Key anthropometric variables associated with front-crawl swimming performance in youth swimmers: an allometric approach

Running head: Allometric models and front crawl swimming performance.

Abstract

This study aimed to establish key anthropometric characteristics (e.g., optimal body height, limb-segment length and girth/breadth ratios) related to 100-m front crawl performance in young swimmers. In total, 74 swimmers (boys [n=41; age: 18.1 ± 3.5 years]; girls [n=33; age: 15.9 ± 3.1 years]) participated in this study. We adopted a multiplicative allometric log-linear regression model to identify key anthropometric characteristics associated with 100-m front crawl swimming performance. The main outcomes indicated that length ratio= ([height/leg length]), foot length and ankle girth, biacromial breadth and % of body fat were associated with 100-m front crawl mean swimming speed performance. These findings highlight the importance of assessing anthropometric characteristics in young front crawl swimmers for talent identification and development.

Key Words: allometric model; somatic measurements; swimmer athletes.

INTRODUCTION

Optimal performance in sports is multifactorial and affords the assessment of anthropometrics, technical/tactical, physiological and physical qualities to identify and develop young talents (1,17). Some of these factors are rather difficult to assess (e.g., technical/tactical). Others however (e.g., anthropometrics) can be accurately tested using standardized methods that may provide useful information for talent scouts, coaches and strength and conditioning trainers (25).

In fact, understanding the main anthropometric variables underpinning youth's swimming performance is crucial for talent identification (21). There is compelling evidence from swimming studies that anthropometric variables are related to swimming performance (15, 21, 23, 24, 25). It is well-known from previous studies that tall and heavier swimmers are able to produce greater force per stroke (14). This observation is mainly due to their longer stroke length (21). Shorter swimmers, on the other hand, cannot achieve such long stroke length and they generally compensate by utilising a higher stroke rate (14). Of note, better swimming (i.e., propelling) economy and longer stroke length are associated with a greater stature and segment length in front-crawl adult male swimmers (28). Likewise, arm span appears to be the principal anthropometric variable predicting 100-m front crawl swimming performance in young swimmers aged 12 years (20).

Recently, Nevill et al. (21) applied an allometric approach to identify the optimal body size and limb length segment associated with 100-m front-crawl speed performance in young swimmers aged 11–16 years. These authors revealed that lean body mass was the most important whole body characteristic associated with front-crawl swimming performance. In addition, the same authors revealed that limb segment length ratios (i.e., arm ratio = lower arm/upper arm; foot-to- leg ratio = foot/lower leg) was a key front-crawl swimming speed predictor. Yet, the same authors did not consider the girth of the associated segment. This needs to be further explored as segment girths have been shown to be key performance determinants associated with breastroke (forearm and wrist girth) (24), butterfly (calf and ankle girth) (23), and backstroke (forearm and arm relaxed girth) (25) swimming performances in young swimmers.

Previously, Sammoud et al. (24) reported positive associations between 100-m breastroke performance and upper limb-girth ratio (girth ratio = forearm girth/wrist girth) in young swimmers aged □12 years. Moreover, limb-girth ratio (girth ratio =calf girth/ankle girth) has been shown to be one of the key determinants in butterfly swimming performance in a large sample of youth male and female swimmers aged □13 years (24). More recently, Sammoud et al (25) revealed that forearm girth as well as arm relaxed girth are among the main backstroke performance predictors in young swimmers aged 13-14 years.

Taken together, lower and upper limb girths appear to be key anthropometric variables related to breastroke (forearm and wrist girth) (24), butterfly (calf and ankle girth) (23), and backstroke (forearm and arm relaxed girth) (25) swimming performance. Surprisingly, the impact of limb girth on front crawl swimming perfromance has not yet been examined. Therefore, this study aimed to establish key anthropometric characteristics (e.g., limb girth, body height, mass etc) associated with 100-m front crawl speed performance in male and female young national level swimmers.

METHODS

Experimental approach to the problem

Several body measures were assessed including body height, body-mass, sitting-height, skinfold thicknesses, limb lengths, girths, and breadths. Swimmers' body composition was then calculated using established equations from the literature (10, 26)

Participants

In total, 74 front crawl swimmers (boys [n=41; age: 18.1 ± 3.5 years]; girls [n=33; age: 15.9 ± 3.1 years]) participated in this study. All participants were involved in five to six training sessions per week (distance 5 km± 1 km per session; 8 ± 1 hour per week) including the four swimming strokes. All swimmers are specialists in 50-m, and 100-m front-crawl race. The study was approved by the local Ethics Institutional Review Committee for the ethical use of human subjects at Ksar Saïd University, La Manouba, Tunisia.

Performance time and avearge swimming speed (m.s^{-1})

The 100-m 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 front-crawl mean 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 participants from the official results published by the Tunisian Swimming Federation during the Winter National Championships. Water temperature was kept between 25 and 28 degrees celsius, as determined by Fédération Internationale De Natation (12).

Anthropometric measurements

All anthropometric measurements were taken by a qualified anthropometrist trained in accordance with standardized procedures of the International Society for the Advancement of Kinanthropometry (ISAK) (27) (Table 1). Testing was carried out in a standardized order after careful calibration of the measuring devices. Each swimmer's anthropometrics were assessed including body height (against the wall), body-mass, sitting-height, skinfold thicknesses, limb lengths, girths, and breadths (m) and body-mass (kg). Skinfold measurements (mm) were taken from the right-hand side of the body using Harpenden skinfold calipers (Harpenden Instruments, Cambridge, UK). Skinfold data, alongside the skinfold equation of Slaughter et al. (26), were used to estimate 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-breadths.

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 was 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 was measured distal to the styloid processes. This corresponds to the minimum girth in this region. Thigh girth measures were 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. Biiliocristal breath was defined as the distance between the most lateral points on the iliac crests. All somatic measures were recorded twice and the mean scores were retained for further statistical analysis. Intraclass correlation coefficients (ICCs) for test-retest reliability ranged from 0.97 to 0.99 for all anthropometric and skinfolds measures.

Table 1 near here

Statistical analyses

Descriptive statistics were computed and expressed as means and standard deviations. Data were tested for normality using Shapiro-Wilk’s test. Between-group (boys vs. girls) differences were examined using the independent t-test. Cohen’s d effect size (ES) was determined and classified as small ($0.00< d < 0.49$), medium ($0.50< d <0.79$), and large ($d > 0.80$) (8). Test-retest reliability was assessed using ICCs. To identify the most suitable somatic characteristics (i.e., body-mass [M], fat-free mass [FFM], fat mass [FM], height [H], limb-lengths, girths or breadths [L]) that are associated with 100-m front crawl swimming performance, we adopted the proportional multiplicative model with allometric body size components, similar to the 100-m backstroke speed model used to analyze swimming speed in children (25). Statistical analyses were performed using SPSS 20.0 (SPSS, Inc., Chicago, IL, USA).

The multiplicative model:

$$\text{Front crawl mean speed (m.s}^{-1}) = a \cdot (M)^{k_1} \cdot (H)^{k_2} \cdot (\%BF)^{k_3} \cdot \Pi\, (L_i)^{k_i} \cdot \varepsilon \qquad \text{(Eq 1)}$$

where 'a' is a constant, M is mass, H is height, %BF is body fat percent and $\Pi\,(L_i)^{k_i}$ (i=4,…, n) signifies the product of all limb segment-lengths, girths or breadths measurements raised to the power of k_i; with i=4 to i=n representing the full range of limb lengths, girths, and breadths recorded for the swimmers.

The benefits of this model are that we included proportional body size components. Note that "ε", the multiplicative error ratio, also assumes the error associated with mean swimming speed will increase in proportion with the athlete's body size.

The model (Eq 1) can be linearized with a log transformation. A linear regression analysis on log (front crawl mean speed [$m.s^{-1}$]) can then be used to estimate the unknown parameters of the log-transformed model:

$$\text{Ln (front crawl mean speed (m.s}^{-1})) = k_1.\log(M) + k_2.\log(H) + k_3.\log(\%BF) + \Sigma\, k_i \cdot \ln(L_i) + a + \log(\varepsilon) \text{ (Eq 2)}$$

Having fitted the saturated model with all available body size variables, an appropriate ''parsimonious'' model was obtained using ''backward elimination'' (21), in which the least important (non-significant) body size, limb segment length, girth, and breadth variables was eliminated during each processing step. A parsimonious model is a model that achieves an acceptable level of explanation or prediction with as few predictor variables as possible. The constant intercept parameter [ln(a) refers to natural logarithms in Eq 2] can vary for each group (girls and boys) by introducing boys as a [0,1] indicator variable in the regression analysis, see Table 2.

RESULTS

Table 1 shows anthropometric characteristics and swimming performance data of all participants. All data were normally distributed (all $p > 0.05$). Boys and girls were aged 18.1 ± 3.5 years and 15.9 ± 3.1 years, respectively. Table 2 indicates the parsimonious solution to the backward elimination regression analysis of ln(Front Crawl mean speed [m/s^{-1}]). The multiplicative allometric model exploring the association between 100-m front crawl mean speed performance ($m.s^{-1}$) and the different somatic characteristics estimated that foot length is one of the main positive significant predictors of mean swimming performance (exp(0.264, and $p<0.05$). In addition, our allometric model revealed positive significant associations between height, and biacromial-breadth, with the 100-m swim performance (exp(0.789, and 0.537), for height and biacromial breadth, respectively; all $p<0.05$). However, our statistical calculation showed negative associations between the % body fat, leg length, ankle girth, with the 100-m swimming performance (exp(-0.053, -0.346, and -0.159), for body fat, leg length, and ankle girth, respectively; all $p<0.05$).

The constant [ln(a)] varied significantly by sex, with boys being 3.8% (exp(0.037)=1.038) faster than girls, see Table 2 .

Table 2 near here

DISCUSSION

This study attempted to elucidate key anthropometric variables related to 100-m front-crawl mean speed performance in national Tunisian male and female swimmers. Results of this study support previous investigations, indicating that anthropometrics are highly related to swimmers' performance (15, 23).

Our results revealed that height and percentage of body fat are the most important whole body sizes that contribute significantly to the allometric model. This is in agreement with previously published studies (3, 19, 23).

Particularly, Latt et al. (19) reported that swimming performance was primarily associated with body size (height) and arm span, thereby reflecting a higher VO_{2peak} (ml.kg-1·min-1) and improved biomechanical swimming variables. It appears that a longer torso allows swimmers to cut the water with less water resistance and their long bodies give them an automatic edge (25). In addition, Caputo et al. (3) showed that for events with a short duration, in which power production capacity is considered a key variable, anthropometric characteristic such as body height, and body composition may also contribute to the level of performance. However, these morphological attributes largely depend on genetic factors and may have a decisive influence on swimming performance (Latt et al., 2010). In addition, Sammoud et al (2017) revealed that fat mass was the only whole-body size characteristic negatively associated with butterfly speed performance in children and adolescent swimmers. In the same context, Jürimäe et al. (17) reported a significant correlation between fat-free mass and 400-m front crawl performance in young swimmers. The disadvantage of having higher fat mass suggests that swimmers require greater fat-free mass, implying that they require more muscle mass to swim fast (14, 21, 22).

Our statistical calculations showed that boys front crawl mean speed performance is 3.8% faster than girls' elite swimmers. Our findings are in accordance with those established by Sammoud et al. (23) who found that male butterfly mean speed performance is 5.6% greater than female swimmers. Likewise, Geladas et al. (15) found that elite male 100-m front-crawl speed performance is 3.8% faster than female elite swimmers. More recently, Sammoud et al. (25) revealed that girls' backstroke mean speed performance is 4.1% less than boys. In the same context, Kennedy et al. (18) showed that males usually swam faster (about 10% on mean) than women in the four 100-m swimming events (i.e., backstroke, breaststroke, butterfly, and front crawl) during the Seoul Olympic Games (1988). East, (11) found that male swimmers had longer stroke lengths but similar stroke rates than their female counterparts. The same author concluded that the longer stroke length produced by men was most likely the result of greater propulsive force.

The advantage of having greater limb segment length ratios (i.e., leg length ratio = [height]/[leg-length]) appears to be the most important indicator derived from the allometric model on front crawl mean speed performance (Table 2). In addition, our results indicated that the foot-length made a positive contribution to the 100-m front crawl mean speed performance, but having a longer leg length impairs performance. These findings support those reported by Nevill et al. (21) who detected a negative contribution of leg length and a positive contribution of foot length in 100-m front crawl performance in male and female swimmers. According to Zamparo et al. (29), the advantage of having a greater foot length permits increasing surface area, thus leading to greater propelling economy (29). However, having longer legs are unnecessary in swimming, as increased leg length will alter the flotation of the swimmer, potentially resulting in sinking of the legs. An increase in the downward inclination of the legs would increase resistance through water, therefore increasing the energy cost of swimming (5). This may at least partially explain the advantage of having shorter lower legs.

Our findings further illustrate positive associations between the biacromial breadth with 100-m front-crawl speed performance (Table 2). Geladas et al. (15) showed that swimming sprint time was significantly correlated with biacromial breadth (r= - 0.61) in male swimmers (the negative correlation is the result of using performance time not speed). More recently, Sammoud et al. (23) and Sammoud et al. (25) demonstrated that having greater biacromial breadth is a key anthropometric feature associated with better 100-m butterfly and backstroke speed performance in young male and female swimmers. Altogether, these findings may be related to the fact that swimmers with broad shoulders are better suited for high power output in the water (4). In addition, the positive association between body breadths and 100-m front crawl performance in our study suggests that a larger body cross-sectional area in swimmers may be related to better sprint performance time (16). According to the effect of cross-sectional area on the pressure drag, several studies (2, 5) have shown that some anthropometric parameters like the chest girth, depth and breadth are correlated with drag values. In addition to the anthropometric parameters, the shape and the contour of the body are also important factors affecting the pressure drag because they determine how the flow moves over the body (13).

We also identified that the ankle-girth made a negative contribution to the prediction of 100-m front-crawl speed performance. These results are supported by those of Sammoud et al. (23) who showed that having a greater ankle-girth impairs butterfly speed performance in youth swimmers. Therefore, having a greater ankle-girth impairs performance. Of note, it has been suggested that increased joint flexibility enables the swimmer to achieve a greater range of motion (ROM) (9). In the same context, Cohen el al. (7) revealed that swimmers require good plantar flexion of the ankles. The same authors found a significant effect between ankle flexibility and propulsive force which allows swimmers a larger range of motion.

Conclusions

Findings from the present study suggest that foot length, length ratio ([height/leg length]) and ankle girth, biacromial breadth and % of body fat were related to 100-m front crawl mean swim speed performace. These findings are of practical relevance for talent identification and development for talent scouts, coaches and practitioners in the field of youth swimming.

Disclosure statement

All authors report no potential conflict of interest.

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