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ORIGINAL ARTICLE

Assessment of individual anaerobic threshold and stroking parameters in swimmers aged 10–11 years

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Abstract

The assessment of blood lactate concentration is considered essential for the physiological diagnosis of swimming performance. But for a more detailed and complete analysis of a swimmer's strengths and weaknesses, it is also important to examine his or her technical characteristics. However, few studies have combined physiological and technical evaluation in child swimmers. The aim of the present study was to assess the metabolic anaerobic threshold (blood lactate concentration and corresponding swimming velocity) of 10- to 11-year-old swimmers ($n = 15$) using an individualized intermittent incremental protocol. Comparison was made with the traditionally used 4 mmol $\cdot$ l^{-1} lactate threshold. In addition, stroke rate, stroke length, and stroke index were measured throughout the experimental protocol for assessment of the anaerobic threshold. Each swimmer performed a front crawl 5 $\times$ 200 m test, in which the swimming velocity was controlled by an acoustic signal each 50 m. Blood samples were collected from the ear lobe (Lactate Pro, Arkay, Inc., Kyoto, Japan), at rest and after each step. Stroke rate was registered by a Seiko base 3 chronofrequencemeter; stroke length, stroke index, and velocity were calculated at the end of each 200 m. The individual anaerobic threshold occurred at 2.3 mmol $\cdot$ l^{-1} ($s = 0.59$), and the corresponding velocity was 1.026 m $\cdot$ s^{-1} ($s = 0.053$), much lower than the traditionally used 4 mmol $\cdot$ l^{-1} value (or even 3.5 mmol $\cdot$ l^{-1}). The velocity corresponding to 4 mmol $\cdot$ l^{-1} and 3.5 mmol $\cdot$ l^{-1} was 1.081 m $\cdot$ s^{-1} ($s = 0.056$) and 1.067 m $\cdot$ s^{-1} ($s = 0.055$), respectively. Stroke rate increased and stroke length decreased throughout the incremental protocol (i.e. with increasing velocity). The stroke index showed a tendency to increase throughout the protocol, with a significant difference from the first to the second step. The velocity corresponding to 4 mmol $\cdot$ l^{-1} (and 3.5 mmol $\cdot$ l^{-1}) does not represent the metabolic individual anaerobic threshold in trained swimmers, independently of their age, and age-group swimmers prefer to increase their velocity through an increase in stroke rate. Thus, given the importance of developing swimming technique in age-group swimmers, coaches should implement the lengthening of swimmers' stroke cycles in their training practice routines, so that they limit the effects of reduced stroke length when velocity increases.

Keywords: *Swimming, children, anaerobic threshold, blood lactate*

Introduction

The relationship between blood lactate concentration and swimming velocity is important for the assessment of swimming performance (Anderson, Hopkins, Roberts, & Pyne, 2006; Bonifazi, Martelli, Marugo, Sardella, & Carli, 1993; Costill, Maglischo, & Richardson, 1992; Kelly et al., 1992; Olbrecht, 2000; Simon, 1997). One of its main purposes is to assess the metabolic anaerobic threshold – that is, the highest exercise intensity during which the balance between production and removal of lactate occurs, which is taken to express the development of the swimmer's aerobic capacity (Heck et al., 1985; Simon, 1997). More than 30 years ago, Mader and colleagues (Mader, Heck, & Hollmann, 1978) proposed a mean blood lactate concentration of 4 mmol $\cdot$ l^{-1} to assess anaerobic threshold in swimming, which led to the generalization of its corresponding velocity ($v4$) to the training and evaluation of swimmers' aerobic capacity. In fact, in several studies, the $v4$ value was accepted as a standard for anaerobic threshold assessment (for a detailed

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review, see Svedahl & MacIntosh, 2003) despite the variability of the lactate concentration corresponding to the anaerobic threshold in swimmers (Jacobs, 1986; Kelly et al., 1992; Pyne, Lee, & Swanwick, 2001; Stegmann, Kindermann, & Schnabel, 1981).

Despite the importance of lactate concentration when determining the swimmer's anaerobic threshold, few studies have been conducted with children involved in age-group swimming training. Indeed, simultaneously with the mastery of the proper starting, swimming, and turning techniques, children engaged in the first steps of the training process, (i.e. the "basic training" phase) should develop their basic conditional capacities, namely their aerobic capacity (Olbrecht, 2000). Thus, in line with technique improvement, aerobic capacity training should gradually be introduced at 6–8 years of age, since its development is fundamental in the early stages of the swimmer's career plan to prepare for future intense high-volume training.

In addition, it is very important to emphasize that children are not mini-adults but individuals with specific characteristics and constraints (Armstrong & Welsman, 2002). For instance, during exercise performed at submaximal intensities, children have been reported to have a lower lactate concentration than adults due to lower glycolytic metabolic adaptations and higher oxidative activity, which could be related to a reduced production of lactate, its high oxidation or both (Bar-Or, 1995; Costill et al., 1992; Eriksson & Saltin, 1974). Takahashi and colleagues (Takahashi, Bone, Spry, Trappe, & Troup, 1992) reported that, at race paces, the aerobic contribution in children is higher than in adults. Thus, more research should be conducted in children and young swimmers.

Anderson et al. (2006) and Psycharakis and colleagues (Psycharakis, Cooke, Paradisis, O'Hara, & Phillips, 2008) stressed that, despite the importance of the physiological determinants of swimming, it is a sport in which technical skills assume fundamental importance, suggesting a combined evaluation of stroking and physiological parameters. Indeed, the study of the stroking parameters has a long tradition among the technical and scientific swimming community, since the swimmer's velocity may be explained by the product of the stroke rate (the number of complete cycles of one arm per unit time) and stroke length (the distance the swimmer moves forward per stroke) (Craig & Pendergast, 1979). Inter-individually, stroke length has been identified as the main swimming performance determinant (Cardelli, Lerda, & Chollet, 2000; Costill et al., 1992; Craig & Pendergast, 1979; Hay, 1987), although, from an individual point of view, it was also reported that swimmers choose to increase their stroke rate to achieve higher velocities (Chollet, Pelayo, Tourny, & Sidney, 1996; Costill et al., 1992; Hay, 1987; Hout-Marchand, Nesi, Sidney, Alberty, & Pelayo, 2005; Keskinen & Komi, 1993). Indeed, to obtain high-level performance, it is accepted that swimmers must have a good combination and control of both stroke rate and stroke length (Chollet et al., 1996; Pelayo, Sidney, Kherif, Chollet, & Tourny, 1996; Swaine & Reilly, 1983). Furthermore, Costill et al. (1992) proposed the stroke index to represent the swimmer's ability to move at a given velocity with the least number of strokes, thus being an indicator of swimming efficiency. Although incremental swimming tests can also provide feedback on performance measures such as stroking parameters (Anderson et al., 2006; Psycharakis et al., 2008), the study of children involved in age-group training is limited.

In the present study of age-group swimmers aged 10–11 years, our aims were twofold: (1) to assess the individual anaerobic threshold of each swimmer by determining its specific corresponding lactate concentration and swimming velocity, and (2) to analyse the kinetics of the stroking parameters (stroke rate, stroke length, stroke index) during the intermittent incremental protocol used for the assessment of the individual anaerobic threshold.

Methods

Participants

Fifteen children (eight boys and seven girls) voluntarily participated in the present study. Their mean physical and training background characteristics were as follows: age 10.7 years, $s = 0.70$; height 1.49 m, $s = 0.08$; arm span 149.5 cm, $s = 9.7$; body mass 41.1 kg, $s = 7.5$; swimming experience 5.3 years, $s = 2.1$; 400-m freestyle speed 1.138 $m \cdot s^{-1}$, $s = 0.059$. All swimmers trained four times per week, covering 12,000–14,000 m per week, mainly at aerobic regimens during the training macrocycle in which the testing took place. The criterion for children's participation was a performance time of 180 s (or less) in the 200-m freestyle event. The local ethics committee approved the procedures and all the swimmers' parents signed a consent form in which the protocol was explained.

Test protocol

Briefly, each participant performed a 5×200 m front crawl individualized intermittent incremental protocol, with increments of 0.05 $m \cdot s^{-1}$ each 200-m step, and 1 min rest intervals (adapted from Fernandes et al., 2003). Researchers and coaches determined the velocity of the last step based on the best hypothetical time in the 200-m front crawl event that the swimmers were able to accomplish at that time. Successive $0.05\ m \cdot s^{-1}$ was subtracted from the swimming velocity corresponding to the referred hypothetical time, allowing the determination of the mean target velocity for each step of the incremental protocol. Swimming velocity was measured using a Seiko base 3 chronofrequencemeter and controlled by an acoustic signal each 50 m. A standardized warm-up of 600 m, consisting primarily of aerobic swimming of low to moderate intensity, was conducted before the test protocol.

Capillary blood samples for blood lactate analysis were collected from the earlobe at rest, during the 1-min rest intervals, at the end of exercise, and during the recovery period (Lactate Pro, Arkay, Inc., Kyoto, Japan). These data allowed us to assess individual anaerobic threshold (IndAnT), which was determined by the lactate concentration/velocity curve modelling method (least square method; cf. Fernandes et al., 2005; Machado et al., 2006), as described in Figure 1 for one swimmer. The individual anaerobic threshold was assumed to be the interception point of a combined pair of regressions (linear and exponential), used to determine the exact point for the beginning of an exponential rise in lactate concentration. *v*4 was determined by linear interpolation of the lactate concentration/velocity curve and *v*3.5 was also assessed as a more adequate value for aerobically trained swimmers performing a 3-min steps test, as suggested by Heck et al. (1985).

Following the proposals of Craig and Pendergast (1979) and Costill et al. (1992), stroke rate was determined as the number of cycles per minute in each 50 m of each step of the protocol (registered by a Seiko base 3 chronofrequencemeter), stroke length was calculated by dividing velocity by stroke rate, and the stroke index was calculated as the product of stroke length and velocity.

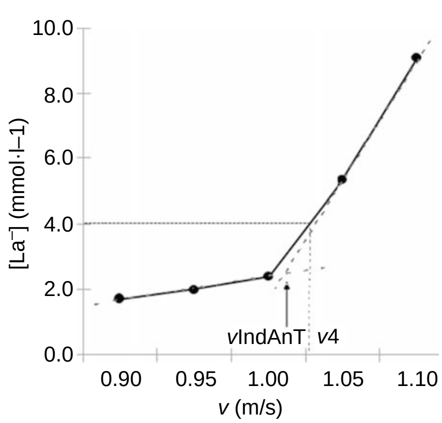

Figure 1. Example of an individual ([La$^-$]/*v*) curve in the intermittent incremental protocol for IndAnT assessment, which is represented by the interception of a linear and an exponential line (*v*4 is also pointed out).

All tests were conducted in a 25-m indoor swimming pool, 1.90 m deep, with a water temperature of 27.5°C. In-water starts and rollover turns were used.

Statistical analysis

Descriptive statistics (means and standard deviations) were obtained for all variables (all data were checked for normality of distribution using the Shapiro-Wilk test). Pearson's correlation coefficient, unpaired samples Student's *t*-test (between boys and girls), and repeated-measures analysis of variance (for *v*IndAnT, *v*4 and *v*3.5, and the stroking parameters between the different steps of the protocol) were also used. A significance level of 5% was accepted.

Results

Figure 2 shows the lactate concentration/velocity curves of each participant. Lactate concentration after each of the five 200-m repetitions was $2.05\ mmol \cdot l^{-1}$ ($s=0.50$), $2.07\ mmol \cdot l^{-1}$ ($s=0.51$), $2.39\ mmol \cdot l^{-1}$ ($s=0.63$), $3.48\ mmol \cdot l^{-1}$ ($s=1.19$), and $6.52\ mmol \cdot l^{-1}$ ($s=1.78$) $mmol \cdot l^{-1}$, respectively, at velocities of $0.917\ m \cdot s^{-1}$ ($s=0.437$), $0.982\ m \cdot s^{-1}$ ($s=0.645$), $1.025\ m \cdot s^{-1}$ ($s=0.060$), $1.073\ m \cdot s^{-1}$ ($s=0.440$), and $1.109\ m \cdot s^{-1}$ ($s=0.801$). Mean values and standard deviations of the variables obtained in the incremental test, namely lactate concentration corresponding to individual anaerobic threshold ([La$^-$]IndAnT), swimming velocity corresponding to individual anaerobic threshold (*v*IndAnT), *v*4 and *v*3.5, are reported in Table I.

The lactate concentrations corresponding to individual anaerobic threshold observed in the total sample (as well as by gender) are substantially lower than the traditionally used $4\ mmol \cdot l^{-1}$ criterion value (and even the value of $3.5\ mmol \cdot l^{-1}$). Moreover,

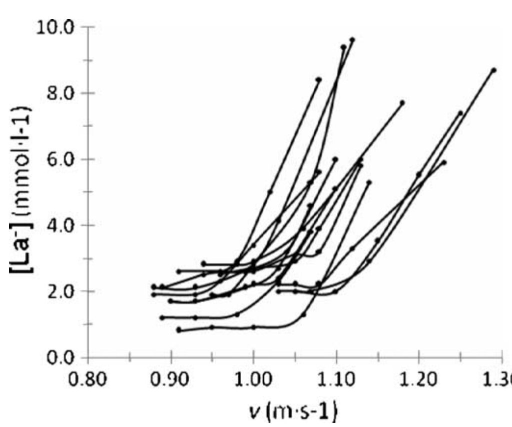

Figure 2. Individual lactate concentration/velocity ([La$^-$]/*v*) curves ($n=15$) in the intermittent incremental protocol for assessment of individual anaerobic threshold.

Table I. Mean and standard deviations for [La⁻]IndAnT, *v*IndAnT, *v*4, and *v*3.5 obtained for male and female child swimmers, and for the total sample

	Total ($n = 15$)		Boys ($n = 8$)		Girls ($n = 7$)	
	mean	*s*	mean	*s*	mean	*s*
[La⁻]IndAnT (mmol · l^{-1})	2.29	0.59	2.26	0.59	2.32	0.64
*v*IndAnT (m · s^{-1})^{a,b}	1.026	0.053	1.044	0.051	1.006	0.050
*v*4 (m · s^{-1})^{a,c}	1.081	0.056	1.099	0.069	1.061	0.030
*v*3.5 (m · s^{-1})^{b,c}	1.067	0.055	1.083	0.067	1.050	0.032

^{a,b,c}Significant differences between *v*IndAnT, *v*4, and *v*3.5 in the combined and gender groups.

based on the high correlation observed between velocity corresponding to individual anaerobic threshold and *v*4 ($r = 0.888$, $P < 0.001$), the 0.055 m · s^{-1} difference between the velocity corresponding to individual anaerobic threshold and *v*4 (considering all participants) corresponds to ~5 s of difference in a 100 m front crawl effort, meaning that velocity corresponding to individual anaerobic threshold and *v*4 are not coincident and interchangeable. No significant differences were observed in the studied variables between girls and boys.

Of the stroking parameters, stroke rate increased and stroke length decreased throughout the 5 × 200 m protocol (i.e. following the increments in velocity) (cf. Figure 3). Although not shown in Figure 3, the stroke length obtained in the last step was statistically lower than in the first, second, and third steps. The stroke index shows a significant increase from the first to the second step. Between the next successive steps, no statistical differences were observed (suggesting a stabilization of stroke index), but a tendency to a numerical increase of the mean values was observed. Finally, the stroke indexes of the third, fourth, and fifth steps were significantly higher than that obtained for the first step of the protocol.

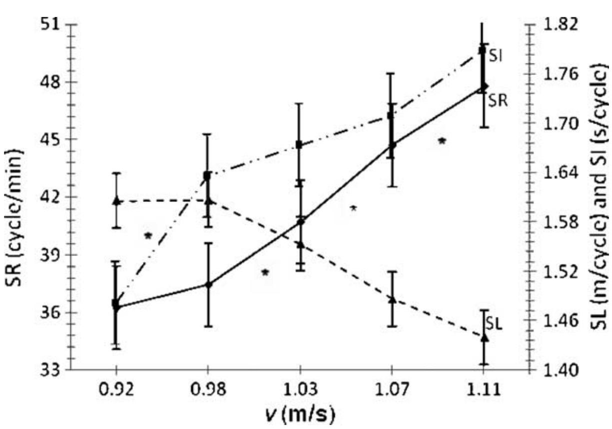

Figure 3. Mean and standard deviations for the stroking parameters (SR: stroke rate; SL: stroke length; SI: stroke index) and velocity for the total sample ($n = 15$) during the intermittent incremental protocol for for assessment of individual anaerobic threshold. *Significant differences between consecutive steps.

Discussion

To our knowledge, the determination of individual anaerobic threshold using blood lactate concentration in age-group swimmers, younger than 12 years, had never been undertaken before in normal swimming conditions (i.e. free swimming). The lactate analyser used is considered an accurate and reliable device for assessing lactate concentration in sports research (Baldari et al., 2009; McNaughton, Thompson, Philips, Backx, & Crickmore, 2002). Also, no study had been conducted previously of the specific stroking parameters in an intermittent incremental protocol performed by children.

Based on our results, the use of the present swimming intermittent incremental protocol for assessment of children's individual anaerobic threshold seems to be a valid procedure for diagnostic purposes, as observed previously for adult swimmers (Fernandes et al., 2005; Machado et al., 2006). In the literature it is stated that a test to directly determine the anaerobic threshold using lactate concentration typically involves stages of 2–4 min or 200 m duration with small increments between stages (Anderson et al., 2006; Costill et al., 1992; Hebestreit & Beneke, 2008; Kelly et al., 1992; Psycharakis et al., 2008; Pyne et al., 2001; Simon, 1997). Since the lactate concentration corresponding to the anaerobic threshold has been reported to vary widely between swimmers and the fixed value of 4 mmol · l^{-1} does not take into account the individual kinetics of the lactate curve (Fernandes et al., 2005; Jacobs, 1986; Kelly et al., 1992; Simon, 1997; Stegmann et al., 1981), the method used in this study for the assessment of the velocity corresponding to the individual anaerobic threshold appears to overcome some of the deficiencies of the *v*4 value obtained by the traditional "two speed test" of Mader et al. (1978), namely: (i) it was an averaged value; (ii) it was assessed with a lactate analyser of previous generation; (iii) it was conducted in recreational swimmers, not especially aerobically trained; (iv) it was at an intensity poorly tolerated by well-trained individuals (Hebestreit & Beneke, 2008; Simon, 1997). Heck et al. (1985) tried to overcome some of these drawbacks by assessing the anaerobic threshold in aerobic-trained swimmers performing a 3-min steps test, but their proposed value of 3.5 $mmol \cdot l^{-1}$ for the lactate threshold is still an averaged value and ignores individual variability. Thus, the present results highlight that, in accordance with the above-mentioned literature on older participants, the swimming velocity corresponding to a lactate concentration 4 $mmol \cdot l^{-1}$ does not represent the individualized anaerobic threshold of age-group swimmers aged 10–11 years. Other more specific and individualized methodologies are reported in the literature but also have significant limitations, which prevent coaches and scientists using them (principally when testing children): (i) the subjectivity of the simple observation of the inflection point of the lactate concentration/velocity curves; (ii) the use of prolonged test distances (up to 30 min duration) with significant velocity differences between steps; and (iii) the need for very high lactate concentrations (15 $mmol \cdot l^{-1}$), which implies strenuous exercise intensities.

In addition, the lactate concentrations corresponding to the individual anaerobic threshold of our participants are lower than those reported in the literature for older front crawl swimmers, with mean values ranging between 2.6 and 3.9 $mmol \cdot l^{-1}$ (Fernandes et al., 2005, 2008; Kelly et al., 1992; Pyne et al., 2001; Stegmann et al., 1981). In fact, Williams and Armstrong (1991) and Hebestreit and Beneke (2008) suggested fixed values of 2.5 and 3.0 $mmol \cdot l^{-1}$, respectively, as the reference for anaerobic threshold assessment in children. When assessing the lactate threshold in age-group swimmers aged 12–14 years, Toubekis and colleagues (Toubekis, Tsami, & Tokmakidis, 2006) reported a value of 3.16 $mmol \cdot l^{-1}$ ($s = 1.20$) when participants' performed front crawl, breaststroke, and backstroke techniques. Although comparisons between studies using different methods and lactate analysers for assessing metabolic anaerobic threshold should be done with caution, the lower values obtained in the present study may be explained by: (i) the training regimen of our age-group swimmers, focusing more on technique development at slow to moderate aerobic paces; (ii) the higher ratio of oxidative to glycolytic enzyme activity in children (Bar-Or, 1995; Costill et al., 1992; Eriksson & Saltin, 1974; Takahashi et al., 1992); (iii) the reduced muscle mass of younger swimmers (Hebestreit & Beneke, 2008; Takahashi et al., 1992), in that it has a marked effect on blood lactate patterns (Kelly et al., 1992); (iv) the different swimming techniques evaluated; and (v) the use of an up-to-date effective lactate analyser. In this sense, our child swimmers seemed to be well trained in aerobic regimen, which is in accordance with the training principles of the earlier stages of a training programme (Olbrecht, 2000). This could be confirmed by the fact that 97% of the macrocycle total volume was accomplished in the aerobic bioenergetic areas. Additionally, the training volume per week accomplished by our participants is in accordance with the specialized literature (Costill et al., 1992; Olbrecht, 2000).

The velocity corresponding to the individual anaerobic threshold and $v4$ values obtained in this study were, as expected, lower than those reported for older swimmers, since swimming performance increases with age and maturation. As mentioned above, the most similar study was that carried out by Toubekis et al. (2006), who observed values of 1.079 ($s = 0.114$) and 1.106 ($s = 0.112$) for the velocity corresponding to the lactate threshold and $v4$, respectively. The fact that we observed a significant difference between the velocity corresponding to the lactate threshold and $v4$ (close to 5 s for 100 m distance) means that $v4$ (and even of $v3.5$) is not representative of the velocity corresponding to the lactate threshold and limits the use of the traditional $v4$ value to assess the proper intensities to develop swimming aerobic capacity. In fact, in the present study, $v4$ was closer to the velocity obtained in a 400-m freestyle event ($v400$) performed at an official competition swam close, in time, to the testing date. Like the velocity corresponding to the lactate threshold, $v4$ was highly correlated with $v400$ ($r = 0.853$, $P = 0.01$), in accordance with Bonifazi et al. (1993), showing not a 5 s but a 4 s difference between them on a 100 m distance base. In this sense, accepting that the 400-m freestyle event is an effort conducted at an intensity close to the aerobic power bioenergetic training area (Fernandes et al., 2008), $v4$ seems to be closer to the velocity corresponding to maximal oxygen consumption than to the metabolic anaerobic threshold, somewhere in between the two exercise intensities.

Regarding the stroking parameters, our results indicate a general progressive increase in stroke rate throughout the incremental protocol, with a simultaneous decrease in stroke length (existing significant differences between steps after the second one, inclusively). These patterns are in accordance with the literature (cf. Dekerle et al., 2005; Hout-Marchand et al., 2005; Psycharakis et al., 2008), since it has been shown that stroke rate/stroke length combinations change with increasing velocity, and that swimmers reach maximum velocity by increasing stroke rate and decreasing stroke length, while lactate concentration increased (Costill et al., 1992; Craig & Pendergast, 1979; Keskinen & Komi, 1993). Indeed, although the decline in stroke length throughout the experimental protocol could be explained by the progressive accumulation of fatigue during the last steps – Dekerle et al. (2005) observed the existence of a biomechanical boundary well related to the intensity corresponding to the anaerobic threshold beyond which stroke length becomes compromised – it seems natural that these 10- to 11-year-old age-group swimmers achieved high swimming velocities through the increment of stroke rate.

We cannot not deny the possibility of the use of a "freely chosen stroke rate" by each swimmer (Swaine & Reilly, 1983), which means that the combination of stroke rate and stroke length in producing swimming velocity has great variability, which implies a highly individual process (Chollet et al., 1996; Keskinen & Komi, 1993; Pelayo et al., 1996). In fact, it was observed that swimmers tend to increase their swimming efficiency after the second step – after the anaerobic threshold – which suggests that they were able to increase their velocity without losing their effective swimming technique.

Conclusion

In line with the literature for older, aerobically trained swimmers, $v4$ (and $v3.5$) seems not to represent the individual anaerobic threshold in children involved in competitive swimming. Thus, independent of the swimmer's age, a 200-m intermittent incremental protocol, with the later determination of the precise point of the rise in lactate concentration, seems to be advised for assessment of individual anaerobic threshold. Moreover, as expected, swimmers aged 10–11 years increased their swimming velocity by raising stroke rate in detriment of stroke length. Thus, given the importance of developing swimming technique in age-group swimmers, coaches should implement the lengthening of swimmers' stroke cycles in their training practice routines, so that they limit the effects of reduced stroke length when velocity increases. The individualization of training and testing methodologies is also important to implement in age-group swimmers.

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