Linking Selected Kinematic, Anthropometric and Hydrodynamic Variables to Young Swimmer Performance

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The aim of this study was to develop a structural equation model (i.e., a confirmatory technique that analyzes relationships among observed variables) for young swimmer performance based on selected kinematic, anthropometric and hydrodynamic variables. A total of 114 subjects (73 boys and 41 girls of mean age of 12.31 ± 1.09 years; 47.91 ± 10.81 kg body mass; 156.57 ± 10.90 cm height and Tanner stages 1–2) were evaluated. The variables assessed were the: (i) 100 m freestyle performance; (ii) stroke index; (iii) speed fluctuation; (iv) stroke distance; (v) active drag; (vi) arm span and; (vii) hand surface area. All paths were significant (p < .05). However, in deleting the path between the hand surface area and the stroke index, the model goodness-of-fit significantly improved. Swimming performance in young swimmers appeared to be dependent on swimming efficiency (i.e., stroke index), which is determined by the remaining variables assessed, except for the hand surface area. Therefore, young swimmer coaches and practitioners should design training programs with a focus on technical training enhancement (i.e., improving swimming efficiency).

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Swimming performance results from a multifactorial process that involves several scientific domains, such as the anthropometrics (13,15,25), hydrodynamics (21,28), kinematics (3,20) and energetics (12,17,32).

As in adult/elite swimmers, one of the main goals of swimming research is to identify the scientific domains and/or variables that predict swimming performance in children (i.e., young athletes) thereby enhancing the detection of future talent (19,38). Nevertheless, research in young athletes ought to be less invasive, expensive and time-consuming than in adult/elite counterparts (14). In this sense, several authors (3,21,27) have estimated and/or measured variables in various scientific domains (i.e., anthropometric, hydrodynamic, kinematic and energetic) that are easy to collect and may predict performance and/or detect talented swimmers.

Since swimming competition starts at an early age, it is important to know when and how these variables interact with each other, as well as with performance. Several authors studied these relationships (3,21,34) aiming to describe and/or better understand this phenomenon. It is reported that young swimmer performance is strongly related with anthropometric and kinematic variables (3,41). Moreover, both sets of variables are affected by the processes of growth and maturation (26).

Given this rationale, it seems that kinematic variables are those that best explain young swimmer performance. Swimming velocity ($r^2 = -0.93$) and stroke rate ($r^2 = -0.78$) were highly correlated with 100 [m] freestyle performance (27). However, during growth and maturation processes, anthropometric variables are also related with swimming performance in young athletes (25,26,34). The arm span (AS), seems to be a major performance determinant since it is correlated with stroke mechanics, namely the stroke length (SL) and stroke index (SI; 20). Arm span ($r^2 = .48$) and SI ($r^2 = .78$) were reported as the best overall predictors in 100 [m] freestyle event (27). Moreover, hydrodynamic variables also play an important role in swimming performance (40) and are also commonly reported in studies involving young swimmers (4,28). Understanding the relationships between human morphology and hydrodynamic resistance allows coaches to modify stroke mechanics to enhance performance (7). Furthermore, active drag ($D_a$) has an important role in swimming performance, being highly dependent on swimming technique (21).

A key question is to understand how these different scientific domains and variables interact to enhance swimming performance. In confirmatory research, analysis is driven by theoretical relationships among variables that are hypothesized and tested by the researchers. The present study aimed to confirm whether the hypothesized interaction takes place. A confirmatory model of such relationships based on existing exploratory research reported in the main literature could be useful, not only to prescribe appropriate periodization programs and training sets for young swimmers, but also to promote feasible and effective programs to detect and to select talent in competitive swimming. Structural equation modeling is a confirmatory technique (i.e., data analysis procedure) that assesses relationships among observed variables with the main goal of providing a quantitative test of the theoretical model hypothesized by the researchers. To our knowledge only one study has so far attempted to confirm correlates between young swimmer performance and at least some of these scientific domains (3). The present paper is a follow-up from that study but more specially focused on understanding and developing the biomechanical factor (i.e., quantifying the partial contribution of the biomechanics domain to young swimmer performance) in the model reported by these authors (3).
The aim of this study was to develop a structural equation model for performance in young swimmers based on selected kinematic, anthropometric and hydrodynamic variables. It was hypothesized that swimming performance in young swimmers might be related with these variables. The swimming performance is mainly related to swimming efficiency and this one to several kinematic, anthropometric and hydrodynamic variables.

Methods

Participants
A total of 114 young swimmers participating on a regular basis in regional and national level competitions volunteered as subjects. They comprised 73 boys and 41 girls with a chronological age of 12.31 ± 1.09 years (overall: 47.91 ± 10.81 kg of body mass; 156.57 ± 10.90 cm of height and Tanner stages 1–2 assessed by self-evaluation; boys: 12.72 ± 1.03 years old; 47.41 ± 10.09 kg of body mass, 157.20 ± 11.17 cm of height and Tanner stages 1–2 assessed by self-evaluation; girls: 11.47 ± 0.66 years old; 45.79 ± 6.66 kg of body mass, 154.56 ± 8.26 cm of height and Tanner stages 1–2 by self-evaluation).

Coaches and parents gave their consent for swimmer participation in this study and all procedures were in accordance to the Helsinki Declaration concerning human research. The Institutional Review Board of the University approved the study design.

Study Design

Theoretical Model. The theoretical model was designed according to exploratory state-of-the-art research and to test it was the object of our research. Figure 1 presents the theoretical model adopted for swimming performance based on selected kinematic, anthropometric and hydrodynamic variables in young swimmers. Swimming performance is related to kinematic (3), anthropometric (13,25) and hydrodynamic (21) variables. It was suggested that swimming performance depends on the relationship between the swimmer morphology, hydrodynamic resistance and swimming stroke mechanics (7). The sequence of the theoretical model was designed according to these facts. For anthropometric assessment the surface area of the dominant hand (HSA) was computed. It is known that the propulsive surface is a key variable in increasing propulsive forces (e.g., propulsive drag and lift force). However, to the best of our knowledge, there are no studies deploying this variable in young swimmers. The AS is a variable reported on a regular basis in talent detection and selection (19,38). The AS strongly affects not only the SL but also some hydrodynamic variables related to the body length (21). Swimming with lower drag at constant speed reduces the energy cost of swimming (28). The hydrodynamic variable assessed was the Da. The kinematic variables analyzed were the speed fluctuation (dv; 2), the SL (10) and the SI (11). Speed fluctuation is the result of the propulsive and drag forces that interact on the swimmer and thus allows an overall assessment of the stroke mechanics (2). Stability or minimal change in SL at a high value is associated with higher performances (37). The
SI is strongly related to the energy cost of swimming (11). Indeed, the SI is the swimming economy estimator most often cited by the scientific community. It describes the swimmers ability to move at a given velocity with the fewest number of strokes (11). Performance was measured as the time spent in completing the 100 [m] freestyle event in an official competition. The 100 [m] freestyle was selected because it is the event in which most young swimmers participate on regular basis. It is also the most popular swimming event not only for young but also for adult/elite and master swimmers.

**Performance data collection**

Swimming performance was assessed against time lists of the 100 [m] freestyle event in short course competitions (i.e., 25 [m] swimming pool) at local, regional or national level competitions. The time gap between assessment of all variables and swimming performance was less than the two weeks reported in other studies on the relationships between swimming performance and kinematic and/or energetic variables in young swimmers (3,28).
Anthropometric data collection

The anthropometric variables selected for the path-flow model were the AS and the HSA. For the AS assessment, subjects were placed in an orthostatic position, with both arms in lateral abduction at a 90° angle with the trunk. Both arms and fingers were fully extended. The distance between the tip of each third finger was measured with a flexible anthropometric tape (RossCraft, Canada). The test/retest evaluation (i.e., Intraclass Correlation Coefficient) was very high for the AS (ICC = 0.99).

For the HSA measurement, swimmers placed their dominant hand on the scan surface of a copy machine with fingers in the position they usually adopt while swimming. The scan surface was also fitted with a 2D calibration frame. Thereafter, the perimeter of the HSA was digitized in the Xerox machine (Xerox 4110, Norwalk, Connecticut, USA) and files were converted into pdf format. The HSA was afterward computed with dedicated software (Universal Desktop Ruler, v3.3.3268, AVPSoft, USA). The measurement procedures were: (i) scale calibration; (ii) digitization of hand surface perimeter and; (iii) computation and record of the HSA value (30). The test/retest evaluation was very high for the HSA (ICC = 0.99).

Biomechanical data collection

Speed fluctuation, SL and SI were selected as kinematic variables. Each swimmer performed three bouts of 25 [m] freestyle from an underwater start. For further analysis the mean value of the three repetitions was computed. Subjects performed the bouts alone without other swimmers in the same swim lane or in nearby lanes to reduce drafting, pacing effects and bias in the drag force (28). The subjects were advised to reduce gliding after the start (4). To assess dv a speedometer cable (Swim speedo-meter, Swimsportec, Hildesheim, Germany) was attached to the swimmer’s hip and the biosignal reading was acquired on-line at a sampling rate of 50 [Hz]. LabVIEW (v. 2009) software interface was used to acquire, display and process pairwise velocity-time data on-line during the swim bout. To transfer data from the speedometer to the software application a 12-bit resolution acquisition card (USB-6008, National Instruments, Austin, Texas, USA) was used (6). Data were exported to signal processing software (AcqKnowledge v. 3.5, Biopac Systems, Santa Barbara, USA) and filtered with a 5 [Hz] cut-off low-pass 4th order Butterworth filter. Speed fluctuation was computed as (5):

\[ dv = \sqrt{\sum_i \left( v_i - \bar{v} \right)^2 F_i / n } \]

Where \( dv \) represents speed fluctuation [dimensionless], \( \bar{v} \) represents the mean swimming velocity in \([m\cdot s^{-1}]\), \( v_i \) represents the instant swimming velocity in \([m\cdot s^{-1}]\), \( F_i \) represents the absolute frequency and \( n \) represents the number of observations. Stroke length was computed as (10):

\[ SL = \frac{\bar{v}}{SF} \]

Where \( SL \) represents stroke length in \([m]\), \( \bar{v} \) represents the mean swimming velocity in \([m\cdot s^{-1}]\) and \( SF \) represents the stroke frequency in \([Hz]\). The \( \bar{v} \) was cal-
culated dividing the 13 [m] distance swam in the middle of the swimming pool by the time spent with a manual chronometer (Golfinho Sports MC 815, Aveiro, Portugal) by two expert evaluators (ICC = 0.97). The SF was measured with a chrono-frequency counter during three consecutive strokes by two expert evaluators (ICC = 0.96). Stroke index was also computed as a swim efficiency estimator (11):

$$SI = SL \cdot \bar{v}$$

(3)

Where $SI$ represents stroke index in $[m^2 \cdot c^{-1} \cdot s^{-1}]$, $SL$ represents stroke length in [m] and $\bar{v}$ is the mean swimming velocity in [m·s⁻¹].

**Hydrodynamic data collection**

In the hydrodynamic domain, the $D_a$ was computed using the velocity perturbation method (23). Each swimmer performed two maximal 25 [m] bouts of freestyle with an underwater start. The first bout was performed without the perturbation device and the second one with the perturbation device. Subjects performed the bouts alone without other swimmers in the same or nearby swim lanes to reduce drafting, pacing effects and bias in the drag force (28).

Active drag was calculated from the difference between the swimming velocities both towing and without towing a perturbation buoy (additional hydrodynamic body; 23,24). The drag of the perturbation buoy was computed from the manufacturer’s calibration of the buoy-drag characteristics and its velocity (23). Swimming velocity was assessed over 13 [m] (between 11th [m] and 24th [m] from the starting wall). The time spent to cover this distance was measured with a manual chronometer (Golfinho Sports MC 815, Aveiro, Portugal) by two expert evaluators as is customary with this method (28). The ICC for both evaluators was very high (ICC = 0.97). Active drag was calculated as (23):

$$D_a = \frac{D_b v_b v^2}{v^3 - v_b^3}$$

(4)

Where $D_a$ represents the swimmer’s active drag at maximal velocity in [N], $D_b$ is the resistance of the perturbation buoy in [N] and, $v_b$ and $v$ are the swimming velocities with and without the perturbation device in [m·s⁻¹], respectively.

**Statistical analysis**

The Kolmogorov-Smirnov and the Levene tests were used to analyze normality and homoscedasticity assumptions, respectively. Descriptive statistics (mean, one standard deviation, minimum and maximum) were computed.

To assess the association between performance and remaining variables, Pearson correlation coefficients were computed between swimming performance and all selected variables ($p \leq .05$). As rule of thumb, for qualitative and effect size assessments, the relationship was defined as: (i) very weak if $R^2 < .04$; weak if $0.04 \leq R^2 < .16$; moderate if $0.16 \leq R^2 < .49$; high if $0.49 \leq R^2 < .81$ and; very high of $0.81 \leq R^2 < 1.0$. The level of statistical significance was set at $p \leq .05$.

For the structural equation modeling the path-flow analysis procedure was used. The interpretation of this kind of approach is based on: (i) the variables
included (variables are inserted inside squares); (ii) the paths (i.e., arrows; an arrow between two variables means that one variable determines the other); (iii) beta values (i.e., these suggest the contribution of one variable to the other: when the origin variable increases by one unit the destination variable increases by the amount of the beta value) and; (iv) residual errors and/or determination coefficient (represents the variable predictive error or the variable predictive value, respectively). Thereafter the model was computed and a confirmatory model obtained (i.e., a model that verified and confirmed the theoretical one). The estimation of linear regression standardized coefficients between exogenous and endogenous variables was computed. Standardized regression coefficients (b) were considered, and the significance of each one was assessed with the Student’s t test (p £ .05). When a given path was significant (p £ .05) and with a moderate/strong association it was reported as being “meaningful” (43).

The quality of the model goodness-of-fit was measured by computing: (i) the ratio Chi-square/degrees of freedom (x2/df) and; (ii) the comparative fit index (CFI). The ratio Chi-square/degrees of freedom was considered qualitatively if (42): x2/df > 5 bad adjustment; 5 ≥ x2/df > 2 low adjustment; 2 ≥ x2/df > 1 good adjustment; x2/df ≤1 very good adjustment. The comparative fit index was considered qualitatively if (8): CFI < 0.90 bad adjustment; 0.90 ≤ CFI < 0.95 good adjustment; CFI ≥ 0.95 very good adjustment.

**Results**

Table 1 presents descriptive statistics for overall sample (boys plus girls), boys only and girls only for all selected variables. Data variability, assessed by one standard deviation value, were moderate-high. This is especially obvious, concerning the overall statistics, for the HSA, ranging between 83.26 [cm²] and 163.84 [cm²], for the Da, ranging between 11.81 [N] and 73.15 [N], as well as for the swimming performance, ranging between 65.21 [s] and 128.30 [s]. For boys, the HSA ranged between 100.35 [cm²] and 163.84 [cm²], the Da between 11.81 [N] and 73.15 [N] and swimming performance between 65.21 [s] and 106.18 [s]. For girls, the HSA, Da and swimming performance ranged between 83.26 [cm²] and 133.76 [cm²], 16.49 [N] and 54.59 [N], and 69.90 [s] and 128.30 [s], respectively.

Table 2 presents the Pearson’s correlation coefficients between swimming performance and remaining selected variables for overall total (boys plus girls), boys only and girls only. Data revealed that swimming performance was meaningfully associated with SI (overall: r = -0.80, p < .01; boys: r = -0.87, p < .01; girls: r = -0.82, p < .01) and SL (overall: r = -0.64, p < .01; boys: r = -0.61, p = .04; girls: r = -0.61, p = .02). On the other hand, swimming performance was not significantly associated with the dv (overall: r = .18, p = .39; boys: r = -0.05, p = .86; girls: r = .13, p = .64) nor with the HSA (overall: r = -0.27, p = .11; boys: r = -0.17, p = .57; girls: r = -0.09, p = .66).

Figure 2 presents the confirmatory path-flow models for young swimmer performance (overall: 2A and 2B; boys: 2C and 2D; girls: 2E and 2F) based on selected anthropometric, hydrodynamic and kinematic variables. In each path the b value is reported (i.e., the standardized regression weight) for the regression model between each exogenous and endogenous variable. When the exogenous
<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Boys</th>
<th>Girls</th>
<th>Overall</th>
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<th>Girls</th>
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<th>Boys</th>
<th>Girls</th>
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<tr>
<td>AS [cm]</td>
<td>156.36</td>
<td>161.56</td>
<td>152.47</td>
<td>11.72</td>
<td>12.99</td>
<td>9.26</td>
<td>135.00</td>
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<td>187.00</td>
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<td>170.00</td>
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<td>HSA [cm²]</td>
<td>120.16</td>
<td>129.52</td>
<td>112.23</td>
<td>18.50</td>
<td>20.16</td>
<td>12.51</td>
<td>83.26</td>
<td>100.35</td>
<td>83.26</td>
<td>163.84</td>
<td>163.84</td>
<td>133.76</td>
</tr>
<tr>
<td>dv [dimensionless]</td>
<td>0.09</td>
<td>0.08</td>
<td>0.10</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
<td>0.19</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>SL [m]</td>
<td>1.54</td>
<td>1.58</td>
<td>1.47</td>
<td>0.23</td>
<td>0.23</td>
<td>0.23</td>
<td>1.04</td>
<td>1.04</td>
<td>1.04</td>
<td>1.98</td>
<td>1.98</td>
<td>1.92</td>
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<tr>
<td>Dₘ [N]</td>
<td>38.96</td>
<td>43.82</td>
<td>34.20</td>
<td>17.16</td>
<td>18.14</td>
<td>12.29</td>
<td>11.81</td>
<td>11.81</td>
<td>16.49</td>
<td>73.15</td>
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<td>SI [m²·c⁻¹·s⁻¹]</td>
<td>1.92</td>
<td>2.06</td>
<td>1.79</td>
<td>0.47</td>
<td>0.56</td>
<td>0.36</td>
<td>0.90</td>
<td>0.90</td>
<td>1.01</td>
<td>2.86</td>
<td>2.86</td>
<td>2.45</td>
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<td>100-m Freestyle</td>
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<td>78.33</td>
<td>85.25</td>
<td>12.96</td>
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<td>13.89</td>
<td>65.21</td>
<td>65.21</td>
<td>69.90</td>
<td>128.30</td>
<td>106.18</td>
<td>128.30</td>
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</table>

AS—arm span; HSA—hand surface area; dv—speed fluctuation; SL—stroke length; Dₘ—active drag; SI—stroke index.
variable changes (i.e., origin of the path) by one unit, the endogenous variable (i.e., destination of the path) changes by the same quantity as the beta value. All paths linked in the theoretical model were significant in the confirmatory model. The overall model goodness-of-fit when including all variables (Figure 2A) was: (i) \( \chi^2/df = 7.058 \) (i.e., bad adjustment) and; (ii) CFI = 0.601 (i.e., bad adjustment). For boys (Figure 2C) was: (i) \( \chi^2/df = 4.607 \) (i.e., low adjustment) and; (ii) CFI = 0.592 (i.e., bad adjustment). For girls (Figure 2E) was: (i) \( \chi^2/df = 3.516 \) (i.e., low adjustment) and; (ii) CFI = 0.640 (i.e., bad adjustment).

Deleting the HSA-SI path in the overall model (Figure 2B), for boys (Figure 2D) and for girls (Figure 2F) with subsequent recomputation of the remaining data, the new confirmatory model increased the predictive value of the models. The prediction of swimming performance based solely on biomechanics and its determining domains was 50%, 58% and 62% for overall data, boys and girls respectively. The SI was predicted based on remaining kinematic, anthropometric and hydrodynamic variables at 92%, 97% and 94% for overall data, boys and girls respectively. Moreover, the model goodness-of-fit improved meaningfully: (i) \( \chi^2/df = 1.908 \) (i.e., good adjustment); CFI = 0.940 (i.e., good adjustment) for overall data; (ii) \( \chi^2/df = 1.612 \) (i.e., good adjustment) and; CFI = 0.931 (i.e., good adjustment) for boys; (iii) \( \chi^2/df = 3.010 \) (i.e., low adjustment); CFI = 0.779 (i.e., bad adjustment) for girls. In this sense, the overall and boys confirmatory models had a good adjustment, although it was low for girls.

### Discussion

The aim of this study was to develop a structural equation model for young swimmer performance based on selected kinematic, anthropometric and hydrodynamic variables and to quantify the partial contribution of biomechanics to young swimmer performance. Main data showed that swimming performance is dependent on SI (an efficiency estimator) and this in turn on the dv, SL, AS and Da. The prediction
Figure 2 — Overall confirmatory path-flow model including all variables computed (2A) and deleting variable that allowed to reduce the residual error and improve the goodness-of-fit (2B) with the subsequent recomputation of remain data. Boy’s confirmatory path-flow model including all variables computed (2C) (continued)
Figure 2 — (continued) and deleting variable that allowed to improve significantly the goodness-of-fit (2D). Girl’s confirmatory path-flow model including all variables computed (2E) and deleting variable that allowed to improve the goodness-of-fit. HSA—hand surface area; AS—arm span; SL—stroke length; dv—speed fluctuation; Da—active drag; SI—stroke index; ; $x_i \rightarrow y_i$—variable $y_i$ depends from variable(s) $x_i$; $x_i \leftrightarrow y_i$—variable $y_i$ is associated to variable $x_i$. 
of swimming performance based solely on biomechanics was very high ($0.50 \leq r^2 \leq 0.62$).

Mean data reported are similar to other studies involving prepubescent swimmers (3,4,20,25). To the best of our knowledge, the HSA has never been assessed in young swimmers, except for hand length and width (41), and hand size (18). The data revealed a moderate-high dispersion, namely for performance and the HSA, which allowed the analysis of hypothetical relationships between these selected variables and swimming performance over a broader scope.

Pearson’s correlation coefficients showed that swimming performance was significantly correlated with all variables, except for the dv and the HSA. The highest correlation values were for the SI and the SL. At least in adult/elite swimmers, higher-skilled swimmers present a higher SL than lower-skilled counterparts (5). The SI is also higher in international level than in national level swimmers (35). Scientific evidence for young swimmers is not so obvious, mainly because research with this cohort is scarce. However, it seems that the data for young swimmers is similar to that for their older counterparts. A higher AS is also associated with a higher performance level in young swimmers (20). Arm span imposes an increase in the SL (31). The Da was also correlated with performance. To enhance performance, swimmers have to increase swimming velocity, which is one of the main determinants of Da. It was hypothesized that a higher HSA might increase propulsion. However, the correlation was not significant. Although an increased HSA might be an advantage, it should be stressed that the appropriate hand orientation (i.e., attack and pitch angles) on stroking has a role in enhancing performance (9,33). Probably some of the subjects assessed did not perform an appropriate hand orientation as well as varying in HSA.

The first overall confirmatory model (Figure 2A overall; boys 2C and girls 2E), including the HSA linked to SI, had a bad adjustment. Some studies suggested a relationship between hand shape (i.e., hand length) and swimming efficiency, or at any rate its thrust (1,29). However, most of those studies assessed adult swimmers (16) or made numerical simulations from adult models (9,33). There are few studies regarding its relationship in young swimmers, including pubescent ones (e.g., 1,18). However, one study (18) reported a positive correlation between hand size and swimming performance in young swimmers. Despite this, it can be stated that there is no solid scientific evidence that at such early ages the HSA is as determinant of swimming performance or of swimming efficiency as it is in adult/elite swimmers.

The second confirmatory model (Figure 2B overall; boys 2D and girls 2F) removed the HSA-SI path presenting two hierarchical levels, and increased the model goodness-of-fit (i.e., good adjustment). The second level is the relationship between the SI and remaining kinematic, anthropometric and hydrodynamic variables selected. The SI is considered a viable variable by which to estimate overall swimming efficiency (11). The capacity to cover a given distance (i.e., SL) at greater velocity represents an increased swimming efficiency. The variables maintained in the final overall confirmatory model (i.e., AS, SL, dv and Da) had high ability to predict SI (overall: $r^2 = .92$; boys: $r^2 = .97$; girls: $r^2 = .94$). From those variables, the SL had the higher standardized direct effect to SI (overall: $\beta = 0.80, p < .001$; boys: $\beta = 0.87, p < .001$; girls: $\beta = 0.88, p < .001$). This signifies that when SL increased by one meter, SI increased by 0.80, 0.87 and 0.88 m$^2$·c$^{-1}$·s$^{-1}$ overall, boys and girls respectively. This is obvious since the SI
is computed on the basis of SL and the swimming velocity. Arm span is usually reported as being related to swimming performance (25) because it is associated with improved swim efficiency (34). Another viable method of analyzing the overall swim mechanics is by means of the swimmer’s dv. Swimmers do not maintain a constant swim velocity due to variations of the limbs and trunk within the stroke cycle (2). Such a fact might decrease energy cost and thus improve swim efficiency. In this particular case, when dv increased by one arbitrary unit (a.u.), SI decreased by 0.09 m²·c⁻¹·s⁻¹ and 0.19 m²·c⁻¹·s⁻¹ for overall and girls models, respectively, though for boys it had essentially no effect. Active drag was also included in the model, since to maintain displacement, swimmers must overcome drag forces (21). To do this, they have to adopt the best possible hydrodynamic positions and segmental kinematics throughout the stroke.

The final confirmatory first level included the SI-performance relationship. The SI had a moderate-high standardized direct effect on performance (overall: $\beta = -0.71$, $p < .001$; boys: $\beta = -0.76$, $p < .001$; girls: $\beta = -0.78$, $p < .001$). Without considering other scientific domains, the biomechanical domain and its determinants were good predictors of the performance (overall: $r^2 = .50$; boys: $r^2 = .58$; girls: $r^2 = .62$). A previous study (3) predicted performance in roughly 80% of cases, based only on biomechanical and energetic domains. It was not the aim of this paper to replicate this study (3), using the same variables. Instead, the goal was to expand the biomechanical “branch” of the model reported by (3) and to identify the anthropometric and hydrodynamic determinants and to understand the interplay between them. Thus, it can be speculated that remaining 30% (to increase the performance prediction up to 80% as previously reported) might be attributable to energetics, a domain not considered here. It could therefore be interesting in future to develop the energetics “branch” of the original model. Indeed, most of the technical and scientific evidence for young swimmers suggests that the best way to enhance performance is through improving technique. Swimming efficiency should be the focus at these ages, more so than the energy profile or other fitness components such as muscle strength or anaerobic fitness (14,39). Our data also suggests that, for young swimmers, biomechanics may well have a higher performance prediction power than energetics. Therefore, technique should represent the core of the training program at these ages. Coaches should therefore design training programs focusing on improvement swimming technique (i.e., increasing the swimming efficiency). In prior exploratory researches the SI was one of the best performance predictors (22,25,41). For these studies, the SI-performance ranged from moderate to very high associations.

Young swimmer coaches and practitioners should thus design training programs with a focus on specific training sets for technique correction using a large variety of drills. By increasing swimming efficiency it is possible to meaningfully enhance the performance for this age-group. However, to increase swimming efficiency some further variables should be manipulated. Coaches must pay extra attention to technical issues such as an increased SL (related to a higher AS) and a better hydrodynamic position so as to decrease $D_a$. Emphasis should also be given to improving stroke mechanics (e.g., interlimb coordination in opposition and/or superposition) to avoid swim discontinuities as observed in adult/elite swimmers (36). This same logic ought also be applied in talent identification and selection programs.
The main limitations of this research were as follows: (i) a direct measure of the propulsive efficiency was not adopted, merely a swim efficiency estimator; (ii) short distance events such as the 100 [m] freestyle are strongly associated with energetics variables, at least in adult/elite swimmers, but not so obviously in younger counterparts; (iii) not included in the model were variables related to functional fitness (e.g., muscular strength or flexibility) that might influence stroke mechanics.

Conclusions

To conclude, it was possible to develop a confirmatory model to explain swimming performance in young swimmers. The data suggested that the biomechanical domain contributed 50% to overall sample performance (boys plus girls), 58% to boys-only performance and 62% only to girls-only performance. Increasing swimming efficiency (i.e., improving swim technique) leads to a performance enhancement. On the other hand, swimming efficiency improvement is related to a decrease in the dv and an increase of the SL and AS. However, the increase in the Da is a result of the increase in swimming velocity.

It would appear that the best way to improve performance is to improve technique, thus increasing efficiency and optimizing hydrodynamic position. Therefore, the focus of training sessions for young swimmers should be on the enhancement of technique.

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References

Assessment of Young Swimmer Performance


