Step Length and Individual Anaerobic Threshold Assessment in Swimming

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Key words
- swimming
- testing
- aerobic evaluation

Abstract

Anaerobic threshold is widely used for diagnosis of swimming aerobic endurance but the precise incremental protocols step duration for its assessment is controversial. A physiological and biomechanical comparison between intermittent incremental protocols with different step lengths and a maximal lactate steady state (MLSS) test was conducted. 17 swimmers performed 7×200, 300 and 400 m (30 s and 24 h rest between steps and protocols) in front crawl until exhaustion and an MLSS test. The blood lactate concentration values ([La$^-$]) at individual anaerobic threshold were 2.1±0.1, 2.2±0.2 and 1.8±0.1 mmol.l^{-1} in the 200, 300 and 400 m protocols (with significant differences between 300 and 400 m tests), and 2.9±1.2 mmol.l^{-1} at MLSS (higher than the incremental protocols); all these values are much lower than the traditional 4 mmol.l^{-1} value. The velocities at individual anaerobic threshold obtained in incremental protocols were similar (and highly related) to the MLSS, being considerably lower than the velocity at 4 mmol.l^{-1}. Stroke rate increased and stroke length decreased throughout the different incremental protocols. It was concluded that it is valid to use intermittent incremental protocols of 200 and 300 m lengths to assess the swimming velocity corresponding to individual anaerobic threshold, the progressive protocols tend to underestimate the [La$^-$] at anaerobic threshold assessed by the MLSS test, and swimmers increase velocity through stroke rate increases.

Introduction

Testing is often used as part of an elite training program to objectively assess the likely outcome of a swimming competitive performance [1] that is influenced by physiological, biomechanical and psychological parameters [29], and serving also as a training prescription tool [21]. From the above referred influencing factors, the physiological variables are of essential importance [7,15,21], and some of the most studied in aquatic activities in general, and in swimming in particular [33]. However, a combined physiological and biomechanical diagnosis of swimming performance seems to be one of today's major areas of interest, which possibly can be explained by the fact that swimmer's performance is strongly influenced by his/her physiological profile and swimming technique [14,24,25,35].

Among the different measurements possible to implement in a swimming physiological evaluation, the assessment of blood lactate concentration values ([La$^-$]) at different exercise intensities is frequently conducted in athletes of different levels, particularly in competitive junior and senior swimmers of both genders [1,7,12,13,15,21,24–28], in child swimmers [8,32], and in triathletes [20]. The [La$^-$] determinations are fast, easy and accurate, being conducted at the swimming pool, allowing immediate results [19]. One of the main purposes for using [La$^-$] in swimming is to assess the anaerobic threshold, which is considered to be the highest sustained exercise intensity at which the balance between production and removal of lactate persists, expressing a traditional measure of the athlete's aerobic capacity [6,8,12,24,28,31]. In fact, the maximal lactate steady state (MLSS) test is still considered the "gold-standard" procedure to assess anaerobic threshold [2,5,22,27], and different intermittent incremental protocols for its determination are described in the swimming related literature [11,18], some allowing an individualized anaerobic threshold assessment [7,8,10,13,15,24,27,32]. However, some authors [9,16,19] claim that to accurately determine the blood [La$^-$] corresponding to each step of incremental exercise it should last 4–6 min or more, since this is the minimum

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time necessary for a reliable representation of the muscular production of lactate in the blood stream at a given workload intensity, and its failure might contribute to incorrect anaerobic threshold assessment.

Complementarily, among the important swimming biomechanical factors that should be evaluated, the stroking parameters – stroke rate (the rate at which the stroke cycle is repeated) and stroke length (the distance travelled during each cycle) – are some of the most studied and relevant for coaches [5,29]. In fact, since the 1970s the assessment of stroking parameters has been applicable for training and performance diagnosis recommendations [14,23,25,35], but few studies have related stroke rate and stroke length with the physiological parameters obtained in incremental tests for anaerobic threshold assessment. The former above-mentioned studies were exceptions, as the reduction of the stroke length above the anaerobic threshold intensity was observed; however, as an MLSS test was not conducted, it was not possible to confirm this phenomenon in a continuous test. The biophysical evaluation of the anaerobic threshold is fundamental in long distance swimmers, once they train and compete at this swimming intensity [19].

The purpose of this study was to evaluate the most adequate step length of incremental intermittent testing to estimate the individual anaerobic threshold (through the determination of the lactate inflection point) in front crawl swimmers. To this end we compared the following physiological and stroking parameters assessed in 3 incremental and intermittent protocols with different step lengths, and in a 30 min continuous test (MLSS): (i) $[La^-]$ corresponding to individual anaerobic threshold ($[La^-]_{AnT}$), and maximal $[La^-]$ ($[La^-]_{max}$); (ii) swimming velocity corresponding to individual anaerobic threshold (v_{AnT}), 4 mmol.l^{-1} (v_4) and 8 mmol.l^{-1} (v_8); (iii) heart rate corresponding to individual anaerobic threshold (HR_{AnT}) and maximal heart rate (HR_{max}); and (iv) stroke rate and stroke length.

Material and Methods

Subjects

17 long distance swimmers voluntary participated in the present study. Their main physical and training background characteristics were: 28.9 ± 10.8 years of age, 1.75 ± 0.51 m of height, 178.0 ± 5.8 cm of arm span, 67.1 ± 5.7 kg of body mass, 21.89 ± 1.61 of body mass index, and 6.3 ± 3.1 years of long distance swimming experience. The local ethics committee approved the experimental procedures and all swimmers signed a consent form in which the protocol was explained. Additionally, this study has been performed in accordance with the ethical standards proposed by Harriss and Atkinson [10].

Testing procedure

All test sessions took place in a 25 m indoor pool, 1.90 m deep, with a water temperature of 27.5 °C. A standardized warm-up, consisting primarily of 1 000 m of aerobic swimming of low-to-moderate intensity, was conducted before each protocol. In-water starts and flip turns were used. Each participant performed, in randomized order, 3 front crawl intermittent incremental protocols until exhaustion with different step lengths (200, 300 and 400 m), increments of 0.05 m.s^{-1} between steps, and 30 s rest intervals; a 24 h rest period was respected between each protocol. The predefined velocity of the last step was common to the intermittent incremental protocols, being established through the best hypothetical time in the 400 m front crawl distance that the swimmers were able to accomplish at that time; then, 0.05 m.s^{-1} was successively subtracted, allowing the determination of the mean target velocity for each step of the incremental protocols [7]. All subjects were able to perform 7 × 200 and 7 × 300 m, but only 3 swimmers completed totally the last step of the 7 × 400 m test at the pre-defined velocity (the sixth step was completely accomplished by all subjects). Capillary blood samples were collected from the earlobe at rest, during the 30 s rest intervals, at the end of exercise, and during the 1st and 3rd min of the recovery period (Lactate Pro, Arkay, Inc, Kyoto, Japan, which was considered before as an accurate analyser [3]). These data allowed assessing the individual anaerobic threshold through the $[La^-]$ vs. velocity curve modelling method (assumed to be the interception point of the best fit of a combined linear and exponential pair of regressions used to determine the exact point for the beginning of an exponential rise in $[La^-]$, also known as lactate inflexion point [17]), the swimming velocity corresponding to 4 and 8 mmol.l^{-1} (v_4 and v_8, proposed as standards for anaerobic threshold and aerobic power evaluations [7,18]) were assessed by linear interpolation or extrapolation of the lactate $[La^-]$ vs. velocity curve (▶ **Fig. 1**, left panel). Heart rate was monitored and registered continuously each 5 s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).

After 24 h rest interval, a MLSS test – a continuous intensity test proposed by Stegmann et al. [31] and Heck et al. [11] – was also implemented: swimmers performed at least two 30 min trials at different velocities with 24 h rest in-between. The swimming velocity for the first trial was established based on the averaged individual v_{AnT} obtained in the 3 intermittent incremental protocols. The velocity increments (or declines) between 30min repetitions were 2.5 % of the initial 30 min velocity (as used by Pelarigo et al. [22]). The velocity corresponding to MLSS (v_{MLSS}) was defined as the highest swimming velocity during which $[La^-]$ increased < 1 mmol.l^{-1} during the final 20 min of the test [4,5,12], and the $[La^-]$ corresponding to MLSS ($[La\text{-}]_{MLSS}$) was obtained through the mean of $[La^-]$ measured at the 10th and 30th min (▶ **Fig. 1**, right panel); blood samples were also taken at rest, and heart rate was also registered continuously. During the incremental and continuous tests, velocity was controlled through a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal), with flashing lights on the bottom of the pool, helping swimmers to keep up the predetermined velocity. Following Martin and Whyte [19], the use of pacing systems implies high accuracy when determining the metabolic anaerobic threshold.

Swimmers were videotaped in the sagittal plane using a camera (Sony® DCR-HC42E, 1/250 digital shutter) placed 0.30 m above the water at the lateral wall of the pool, 6.78 m from the plane of movement, and 12.5 m from the starting wall. For a higher precision, stroke rate was determined using the Ariel Performance Analysis System software (Ariel Dynamics, USA) and computed as the inverse of the time (s) to complete one stroke cycle, which was multiplied by 60 to yield units of strokes per min. Stroke length was calculated by dividing mean velocity to stroke rate. In the intermittent incremental protocols, stroke rate and stroke length were calculated in each step, as the mean value of the data obtained in each 50m; in the MLSS test, these parameters were assessed through the mean of the values obtained in the 9th, 18th and 27th min of the test.

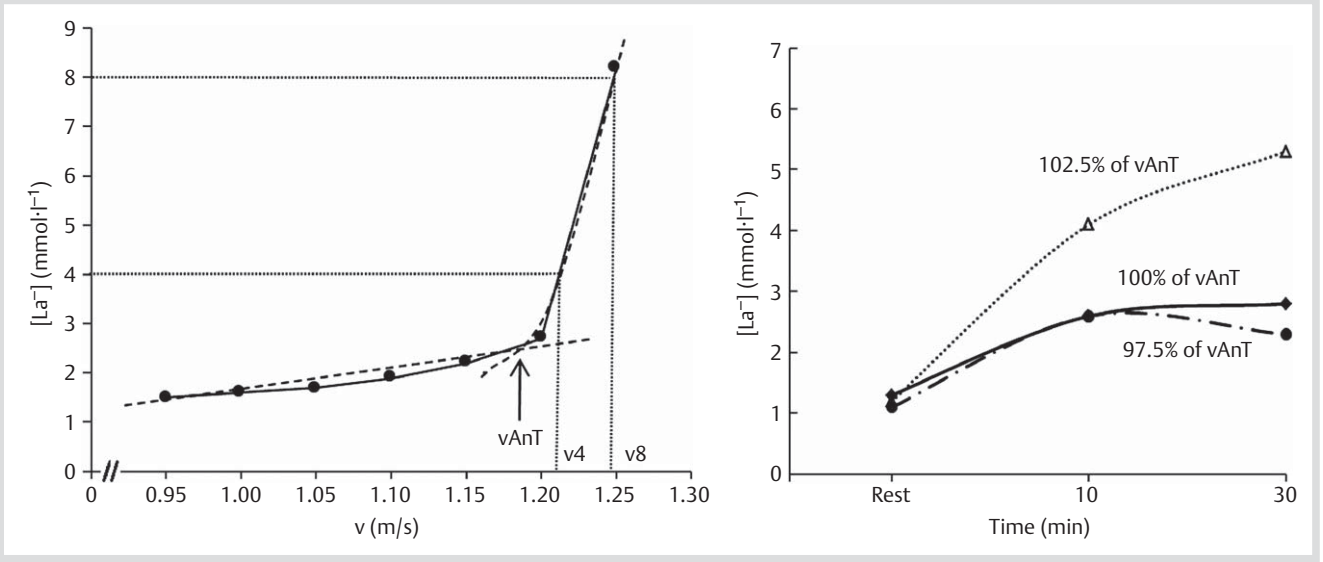

Fig. 1 Example of a blood lactate concentration to velocity curve in the 7×200 m protocol for individual anaerobic threshold assessment, being represented by the interception of a linear and an exponential line (v4 and v8 are also displayed; left panel), and blood lactate concentration during the MLSS test (right panel).

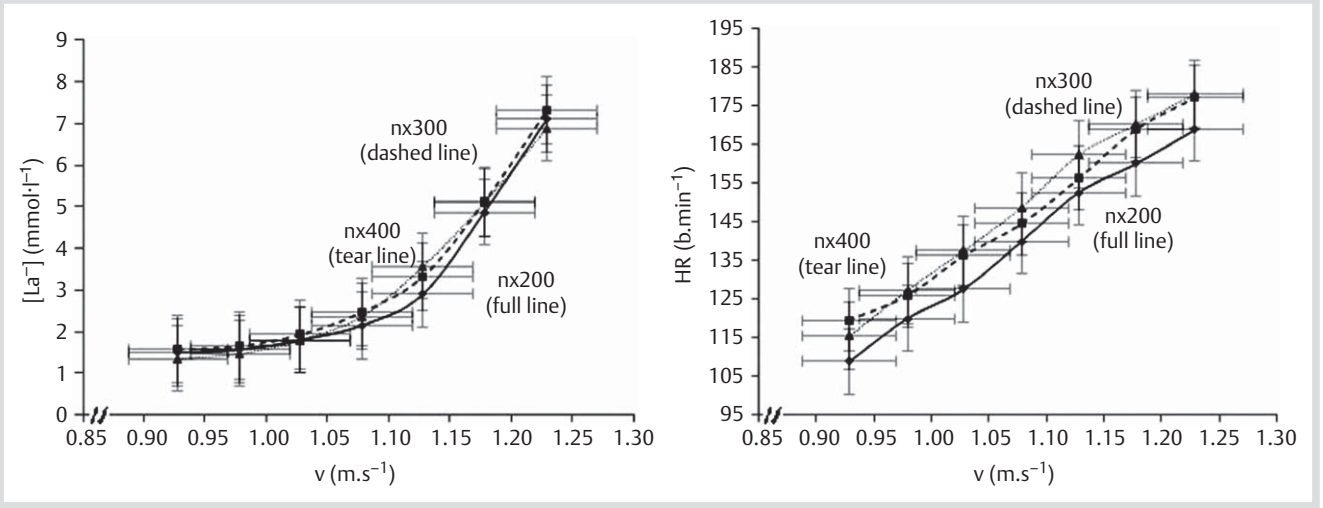

Fig. 2 Blood lactate concentration vs. velocity (left panel) and heart rate vs. velocity curves (right panel) obtained in the 3 intermittent incremental protocols (n = 17).

Statistical analysis

All statistics were performed using SPSS (version 18.0 for Windows). Normal Gaussian distribution of the data was verified by Shapiro-Wilks test, and standard statistical methods were used for the calculation of mean and standard deviation (mean ± SD). Repeated measurements ANOVA was used, and multiple comparisons were made with Bonferroni post hoc test. Pearson correlation coefficient was also applied. Level of significance was established at 5%.

Results

In **Fig. 2** it is possible to observe the [La-] vs. velocity and heart rate vs. velocity curves (left and right panel, respectively) obtained in the 3 intermittent incremental protocols.

The variables assessed in the intermittent incremental protocols and in the continuous test are reported in **Table 1**.

From a general point of view, the values concerning the studied variables are similar among the 3 intermittent incremental protocols; the exception is the higher value of $[La\text{-}]_{AnT}$ obtained in the 7×300 compared to 7×400 m, although with a difference of only 0.4 mmol.l^{-1}. When comparing the incremental tests with the MLSS, it is possible to observe similar values in the v_{AnT}, and higher values for MLSS in the $[La^{-}]_{AnT}$ and HR_{AnT}. Additional information regarding the relationships between these parameters are given in **Table 2**.

The $[La\text{-}]_{AnT}$ values obtained in intermittent incremental protocols, as well as in the MLSS test, are lower than the fixed blood lactate concentration reference of 4 mmol.l^{-1}. The v_{AnT} values were significantly lower than v_4 (and v_8) in all intermittent incremental protocols (the difference between v_{AnT} and v4 correspond, at least, to 8 s of performance difference in a 100 m front crawl effort, in all intermittent incremental protocols); moreover, the difference between the highest v_{AnT} value (obtained in the 7×200 m protocol) and the lower v_{AnT} value

	7×200 m	7×300 m	7×400 m	MLSS
$[La^-]_{AnT}$ (mmol.l^{-1})	2.1 ± 0.1[a]	2.2 ± 0.2[b,c]	1.8 ± 0.1[b,d]	2.9 ± 1.2[a,c,d]
$[La^-]_{max}$ (mmol.l^{-1})	7.3 ± 2.0	7.39 ± 2.02	6.9 ± 2.1	–
v_{AnT} (m.s^{-1})*	1.10 ± 0.04	1.09 ± 0.04	1.07 ± 0.04	1.09 ± 0.14
v_4 (m.s^{-1})*	1.20 ± 0.15	1.18 ± 0.16	1.18 ± 0.15	–
v_8 (m.s^{-1})*	1.30 ± 0.17	1.27 ± 0.16	1.29 ± 0.16	–
HR_{AnT} (b.min^{-1})	145.4 ± 14.7[a]	147.4 ± 14.2[b]	142.5 ± 15.6[c]	156.0 ± 16.3[a,b,c]
HR_{max} (b.min^{-1})	173.2 ± 11.6	176.8 ± 11.8	174.2 ± 10.9	–

Table 1 Mean ± SD values of the physiological variables assessed in the intermittent incremental and continuous tests.

Blood lactate concentrations corresponding to individual anaerobic threshold ($[La^-]_{AnT}$), maximal blood lactate concentrations ($[La^-]_{max}$), velocity corresponding to individual anaerobic threshold, 4 mmol.l^{-1} and 8 mmol.l^{-1} of blood lactate concentrations (v_{AnT} , v4 and v8, respectively), heart rate corresponding to individual anaerobic threshold (HR_{AnT}) and maximal heart rate (HR_{max}). Significant differences between tests are represented by [a](7×200 vs. MLSS), [b](7×300 vs. 7×400), [c](7×300 vs. MLSS) and [d](7×400 vs. MLSS); significant differences between v_{AnT}, v_4 and v_8 are represented by *($p \leq 0.05$)

Table 2 Correlation coefficient values between the intermittent incremental protocols and the continuous test.

	7×200 vs. MLSS	7×300 vs. MLSS	7×400 vs. MLSS
$[La^-]_{AnT}$ (mmol.l^{-1})	0.576*	0.779**	0.647**
v_{AnT} (m.s^{-1})	0.841**	0.898**	0.898**
HR_{AnT} (b.min^{-1})	0.565*	0.712**	0.774**

Blood lactate concentrations corresponding to individual anaerobic threshold ($[La^-]_{AnT}$), velocity corresponding to individual anaerobic threshold (v_{AnT}) and heart rate corresponding to individual anaerobic threshold (HR_{AnT}). Significant correlations are represented by *($p \leq 0.05$) and **($p \leq 0.01$)

(corresponding to 7×400 m test) evidenced a 3 s variation in a 100 m front crawl effort.

Regarding the stroking parameters, it is possible to observe in **Fig. 3** (left, center and right panels for 7×200, 300 and 400 m protocols, respectively) that stroke rate increased and stroke length decreased throughout the incremental tests, following the velocity increments.

Regarding stroke rate, differences were observed between the first and the last steps in the 3 intermittent and incremental protocols; also, stroke rate was different between subsequent steps, particularly after the 4th in the 7×200 m test, and between the 4th and 5th, and the 6th and 7th steps in the nx400 m protocol (no differences were observed in the 7×300 m test). The stroke length decreased throughout the intermittent incremental protocols, significant differences existing between the first and last protocol steps, but no changes in subsequent steps (with exception of the 6th and 7th step in the 200 m protocol). The mean ± SD values regarding stroke rate and stroke length in the MLSS test were 39.9 ± 4.86 and 1.65 ± 0.21, respectively.

Discussion

Since the 1980s the [La$^-$] assessment has become a fundamental part of training control and evaluation of swimmers [1,12, 19,21,28,29,35], and the anaerobic threshold assessment is a major example of its use [18,27,28]. The present study used [La$^-$] (and other related parameters: e.g., v_{AnT}) to understand which are the best step lengths to use in a graded protocol for individual anaerobic threshold assessment in swimming; comparisons between different step length protocols and MLSS, the gold standard for anaerobic threshold assessment, were also made. The individual anaerobic threshold was assessed using a methodology that allowed an individual analysis of each swimmer – the [La$^-$]/velocity curve modelling method previously applied both for adult [7,17] and child swimmers [8] – once the use of the 4 mmol/l fixed reference lactate concentration as a mark of the individual anaerobic threshold and for evaluation of individual aerobic endurance has been considered not useful [13,26,28,30,31]. The determination of the lactate inflexion point through our methodology has also the advantage of not needing the inducement of acidosis previously to the incremental exercise, as required in the lactate minimum test (cf. [27]). As, up to now, no generally accepted fitting procedure has been established [6], we find the use of our methodology perfectly justified.

From a general point of view, few differences were observed between intermittent incremental protocols, evidencing that the use of 200 to 400 m step lengths, i.e., from ~[2.40–3.40] and ~[5.20–7.20] min durations, respectively, seems not to influence the studied physiological and biomechanical parameters in these long distance swimmers; this is in accordance with Ribeiro et al. [27] for comparisons between 200 and 300 m steps lengths, and in opposition to Madsen and Lohberg [19] that stated that the use of 200 m steps (rather 400 m) overestimate the swimming aerobic capacity. However, when comparing the specific individual anaerobic threshold related parameters obtained in the intermittent incremental protocols and in MLSS, similar v_{AnT} values were observed (with very high correlation values between them), but higher $[La^-]_{AnT}$ and HR_{AnT} values in the latter. Moreover, although the significant correlation values were obtained with the MLSS, from the 3 incremental protocols, the $[La^-]_{AnT}$, HR_{AnT} and v_{AnT} values obtained in 7×400 m were the lowest in comparison with the continuous test, suggesting that the 400 m step length seems to be less adequate to use in an intermittent incremental protocol for the individual anaerobic threshold assessment.

The individual anaerobic threshold has been reported to have great variability between swimmers, and the fixed value of 4 mmol.l^{-1} proposed more than 30 years ago by Mader et al. [18] does not take into account the individual kinetics of the [La$^-$] curve [8,9,12,13,19,21,24,27,28,30–32,34], and can be affected by previous muscle glycogen content [26]. The results of the present study corroborate the literature, once the $[La^-]_{AnT}$ values found both in the intermittent incremental and in the MLSS tests are lower than the traditionally used 4mmol.l^{-1} value, and similar to those previously observed by aerobically well-trained swimmers [7,13,20,24,35], even if they are of a young age [8,32]. This fact was evidenced a long time ago by Stegmann et al. [30] and Stegmann and Kinderman [31], who found that the [La$^-$] corresponding to anaerobic threshold in groups of untrained subjects or athletes not especially aerobically trained was near 4 mmol.l^{-1}, but for aerobically trained subjects (especially in highly trained long-distance runners) the lactate inflection point was found to be distinctively lower (see also [6,9]);

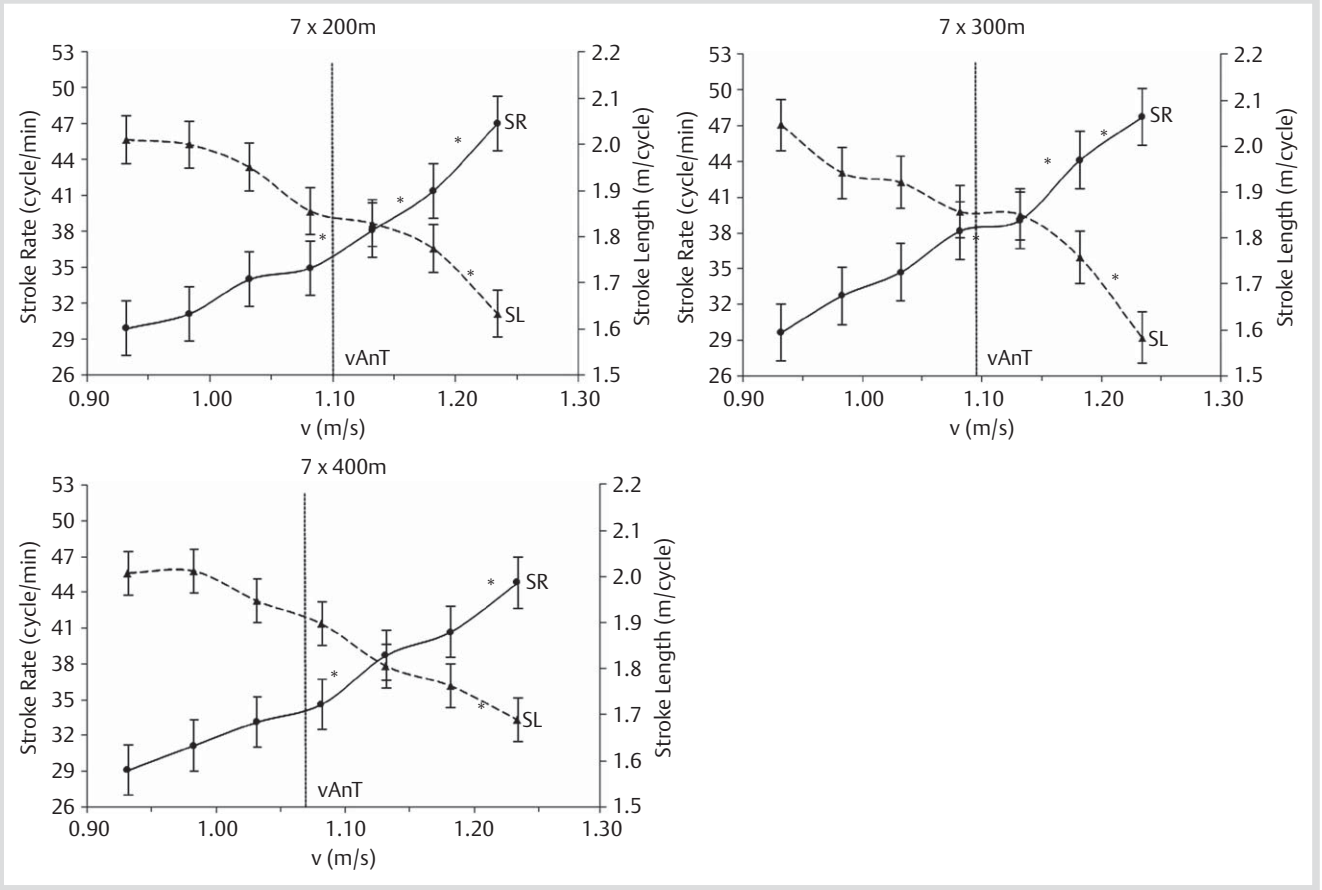

Fig. 3 Stroking parameters behaviour during the 7×200, 300 and 400 m protocols (left, right and down panels, respectively). Mean velocity corresponding to individual anaerobic threshold is also displayed. * represents significant differences between consecutive steps ($p<0.05$).

Madsen and Lohberg [19] also stated that the $[La^-]_{AnT}$ are situated anywhere from 2 mmol.l^{-1} (for the aerobically well-trained swimmer, as our long-distance swimmers) and 5 mmol.l^{-1} (for the sprinter with a poorer aerobic resistance capacity). The only exception found in the literature was the study of Ribeiro et al. [27] that reported $[La^-]_{AnT}$ values found between 3.0 and 11.4 mmol.l^{-1}, which can be explained by the methodological requirement of inducing high acidosis specific to the lactate minimum velocity incremental test. The lower value of $[La^-]_{AnT}$ obtained in the 400 m protocol is in agreement with the fact that longer workload durations will lead to lower individual anaerobic threshold values, mostly due to premature fatigue [9,16]; this fatigue accumulation is a consequence of the metabolic acidosis, particularly due to the increase in H^+ associated to the increase in lactic acid [20] that impairs swimmers of going forward in the graded test and achieving peak values of oxygen consumption, of $[La^-]$ and heart rate [16]. In fact, swimmers perform higher number of strokes in longer steps and, at the end of 400 m incremental protocol, subjects were clearly more exhausted (from the researcher perceived exhaustion point of view) when compared with the last step of the 200 and 300 m protocols; moreover only 3 of the 17 subjects were able to accomplish all the length of the 7th step of the 400 m protocol at the predetermined swimming velocity.

The $[La^-]_{MLSS}$ mean value observed is in the range from 2.8 to 4.3 mmol.l^{-1} described in literature [4,5,22,27,34], and, although MLSS is considered the gold-standard in regard to the anaerobic threshold assessment, this value is significantly higher than the $[La^-]_{AnT}$ values obtained in the incremental protocols. It seems that the effort-break relation in intermittent incremental tests allows a physiological stability by allowing a $[La^-]$ removal during recovery periods, with consequent lower $[La^-]$ accumulation; as MLSS is a quasi continuous test, there are almost no recovery periods, leading to progressive $[La^-]$ accumulation.

Regarding the v_{AnT}, it was observed that its highest value was obtained in the 7×200 and 7×300 tests, with values similar to the v_{MLSS}, corroborating the validity of this protocol for the individual anaerobic threshold assessment (as shown before by [6,7,16] for different swimming populations). Moreover, and as previously mentioned, the ~3 s difference in a 100 m front crawl effort between the 200 and 400 m protocols seems to show that the implementation of the 400 m length steps (of an averaged duration of 6 min) for the individual anaerobic threshold assessment could lead to inadequate values. Even for aerobic power diagnosis, the use of intermittent incremental protocols with 400 m step length seems to be less valid since the $[La^-]_{max}$ value obtained was the one least similar to the 8 mmol.l^{-1} usually used as a criterion for maximal oxygen consumption evaluation (cf. [7]). With regard to v_{MLSS}, the results of the present study are similar to that described in swimming literature [4,5]. However, other studies that differed in the competitive level of the sample, and in the MLSS protocol, have presented higher v_{MLSS} [22,27,34]: Wakayoshi et al. [34] and Ribeiro et al. [27] implemented a 1 600 m and 2 000 m test, respectively, divided into 400 m repetitions with rest periods of 30–45 s.

The 8 s of difference in a 100 m front crawl effort between v_{AnT} and v4 obtained in the intermittent incremental protocols show the limitations of the conventional v4 value obtained by the tra-

ditional 2 speed test of Mader et al. [18], particularly the fact of it being an average value and obtained in recreational swimmers who were not especially aerobically trained. Hein et al. [12] have also observed a difference of 3.1 ± 2.4 s on 100 yds between individual anaerobic threshold velocity and extrapolated v4 (one swimmer achieved 8.7 s difference). Mader's group proposed afterwards the 3.5 mmol.l^{-1} value as a more adequate indicator for anaerobic threshold assessment for aerobically trained runners [11], but the v3.5 is still an average value that ignores individual variability. Therefore, the present results highlight that, in accordance with several studies (e. g., [7, 8, 13, 24, 28, 30, 31]), the v4 value does not represent the individualized anaerobic threshold, and coaches should use it with caution to assess the proper intensities to develop swimmers' aerobic capacity since it is an intensity poorly tolerated by well-trained swimmers [28]. Nevertheless, it should be taken into account that the 7 steps incremental intermittent protocol is a more time consuming and costly test compared with the 2 speed test of Mader et al. [18]. The HR_{max} and HR_{AnT} values obtained in incremental intermittent protocols were also close to those described in swimming literature for this kind of test [7, 13, 15, 24].

Regarding the characterization of the stroking parameters, our results indicate a general progressive increase in stroke rate throughout the intermittent incremental protocols, with a concurrent decrease in stroke length. These patterns are in accordance with the literature in adult [5, 24, 25, 35] and child swimmers [8], since research has shown that the stroke rate and stroke length combinations change with increasing velocity; this was shown also when comparing long to short distance competitive events [23]. In fact, it has been reported that swimmers reach maximum velocity by increasing stroke rate and decreasing stroke length, while [La$^-$] increased [14, 24, 25, 35]. Therefore, although the decline of the stroke length along the incremental protocols could be explained by the progressive fatigue accumulation [5], these swimmers preferred to achieve high swimming velocity through the increment of stroke rate.

Complementary, it should not be neglected the possibility that each swimmer has used a freely chosen stroke rate, which should be taken into account both in graded and continuous tests. In fact, the combination of stroke rate and stroke length has a large variability that implies a highly individual process [4, 14, 23] that can be explained by differences between swimmers in anthropometric characteristics, stroking technique, muscle flexibility, and coordination [23, 25]. The lower stroke rate value in the 7th step of the 400 m protocol is explained by the fact that 14 swimmers ended the protocol prematurely (not ending this step at the pre-determined velocity), possibly due to high [La$^-$] that is associated with local muscle fatigue; however, the [La$^-$]max at the 7 × 400 m test was not higher than the values reported for the 200 and 300 m tests. Thus, when reporting stroke rate at the last step, the step length influence has to be taken into account, as steps that are too long seem to contribute decisively to the deterioration of the swimming technique, probably related to a decreasing ability to develop the necessary force to overcome resistance to forward movement [5]. Another possibility is that swimmers adapt their stroke to be able to perform at higher intensities [2, 4, 7, 24].

In conclusion intermittent incremental protocols of 200 and 300 m step lengths are valid procedures for individual anaerobic threshold assessment, and the use of the 400 m distance seems to underestimate [La-]$_{AnT}$, suggesting that this step length should be used with caution. The shorter 200 m steps are more suitable to the training and competitive requirements of swimmers, who are then more motivated to perform a maximal effort if the swimming distance is relatively short. In addition, coaches are more easily prepared to have their swimmers tested if less time is taken from their workout schedule. The single-session 7 × 200 m incremental protocol seems to be a good evaluation tool to assess swimmer's aerobic capacity development, as an alternative to the MLSS test, which is a direct but lengthy evaluation that requires various prolonged exercise sessions on different days.

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