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Multivariate analysis of 200-m front crawl swimming performance in young male swimmers

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The aim of the present study was to evaluate the biomechanical (stroke rate, stroke length, and stroke index), anthropometrical (body height, body mass, body mass index, arm span, shoulders width, thigh, leg and upper arm lengths), and muscle architectural (muscle thickness, pennation angle, and fascicle length) parameters as predictors of 200-m front crawl swimming performance in young male swimmers. Twenty-two county level male swimmers (mean ±SD: age: 14.52 ± 0.77 years; body height: 173 ± 5 m; body mass: 60.5 ± 5.7 kg) performed a 200-m front crawl swimming test in a 25-m pool. Stepwise regression analysis revealed that biomechanical parameters (87%) characterized best 200-m front crawl swimming performance, followed by anthropometrical (82%) and muscle architectural (72%) parameters. Also, stroke length (R^2 = 0.623), body height (R^2 = 0.541), fascicle length of Triceps Brachii (R^2 = 0.392) were the best single predictors that together explained 92% of the variability of the 200-m front crawl swimming performance in these swimmers. As a conclusion, with respect to higher performance prediction power of biomechanical parameters, technique should represent the core of the training program at these ages. In addition, these findings could be used for male young swimmers selection and talent identification.

Key words: *Stepwise regression, stroke length, anthropometry, fascicle length, front-crawl*

1. Introduction

Swimmers usually start serious training before the onset of puberty and achieve international competitive level at a relatively early age. Accordingly, it is necessary to study different parameters that might affect swimming performance in complex, taking into account various biomechanical, anthropometrical, and physiological aspects of swimming at this age [14]. This enables consideration of specific parameters when predicting success and planning specific training programs in young swimmers [18]. Based on our information, only one study has investigated the relationship between 200-m front crawl swimming performance and different parameters as predictors in young swimmers. Barbosa et al. [3] developed a path-flow analysis model for young male swimmers (age: 12.53 ± 0.53 years) performance based on biomechanical and energetic parameters, using structural equation modeling, and found that the model is appropriate to explain performance in young swimmers, and biomechanical factors were more relevant. In 10 elite swimmers (age: 21.6 ± 2.4 years), Figueiredo et al. [10] used multiple linear regression analysis to determine the relative contribution of selected biomechanical, energetic, coordinative, and muscular factors for the 200-m each of four laps (i.e., 50, 100, 150 and 200-m pace) front crawl performance prediction, and showed the relative contribution of the factors was closely related to the task constraints, especially fatigue, as the major changes occurred from the first to the last lap. Similar studies were performed on longer or shorter distances than 200-m [11], [12], [14], [16],

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[18], [22], [23], [27], [29], [33], [34]. The important point about these studies is that researchers tried to investigate new parameters and methods to increase the prediction level and achieve a deeper understanding of the swimming performance, especially if we bear in mind that only about forty out of the one hundred best swimmers in the 13–14 years old ranking will continue to rank among the one-hundred best at 17–18 years [31].

It seems that the parameters that could affect the performance of young swimmers, and could be considered as predictors of swimming performance are muscle architectural parameters such as muscle thickness, pennation angle, and especially fascicle length [24], [25]. Potentially, these parameters are influencing force–velocity relationship, improve muscle power output, and therefore enhance swimming performance [25]. In this regard, Nasirzade et al. [25] studied the relationship between muscle architectural parameters (i.e., muscle thickness, pennation angle, and fascicle length) and 25-m sprint front crawl swimming performance in young male swimmers, and reported correlations between some of these parameters. Also, Nasirzade et al. [24] examined muscle architectural with biomechanical and anthropometrical parameters to predict 50-m sprint front crawl swimming performance. Since no study examined the impact of a combination of these parameters in predicting 200-m front crawl swimming performance, the purposes of the present investigation were:

1. To investigate the relationship among biomechanical, anthropometrical, and muscle architectural parameters and 200-m front crawl swimming performance in young male swimmers;
2. To determine best combination among biomechanical, anthropometrical, and muscle architectural parameters that predicting 200-m front crawl swimming performance in young male swimmers.

2. Materials and methods

Participants: Twenty-two county level young male swimmers (age: 14.52±0.77 years) belonging to the same local swimming club, with background of 4 to 6 years of regular training experience (8.8 ± 0.9 h/week) participated in this study. All children and parents were thoroughly informed of the purposes and contents of the study and a written informed consent was obtained from the parents before participation. The study was approved by the local University Ethics Committee.

Study design: Each participant was measured on two separate days at approximately the same times of day on three different occasions. On the first day, selected anthropometrical parameters and swimming performance time were determined. Anthropometric measurements were taken before swimming test. On the second day, ultrasound images for muscle architectural parameters assessment were taken.

Measurement of biomechanical parameters: The stroking parameters in boys were assessed over maximal 200-m front crawl swimming. All swimmers performed a 400-m warm-up swim, followed by a 10 min passive resting period. Then each swimmer performed 200-m maximal front crawl trial in 25-m pool. A video camera with rate of 60 frames per second filmed the trials of each swimmer with a profile view from above the pool. Swimming velocity and stroking parameters were measured by means of time video analysis. To exclude the influence of starting and turning, the average swimming speed (V; $m.s^{-1}$) maintained by each swimmer during the trial was measured over all 15-m distances within two points 5.0 m distance from each end of the pool [9]. Average stroke rate (SR; $cycles \cdot min^{-1}$) was the average number of strokes completed by the swimmers during the 15-m distances [18]. One SR cycle was defined as the time between the entry of one hand until the following entry of the same hand [33]. The stroke length (SL; $m \cdot cycle^{-1}$) was calculated by dividing the average speed by the corresponding SR [18]. Finally, the stroke index (SI; $m^2 \cdot s^{-1} \cdot cycles^{-1}$) was calculated by multiplying the V ($m.s^{-1}$) by SL ($m \cdot cycle^{-1}$) [7]. This index assumes that, at a given speed, the swimmer who moves the greatest distance per stroke has the most efficient swimming technique [30].

Measurement of anthropometrical parameters: Height (cm) was measured with a precision of 0.1 cm and body mass (kg) was recorded with a scale to the nearest 100 g. Arm span and shoulders width was measured to the nearest 0.1 cm according to the standard recommendations. Also limb length were measured from the right side of body in standing position by using anatomic landmarks: Thigh length, the distance between the lateral condyle of the Femur and greater trochanter, leg length, the distance between the lateral malleolus of the Fibula and the lateral condyle of the Tibia, and upper arm length, the distance between the lateral epicondyle of the Humerus and the acromial process of the Scapula. All anthropometric parameters were measured to the nearest 0.1 cm in accordance with the ISAK guidelines [32].

Measurement of skeletal muscle architectural parameters: We investigated five different muscles in-

cluding, Vastus Lateralis (VL; midway between the lateral condyle of the Femur and greater trochanter), Gastrocnemius Lateralis (GL; 30% proximal between the lateral malleoulus of the Fibula and the lateral condyle of the Tibia), Gastrocnemius Medialis (GM; at the same level as GL) in lower extremity [17], lateral head of Triceps Brachii (TB; midway of lateral epicondyle of the Humerus and the acromial process of the Scapula), and Biceps Brachii (BB; at the same level as TB) in upper extremity [20]. These muscles are highly activated and recruited during front crawl swimming propulsion [4], [21].

Muscle architectural characteristics were measured in vivo as described previously [17], [20]. Briefly, after determining the measurement sites and coating them with Water-Soluble Transmission Gel to make optimum acoustic relation, the probe was placed perpendicularly to the specific muscle to observe a cross-sectional image in order to measure the muscle thickness (MT). After imaging and marking the images for later analysis, the probe was placed at the same point and parallel to the specific muscle resulting in a longitudinal image to measure the pennation angle (PA). The distance between muscles deep aponeurosis and superficial aponeurosis in the cross-sectional image was accepted as MT (Fig. 1, left). The angle between the echo of the deep aponeurosis of the muscle and interspaces among the fascicles of the muscles in the longitudinal image was measured as PA (see α in Fig. 1, right). Fascicle length (FL) was measured by the following geometric formula

$$FL = MT \cdot (\sin(\alpha))^{-1}$$

where α is the PA [17]. Thus, fascicles were assumed straight and the model did not account for fascicle curvature. The error involved with this technique has been shown to be reasonably low (~2.3%) in contracted Tibialis Anterior [26], where fascicle curvature is significant. Given that fascicles in the relaxed muscle are relatively straight (see Fig. 1, right), we estimated that our error would be somewhat lower.

All measurements were conducted from the right side of body in the morning before doing any physical activity and with the same condition for all subjects. Imaging from BB and VL were taken in supine position and TB, GM, and GL recorded in prone position. Images were taken by B-mode ultrasonography device (EUB-405; Hitachi; Japan), with a linear probe of 7.5 MHz.

Statistical analysis: Results are expressed as means ±SD. Normality of distribution was checked with Kolmogorov–Smirnov test and normal distribution was found in all the subgroups. Pearson's product–moment correlations were used to determine the degree of association among assessment variables and swimming performance. For each type of assessment stepwise regression analysis (forward method) was used to assess the potential relationships with swimming performance and to evaluate which group of parameters (i.e., biomechanical, anthropometrical, muscle architectural, and all parameters together) best characterized swimming performance [14], [18], [27], [34]. Significance was set at $p \leq .05$.

3. Results

Mean (±SD) 200-m performance time was 162.66 ± 13.45 s and the *V* without start and turnings

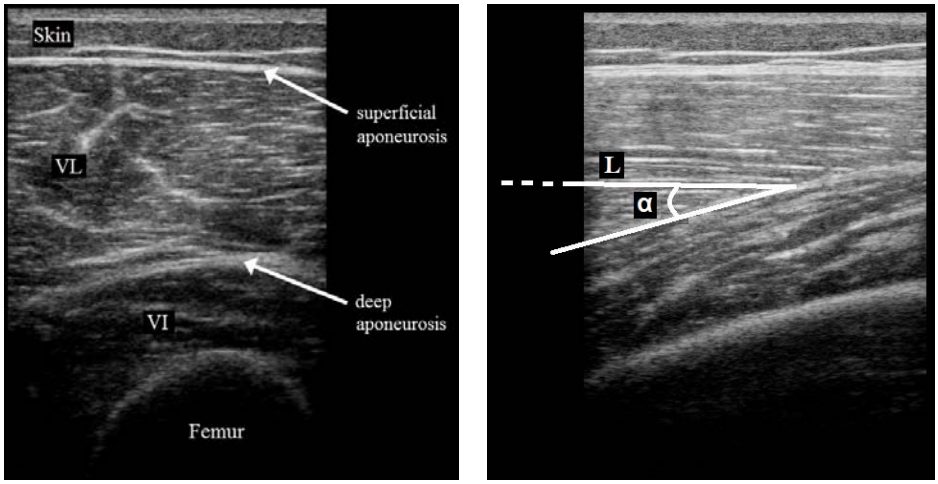

Fig. 1. Ultrasonographic images representing Vastus Lateralis (VL) and Intermedius (VI) muscles. Left: cross-sectional image representing their positions. Right: longitudinal image representing pennation angle (α) and fascicle length (*L*) of VL

was 1.40 ± 0.14 m·s^{-1}. Descriptive statistics for biomechanical, anthropometrical and muscle architectural parameters and their relationship with 200-m front crawl swimming performance are presented in Table 1. Correlation analysis demonstrated that swimming performance from biomechanical parameters with SL, SR, and SI, from anthropometrical parameters with body height, arm span, shoulders width, upper arm length, and from muscle architectural parameters with MT of VL, GL, and TB, and FL of VL and TB were significantly correlated ($p < .05$).

Multiple regression analysis revealed that SL ($R^2 = 0.623$, $p < 0.001$), body height ($R^2 = 0.541$, $p < 0.001$), and FL of TB ($R^2 = 0.392$, $p < 0.001$) were the best single predictors of 200-m front crawl swimming performance from all measured parameters in these young swimmers. Also from this analysis, it appeared that biomechanical parameters that were entered into the model (Table 2) characterized best the 200-m swimming performance in these young swimmers (87%; $p < 0.001$), followed by anthropometrical (82%; $p < 0.001$) and muscle architectural parameters (72%; $p < 0.001$). Multiple regression analysis for all parameters indicated that SL, body height, and FL of TB explained 92% of the variance of 200-m swimming performance (Table 2).

Table 1. Biomechanical, anthropometrical and muscle architectural parameters and their correlation with 200-m front crawl swimming performance in young swimmers ($n = 23$)

Variable			Mean ± SD	Range	r
Biomechanical	SL (m·cycle^{-1})		1.74 ± 0.15	1.28–2.18	–0.79**
	SR (cycle·min^{-1})		48.53 ± 3.78	39–55	–0.42*
	SI (m^2·sec^{-1}·cycle^{-1})		2.46 ± 0.39	1.92–3.18	–0.72**
Anthropometrical	Body height (cm)		173 ± 5	160–184	–0.71**
	Body mass (kg)		60.5 ± 5.7	49.9–71	–0.37
	BMI (kg·m^{-2})		20.4 ± 1.1	17.7–23.2	–0.23
	Arm span (cm)		181 ± 8.2	167–197	–0.62*
	Shoulders width (cm)		37.3 ± 2.7	32–42	–0.48*
	Upper arm length (cm)		38.1 ± 1.6	34.8–40.8	–0.44*
	Thigh length (cm)		40.2 ± 1.8	37–46	–0.24
	Leg length (cm)		41.4 ± 2.3	36–47	–0.17
Muscle architectural	Muscle thickness (cm)	VL	2.25 ± 0.14	2.04–2.53	–0.48*
		GM	1.83 ± 0.17	1.48–2.22	–0.32
		GL	1.70 ± 0.19	1.37–2.12	–0.42*
		TB	2.22 ± 0.14	1.91–2.49	–0.56*
		BB	2.11 ± 0.20	1.84–2.52	–0.21
	Pennation angle (°)	VL	16.7 ± 3.3	12.2–24.7	0.30
		GM	20.1 ± 4.2	13.1–27.8	0.14
		GL	15.9 ± 2.2	12.5–21.8	0.28
		TB	17.3 ± 3.6	13.1–23.9	0.36
	Fascicle length (cm)	VL	7.78 ± 0.14	5.21–11.6	–0.45*
		GM	5.42 ± 0.12	3.41–8.29	–0.38
		GL	6.08 ± 0.10	3.78–7.94	–0.25
		TB	7.34 ± 0.14	5.38–11.5	–0.64**

Note. BMI – body mass index; SL – stroke length; SR – stroke rate; SI – stroke index; VL – Vastus Lateralis; GM – Gastrocnemius Medialis; GL – Gastrocnemius Lateralis; TB – Triceps Brachii; BB – Biceps Brachii. * $p < .05$; ** $p < .01$.

Table 2. Stepwise regression analysis to evaluate which group of parameters (i.e., biomechanical, anthropometrical, muscle architectural, and all variables) best characterize 200-m swimming performance

Variables	Variables entered in model	R^2	Adjusted R^2	SE	F
Biomechanical	SL, SI	0.882	0.866	1.81	(2;20)=65.724 *
Anthropometrical	Body height, Arm span	0.829	0.817	2.95	(2;20)=53.349 *
Muscular architecture	FL of TB, MT of VL	0.742	0.724	2.36	(2;20)=45.412 *
In all variables	SL, Body height, FL of TB	0.936	0.921	1.27	(3;19)=61.371 *

Note. SL – stroke length; SI – stroke index; FL – fascicle length; MT – muscle thickness; TB – Triceps Brachii; VL – Vastus Lateralis. *$p < .001$.

4. Discussion

This study investigated the contribution of different biomechanical, anthropometrical, and muscle architectural parameters to 200-m front crawl swimming performance in young male swimmers. Present data showed a significant relationship between 200-m front crawl swimming performance with seven (SL, SR, SI, body height, arm span, MT of VL, GL and TB, and FL of VL and TB) of twenty four variables measured (Table 1). Also, findings showed that biomechanical parameters (87%) explained 200-m front crawl swimming performance properly, followed by anthropometrical (82%) and muscle architectural parameters (72%). Also, SL (R^2 = 0.623), body height (R^2 = 0.541), and FL of TB (R^2 = 0.392) were the best single predictors that together explained 92% of the variability of the 200-m front crawl swimming performance in these young male swimmers.

The majority of studies in this field have reported a relatively high association between biomechanical parameters and swimming performance in young swimmers. Consistent with our findings, Lätt et al. [18] demonstrated significant relationships between 100-m front crawl swimming performance with SL, SR and SI (respectively: r = –0.506, r = –0.785, r = –0.643, all $p > 0.05$) and found that SL and SI explained 90% of the variance of swimming performance in 15.2 ± 1.9 year old boys. Vitor et al. [34] found significant relationships between 100-m front crawl swimming performance with SL, and SI (respectively: r = –0.82, r = –0.53, both $p > 0.05$), but this relationship was not significant for SR (r = 0.03), and from biomechanical parameters SI was also significant to predicted model in this study. Barbosa et al. [3] also demonstrated significant relationship between 200-m front crawl swimming performance and SI in 12.53±0.58 years old boys and found that the effect of SI on swimming performance is mediated by propulsive efficiency of body movement in the water, and suggested that SI could be used as an evaluation criterion of swimming performance in young swimmers on a regular basis.

Studies on adult elite swimmers have shown that front crawl swimming results are most strongly correlated with SL [1],[15], and higher-skilled adult swimmers present a higher SL than lower-skilled counter parts [2]. Therefore, based on the results of these studies it seems that learning proper stroke-technique is very important in early years of swimming training. Marinho et al. [19] also recommended that specific training sets concerning technique correction and improvement in young swimmers might be a main aim during training planning in swimming. Also, due to the simplicity of measurement and evaluation, as well as their relatively high correlation with the front crawl swimming performance, applying these parameters for classification technique in young swimmers can be recommended.

Several studies examined the anthropometric parameters and their association with front crawl swimming performance, as the beginning of serious training at the onset of puberty could suggest that anthropometric parameters together with body composition values might affect swimming performance to some extent [5]. Jürimäe et al. [14] reported that body composition parameters explained 45.4% of 400-m front crawl swimming performance variation and arm span was the best predictor from these parameters in young swimmers. Saavedra et al. [27] showed that approximately 62% of front crawl swimming performance of their young swimmers were due to body height, age, and arm span. Also, Lätt et al. [18] demonstrated that arm span, body height, bone mass, and spine bone mineral density explained 46% of the variance of 100-m front crawl swimming performance. However, anthropometrical parameters did not entered in the predictive model from all biomechanical, anthropometrical, and physiological parameters that were measured. In similar studies [24], [34] anthropometry did not have any variable that could explain front crawl performance in regression prediction model. However, anthropometric parameters in the present study appropriately described swimming performance and body height was the second best single predictor. Maybe the difference between the results of these studies is due to examine different swimming distances and various predictive parameters.

The negative correlation of front crawl swimming performance with body height and arm span from anthropometric parameters are in agreement with the literature [11], [14], [18], [29]. It seems that taller swimmers glide better through the water [11] and usually show a larger arm span which benefits swimming efficiency (i.e., larger SL) [27].

Nasirzade et al. [25] investigated the relationship between muscle architectural parameters with sprint front crawl swimming performance in young swimmers, and showed the possible influence of these parameters on swimming performance. Another study [24] has reported that approximately 52% of 50-m front crawl swimming performance described by muscle architectural parameters, and MT of VL was one of the most important parameters (R^2 = 0.418, $p < 0.001$). The results of present study also demon-

strated the predictive power of these parameters. It seems that muscle architectural parameters influence the length-tension and force-velocity relationships of the muscles, which could promote swimmers performance [25].

Based on the results of present study FL of TB was the third best single predictor of 200-m front crawl swimming performance. Potentially longer FL enables swimmers to gain more muscle power [25]. Considering the determining role of arm movement in generating propulsive force in front crawl swimming [8], [28], and positive correlation between mean power of arm active muscles and front crawl swimming performance in young swimmers [12], [13], it would be expected that there should be an association between muscle architectural characteristics especially FL of TB and front crawl swimming performance. It seems that young swimmers with better front crawl swimming performance benefit from these advantages. However, with respect to indeterminate origin of this architectural difference [6], [25], it is unclear if these results are a result of genetic predisposition or if an adaptation to the modalities of training commonly used by swimmers, which indicates the need for further studies in this area.

Taking into account all measured parameters regression analysis revealed that SL, body height, and FL of TB explained 92% of swimming performance of our swimmers. In contrast with studies that evaluate the combination of different parameters to explain 200-m front crawl swimming performance, Barbosa et al. [3] described 79% of the performance variance by biomechanical and energetics profiles. Also, Figueiredo et al. [10] reported that biomechanical, energetic, coordinative and muscular factors respectively explained 58.1%, 11.2%, 18.9%, and 11.8% of the average velocity (1.41 ± 0.04 m s^{-1}).

In swimming with shorter distances several authors have been trying to isolate, from a wide range of variables, those which determine mostly the swimming performance in young swimmers. Nasirzade et al. [24] reported SI, SL, and MT of VL described 89% of 50-m front crawl swimming performance. Geladas et al. [11] found 59% of the variance in the 100-m front crawl swimming performance explained by the combination of the total extremity length, horizontal jump, and grip strength in swimmers between 12–14 years old. Lätt et al. [18] reported 92.6% of the variance in the 100-m front crawl swimming performance explained by SI and SR in young swimmers. Also Vitor et al. [34] observed anaerobic power test, SI, and critical speed test explained 88% of the variability of the average speed for the 100-m front crawl swim in male swimmers with 13 ± 0.7 years old. Morais et al. [22] explained 58% of 100-m front crawl swimming performance by biomechanical parameters.

Despite the importance of anthropometric parameters such as body height at shorter swimming distances [33], in contrast to the present study, some of these studies [18], [24], [27], [34] reported anthropometry are less relevant and did not have any variable that could explain front crawl performance in prediction model consists of all measured parameters. However, in the present study anthropometrical parameters have strong predictive power, which suggested that these parameters especially body height could be more determinant in longer swimming distances such as 200-m.

Based on the results of these studies, it seems that biomechanical parameters that play a major role in the swimmer's technique, are the best parameters for predicting performance in young swimmers. Accordingly, it would appear that in these ages the best way to improve swimming performance is to improve technique, thus coaches must pay extra attention to technical issues such as an increased SL. Among these studding other parameters increase the prediction level and enable us to achieve a deeper understanding of the swimming performance. Thus, future studies should examine the new parameters in the groups of swimmers with more participants.

5. Conclusion

In summary, our findings showed the importance of anthropometrical and muscle architectural parameters in predicting success in young swimmers. Moreover, based on our findings to improve 200-m front crawl swimming performance in young swimmers technical training should be considered as the core of the training program at these ages. Considering the fact that training program in young swimmers mostly includes endurance training, and muscle architectural parameters seem to have an important role in predicting swimming performance, applying power training for optimizing these parameters might be an effective way for improving swimming performance. Finally, the results of this study also could be used for young male swimmers' selection and talent identification.

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