical terms.
AIM: This study aimed to characterize the front crawl metabolic, kinematic, and coordination behaviors of a trained para swimmer subjected to an incremental protocol.
METHOD: A 44 year-old male, with moderate right side hemiparesis of the body, performed a 200-m front crawl at 5 incrementally paces until exhaustion (0.05 m/s increases and 30-s intervals), with images from two cycles at each step (at 50, 100, 150, and 200-m laps) recorded by two video cameras (one surface and one underwater). Kinematic and coordinative variables were collected as follows: stroke frequency (SF), stroke length (SL), stroke index (SI), intracyclic velocity variations (IVV), and index of interlimb coordination (IdC), respectively. Lactate concentrations ([La-]), heart rate, and blood pressure were also measured at each step of the incremental protocol.
RESULTS: The para swimmer achieved the anaerobic threshold at (or closer to) the fourth 200-m step, followed by an increase in heart rate and blood pressure. Speed and SF were higher and SL was lower along the 200-m steps. In contrast, a slight increase in SI and stability in IVV occurred across intensity increments, and IdC was maintained as a superposition mode.
CONCLUSION: The findings suggest that the swimming intensity seems to influence the para swimmer metabolic, kinematic, and coordinative behavior, with sharper alterations after the point when AnT is achieved. In addition to having practical interest for adapted swimming, coaches should emphasize the physiological and biomechanical evaluation on training monitoring to better prescribe and improve the adapted swimming performance.

KEYWORDS: Physical disability | Adapted swimming | Metabolic behavior | Linear kinematics | Coordination | Performance

INTRODUCTION

Researchers have been increasingly interested in para swimming by dedicating to assess the physiological and biomechanical demands of the sport and improve athlete's potentialities and singularities on training programs, as well as performance on competitions. Studying physiological variables is fundamental in the para swimming scope to prescribe training intensity as effort [1,2,3] or fatigue [4,5] during the training session. However, a combined physiological and biomechanical diagnosis in para swimming performance seems to be a major area of current interest, possibly because of the different cases of disabilities in para swimmers. Additionally, the relation of physiological and biomechanical variables can provide useful information for training strategies based on the metabolic and technical improvement of these swimmers.

Among the measurements that can be implemented in swimming physiological evaluation, the assessment of blood lactate concentration values [(La^-)] at different exercises intensities is frequently conducted in athletes with different physical impairments [1,3,2] to assess the anaerobic threshold, regarded as the highest sustained exercise intensity at which the balance between production and removal of lactate persists, expressing a traditional measure of athlete's aerobic capacity [6]. However, this physiological parameter varies among swimmers with physical or intellectual disabilities, between male and female individuals, as well as according to the different classes. Most studies addressing para swimmers address this variable as a mean value for disabled swimmers, which may have led to a failure in the anaerobic threshold assessment.

Complementarily, important biomechanical factors that should be evaluated for para swimming, particularly kinematic parameters, such as clean swimming speed, stroke length, stroke frequency, include some of the most studied and relevant in the context of coaches [7,5], providing useful information about techniques and classification system in competitive swimming in a less complex way [8]. Variables that require more accurate techniques are intracyclic velocity variations [9], coordination parameters [10], and adapted index of coordination for those with amputation or malformation in only one upper limb [11,4]. In fact, since the 2000s, the assessment of kinematic parameters has been applicable for para swimming training diagnosis recommendations [8,11,4,12]. Even though, only few studies on para swimming have related kinematic and physiological parameters obtained at different swimming speeds, specially analyzing the singularity of each physical impairment (eg.[4,2]).

The studies that related results regarding the S6 class (i.e., swimmers with coordination moderately affected on one side of the body, highly affected in the lower trunk and legs, short stature, or absence of limbs [13]) have reported conclusions that are difficult to apply on swimming training. For example, in the case of cerebral palsy, there are primary problems as abnormal muscle tone, impairment of balance and coordination, decrease muscle strength, and loss of selective motor control that can impact directly on swimming technique. Notwithstanding, some authors have emphasized that daily swimming practice, accompanied by a structured biomechanical evaluation, can improve muscle strength and mobility, functional motor skills and encouraging functional independence [13,14,15].

As already known, paralympic sports classification should be based on function and not performance [16]. However, it is common to question whether these swimmers' functional classification is fair or not based on performance characteristics [17,18]. In this sense, it is possible to develop individual analysis based on the relation between physiological and biomechanical parameters in swimming performance, as well as the adapted swimming categories according to their results in protocols and official competitions. Thus, assessing physiological and biomechanical variables can add crucial information to the adapted sport context. Considering the poor availability of research addressing the individual characterization of the physiological and biomechanical behavior at different swimming intensities [4,2], our goal was to characterize the metabolic, kinematic, and coordination variables of a well-trained para swimmer with moderate cerebral palsy subjected to an intermittent incremental protocol.

MATERIAL AND METHODS

Participant

A 44 year-old male para swimmer (classified as S6 by the International Functional Classification System) specializing in front crawl events participated in this study. From 1997 to 2005, he integrated the Brazilian National Para Swimming Team. Since 2015, he has held the first place in the North Brazilian Para Swimming ranking. The participant has a moderate cerebral palsy with right-side hemiparesis of the body, caused by a hypoxic-ischemic injury during his birth. He started to sit at 8 months, to walk at 2 years, and to speak at 5 years. Since then, he has been constantly monitored through phonoaudiology, occupational therapy, physiotherapy, hydrotherapy, and strength training for upper and lower limbs. Table 1 shows the main anthropometric characteristics and the best time in front crawl events. Before the experiment, the participant provided a written informed consent to participate in this study and a brief interview verified the absence of injuries and diseases. This study was approved by the institutional review board (Ref. 79527917.5.0000.5020) according to the Helsinki Declaration.

Table 1. Main characteristics of the participant.

Para swimmer	
Age (yrs)	44
Height (cm)	176
Arm spam cm)	142.5
Body mass (Kg)	62
Adipose tissue (%)	11
Diameters (cm)	
Shoulder	41
Right elbow	6.5
Left elbow	7
Right wrist	4.5
Left wrist	5.4
Right knee	10
Left knee	10.7
Right ankle	7.1
Left ankle	7.2
Circunferences (cm)	
Right arm	27
Left arm	35
Chest	91
Hip	98
Right calf	31
Left calf	37
Front crawl events time (s)	
50 (m)	42.18
100 (m)	89.30
200 (m)	199.21
400 (m)	490.16

The participant was familiar with the testing procedures as he had participated in similar evaluations previously. After receiving a full explanation on the purpose of the study, the para swimmer was marked with a black tape waterproof with reflexive markers with a 30 mm diameter circle, identifying the following anatomical landmarks: right and left acromion, lateral humeral epicondyle, ulnar styloid process, third distal phalanx, prominence of great femoral trochanter external surface, lateral femoral epicondyle, lateral malleolus, and calcaneus (cf. Figure 1). All these markers were used to improve the image viewing for further kinematic analysis.

Figure 1. Para swimmer with body landmarks marked.

Experimental procedure

We performed the experiments in an indoor swimming pool (2.00-m deep) under constant environmental conditions (mean ± SD 25.8 ± 0.3ºC, room temperature 29.5 ± 0.2ºC, and humidity 67.5 ± 0.3% between 7:00 and 10:00 AM. Before the experiment, the para swimmer performed a 20-min low to moderate intensity warm-up. Testing consisted of a front crawl intermittent incremental protocol of 5 x 200 m (using in-water starts and flip turns), with increments of 0.05 m/s and 30-s rest intervals between steps until exhaustion, adapted from Fernandes et al [19]. Researchers and coach determined the speed of the last step based on the best hypothetical time in the 200-m front crawl event that the para swimmer was able to accomplish at that time. Sucessive 0.05 m/s was subtracted from the swimming speed corresponding to the referred hypothetical time, allowing to determine the mean target speed for each step of the incremental protocol. The elapsed time for each 200-m swim was timed manually using a manual digital chronometer (Seiko, 140, Tokyo, Japan) and controlled by an acoustic signal every 50 m.

Data collection and analysis

Physiological variables

Capillary blood samples were collected from the ear lobe during the resting period, after each 200-m step, and at the third and fifth minutes of the recovery period for lactate [La^-] analysis (Accutrend® Plus, ROCHE). These data allowed researchers to assess the anaerobic threshold (AnT) determined by the lactate concentration/velocity curve modeling method (least square method; cf. Fernandes et al. [17]).

Heart rate (HR) was monitored and registered continuously by a heart rate monitor system (Polar Vantage NV, Polar electro Oy, Kempele, Finland) and blood pressure (Pa) was also collected during the resting periods of the incremental protocol (HEM 6122 – OMRON Healthcare, Brazil).

Kinematic variables

Front crawl kinematics was subjected to 2D analysis (horizontal [x] and vertical [y] video recordings by one surface and one underwater stationary video cameras (Go Pro Hero black 7) operating at a frequency of 60 Hz. Both cameras were positioned at 60 cm above and bellow water surface, and 8.00-m from the plane of movement. The camera images were recorded independently, and the para swimmer was monitored when passing through a specific precalibrated space using a calibration frame of (6.0 x 2.5 m, for x and y directions). Image synchronization was obtained using a pair of LEDs under and over the water surface (fixed to the calibration volume) visible on each video camera field of view (Figure 2).

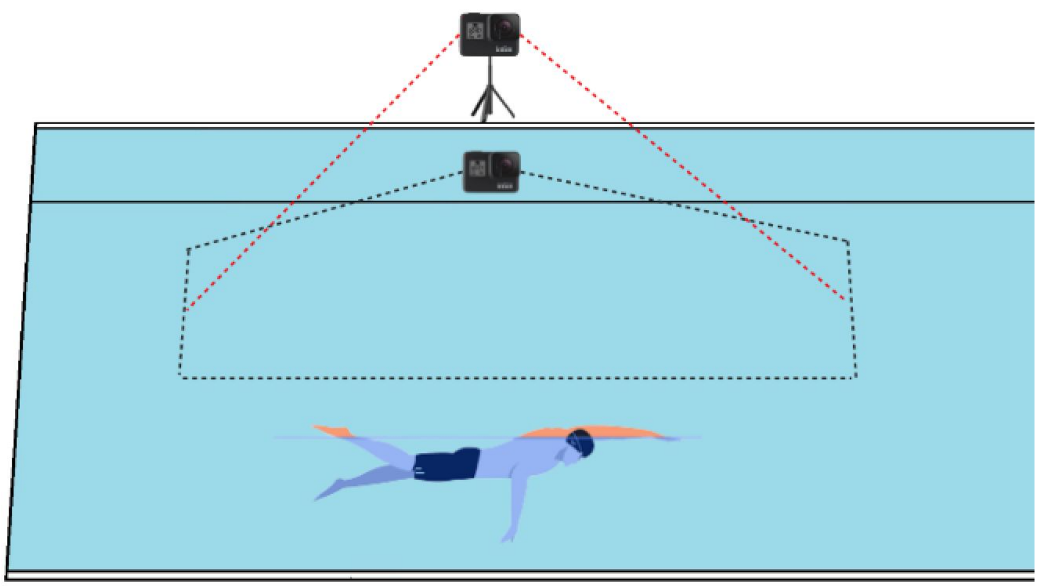

Figure 2. Schematic representation of the 2D experimental setup with surface and underwater cameras, calibration volume and swimmer.

Two consecutive swimming cycles were captured during the second, fourth, sixth, and eighth laps (50, 100, 150, 200-m) of each 200-m step in the incremental protocol (a total of 40 cycles). As each 200-m step was initiated from a push start and recorded by the 2D calibration volume positioned 11.0-m from the starting wall, any possible influence of the swimming turn on swimming kinematics was avoided. Each of the cycles was defined as the period between the two successive entries of the same hand, with the mean values used in subsequent statistical analysis. We adopted this pattern of image analysis because the para swimmer presents a mild physical impairment on his affected body side. The Adobe Pro CC, 2018 was used to cut and convert the video images and the APAS (Ariel Dynamics, Inc, USA) was used to manually digitize the 20 anatomical landmarks. A 2D reconstruction was developed using Direct Linear Transformation algorithm and a low pass digital filter of 5Hz.

Stroke frequency (SF) was assessed through the inverse time needed to complete one stroke cycle and stroke length (SL) by the horizontal displacement of the left hip. The stroke index (SI) was calculated by the product generated from the speed and SL. The intracyclic velocity variations (IVV) was calculated through the coefficient of variation of the speed to time mean values (Equation 1):

$$CV = SD.\text{mean}^{-1} \qquad (1)$$

Arm coordination was quantified through index of interlimb coordination (IdC) (cf. Chollet et al. [10]) as the para swimmer presents a mild physical impairment on the body side affected by the cerebral palsy. Thus, we assessed arm coordination based on the time duration between the final propulsive action of one arm and the beginning of the propulsion of the other, expressed as percentage of the overall duration of the stroke cycle. The propulsive phase was considered to begin with the start of the backward movement of the hand until the moment it leaves the water (pull and push phases), whereas the non-propulsive phases initiate with the hand water release and ends at the beginning of the propulsive phase (recovery, entry, and catch phases). Therefore, we propose three coordination modes: 1) catch-up, when a lag time occurred between the propulsive phases of the two arms (IdC < 0 %); 2) opposition, when the propulsive phase of one arm started when the other arm ended its propulsive phase (IdC = 0); 3), and superposition, when the propulsive phases of the two arms are overlapped (IdC > 0 %).

Test-retest reliability of the digitized process was calculated through intraclass correlation coefficient (ICC) for the following variables: (i) .83 for horizontal right hip speed and (ii) .88 for horizontal right hip displacement.

Statistical analysis

Individual values for each physiological, kinematic, and coordinative variable were computed for all 200-m incremental steps.

RESULTS

Figure 3 shows the results of physiological variables ([La$^-$], Pa and HR) for each step of the intermittent incremental protocol. AnT was achieved at (or closer to) the fourth 200-m step. Pa and HR increased throughout the intermittent incremental protocol.

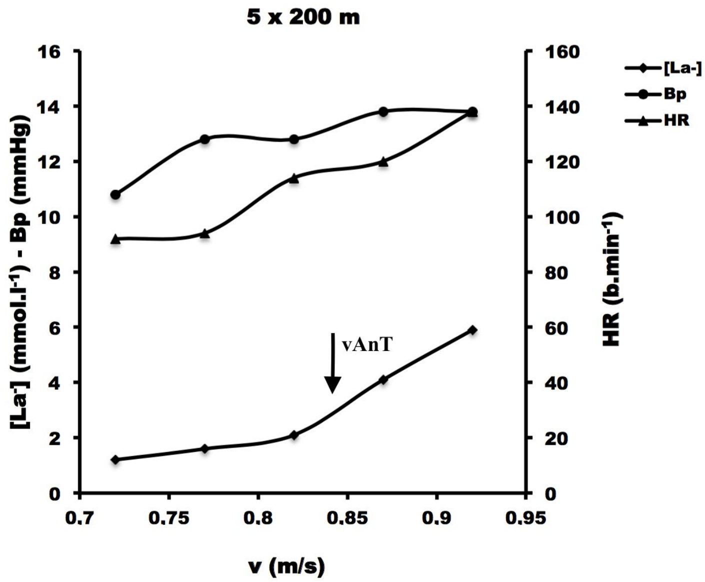

Figure 3. Blood lactate concentration vs. speed, heart rate vs. speed and blood pressure vs. speed curves obtained in each 200-m step of the intermittent incremental protocol.

Table 2 depicts the results of the general swimming kinematics, intracyclic velocity variations, and index of interlimb coordination variables for each lap analyzed during the incremental protocol. There was an increase in speed and SF and a decrease in SL from the first to the fifth 200-m steps. In contrast, a slight increase in SI and stability in IVV was observed across intensity increments. The IdC from the first to the fifth 200-m step was characterized as a superposition mode.

Table 2. Individual values of general swimming kinematics, intracyclic velocity variations and interlimb coordination for each 200-m step of the incremental protocol.

	Step																			
	1				2				3				4				5			
	Laps (m)																			
	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200
SF (Hz)	0.45	0.45	0.45	0.45	0.49	0.49	0.49	0.49	0.54	0.54	0.56	0.56	0.60	0.61	0.60	0.60	0.69	0.69	0.71	0.71
SL (m)	1.60	1.60	1.61	1.60	1.58	1.59	1.58	1.58	1.54	1.54	1.52	1.52	1.46	1.45	1.45	1.45	1.35	1.34	1.33	1.33
SI	1.15	1.15	1.15	1.15	1.21	1.22	1.21	1.21	1.27	1.27	1.29	1.29	1.27	1.27	1.27	1.27	1.25	1.23	1.25	1.25
IVV	0.08	0.04	0.05	0.04	0.05	0.04	0.05	0.05	0.07	0.04	0.03	0.05	0.04	0.05	0.05	0.05	0.11	0.04	0.06	0.04
IdC (%)	3.1	7.1	3	6.3	3.9	5.7	5.1	4.7	4.1	5.6	3.8	3.4	3.8	6.6	4.5	3.9	3.3	3.2	4	4.3

SF – Stroke frequency; SL – Stroke length; SI – Stroke Index; IVV – Intracyclic velocity variations; IdC – Index of coordination

DISCUSSION

This study introduces original findings encompassing physiological, kinematical, and coordinative variables of a national-level para swimmer subjected to a front crawl intermittent incremental protocol. The main findings indicate that the general swimming parameters (i.e., SF, SL, and SI) of the para swimmer changed after the AnT was reached.

The IVV remained stable across the incremental protocol and the IdC was characterized as a superposition mode, suggesting that the para swimmer changed his technique to adapt to the demands of the swimming speed increments.

As developmental disability, cerebral palsy has a strong impact on the daily life of athletes and their families [13,15]. Athletes often struggle for their autonomy to perform sports activities independently [15]. In the case of swimming training, the modality by itself offers excellent mechanical conditions to overcome constraints (e.g., abnormal muscle tone [13]) imposed by the mentioned disability. Thus, a rigorous monitoring of adapted swimming training is required (i.e., using physiological and biomechanical tools) to better understand the progression on para swimmer performance.

Assessing [La^-] has become a fundamental part of training control and evaluation in para swimmers [1,2], and the anaerobic threshold assessment is an example of its use [1,6]. Our results corroborate the literature addressing well-trained para swimmers competing in S6 class [2] since the AnT found in the intermittent incremental test was ≤ 3.0 $mmol.l^{-1}$. However, Puce et al. [2] observed a para swimmer with different syndrome characteristics (i.e., progressive severe worsening involving decreased strength and coordination in upper limbs, and accentuation of typical positive effects of upper motor neuron lesions), suggesting an individual variation on swimming training process.

AnT marks the point beyond which any attempt of the body to maintain metabolic equilibrium at constants swimming intensity fails [19]. The progressive increase in [La^-] values in the 200-m protocol is related to the fatigue accumulation, resulting from the metabolic acidosis, particularly due to the higher H+ associated with the increase in lactic acid [20,21] that allows para swimmers to advance in the graded test and achieve peak values of oxygen uptake, [La^-], and HR values (eg. [1,3]). It is worth highlighting that the HR values obtained in the incremental intermittent protocol differed from those described in the specific literature for this type of test [1,3]. For example, Souza et al. [1] analyzed a class-S6 para swimmer with paraplegia and found HR values superior to the values herein, showing a considerable difference within the same competitive class.

Regarding the characterization of the general swimming kinematics, our results indicate progressive increase in SR throughout the intermittent incremental protocol, with a concurrent decrease in SL. These patterns are in accordance with the literature concerning able-bodied swimmers [19,22,23] and disabled swimmers [4,7,2], since research has shown that the SR and SL combinations change with increasing velocity, which was also demonstrated when comparing long to short competitive events [8,27,28,5]. In fact, it has been reported that para swimmers reach maximum velocity by increasing SR and decreasing SL, while [La^-] increased [2]. Therefore, although the progressive fatigue accumulation can explain the decline in the stroke length along the incremental protocol, the para swimmer preferred to achieve high swimming speed through the increment of stroke frequency.

Evaluating IVV in swimming context requires a more accurate technique [26] and is considered quite relevant to enhance para swimming and understand factors that could constrain performance evaluation [27,26]. In this study, the IVV stability observed from the first to fifth 200-m steps is possibly justified by the adaptation of upper and lower-limb actions to overcome the hydrodynamic drag resulting from higher speed. In fact, it has been suggested that both able and impaired swimmers [4,23,7] need to maintain low IVV values by continuous actions of upper and lower limbs to minimize their energy cost when performing at high speeds. The SI had a slight increase between 200-m steps, suggesting that the para swimmer was economical when performing intensity increments, which would constrain energy cost [28]. Evidence suggests that the maintenance of IVV could have occurred due to SF and SL adaptations.

The IdC is accepted as an important feature in performance [10,29,12], measuring the latency time of upper limbs' propulsive actions. In this study, the coordination of the para swimmer remained in a superposition mode from the first to the fifth 200-m steps, evidencing much more time spent during the propulsive phases, mainly on the side that was not affect by cerebral palsy. Contrary to our findings, previous studies have observed maintenance of the catch-up mode throughout the incremental protocol [11,4]. However, the studies involve both male and female swimmers with arm amputations. Further studies should verify the IdC in para swimmers with cerebral palsy to observe whether the increase in speed implemented through the incremental protocols could affect the interlimb-coordination mode.

Study limitations

This study provides detailed and relevant findings regarding the para swimmer with cerebral palsy for metabolic and kinematic behavior based on a range of common training intensities. However, it is worth recognizing two main limitations. Firstly, although the individual analysis in para swimming is crucial to better represent the disability studied, comparing a higher number of para swimmers competing into S6 class seems to be a good alternative to verify the variability on physiological and biomechanical variables embedded on this class. Secondly, it is fundamental to highlight the two swimming cycles analyzed per lap for not being suitable to represent a front crawl event. Recent technologies in swimming kinematic analysis (e.g. wearable sensors for swimmers with disability, optoelectronic cameras) may provide alternative solutions to enable an increase in the number of stroke cycles accessed in each lap at different swimming intensities and to reduce testing and analysis time.

CONCLUSION

This study showed that the para swimmer participating in the study changed his general swimming kinematics from the first to the fifth 200-m steps in the incremental protocol. Stability was observed for IVV and IdC, even with the increase in the metabolic demands required during the speed increments. An experiment conducted to analyze a high-level S6-class para swimmer individually, considering physiological and biomechanical adaptations through an incremental protocol, may indicate responses to different training intensities. Such indicators can be useful to coaches when planning and monitoring training sets by exploring each swimmer's potentialities and singularities.

PRACTICAL APPLICATIONS

This case study outlines can be used by sport scientists and coaches to quantify key aspects of the performance of swimmers with cerebral palsy. Swimming intensity seems to influence the para swimmer physiological and kinematical behavior, with sharper alterations after the point when AnT is achieved. Swimmers with cerebral palsy, probably at different levels of disability, may benefit from metabolic, SF, and coordination training in an attempt to minimize their impairment on swimming performance. However, training should be guided by a careful physiological and biomechanical evaluation, respecting individual characteristics and without disrupting body alignment. Furthermore, researchers and coaches should take the original observation presented in this study into account.

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