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Sports Science

200-m front crawl performance over a training season in 12 years and underage-group swimmers: growth and kinematics effects

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Abstract - Aims: analyze kinematics, anthropometrics, and maturation during a training season in 12 y and underage-group swimmers, quantifying changes and estimating their contributions to the 200-m maximal front crawl time trial test (T200) (time trial/fixed distance), as an event representative of the swimming performance. **Methods:** Nineteen age-group swimmers (11 girls and 8 boys; age 10.0 ± 1.3 y and 10.6 ± 1.0 y) performed a T200 four times during the training season. Changes in kinematic and anthropometric variables throughout the season were calculated. We applied generalized estimating equations to compare the variables over the four experimental tests. Multiple linear regressions were applied to identify the most influential variables and the relative contribution of anthropometrics and kinematics to swimming performance of T200 at baseline (pre-season) and after (using delta values) each macrocycle. **Results:** Large improvements (d = 1.76) were observed in the T200's performance (from 85.5 ± 38.2 at pre-season to 175.2 ± 50.1 FINA points at the end season). A gender effect was not identified. Stroke rate, stroke length, and stroke index explained, respectively 59, 23, and 17% of the T200 performance changes along the season ($R^2 = 0.81$; $F = 26.9$; $p < 0.001$; Durbin-Watson: 1.5). Anthropometric was not related to performance changes, with kinematic being the most determinant factor. **Conclusion:** Kinematical approaches must be carefully considered by coaches when planning 12 y and underage-group swimmers training programs.

Keywords: exercise, swimming, kinematics, anthropometrics, longitudinal analysis.

Introduction

Swimming performance is influenced by kinematics, energetics, anthropometrics, puberty, and other related factors[1,2]. The integrated analysis of these variables provides important insights for coaches when trying to understand swimming performance over a training period[3]. Therefore, longitudinal data on swimmers' training are required since conclusive information on the relationships between swimming determinant factors and performance cannot be provided by cross-sectional swimming-related studies[3,4].

Swimming is one of the mainly practiced sports at early ages[5], which highlights the importance of verifying possible physiological and biomechanical effects of swimming training over a season[6]. It is important to quantify and analyze fluctuations of these sports performance-related variables during the training process, particularly in swimmers at so sensitive age (childhood's end and onset of adolescence)[7,8]. When training prepubescent swimmers, coaches should be aware that few fluctuations at any variable can lead to positive responses in a short-term period, because of their trainability[7,9]. These issues should be carefully considered since coaches´ interventions aim to achieve the best long-term result. It is suggested that each fitness component has its optimal moment to be manipulated, as seen in the "Youth Physical Development" (YPD) model as a "window of opportunity"[7].

Movement and sport-specific skills should always be present throughout childhood and adolescence, but the importance placed on each one differs according to the maturation stage[7]. However, regarding sport-specific skills, such knowledge needs to be more investigated within each sport, such as hierarchy and the correct handling of each biomechanical variable in sensitive periods. There are several variables related to swimming kinematics, but their true influence at each moment of swimming development at early ages is little studied[4,10,11]. Besides, since anthropometric characteristics fluctuations over time can influence swimming technique, and hence, kinematics and performance, it is important to monitor growth and other maturational aspects[12]. Identifying the swimmers' biological age provides base information for long-term athletic development[7,13]. The non-invasive model proposed by Mirwald et al.[14], by using the peak height velocity (PHV) as a reference point for maturation status[13,14] is a practical solution for this issue. Biological maturation is often discussed in terms of status and timing[16], where "status" refers to a maturation level in a specific period, and "timing" refers to chronological age at such maturation "status". In this regard, PHV is an important variable for maturation status assessment, indicating a natural process of growth in which the individual reaches a high gain in stature[15]. To indicate not only maturity status but also maturation timing[14] the non-invasive method has been used for monitoring the young athlete's development, to estimate age at PHV, as well years before and after PHV[7,16].

Since both metabolic power and energy cost affect maximal swimming speed (v)[2], it is important to understand young swimmers' development by tracking kinematical fluctuations. It is well reported that the 400-m maximal front crawl time trial test (T400) is valid for aerobic capacity and power assessments in swimming[17]. However, the time to complete T400 is longer for children and other populations[18]. Regarding kinematics, changes in performance are influenced by stroke rate (SR), stroke length (SL), v, and stroke index (SI, an indirect measure of efficiency)[19], typically used to assess a swimmer's technical development.

It is important to highlight that coaches' job at early ages lies with the 'onset' of long-term athlete development (LTAD) project of a professional athlete[20,21]. Considering the need for longitudinal data to better understand the relationships between performance and growth-related aspects in age-group swimmers, particularly at an early ages[5,22], this study aimed to analyze kinematics, anthropometrics, and maturation during a training season in 12 y and under age-group swimmers, quantifying changes and estimate their contributions to the swimming performance of the 200-m front crawl test, as an event representative of the swimming performance. Additionally, possible differences between boys and girls were analyzed.

Methods

This research was duly approved by the Institutional Review Board of Universidade Federal do Rio Grande do Sul (UFRGS), under the number 20416119.5.0000.5347. The study design is experimental with four tests in a single-center setting.

Participants

Nineteen swimmers, 11 girls (10.0 ± 1.3 y) and 8 boys (10.6 ± 1.0 y), all inserted in competitive swimming, volunteered to take part in the current study. Each athlete and his or her legal guardian signed a written informed consent before participating. The participants used to swim 3 to 5 times per week, 1.000 to 2.000 m per session and were involved in a swimming training program for at least six months. All swimmers were evaluated four times during the training season. The first data collection (pre-season) was conducted during the first week of the training season. The second data collection was conducted 11 weeks later, at the end of the first macrocycle training (1st macro - 1M). The third data collection was conducted at the end of the second macrocycle (2nd macro - 2M), 37 weeks after pre-season. Finally, the last data collection was conducted 47 weeks after pre-season, at the end of the last macrocycle of the season (3rd macro - 3M). Data from 1M, 2M, and 3M were collected from 24 to 48 h after a competition. The macrocycles correspond to the preparation period for the most important competitions of the season for swimmers. The competitions occurred at the end of each macrocycle, without vacation (off-season) during the study process.

Anthropometrics and maturation status

Height (HE), arm span (AS), total body mass (BM), sitting height (SH), and leg length (LL) were measured in all experimental tests[23]. Maturity-offset equations[14] were applied through anthropometric data and age. Maturity-offset equations are sex-specific, considering biological significance and statistics to predict maturity, and indicate in years how far the subject is approaching or moving away (if has passed already) from PHV. The equations for boys (Equation 1) and girls (Equation 2) are:

$$\mathrm{BMO} = \{-9,236 + [0,0002708*(\mathrm{LL}*\mathrm{SH})] - [0,001663*(\mathrm{A}*\mathrm{LL})] + [0,007216*(\mathrm{A}*\mathrm{SH}) + \{0,02292*[(\mathrm{BM}/\mathrm{HE})*100]\} \quad (1)$$

$$\mathrm{GMO} = \{-9,376 + [0,0001882*(\mathrm{LL}*\mathrm{SH})] + [0,0022*(\mathrm{A}*\mathrm{LL})] + [0,005847(*(\mathrm{A}*\mathrm{SH})] - [0,002658*(\mathrm{A}*\mathrm{BM})] + \{0,07693*[(\mathrm{BM}/\mathrm{HE})*100]\} \quad (2)$$

where BMO and GMO are, respectively, boys' and girls' maturity-offset; LL is leg length; SH is sitting height; A is age; BM is body mass and HE is height[14]. Maturity-offset indicates whether a boy or a girl is close or not to the PHV. With BMO and GMO data, any negative result is defined as pre-PHV (maturity-offset < 0) and any positive are post-PHV (maturity-offset > 0). The maturity-offset = 0 suggests the onset of PHV.

Performance and kinematics

Each swimmer performed four 200-m maximal front crawl time trial tests (T200) in a 25 m open swimming pool, with water and air temperature at ~26 °C and ~28 °C, respectively. Performance of T200 was converted to FINA (*Fédération Internationale de Natation*) points (http://swimjournal.free.fr/?Corpus=FinaCalculator). Kinematics data were obtained from the 10 m of the middle of the pool of the last 25-m of each 50-m interval (within 2 points at 7.5 m from each end of the swimming pool, marked with cones, to exclude the influence of the turning phase)[24]. The performance of T200 and time (s) to swim the 10 m and to perform three consecutive upper limbs stroke cycles were collected manually[19] with stopwatches (CASIO HS-70w, Japan). Thus, the kinematics variables were calculated with the Equations (3), (4), (5), and (6), respectively, swimming speed (m.s^{-1}), stroke rate (cycles. min^{-1}), stroke length (m), and stroke index (m^2.s^{-1}):

$$v = \frac{10\text{ m}}{\text{time}} \tag{3}$$

$$SR = \left(\frac{3\text{ cycles}}{\text{times}}\right)\cdot 60 \tag{4}$$

$$SL = \frac{v}{SR} \tag{5}$$

$$SI = v\cdot SL \tag{6}$$

Then, mean values were calculated from the four 50-m intervals.

Training load control

The previous training loads, relative to each evaluation, were calculated over the two weeks prior to each experimental test using standard methodologies[25]. Swimming and dryland training were categorized by using a five-training zone system[26]. Swimming distance values were multiplied by the intensity factor and then totaled[25]. The magnitude of the load was expressed in arbitrary training units (T.U.) and quantified from the sum of swimming volumes in each of the five training zones, multiplied by the respective intensity factor, and then totaled[25,26]. Progression of training was monitored[27]. Figure 1 summarizes the training volume per week, the arbitrary training loads over two weeks prior to each test, and the evaluation moments.

Statistical analyses

The Shapiro-Wilk test of normality was applied. Then mean, standard deviation (SD), and 95% confidence limits were calculated. The percentage changes (Δ%) of HE, AS, BM, performance, SR, SL, and SI throughout the season were calculated assuming the immediately preceding one as 100%. Additionally, the total variation between the first and the last assessment was calculated. Generalized Estimating Equations (evaluation moments as factor and gender as covariant) were used to compare the variables over the four experimental tests. Post-Hoc (Bonferroni) was used to identify pairwise differences. The intraclass correlation coefficient was calculated for all longitudinal data. Effect size (ES) was calculated with both, eta squared (η^2) and Cohen's *d*[28,29] and categorized (η^2) as small ($\eta^2 \geq 0.01$), medium ($\eta^2 \geq 0.06$) or large ($\eta^2 \geq 0.14$). Cohen's *d* was interpreted with the following criteria: 0-0.19 trivial, 0.2-0.59 small, 0.6-1.19 moderate, 1.2-1.99 large, 2.0-3.99 very large, and > 4.0 nearly perfect[28,29].

Multiple linear regressions ("Enter" method) were applied to identify the most influential variables and the relative contribution of anthropometrics and kinematics to swimming performance of T200 at baseline (pre-season) and after (using delta values) each macrocycle. In a first attempt, all independent variables (anthropometrics and kinematics) were tested together at each testing moment, but no anthropometric variable was statistically related to performance. Therefore, two multiple linear regression models were applied in the pre-season: (i) T200 performance as the dependent variable with BM, AS, and HE as independent variables; and (ii) T200 performance as the dependent variable with SR, SL, and SI as independent variables. Along the season, multiple linear regressions were applied independently: (i) Δ% of performance as the dependent variable with Δ% of HE, AS, and BM as independent variables; and (ii) Δ% of performance as the dependent variable with Δ% of SR, SL, and SI as independent variables. Adjusted R^2, Durbin-Watson value, standardized β coefficient, standardized β coefficient in %, and the partial r correlations were identified. These regression analyses were not intended to predict T200 performance, but to determine the importance of anthropometrics and kinematics performance-related variables during each period of the competitive season[30]. Alpha of 5% was considered significant. The Statistical Package for the Social Sciences (SPSS) 22.0 was used in statistical analyzes.

Results

FINA points and training load control

Participants improved their FINA points along the season (see Table 1). The mean volume (km•week^{-1}) and training load (T.U.•week^{-1}) in the two weeks before each assessment over the season were, respectively (Figure 1) 2.4 ± 1.7 km and 7.4 ± 1.7 T.U. for 1M; 1.2 ± 0.5 km and 4.6 ± 2.1 T.U. for 2M; and 1.6 ± 0.2 km and 5.5 ± 1.2 T.U. for 3M. Progression of volume (km•week^{-1}) and training load (T.U.•week^{-1}) in the 2 weeks prior to each assessment of each macrocycle were, respectively: 1M (~−27 and ~−34), 2M (~0 and ~−20), and 3M (~−26 and ~−34).

Table 1 - T200 FINA points, kinematics, anthropometric variable, changes (Δ), and statistical results over the training season.

Variables	Statistics		Pre-season (start)	1st macro (11 weeks after PS)		2nd macro (37 weeks after PS)		3rd macro (47 weeks after PS)		Overall Δ
	P	η^2	Mean ± SD	Mean ± SD	Δ (%) PS vs. 1M	Mean ± SD	Δ (%) 1M vs. 2M	Mean ± SD	Δ (%) 2M vs. 3M	Δ (%) PS vs. 3M
FINA points	0.003	0.78	85.5 ± 38.28	110.0±34.88	42.3	152.1±44.98	46.2	175.2 ± 50.18	16.1	154.7
v ($m{\cdot}s^{-1}$)	0.010	0.81	0.76 ± 0.11*	0.85 ± 0.09*	13.0	0.96 ± 0.09*	13.3	1.01 ± 0.1*	5.7	36.0
SR (cycles·min^{-1})	0.011	0.26	36.6 ± 6.0∂	39.6 ± 4.8	10.9	37.8 ± 4.2*	-4.0	40.8 ± 4.2∂*	8.5	14.6
SL (m)	< 0.001	0.59	1.21 ± 0.17ʃ ⌐	1.29 ± 0.19ʃ ⌐	4.9	1.52 ± 0.17ʃ	19.3	1.49 ± 0.18⌐	-2.2	20.4
SI ($m^2{\cdot}s^{-1}$)	< 0.001	0.79	0.95±0.21∂	1.11 ± 0.25∂¥	19.2	1.47 ± 0.27∂¥	35.5	1.52 ± 0.30∂¥	3.5	64.5
BM (kg)	< 0.001	0.74	37.0 ± 8.3*	38.1 ± 8.3*	3.1	40.5 ±8.5*	6.6	41.4 ± 8.5*	2.3	12.5
HE (cm)	< 0.001	0.83	142.3 ± 9.7*	143.8 ± 9.8*	1.0	146.6 ± 9.6*	1.9	147.8 ± 9.5*	0.8	3.8
AS (cm)	< 0.001	0.86	143.6 ±10.4*	145.9 ±10.7*	1.5	149.5 ± 11.5*	2.4	150.8 ± 11.3*	0.8	5.0

v: swimming speed; SR: stroke rate; SL: stroke length; SI: stroke index; MO: maturity-offset; BM: total body mass; HE: height; AS: upper arms span.
*differences along the four assessments ($p < 0.05$); ∂ difference between PS and 1M, PS and 2M or PS and 3M ($p < 0.05$); ¥ difference between 1M and 2M or 1M and 3M ($p < 0.05$).
†difference between 2M and 3M ($p < 0.05$); ʃ difference between PS, 1M and 2M ($p < 0.05$); ⌐ difference between PS, 1M and 3M ($p < 0.05$).PS: pre-season.1M: Macrocycle 1.2M: Macrocycle 2.3M: Macrocycle 3.

Changes in performance and kinematics

Performance has improved along the four assessments ($F = 30.0$; $p < 0.001$, $\eta^2 = 0.63$). There was no interaction between gender and moment of assessment ($p > 0.05$) and no difference between girls and boys in performance ($p > 0.05$). In PS, 1M, 2M and 3M assessments, T200's performances for girls and boys (mean and limits of confidence) were, respectively, 258.1 s (225.4-290.8) vs 244.1 s (204.5-283.6) at PS; 240.0 s (215.9-264.1) vs 207.8 (191.3-224.3) at 1M; 210.5 s (194.2-226.8) vs 189.5 (175.4-203.6) at 2M, and 200.8 s (187.1-214.6) vs 180.4 (164.9-195.9) at 3M (see Figure 2).

The kinematics variables are in Table 1. The *v* increased 13.0 ± 10.9% from PS to 1M, 13.3 ± 7.8% from 1M to 2M and 5.7 ± 5.3% from 2M to 3M, and 36.0 ± 22.4% from PS to 3M (overall improvement). The SR increased from PS to 1M (10.9 ± 20.9%) but decreased from 1M to 2M (−4.0 ± 11.6%) and increased again at the end of the season (2M to 3M;8.5 ± 7.8%). Similar fluctuations were observed for SL (see Table 1). SI increased from PS to 1M (19.2 % ± 26.9) and from 1M to 2M (35.5 % ± 20.3), with a trivial increase from 2M to 3M (3.5 % ± 9.8) and an overall improvement (PS to 3M) of 64.5 % ± 39.6. The ICC, the mean differences, and the Cohen's d results are shown in Table 2.

Anthropometrics and maturation status

As maturity-offset (MO) was not a significant covariable ($p < 0.05$), all the variables were grouped independently of gender and are shown in Table 1. Regarding the anthropometrics results (Table 1), BM, HE, and AS increased over the season. From PS to 3M, BM increased by 12.5 ± 6.5%, HE increased by 3.8 ± 1.3%, and AS increased by 5.0 ± 1.7%. In the MO results (Figure 3), all boys were still pre-PHV along all four assessments. However, two girls have had their peak in the PS assessment. Changes for MO along all the four assessments were observed for both girls and boys (girls: $F = 378.0$; $p < 0.001$; $\eta^2 = 0.97$; boys: $F = 74.3$; $p < 0.001$; $\eta^2 = 0.91$).

Multiple linear regressions

Along the assessments, no significant linear regression model was identified when BM, HE, and AS (absolute or Δ%) were the independent variables and T200 (s) or Δ% were the dependent variables. However, significant regressions were identified when SR, SL, and SI (absolute in pre-season and Δ% along the season) were implemented as independent variables with T200 (s) and Δ% as the dependent variable.

The results corresponding to the linear regressions (R^2, F, and p values; and Durbin-Watson analyses), standardized β coefficient, standardized β coefficient in %, and the partial *r* correlations are presented in Table 3. The per-

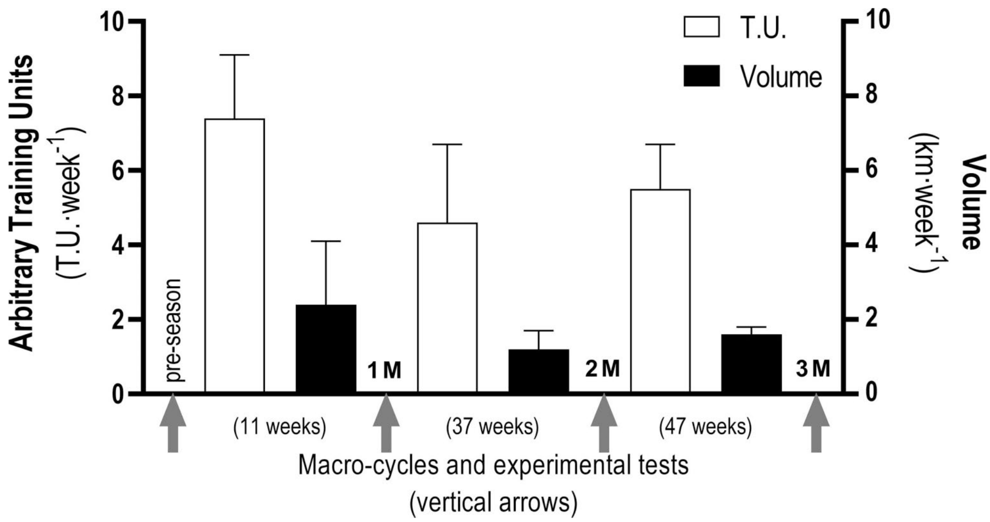

Figure 1 - Training load (T.U.●week^{-1}) and volume (km●week^{-1}) over the last 2-weeks prior to each data collection.

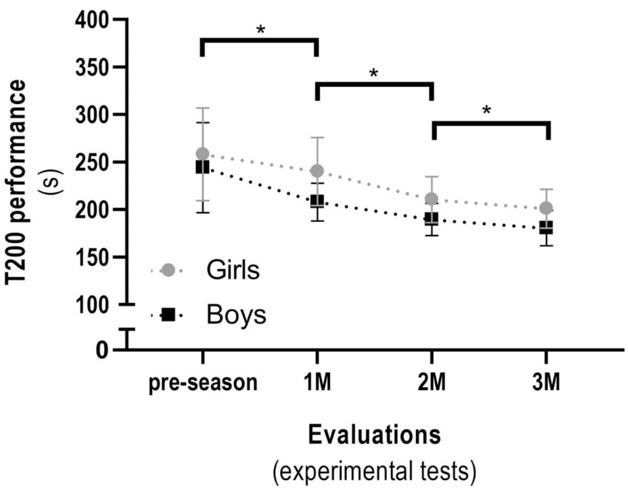

Figure 2 - T200 performance (s) for girls and boys at each evaluation; * $p < 0.05$; n = 11 girls and 8 boys.

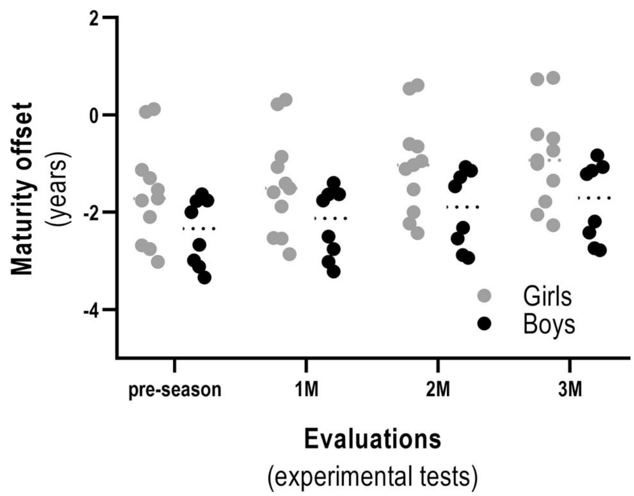

Figure 3 - Maturity offset for girls and boys at baseline (pre-season) and each macrocycle.

centage of SR changes over the season for the performance decreased from 51.4% to 9.6%, but between pre-season to 3M, SR contribution was 59%. The contribution of the SL change to performance was between 29.3 and 48.9% at each assessment. The contribution of SL between pre-season and 3M was 23.6%. The SI changes, throughout the season, contributed between 7.6 and 46.1%, to the performance change. Between pre-season and 3M, the SI contribution to the performance's change was 17.4%.

Discussion

This study aimed to analyze kinematics, anthropometrics, and maturation during training season in 12 y and underage-group swimmers and estimate their contributions (kinematics and anthropometrics) to their swimming performance in the T200. No gender effects were detected for performance (Figure 3), which was also observed by Morais et al.[8] in ~11 years old. Thus, male, and female swimmers were pooled and analyzed as a single group. Performance improved over the 47 weeks (Table 2), something that was expected since they are at a sensitive age to the training process[4,7]. Both kinematics and anthropometric variables changed along the season (Table 1), but only kinematics presented a positive correlation with performance. Maturity-offset has changed to values closer to the PHV during the training season.

Training loads and volumes are adjusted by the coaches in accordingly to the dates of the main competitions, thus exploring the swimmer's best conditions in the season[3]. In fact, their performance can be affected by volume and load depending on the training period[24]. The two weeks before each evaluation (in which volume and

Table 2 - Intraclass correlation coefficient (ICC), differences between evaluations and respective Cohen's d in performance, swimming velocity (v), stroke rate (SR), stroke length (SL), stroke index (SI), body mass (BM), height (HE) and arm span (AS).

	ICC (p-value)	Mean diff ± SD	Cohen's *d*	Mean diff ± SD	Cohen's *d*	Mean diff ± SD	Cohen's *d*	Mean diff ± SD	Cohen's *d*
		PS to 1M		1M to 2M		2M to 3M		PS to 3M	
Performance (s)	0.86 (<0.001)	25.72 ± 5.5	0.64 moderate	24.7 ± 22.7	0.89 moderate	9.4 ± 7.2	0.40 small	59.9 ± 42.6	1.76 large
v ($m \cdot s^{-1}$)	0.78 (<0.001)	−0.09 ± 0.07	0.90 moderate	−0.10 ± 0.05	1.22 large	−0.05 ± 0.05	0.52 small	−0.25 ± 0.11	2.38 very large
SR ($cycles \cdot min^{-1}$)	0.77 (<0.001)	−3.06 ± 6.0	0.55 small	−1.92 ± 4.2	0.40 small	−3.12 ± 2.4	0.71 moderate	−4.2 ± 6.0	0.66 moderate
SL (m)	0.70 (<0.001)	−0.04 ± 0.2	0.22 small	−0.23 ± 0.14	1.27 large	−0.03 ± 0.1	0.17 trivial	−0.24 ± 0.17	1.37 large
SI ($m^2 \cdot s^{-1}$)	0.91 (<0.001)	−0.15 ± 0.2	0.65 moderate	−0.36 ± 0.1	1.38 large	−0.05 ± 0.1	0.17 trivial	−0.56 ± 0.24	2.11 very large
BM (kg)	0.99 (<0.001)	−1.1 ± 0.9	0.13 trivial	−2.4 ± 1.9	0.28 small	−0.9 ± 0.9	0.10 trivial	−4.4 ± 2.1	0.52 small
HE (cm)	1.00 (<0.001)	−1.4 ± 0.8	0.10 trivial	−2.7 ± 1.4	0.30 small	−1.2 ± 0.7	0.10 trivial	−5.4 ± 1.8	0.52 small
AS (cm)	1.00 (<0.001)	−2.2 ± 1.5	0.20 small	−3.6 ± 1.7	0.38 small	−1.3 ± 1.2	0.09 trivial	−7.2 ± 2.5	0.63 moderate

v: swimming speed; SR: stroke rate; SL: stroke length; SI: stroke index; MO: maturity-offset; BM: total body mass; HE: height; AS: upper arms span.PS: pre-season.1M: Macrocycle 1.2M: Macrocycle 2.3M: Macrocycle 3.

Table 3 - The R^2 (F-test; p-value, and Durbin-Watson - DW results), beta coefficients (β), absolute and relative, identifying the importance of each factor in the performance of the 200-m test in front crawl (T200) at PS and when using relative changes (Δ) after 1M, 2M, 3M, and from PS to 3M; and r partial correlations of the significant multiple linear regressions; n = 20.

	PS $R^2 = 0.78$ (F = 22.9; p< 0.001; DW = 2.0)			PS to 1M $R^2 = 0.51$ (F = 7.43; p = 0.003; DW = 1.85)			1M to 2M $R^2 = 0.74$ (F = 18.5; p< 0.001; DW = 2.3)			2M to 3M $R^2 = 0.59$ (F = 9.78; p = 0.001; DW = 1.85)			PS to 3M $R^2 = 0.81$ (F = 26.9; p< 0.001; DW = 1.5)		
	B Coeff	% β Coeff	Part *r*	B Coeff	% β Coeff	Part *r*	β Coeff	% β Coeff	Part *r*	B Coeff	% β Coeff	Part *r*	B Coeff	% β Coeff	Part *r*
SR ($cycles \cdot min^{-1}$)	−1.15	51.4	−0.50	0.23	5.0	0.07	2.02	16.7	0.46	−0.19	9.6	−0.02	−0,85	59.0	−0.35
SL (m)	−0.92	41.0	−0.27	2.24	48.9	0.34	5.64	46.6	0.59	0.58	29.3	0.04	−0,34	23.6	−0.11
SI ($m^2 \cdot s^{-1}$)	0.17	7.6	0.06	−2.11	46.1	−0.45	−4.45	36.7	−0.66	−1.21	61.1	−0.12	−0,25	17.4	−0.09

v: swimming speed; SR: stroke rate; SL: stroke length; SI: stroke index; MO: maturity-offset; BM: total body mass; HE: height; AS: upper arms span.PS: pre-season.1M: Macrocycle 1.2M: Macrocycle 2.3M: Macrocycle 3.

training load were calculated in T.U.•week^{-1}) were in a competition period, the "taper phase", which contains more pace-specific exercises and reduced volume[24,31]. Reducing values while approaching a competition explains the negative progression of volume and T.U. from two weeks before the assessments[32]. However, the workloads and volume were obtained only for the 2 weeks before each evaluation moment, explained by the restricted access given by the coaches. The 1st macro (1M) assessment occurred after one of the first meetings of the year, not after the main competitions of the season, which can explain the higher volume and T.U. in this assessment. Despite that, the previous two weeks of 1M also showed a reduction in volume and T.U., which was related to the "taper"[31]. In contrast, the 3rd macro assessment took place after the last meeting of the year. Then, the volume and T.U. values were reduced to achieve the best results in the competition. Thus, higher training volume and T.U. before 1M are related to the preparatory period, which usually occurs at the beginning of the season. This preparatory period is linked to the return from summer break and contains more high-volume training[24].

Changes in performance and kinematics

Performance (in FINA points) has improved (≅154%) along the four assessments, but we observed only partial correlations with kinematics. Swimming techniques can be developed through training and coaching instructions[19,24]. Changes in anthropometric variables can affect technique, kinematics[11] and hence performance[5]. In fact, there is a consensus that performance tends to improve in longitudinal studies[5,11,32] independently of the group (when it comes to young swimmers), tests, and methodologies. Considering the influence of kinematics over performance, it is acceptable to assume that changes observed in v are related to the training program ($\Delta\% = 36.0 \pm 22.4$; very large ES) (Tables 1 and 2). Morais et al.[4] observed that v at 100-m front crawl test increased after 38 weeks, in similar age-group swimmers. Swimming performance tends to improve in the same way as v, but it can improve even due to technique improvements in starts and turns.

Moderate increases in SR were observed from 2M to 3M ($\Delta\% = 8.5 \pm 7.8$) and from PS to 3M ($\Delta\% = 14.6 \pm 21.7$). Similar results (14% after 16 weeks) were verified for ∼15 years old swimmers in a 400-m front crawl test[25]. Despite that, Zacca et al.[24] suggest that technique is the main contributor to swimming performance in young swimmers during a training macrocycle, with SR showing a greater correlation with changes in performance. In our study, SR showed the same behavior (Table 3) Considering that v is the product of SR and SL, increasing SR is a manner to achieve higher v values and consequently improves performance[33]. However, this relationship behavior between SR and performance is more common for short distance races[34]. For a 4 x 50 m front crawl maximum velocity test, a predominant anaerobic event, 14-16 years old swimmers increased their SR to improve performance, perhaps due to the training stimulus characteristics[35]. However, it is not clear if this relationship can be applied to young swimmers since pre-pubertal athletes do not have their anaerobic system completely developed[36,37]. Young swimmers achieve higher v by increasing both SL and SR, but with more emphasis on SR[38]. Thus, younger swimmers use SR as a tool to reach higher v for different reasons, such as anthropometrics. As they grow, SL seems to improve more than SR[11].

Likewise, the highest change in SL (Δ%) was from 1M to 2M. Previous studies also showed improvements in SL[10] after 11 weeks of swimming training. In a longitudinal study of 28 weeks, Dias, Marques, and Marinho[5] suggested that SL should be improved to enhance the performance of 25 and 50 m (T25 and T50) in ∼15 years old swimmers. The relevance of SL over kinematics changes to reach better performance can be observed in Table 3. The relationship between SL and swimming level was verified for this age-group swimmers, with higher-level swimmers reaching higher values for SL than lower-level swimmers[8]. This is in line with the improvements over the season (Table 1) and ICC (Table 2) in our study. However, SL remained similar for T400 during the first macrocycle (16 weeks) of the training season in other study[24], but it is important to consider the event characteristics (T400) and the older age of the participants (15 y).

The SI is an indirect indicator of swimming efficiency[2,24]. This index is described by some authors as the best contributor to improvements in performance for ∼11 years old swimmers in T25[8], for ∼15 years old swimmers in T400[10,24], and 12-14 years female swimmers for 2 years of study[22]. When applying the maximum anaerobic test (4x50 m) before and after 12 weeks, 14-16 years old swimmers were able to improve SI both when they were rested (the first lap), and also at the end of the test, with a high level of fatigue. This is evidence of improvements in technique[35]. In our study, SI increased along the four assessments, showing a high correlation with performance, especially after 1M (Table 3, 1M-2M $\beta = -4.45$ and partial $r = -0.66$).

The relationships between the kinematic variables' changes and performance improvements can be justified by the training periodization[24]. When the coaches' methodology is characterized by higher aerobic volumes, the relationship between SL and performance is more evident in longer distances. The T25 may not show improvements in SL due to its nature (short event), which requires a high SR to achieve high v. If swimmers do not emphasize fast events in training sessions, they will not have an acute improvement when SR increases[33]. During the preparatory period (typically characterized by higher training volumes), swimmers appear to improve their performance by increasing SL[39]. During a specific phase (typically characterized by increased training intensity), the contribution of SR is better related to changes in performance[10], which is in line with our results (Table 3).

Changes in anthropometrics and maturation status

Anthropometrics results suggest that swimmers have grown over time (Table 1 and Table 2). However, no associations were observed between performance and the HE, AS, and BM. Anthropometrics could affect performance indirectly, through changes in kinematics[8,22], but still, this correlation was not observed in our study. Despite that, swimmers with the largest body dimensions (BM, HE, and AS) were the ones with the best performances in the T200 (Table 2). 17 of the 19 swimmers did not reach PHV throughout the year (Figure 3), suggesting that the training process presented more influence on performance than growth.

Practical applications

We are aware that swimming technique is paramount for young swimmers' development. In fact, we observed high contributions of SR, SL, and SI. For this age-group swimmers, small changes in these variables resulted in improvements in overall performance. Since growth is related to increases in SL[22], not only technical approaches in a training program may determine SL as the main contributor to increases in v[3]. Thus, coaches should be careful not to allow SR to decline when seeking to improve SL. Therefore, it is important to connect the coaches' goals and periodization with the test chosen. The T200 seems to be a sensitive tool for long-term performance analyses for 12 y and underage-group swimmers.

It is important to acknowledge some of the shortcomings and potential limitations in our study. Firstly, all assessments except for the first could only be performed after a competition, so the swimmers may possibly be tired and have compromised motivation. Despite that, all evaluations were performed in the same context. Also, volume and workload were obtained only for the 2 weeks prior to each evaluation moment due to the restricted access given by the coaches. We are aware that physiological assessments, together with kinematics and anthropometrics, could improve the knowledge of swimming performance at so early age. Finally, although one training season follow-up provides valuable information, it would certainly be better if there were more training seasons. Despite that, it's common to notice the abandonment of young swimmers over training seasons.

Conclusion

Longitudinal data for 12 y and underage-group competitive swimmers demonstrated that, for 200-meter front crawl, kinematics were the most determinant factor for performance improvements when compared to maturity and anthropometrics. Anthropometrics also changed along the season, but only two individuals reached PHV. This phenomenon may increase the association between growth and performance. Thus, technical approaches must be carefully considered in coaches' training programs for 12 y and underage-group swimmers when working to develop future elite athletes.

Declarations of interest

None.

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