LONGITUDINAL ASSESSMENT OF YOUNG SWIMMERS' PERFORMANCE AND ITS PREDICTORS

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The purpose of this study was to develop a performance predictor model based on biomechanics. Ninety-one swimmers (44 boys and 47 girls) were evaluated. The decimal age, anthropometrics, kinematics and efficiency parameters were collected in ten different moments over three seasons. Hierarchical linear modeling was the procedure selected to estimate the performance predictors. The decimal age (Estimate: -2.05; $P < 0.001$), arm span (Estimate: -0.59; $P < 0.001$), stroke length (Estimate: 3.82; $P = 0.002$) and propelling efficiency (Estimate: -0.17; $P = 0.001$) entered the final model. The decimal age, arm span, stroke length and propelling efficiency were the main predictors. Longitudinal assessments seems to be the best way to have a deeper knowledge on how performance main determinants act and affect the performance.

KEY WORDS: anthropometrics, kinematics, efficiency, predictors, swimming, performance.

INTRODUCTION: Young swimmers' research is done mainly based on cross-sectional designs (Silva et al., 2013; Strzala et al., 2013). However, new trends in swimming research suggest that the best way to gather insight on performance and its main determinants is selecting longitudinal designs (Morais et al., 2014). As mature and growth processes are inherent to any children, young swimmers may present variances in their performance and main determinants, that may influence the former one. Likewise, biomechanical factors seem to play a major role on the performance enhancement in young swimmers (Barbosa et al., 2010). For example, literature reports height (H) and arm span (AS) as the most informative variables in the anthropometrics domain (Jürimäe et al., 2007). Regarding stroke mechanics, swimming velocity (v) and stroke frequency (SF) were correlated with performance (Barbosa et al., 2010). Therefore, the variables selected are related to the anthropometrics, kinematics and efficiency since these features are strongly related or associated to young swimmers' performance.
The purpose of this study was to develop a performance predictor model based on biomechanics.

METHODS: Ninety one young swimmers (44 boys and 47 girls) participating on regular basis at regional and national competitions were evaluated during 3 years. At the baseline, boys had 12.04±0.81 years-old and girls 11.22±0.98 years-old, and they had 3.18±0.62 years of training experience.
Coaches, parents and/or guardians and the swimmers gave the informed consent to participate on this study. All procedures were in accordance to the Helsinki Declaration regarding Human research.
Repeated measures of anthropometrics, kinematics and efficiency parameters over ten different moments, along three years were performed. The 100-m freestyle event was selected as the main outcome (official race time at regional or national short course meter event).
The swimmers were invited to perform three maximal freestyle swim trials of 25-m with push-off start. Between each trial, they had a 30 minutes rest to ensure a full recovery. For further

analysis the average value of the three trials was calculated. Kinematic data was collected with a mechanical technique (Swim speedo-meter, Swimsportec, Hildesheim, Germany). A 12-bit resolution acquisition card (USB-6008, National Instruments, Austin, Texas, USA) transferred data (f = 50Hz) to a software customized by our group (LabVIEW® interface, v.2009) (Barbosa et al., 2013). The swimming speed (v) was calculated as v=d/t in the middle 15-m. Two experts evaluators measured the stroke frequency (SF) with a stroke counter (base 3) and then converted to SI units (Hz). The stroke length (SL) was calculated as SL=v/SF (Craig and Pendergast, 1979). The intra-cyclic speed fluctuation (dv) was calculated as dv=CV=standard deviation/mean (Barbosa et al., 2013).
The stroke index (SI) was calculated as SI=v·SL (Costil et al., 1985). The propelling efficiency (η_p) was estimated inputting the v, SF and the distance between the shoulder and the tip of the 3rd finger during the insweep (Zamparo et al., 2005).
All anthropometric measurements were carried-out in a regular textile swimsuit, wearing cap and goggles. The body mass (BM) was measured with the swimmers in the upright position with a digital scale (SECA, 884, Hamburg, Germany). The H was measured in the anthropometrical position from vertex to the floor with a digital stadiometer (SECA, 242, Hamburg, Germany). The AS was measured with swimmers standing in the upright position, arms and fingers fully extended in lateral abduction at a 90º angle with the trunk. The distance between the third fingertip of each hand was measured with a flexible anthropometric tape (RossCraft, Canada).
Descriptive statistics included the mean and standard deviation. The longitudinal data analysis was performed by the hierarchical linear modeling (HLM). The decimal age, anthropometrics, kinematics and efficiency variables were tested as swimming performance predictors. The sex effect was also verified. Maximum likelihood estimation was calculated with the HLM5 software.

RESULTS: Overall all variables improved between M1 and M10 (Table 1). Boys and girls enhanced their performance and increased their body dimensions. Kinematics and efficiency presented a similar trend (i.e. improvement) in both sexes. Despite the performance enhancement was significantly higher in the boys (i.e. less 0.50s to cover the distance), a sex effect was not verified. The model's predictors of performance were: the decimal age (Estimate: -2.05; $P < 0.001$), AS (Estimate: -0.59; $P < 0.001$), SL (Estimate: 3.82; $P = 0.002$) and η_p (Estimate: -0.17; $P = 0.001$) (Table 2). The decimal age, AS and η_p had positive effects on the performance. By increasing one unit (in years) in the decimal age, performance enhanced 2.05s. For each unit (in cm) increase in AS performance improve 0.59s. Same trend for the η_p, for each unit (in %) increase the performance improve 0.17s. The SL presented an inverse relationship, where a one unit (in m) increase in the SL meaned a 3.82s decrease in the performance. The age, anthropometrics, kinematics and swim efficiency are the determinant factors responsible for the performance enhancement.

DISCUSSION: The purpose of this study was to develop a performance predictor model based on biomechanics in young swimmers. Main findings included the decimal age, AS, SL and η_p in the prection model. A sex effect was not verified.
All selected variables presented an improvement during the three year assessment (Table 1). Young swimmers, as any other children show growth and maturation processes. So as they get older, these processes lead to an increase in their body dimensions, and hence with an influence their kinematics/efficiency (Morais et al., 2013). Indeed, young swimmers' performance is highly related to anthropometrics, notably the AS (Jürimäe et al., 2007). In this case a higher AS imposed a higher performance. For each unit (in cm) increase in the AS, the performance improve 0.59s. A high AS may lead to a a higher swimming velocity and consequently in the swimmers performance. The η_p presented the same trend (i.e. a positive relationship with the performance). For each unit (in %) increase the performance improve 0.17s. Barbosa et al. (2010) showed that the η_p had a negative direct effect on the young swimmers performance (i.e. more η_p, lower performances) but for a cross-sectional study.

Present data shows that the η_p, during a long time-frame, has a positive effect/contribution to the young swimmers' performance. Contrarily, the SL had an inverse relationship with the performance (one unit increase in the SL meaned a 3.82s decrease in the performance). In oposition to their adult/elite counterparts, it might be speculated that the increase in the swimming velocity relies more in the SF increase rather than in the SL.

Overall, all main determinants increased during the evaluation time-frame, and the performance improved. This data shows that several evaluation moments help to gather a deeper insight on how young swimmers behave, enabling them to excel. The prediction model included different features, which highlights the multidimensional phenomenon that swimming is. Added to that, coaches and athletes should put the focus on the technical training, as it seems that the main features responsible for the performance enhancement at these early ages are mainly technical.

Table 1. Descriptive statistics for the anthropometrics, kinematics, efficiency and performance over time.

		M1 Mean	M2 Mean	M3 Mean	M4 Mean	M5 Mean	M6 Mean	M7 Mean	M8 Mean	M9 Mean	M10 Mean
BM	**Boys**	47.2	48.4	50.1	49.7	50.5	52.1	53.1	57.9	60.0	59.5
[kg]	**Girls**	44.9	45.5	47.2	46.0	46.9	48.2	49.0	52.7	53.8	54.0
H	**Boys**	156.9	158.8	159.7	160.3	161.6	163.5	164.6	168.6	171.0	171.7
[cm]	**Girls**	153.9	155.0	155.4	156.2	156.9	157.3	158.2	161.2	162.3	163.5
AS	**Boys**	161.4	163.6	163.8	165.3	165.4	168.0	169.4	174.9	176.5	177.4
[cm]	**Girls**	154.1	156.2	156.7	157.8	158.3	159.4	160.3	164.3	164.8	165.7
SF	**Boys**	0.83	0.86	0.88	0.88	0.88	0.91	0.90	0.87	0.88	0.90
[Hz]	**Girls**	0.82	0.82	0.80	0.82	0.82	0.80	0.81	0.78	0.81	0.82
SL	**Boys**	1.55	1.10	1.45	1.55	1.58	1.60	1.64	1.76	1.76	1.75
[m]	**Girls**	1.40	1.12	1.38	1.51	1.54	1.66	1.66	1.74	1.70	1.73
v	**Boys**	1.29	0.95	1.28	1.35	1.37	1.44	1.47	1.52	1.55	1.56
[$m \cdot s^{-1}$]	**Girls**	1.18	0.90	1.11	1.23	1.25	1.33	1.33	1.35	1.37	1.41
dv	**Boys**	0.08	0.11	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.08
[n.a.]	**Girls**	0.11	0.10	0.10	0.10	0.09	0.08	0.08	0.10	0.09	0.08
SI	**Boys**	2.06	1.07	1.90	2.11	2.18	2.35	2.43	2.68	2.74	2.74
[$m^2 \cdot s^{-1}$]	**Girls**	1.63	1.05	1.56	1.87	1.93	2.20	2.22	2.36	2.33	2.43
η_p	**Boys**	28.47	20.04	26.47	28.41	29.15	32.02	29.81	29.73	29.58	28.98
[%]	**Girls**	26.15	20.91	26.25	29.55	29.75	34.73	31.61	31.28	30.68	30.63
Perf	**Boys**	76.26	71.73	68.88	73.48	69.93	67.15	66.33	62.00	60.55	60.08
[s]	**Girls**	79.06	74.30	72.50	80.32	77.66	74.16	73.05	69.70	68.54	68.06

Table 2. Parameters of the model computed with standard errors (SE).

Parameter Fixed Effect	Estimate (SE)	P value
Decimal Age	-2.05(0.32)	<0.001
AS	-0.59(0.04)	<0.001
SL	3.82(1.22)	0.002
η_p	-0.17(0.05)	0.001

CONCLUSION: The performance and its determinant factors improved over a 3 years period. Young swimmers' performance is a multifactorial phenomenon where the arm span (anthropometrics), stroke length (kinematics) and η_p (efficiency) were the main predictors.

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Acknowledgement

Jorge Morais gratefully acknowledges the PhD scholarship granted by the Portuguese Science and Technology Foundation (FCT) (SFRH/BD/76287/2011).