1 100-meter Breaststroke swimming performance in youth swimmers: the predictive value of
2 anthropometrics
3
4 **Running title:** Allometric model and Breaststroke performance.
Abstract:
This study aimed to estimate the optimal body size, limb-segment length, and girth or breadth ratios of 100-m Breaststroke performance in youth swimmers. Fifty-nine swimmers (male [n=39; age: 11.5 ± 1.3 years]; female [n=20; age: 12.0 ± 1.0 years]) participated in this study. To identify size/shape characteristics associated with 100-m Breaststroke swimming performance, we computed a multiplicative allometric log-linear regression model, which was refined using backward elimination. Results showed that the 100-m Breaststroke performance revealed a significant negative association with fat-mass and a significant positive association with the segment length ratio [arm-ratio= (hand-length)/(forearm-length)] and limb girth-ratio [girth-ratio=(forearm-girth)/(wrist-girth)]. Additionally, leg length, biacromial and biiliocristal breadths revealed significant positive associations with the 100-m Breaststroke performance. However, height and body mass did not contribute to the model, suggesting that the advantage of longer levers was limb-specific rather than a general whole-body advantage. In fact, it is only by adopting multiplicative allometric models that the abovementioned ratios could have been derived. These results highlighted the importance of considering anthropometric characteristics of youth Breaststroke swimmers for talent identification and/or athlete monitoring purposes. In addition, these findings may assist orienting swimmers to the appropriate stroke based on their anthropometric characteristics.

Key Words: Allometric model; Breaststroke swimming; maturity; limb lengths; girths and breadths.
INTRODUCTION:

Competitive swimming is a type of cyclic sports activity performed with the aim of covering any given distance as fast as possible (1). In this context, many researchers are constantly trying to establish and classify factors associated with optimal swimming performance. Therefore, it remains important to recognize that various factors are important in determining swimming performance success (1,19). These factors include the aerobic-anaerobic capacity (17, 49), technical (e.g., stroke technique, coordination, starts and turns), physical fitness level (e.g., flexibility, strength, and power), psychological traits (e.g., stress control, motivation), and the anthropometrical characteristics (e.g., height, body mass, and body mass index), among others (29).

The relationship between human physical characteristics and sports performance has been a source of unceasing interest among scientists (29, 33, 36, 38). Notably, the association between anthropometric characteristics and sports performance constitutes a worthwhile marker for talent identification to engage children in a long-term athlete development process. A recent review by Morais et al. (34) suggested that anthropometric characteristics are among the critical factors used as precursor for an early recognition of talented athletes. It is worth noting that anthropometrics are more genetically controlled compared with physical fitness attributes (27). Therefore, anthropometrics are less susceptible to training than physical fitness attributes. For instance, it has been established that anthropometrics such as body length (e.g., height, limbs) are strongly determined by genetics (level of inherence of 70%) (6, 46). These facts confirm the importance of anthropometric characteristics to the early detection of talented athletes. In swimming, talent identification and development process play a crucial role in the pursuit of excellence across a long-term career. In this regards, anthropometric characteristics have been argued to be one of the most important factors that enable swimmers to achieve a high-performance level in their careers (21, 29).

It is worth noting that most of the previously published investigations centered their attention in Freestyle swimming (2, 5, 21, 29), while the Breaststroke remains understudied (18, 28). For instance, Lätt et al. (29) indicated that anthropometrical factors explained 45.8% of 100-meter Front crawl swimming performance in male swimmers aged 15 years. Likewise, Morais et al. (33) reported the contribution that anthropometric characteristics made on swimming performance and found that the arm span was significantly correlated with 100-meter Freestyle swimming performance in 12-year-old swimmers of both genders (r= -0.35).
Additionally, Bond et al. (5) suggested that anthropometric variables accounted for 63.8% of 100-meter Freestyle swimming’s total variance in 13 years old male and female swimmers. Further, Geladas et al. (21) revealed that upper extremity length was significantly associated with 100-meter Freestyle swimming performance in boys aged between 12 and 14 years. The same authors revealed that other anthropometric factors such as upper extremity length, stature, and hand length, significantly influenced girls’ swimming performance of the same age group.

Breaststroke is well known as a very challenging stroke because of the discontinuous propulsive action of the arms and legs and its complex time synchronization (44). During Breaststroke, stroke cycle consists of an arm stroke and a leg kick that occur in sequence and determine the stroke cycle from the start and throughout the race, rules that do not apply to any other swimming style (according to the Fédération Internationale de Natation (FINA, 2014)).

According to Barbosa et al. (2), differences between Freestyle and Breaststroke do exist in terms of technique, energy cost, and stroke length. Additionally, previous findings showed that Freestyle is the most economic stroke, followed by Backstroke, Butterfly, and Breaststroke (2). In the same context, by studying the temporal and velocity changes during the stroke cycle for a range of stroke rates, Craig et al. (13) demonstrated that Breaststroke swimming’s mechanics was more critical compared with the other stroke styles. Indeed, swimming velocity can be characterized by its independent variables: stroke length (SL) and stroke rate (SR) (13). Thus, increases or decreases in swimming velocity are mainly due to a combined increase or decrease in stroke rate (SR) and stroke length (SL) (13, 48). In addition, there is general agreement that stroke length (SL) in Breaststroke is the lowest compared with the other strokes (i.e., Freestyle, Butterfly, and Backstroke) (13). Likewise, several studies showed a large intra-cyclic velocity variation of the body’s center of mass during Breaststroke swimming (40, 30, 47). This variation makes this swimming stroke the slowest among the four competitive strokes (13).

Until recently, numerous studies (21, 28, 37, 41) investigated the association between anthropometric characteristics and swimming performance in various age group. However, knowledge on the effect of anthropometric characteristics on swimming performance in young swimmers still limited. Moreover, few studies have investigated the contribution of segment lengths to swimming performance. As stated in previous studies (9, 22, 41), limb segment lengths better predict athletic performance in sports athletes and sedentary population
in comparison with whole-limb lengths. The allometric modeling approach is currently considered a relevant mode for solving this issue given its sound theoretical basis and its biologically driven, as well as its versatile statistical methodology (37). This approach often provides a dimensionless expression of data in the form of ratios [e.g., crural index, upper-arm-to-lower-arm ratio, and reciprocal ponderal index (stature-to-body-mass 0.333 ratio)]. Furthermore, its modeling techniques perfectly address the effects of age and sex differences on growth and biological maturation in motor performance interpretation (41). Recently, Nevill et al. (37) applied an allometric modeling approach to identify the optimal body size and limb-length segment associated with 100-meter Front crawl speed performance in youth swimmers (11 to 16 years). These authors revealed that lean body mass was the singularly most important whole-body characteristic and that having greater limb segment length ratios [i.e., arm ratio = (lower arm)/(upper arm); foot-to-leg ratio = (foot)/(lower-leg)] was key to personal best Front crawl swim speeds. Likewise, Sammoud et al. (41) applied the same approach to estimate the optimal anthropometric factors associated with 100-m Butterfly speed performance in children and adolescent male and female swimmers aged ~13 years. The same authors revealed that body fat was the singularly whole-body characteristic associated with Butterfly performance. Moreover, Sammoud et al. (41) demonstrated that limb segment length-ratio [arm-ratio = (arm-span)/(lower-arm)] and limb girth-ratio [girth-ratio = (calf-girth)/(ankle-girth)] were key to personal best Butterfly swim speed in children and adolescent male and female swimmers.

Based on the considerations described above, there is still a need to carry out further research about the influence of anthropometric characteristics on different swimming styles, particularly, Breaststroke. We believe that our allometric approach to identifying the key anthropometric dimensions and their ratios in youth Breaststroke swimmers is a novel contribution to the literature especially for the purpose of talent identification. Therefore, this study aimed to use allometric models to estimate the optimal body size, limb segment length, girth and breadth ratios associated with 100-meter Breaststroke speed performance in youth swimmer athletes. Based on previous findings (37, 33), we hypothesized that 100-m Breaststroke performance is dependent on limb segment length rather than the whole body size in youth swimmers of both gender.
METHODS

Experimental approach to the problem:

To determine if anthropometric characteristics are important to the progression of swimmers, several body measurements were taken including height, body-mass, arm-span, sitting-height, skinfold thicknesses, limb lengths, girths, and breadths. The body composition was then calculated using various formulas (43). The percentage of body fat (%BF) of children with triceps and subscapular skinfolds <35 mm was calculated as follow: Boys= 1.21 (sum of 2 skinfolds)-0.008 (sum of 2 skinfolds²)-1.7 and for girls= 1.33 (sum of 2 skinfolds)-0.013 (sum of 2 skinfolds²)-2.5. The %BF for children with triceps and subscapular skinfolds >35 mm was calculated as follow: Boys= 0.783 (sum of 2 skinfolds) - 1.7 and for girls= 0.546 (sum of 2 skinfolds) +9.7. Fat-mass was calculated as follow: fat-mass = (body mass * % BF)/100; fat-free mass (kg) = body mass - fat mass.

In addition, maturity offset was assessed by predicting age at peak-height-velocity (PHV) based on age, body mass, height, leg-length, and sitting-height using the predictive equation established by Mirwald et al. (32). In girls, maturity offset = -9.376 + 0.0001882·leg length and sitting height interaction +0.0022·age and leg length interaction +0.005841·age and sitting height interaction -0.002658·age and weight interaction +0.07693·weight by height ratio*100 (32). In boys, maturity offset= - 9.236 + 0.0002708·leg length and sitting height interaction -0.001663·age and leg length interaction + 0.007216·age and sitting height interaction+ 0.02292·weight by height ratio*100 (32). The time of 100-m Breaststroke swimming performance was recorded during competitions, as it represents the peak of the performance of the Tunisian Championship established according to the official measurement rules (FINA, 2004) using a high technology electronic timing (Omega, Switzerland, the presence of officials)”.

Participants

In total, 59 Breaststroke specialist swimmers (male [n=39; age: 11.50 ± 1.26 years]; female [n=20; age: 12.05 ± 0.99 years]) participated in the study. All participants were involved in five to six training sessions per week (4000 ± 1000 m per session; 8 ± 1 hour per-week). In addition, training session included the four-stroke. Written informed parental consent and participant assent was obtained prior to the start of the study. All youth athletes and their parents / legal representatives were informed about the experimental protocol and its potential risks and benefits before the commencement of the research project. The study was approved...
Performance time and average swimming speed (m.s\(^{-1}\))

The swimming times and/or speeds (speed based on the race time) expressed in seconds and meters per second (m.s\(^{-1}\)), respectively, were adopted as our measures of swimming performance. Swimming performance was recorded in a 25-m swimming pool. The Breaststroke average speed was calculated as the ratio between distances swam and the total time recorded in this distance (m.s\(^{-1}\)). Performance (s) was measured with a high technology electronic timing (Omega, Switzerland) and was extracted for all subjects from the official results published by the Tunisian swimming Federation during the Winter National Championships. Water temperature was kept between 25 and 28 degrees, as determined by Fédération Internationale De Natation (FINA, 2014).

Anthropometric measurements

All the anthropometrical measurements were taken by one trained anthropometrist assisted by a recorder in accordance with standardized procedures of the international society for the advancement of kinanthropometry (ISAK) (45) (Table 1). Testing was carried out in a standardized order after a proper calibration of the measuring instruments. Each swimmer’s height (m) and body-mass (kg) were assessed to the nearest 0.1 cm and 0.1 kg, using a SECA stadiometer and a SECA weighing scale (SECA Instruments Ltd, Hamburg, Germany), respectively. Skinfolds measurements (in millimeters) were taken on the right-hand side of the body at two sites (the triceps and the subscapular) using Harpenden skinfold calipers (Harpenden Instruments, Cambridge, UK). Skinfold data, alongside the skinfold equation of Slaughter et al.(43), were used to estimate the body-fat mass and fat-free mass. The following limb-lengths, girths and breadths were assessed using a large sliding caliper and a non-stretchable tape measure via direct measures using landmarks techniques: arm span, upper-limb length, upper-arm length, lower-arm length, hand lengths, lower-limb length, thigh length, leg length, foot length, arm-relaxed girth, forearm girth, wrist girth, thigh girth, calf girth, ankle girth, biacromial and biiliocristal-breaths.

Upper arm length was measured from landmarks placed to acromiale and dactylion while athletes stood in the erect position. Upper arm length was determined as the distance between the marked acromiale and radiale landmarks. The lower-arm length was measured by...
calculating the distance between the radiale and stylion landmarks. For the hand length, the measure was taken as the shortest distance from the marked midstylion line to the Dactylion. Lower limb length was determined by subtracting sitting height from standing height. Thigh length was determined as the distance between the marked trochanterion and tibiale lateral landmarks. Leg length was measured as the distance from the height of the tibiale lateral to the top of the box (or the floor). Foot length was determined as the distance from the Akropodion (i.e., the tip of the longest toe which may be the first or second phalanx) to the Pternion (i.e., most posterior point on the calcaneus of the foot). Arm-relaxed girth was measured at the marked level of the mid-acromiale-radiale. The tape should be positioned perpendicular to the long axis of the arm. Forearm girth was taken at the maximum girth of the forearm distal to the humeral epicondyles. Wrist girth measure is taken distal to the styloid processes. It is the minimum girth in this region. Thigh girth measure was taken at the marked mid-trochanterion-tibiale-lateral site. Calf girth was defined as the maximum girth of the calf taken at the marked medial calf skinfold site. Ankle girth was defined as the minimum girth of the ankle taken at the narrowest point superior to the Sphyrion tibiale. Biacromial breadths were determined as the distance between the most lateral points of the acromion processes. Biliocristal breath was defined as the distance between the most lateral points on the iliac crests.

The Intraclass correlation coefficients (ICCs) for test-retest reliability for all anthropometric and skinfolds measures ranged from 0.96 to 0.99.

Statistical analysis

Descriptive statistics were computed and expressed as means and standard deviations. To identify the most suitable anthropometric characteristics [i.e., body-mass (M), fat-free mass (FFM), fat mass (FM), stature (S), limb-lengths, girths or breadths (L)] that are associated with 100-meter Breaststroke speed performance, we adopted the proportional multiplicative model with allometric body size components, similar to the 100-meter personal best swim Front crawl model used to measure speeds in children and adolescents (36) and to the 100-meter Butterfly speed model used among swimmers of the same age group (41). The benefits of this model are to have proportional body size components. Additionally, this multiplicative allometric model was extensively adopted in physical anthropology (15), and biology (3,7), and a recent call has been made for consideration within molecular biology and gene expression investigations because human size, and what it involves, will always be of concern.
Additionally, this model has been systematically used to partition out differences in size in efficient ways, such as differences in VO2 peak (3) and in a variety of motor tests (37).

**The multiplicative model:**

Breaststroke average speed \( (m.s^{-1}) = a \cdot (M)^{k_1} \cdot (S)^{k_2} \cdot \Pi (L_i)^{k_i} \cdot \exp(b \text{ biological age} + c \cdot \text{FM}) \cdot \varepsilon \) \hspace{1cm} (1)

where ‘a’ is a constant and \( \Pi (L_i)^{k_i} \) \((i=3, 4, \ldots, n)\) signifies the product of all limb segment-lengths, girths or breadths measurements raised to the power of \( k_i \); with \( i=3 \) to \( i=n \) representing the full range of limb lengths, girths, and breadths recorded for the swimmers (for the full list, see anthropometric measurements paragraph).

The benefits of this model are to have proportional body size components. Note that “\( \varepsilon \)”, the multiplicative error ratio, also assumes the error will increase in proportion to the athlete’s swimming performance. The model (Equation 1) can be linearized with a log transformation. A linear regression analysis on log (Breaststroke average speed [m.s\(^{-1}\)]) can then be used to estimate the unknown parameters of the log-transformed model:

\[ \ln(\text{Breaststroke average speed (m.s}^{-1}) = k_1 \cdot \log(M) + k_2 \cdot \log(S) + \sum k_i \cdot \ln(L_i) + a + b \cdot \text{biological age} + c \cdot \text{FM} + \log(\varepsilon) \] \hspace{1cm} (2)

Having fitted the saturated model with all available body size variables, an appropriate “parsimonious” model can be obtained using “backward elimination” (37), in which the least important body size and limb segment length, girth, and breadth variables at each step are eliminated from the model. A parsimonious model is a model that achieves a desired level of explanation or prediction with as few predictor variables as possible. Further categorical or group differences within the population (e.g., sex) can be explored by allowing the constant intercept parameter [e.g. \( \ln(a) \) refers to natural logarithms in equation 2] to vary for each group.

**RESULTS**

Table 1 shows anthropometric characteristics and swimming performance data of participants.

Boys and girls age at peak height velocity was 13.8 ± 0.6 and 12.0 ± 0.5, respectively. No significant difference was detected for all the anthropometric characteristics and the swimming performance between boys and girls (\( p>0.05 \)) except for the arm span, thigh length, lower limb length, upper arm length, and sitting height (all \( p<0.05 \)). Table 2 indicates the parsimonious solution to the backward elimination regression analysis of \( \ln(\text{Breaststroke average speed}) \).
average speed \([\text{m.s}^{-1}]\)). The multiplicative allometric model exploring the association between 100-meter average Breaststroke speed performance \((\text{m.s}^{-1})\) and the different anthropometric characteristics estimated that fat-mass (as a whole body size dimension), two upper-limb lengths (forearm and hand length), leg length for the lower limbs, two breadths (biacromial and biiliocristal breadths) and two girths (forearm and wrist girth) are the main significant predictors of log-transformed swim performance. Our allometric model detected that Breaststroke speed performance increases by 2.5% every additional year in youth swimmers. The adjusted coefficient of determination \((R^2)\) was 76.6% with the log-transformed error ratio being 0.06 or 6%, having taken antilogs. The constant ‘a’ did not vary significantly with sex, suggesting that the model can be regarded as common for children of either sex (Tables 2).

**Table 2 near here**

**DISCUSSION**

To the authors’ knowledge, this is the first study that aimed to identify the most appropriate body-size characteristics related to 100-m Breaststroke performance in youth swimmers. The outcomes of this study support previous investigations, indicating that anthropometrics are highly related to youth swimmers’ performance (21, 28, 37, 39, 41). Specifically, in agreement with previous findings (37, 41), the present results demonstrated that fat-mass was the single most important whole body-size characteristic negatively associated with Breaststroke performance. Particularly, Sammoud et al. (41) revealed that fat-mass was the only whole body-size characteristic negatively associated with Butterfly speed performance in children and adolescent male and female swimmers. Similarly, Nevill et al. (37) demonstrated that fat-free-mass was the single most important whole-body size characteristic positively associated with 100-m Freestyle performance in male and female adolescent swimmers. Jürimäe et al. (21) reported a significant correlation between fat-free mass and 400-m Front crawl performance in young swimmers. Likewise, Nasirzade et al. (35) revealed a significant negative correlation between muscle thickness \((r\) range from 0.42 to 0.56) and 200-m Front crawl performance in young swimmers \((14.5 \pm 0.8 \text{ years})\). In addition, Helmuth (25) found that fat-free mass significantly correlated \((r = 0.73)\) with 100-m Front crawl performance in 8- to 16-year-old male swimmers. The disadvantage of having higher fat-mass suggests that swimmers require greater fat-free mass, implying that they require greater muscularity to propel themselves faster through the water (40). Based on the consideration mentioned above, the positive association between fat-
Free mass and swimming performance may indicate that this anthropometric variable contributed significantly to the prediction of propulsion force. This propulsion force may translate to improve Breaststroke performance in youth boy and girl swimmers. In addition, inertial properties of the limbs may influence stroke rate, particularly, mass and mass distribution (37). Overall, greater fat-free mass is likely to be associated with greater fat-free mass in the limbs, translating into greater stroke rate and subsequent propulsion (37).

Our study showed that height and body mass did not contribute significantly to the model. These findings extended previously reported results (21, 37, 40), suggesting that the advantage of longer levers was either limb-segment length, girth or breadth specific rather than having a more general whole body size advantage. Likewise, our allometric model revealed that swimming performance average speed increases by 2.5% every additional year of the swimmer's biological age (see Table 2). Based on this result, coaches should take into consideration the biological age rather than the chronological one as a key factor in determining performance.

In addition, the key indicator from the allometric model reported in Table 2 is the advantage of having greater limb segment length ratios [i.e., arm length ratio = (hand length)/(forearm length)] and greater limb segment girth ratios [i.e., arm girth ratio = (forearm girth)/(wrist girth)] are associated with swimming faster Breaststroke speeds. Our results illustrated that forearm length made a negative contribution whereas the hand length made a positive contribution to the 100-m Breaststroke performance. These results are in agreement with previous investigations (21, 23). For instance, Perez et al. (38) revealed a significant relationship between hand length and the average of swimming speed (r=0.51). In the same context, Geladas et al. (21) demonstrated a significant relationship between 100-m Freestyle performance time and hand length measures (r= -0.6, -0.3 in boys and girls young swimmers, respectively). The same authors, also, reported a significant relationship between the foot length and the 100-m Freestyle performance time (r= -0.49, -0.16, in boys and girls, respectively). Likewise, Helmuth, (25) reported a significant correlation between hand size and swimming performance in young male and female swimmers (8-16 years). It is noteworthy that the significant relationship between 100-m Breaststroke performance and hand length could be mainly due to the fact that propulsive force and hence swimming performance is positively affected by the large upper extremity length (26). Zamparo et al. (49) argued that having a greater hand length will also act to increase surface area, thus leading to a greater propelling economy. Finally, the finding of the positive contribution of the hand length and Breaststroke performance could be attributed to the fact that propulsive
force and hence swimming performance is positively affected by the large upper extremity length.

As with hand length, our results revealed a significant contribution by the leg length in the 100-m Breaststroke performance. In addition, our findings demonstrated the importance of having shorter forearm length for better 100-m Breaststroke swimming performance. These observations are consistent with those established by Nevill et al. (37), who illustrated that longer lever length (upper-arm and lower leg) is potentially mechanically disadvantageous in some ways in 100-m Front crawl performance in adolescent swimmers of both sex. The same authors indicated that the involved muscles have to exert greater force and, hence, use greater energy. Likewise, the importance of having shorter forearm length for better 100-m Butterfly speed performance in swimmers has been recently shown (40). The same authors (40) indicated that swimmers with a shorter arm length have naturally a better swimming technique with respect to those with longer upper limbs. In the same context, Grimston and Hay (23) reported that the dimensions of body segments, such as the upper limbs or lower limbs lengths, influence the mechanics of swimming technique and muscle activity. Consequently, it seems crucial to focus on teaching the correct swimming technique starting from the early years of training (31, 40).

In addition, our findings revealed that an increase in a forearm-girth or volume would improve the 100-m Breaststroke swimming performance. This is in agreement with findings recently established by Sammoud et al. (40) who revealed that an increase in a calf-girth or volume would increase the 100-m Butterfly speed performance in adolescent swimmer athletes. Santos et al. (42) revealed a significant association between the arm muscle area and the propulsive force of the arm in young male swimmers (14 ± 1.28 years). The same authors (41) demonstrated that the increase of the arm muscle area contributes to a greater capacity for strength. This significant association could be explained by the fact that swimmers having greater limb volume or greater muscularity seem to generate higher propulsive force and propel themselves faster through water (36,40).

The current findings revealed that having a greater wrist-girth impairs performance. This is in agreement with those established by Sammoud et al. (41) who detected a negative contribution of the ankle girth in the 100-m Butterfly speed performance. A large wrist-girth would increase resistance through water, therefore increasing the energy cost of swimming (11, 12, 49). This may at least partially explain the disadvantage of having a larger wrist-girth. Our results also detected a positive association between the biacromial and bililiocristal breadths with the 100-m Breaststroke speed performance (Table 2). Recently, Sammoud et al.
relied that having greater biacromial and biiliocristal breadths are key positive anthropometric indicators associated with better 100-m Butterfly speed performance. Likewise, Geladas et al. (21) showed that swimming sprint time was significantly correlated with biacromial ($r = -0.61$) and biiliocristal breadths ($r = -0.46$) in male swimmers. All together, these findings may be related to the fact that swimmers with broad shoulders are better suited for high power output in the water (8). In addition, the positive association between the body breadths and 100-m Breaststroke performance in our study suggest that a larger body cross-section area in swimmers may be related to sprint performance time (26). According to the effect of cross-sectional area on the pressure drag, several studies (4, 10) have shown that some anthropometric parameters like the chest girth, depth and breadth are significantly correlated with drag values. In addition to the anthropometric parameters, the shape and the contour of the body are important factors too affecting the pressure drag because they determine how the flow moves over the body (14).

The main limitations of this research may be summarised as follows: (1) not included in the model were variables related to functional fitness (e.g., muscular strength or flexibility) that might influence stroke mechanics (2) variables from other domains that may also play an important role in youth swimmers’ performance (e.g. motor control, hydrodynamics, genetics) were not taken into consideration, (3) a direct measure of the propulsive efficiency was not adopted, and (4) biomechanical testing methods should be implemented in future studies to obtain an in-depths knowledge regarding the allometric associations between biomechanical, shape, and 100-m Breaststroke speed performance.

Practical Applications

The current study has several practical applications. First of all, the present results highlighted the importance of considering anthropometric characteristics of youth swimmers for talent identification and/or athlete monitoring purposes by coaches and sports scientists. Additionally, it is only by adopting multiplicative allometric models that the abovementioned ratios could have been derived. Furthermore, results of the present study illustrated that (1) fat mass was the singularly most important whole-body size characteristic, and that height and body mass did not contribute significantly to the allometric model, (2) 100-m Breaststroke average speed performance was strongly positively associated with the segment length ratio (arm-ratio and girth-ratio), and (3) leg length, biacromial and biiliocristal breadths were positively associated with the 100-m Breaststroke performance in youth swimmers.
Acknowledgments

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Disclosure statement

No potential conflict of interest was reported by the authors.
References


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<tr>
<td>Thigh-Girth (cm)</td>
<td>43.9 ± 4.5</td>
<td>46.1 ± 5.6</td>
</tr>
<tr>
<td>Calf-Girth (cm)</td>
<td>30.3 ± 3.1</td>
<td>30.7 ± 3.0</td>
</tr>
<tr>
<td>Ankle-Girth (cm)</td>
<td>20.5 ± 1.8</td>
<td>20.5 ± 1.5</td>
</tr>
<tr>
<td>Biacromial-Breadth (cm)</td>
<td>41.5 ± 3.9</td>
<td>43.3 ± 2.3</td>
</tr>
<tr>
<td>Biiliocristal-Breadth (cm)</td>
<td>24.4 ± 2.4</td>
<td>25.7 ± 2.4</td>
</tr>
<tr>
<td>Arm-Span (cm)</td>
<td>150.4 ± 13.5</td>
<td>158.3 ± 9.7*</td>
</tr>
<tr>
<td>Swimming performance (s)</td>
<td>97.7 ± 13.4</td>
<td>95.4 ± 9.5</td>
</tr>
<tr>
<td>Breaststroke average speed (m.s$^{-1}$)</td>
<td>1.0 ± 0.1</td>
<td>1.1 ± 0.1</td>
</tr>
</tbody>
</table>

* denotes ** denotes
TABLE 2. Estimated body size and limb segment parameter (B) obtained from regression analysis predicting log-transformed 100-m Breaststroke average speed performance.

<table>
<thead>
<tr>
<th>Variables in the Model</th>
<th>B</th>
<th>Std. Error</th>
<th>p</th>
<th>95% Confidence Interval for B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-6.813</td>
<td>0.561</td>
<td>&lt;0.000</td>
<td>-7.942 to -5.685</td>
</tr>
<tr>
<td>Age at peak height velocity</td>
<td>0.025</td>
<td>0.009</td>
<td>0.008</td>
<td>0.007 to 0.042</td>
</tr>
<tr>
<td>lnForearm-girth</td>
<td>0.690</td>
<td>0.240</td>
<td>0.006</td>
<td>0.207 to 1.173</td>
</tr>
<tr>
<td>lnWrist-girth</td>
<td>-0.348</td>
<td>0.128</td>
<td>0.009</td>
<td>-0.604 to -0.091</td>
</tr>
<tr>
<td>lnBiacromial-Breadth</td>
<td>0.565</td>
<td>0.221</td>
<td>0.014</td>
<td>0.121 to 1.009</td>
</tr>
<tr>
<td>lnBiiliocristal-Breath</td>
<td>0.403</td>
<td>0.109</td>
<td>0.001</td>
<td>0.185 to 0.622</td>
</tr>
<tr>
<td>lnLeg-length</td>
<td>0.673</td>
<td>0.264</td>
<td>0.014</td>
<td>0.143 to 1.203</td>
</tr>
<tr>
<td>lnHand-length</td>
<td>0.309</td>
<td>0.195</td>
<td>0.120</td>
<td>-0.083 to 0.702</td>
</tr>
<tr>
<td>LnForearm-length</td>
<td>-0.418</td>
<td>0.220</td>
<td>0.064</td>
<td>-0.861 to 0.025</td>
</tr>
<tr>
<td>Fat-Mass</td>
<td>-0.018</td>
<td>0.004</td>
<td>&lt;0.001</td>
<td>-0.026 to -0.010</td>
</tr>
</tbody>
</table>

Ln: Natural Log; Std: Standard