Key somatic variables in young backstroke swimmers

Running title: Allometric models and backstroke swimming performance.

Abstract:

The purpose of this study was to estimate the optimal body size, limb-segment length, girth or breadth ratios for 100-m backstroke mean speed performance in youth swimmers. Sixty-three young swimmers (boys [n=30 ; age: 13.98 ± 0.58 years]; girls [n=33; age: 13.02 ± 1.20 years]) participated to this study. To identify the optimal body size and body composition components associated with 100-m backstroke speed performance, we adopted a multiplicative allometric log-linear regression model, which was refined using backward elimination. The multiplicative allometric model exploring the association between 100-meter backstroke mean speed performance and the different somatic measurements estimated that biological age, sitting height, leg length for the lower-limbs, and two girths (forearm and arm relaxed girth) are the key predictors. Stature 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 findings highlighted the importance of considering somatic characteristics of youth backstroke swimmers and can help swimming coaches to classify their swimmers and enable them to suggest what might be the swimmers' most appropriate stroke (talent identification).

Key Words: Allometric models; anthropometric measures; backstroke swimming; gender; talent identification.

INTRODUCTION

Assessment of athletes' physique can provide valuable insights into the relationship between anthropometric characteristics and sports performance. When expensive, high technology such as Dual Energy X-ray Absorptiometry (DEXA) is impractical or unavailable, human physique assessment offers a wealth of alternative information that can be used to identify key characteristics associated with elite performance. Human physique consists of the three distinct but interrelated anthropometric components of body size, structure and composition (Nevill, Tsiotra, Tsimeas, & Koutedakis, 2009). Body size refers to the physical magnitude of the body and its segments (stature, mass, surface area, etc). Body structure or shape describes the distribution of body parts expressed as ratios, such as the body mass index (BMI), the inverse ponderal index or the head length-to-body length (exclusive of head) ratio. Body composition consists of the amount of various constituents in the body such as fat, muscle, bone, etc.

It is well documented that differences in human physique confound physical fitness (e.g., endurance, strength, and power) in many sports, for instance, soccer and swimming (Negra, Chaabene, Hammami, Khlifa, Gabett, & Hachana, 2015; Nevill, Oxford, & Duncan, 2015; Sammoud, Nevill, Negra, Bouguezzi, Chaabene, & Hachana, 2017; Chamari, Moussa-Chamari, Boussaïdi, Hachana, Kaouech & Wisløff, 2005). Allometric modelling is currently considered an appropriate analytical procedure to explore this issue given its sound theoretical basis as well as its biologically driven and versatile statistical underpinning (Nevill, Duncan, Lahart, & Sandercock, 2016). It consists of mathematically expressing the extent to which a performance variable (e.g., physiologic, anatomic, or temporal) is often proportionally related to a unit of body size, as both size and performance varies (Nevill et al. 2009).

The allometric approach has been previously used to examine the influence of different body size variables on $\dot{V}O_2$ peak (Nevill, Ramsbottom, Williams, 1992; Batterham, George, Mullineaux, 1997), swimming speed performance (Nevill et al. 2015; Sammoud, Nevill, Negra, Bouguezzi, Chaabene, & Hachana, 2018), and on a variety of physical fitness tests (Chamari et al. 2005; Negra et al. 2015; Nevill, Duncan, Lahart, & Sandercock, 2016).

Recently, Nevill et al. (2016) used the allometric scaling approach in a sample of 4763 adults aged 20–69 years to explore the utility of waist circumference (WC) and waist-to-stature ratios in explaining cardio-metabolic risk. Their work identified a need to scale waist circumference to provide a better index associated with cardio-metabolic risk in adults. They proposed a new somatic index: waist circumference / stature $^{0.5}$ which was a stronger predictor of cardio-metabolic risk than a range of other somatic indices of adiposity status including body mass index, waist circumference, and waist-to-stature ratio. The same authors concluded that there is a need to scale WC to improve understanding of the association between adiposity and health-related variables.

Swimming is a complex sport, where interactions between several factors (e.g., physiological, biomechanical) from different fields of science occur. Hence, swimming performance results from a multifactorial process that involves several domains, such as the anthropometrics (Geladas, Nassis, & Pavlicevic, 2005), hydrodynamics (Kjendlie, & Stallman, 2008; Marinho, Barbosa, Costa, et al. 2010; Naemi, Easson, & Sanders, 2010), kinematics (Jurimae, Cicchella, Latt, Purge, Leppik, & Jurimae, 2007 ; Barbosa, Costa, Marinho, Coelho, Moreira, & Silva, 2010) and energetics (Poujade, Hautier, & Rouard, 2002). Given that swimming competition starts at an early age, it is crucial to know how these variables interact with performance (Sammoud et al. 2018).

In this context, Nevill et al. (2015) provided a novel and valuable insight into the most appropriate body-size and shape characteristics associated with 100-m front crawl swimming performance. The same authors suggested that the advantage of longer levers was limb-segment-specific rather than a more general whole-body advantage. In addition, by adopting allometric models, Sammoud et al. (2017) revealed that 100-m butterfly speed performance was strongly and positively associated with the segment length ratio [(armspan)/(forearm-length) and girth ratio (calf-girth)/(ankle-girth), rather than the whole body size characteristics. Recently, Sammoud et al. (2018) showed that the 100-m breaststroke performance was positively associated with the segment length ratio [arm-ratio= (hand-length)/(forearm-length)] and limb girth-ratio [girth-ratio=(forearm-girth)/(wrist-girth)]. We recognize that in the past, Tanner (1964) has criticized the use of ratios when used in the context of limb size selection. More recently however, Nevill et al. (1992) was able to justify the use of such ratios, using multiplicative allometric modelling, given its sound theoretical procedures that can accommodate the proportional nature of such data as well as its versatile statistical methodology. It is noteworthy that only by adopting multiplicative allometric models could the aforementioned ratios have been derived (Nevill et al. 2015; Nevill et al. 2016).

Nevertheless, most of the studies described previously were performed in front crawl, breaststroke, and butterfly swim strokes (Geladas et al. 2005; Nevill et al. 2015; Sammoud et al. 2017; Sammoud et al. 2018) but not in backstroke. As such, there is a gap in the literature given the relationships between somatic measures and backstroke swimming performance has yet to be explored (Barbosa, Costa, Marinho, Coelho, Moreira, & Silva 2010).

Therefore, the aim of the current study was to adopt allometric models to explore and assess/estimate the optimal body size, limb segment length, girth and breadth ratios associated with 100-meter backstroke speed performance in youth swimmer athletes.

METHODS

Study design

To determine if somatic characteristics are important when predicting 100-meter backstroke speed performance, several body measurements were assessed including stature (against the wall) , body-mass, sitting-height, skinfold thicknesses, limb lengths, girths, and breadths. Swimmers' body composition was then calculated using various formulas (Slaughter, Lohman, Boileau, Horswill, Stillman, VanLoan, & Bemben, 1988).

In addition, maturity status was determined according to the maturity offset method based on age, body-mass, stature , leg-length, and sitting-height using the predictive equation proposed by Mirwald, Baxter-Jones, Bailey, & Beunen, (2002). 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 body mass interaction +0.07693·body mass by stature ratio*100 (Mirwald et al. 2002). 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·body mass by stature ratio*100 (Mirwald et al. 2002).

Participants

In total, 63 backstroke specialist swimmers (boys [n=30 ; age: 13.98 ± 0.58 years]; girls [n=33; age: 13.02 ± 1.20 years]) participated to this study. All participants were involved in five to six training sessions per week (distance 4000 ± 1000 m per session; 8 ± 1 hour per-week) including the four swimming strokes. The study was approved by the local Ethics Institutional Review Committee for the ethical use of human subjects at Ksar Saïd University, Tunisia.

Performance time and mean swmming speed ($m.s^{-1}$)

The swimming times and 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 backstroke mean speed was calculated as the ratio between distances swam and the total time recorded for this distance ($m.s^{-1}$). Performance was measured with an electronic timing (Omega, Switzerland) and was retrieved for all swimmers 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).

Somatic measurements

All somatic measurements were taken by one qualified anthropometrist trained in accordance with standardized procedures of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart, Marfell-Jones, Olds, & de Ridder, 2011) (Table 1). Testing was carried out in a standardized order after a careful calibration of the measuring devices. Each swimmer’s stature (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). The triceps skinfold site is marked over the most posterior part of the triceps when viewed from the side at the marked mid-acromiale-radiale level. In addition the subscapular skinfold site is marked in the inferior angle of the scapula. Skinfold data, alongside the skinfold equation of Slaughter et al. (1988), were used to estimate the body-fat mass and fat-free mass. All anthropometric measures were recorded twice and the mean scores were retained for the statistical analysis.

The Intraclass correlation coefficients (ICCs) for test-retest reliability for all somatic and skinfolds measures ranged from 0.97 to 0.99 and all typical errors of measurement were <5%.

Table 1 near here

Statistical analysis

Descriptive statistics were computed and expressed as means and standard deviations. Data were tested for normality using Shapiro-Wilk’s test. Between-group 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 ($d > 0.80$) (Cohen, 1998). To identify the most suitable somatic 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 backstroke swimming performance, we adopted the proportional multiplicative model with allometric body size components, similar to the 100-meter butterfly speed model used to analyse speeds in children and adolescents (Sammoud et al. 2017). Indeed, this multiplicative allometric model has been chosen because most phenomena (e.g. biological, physical etc) are inherently multiplicative (proportional with body size) rather than additive, and it is this proportional rather than absolute variations that is key, especially across the orders of magnitude spanned by most allometric analyses. In addition, the model has been extensively used to normalize physiological variables for differences in body size in an efficient manner, for example, variables such as $\dot{V}O_2$ peak, waist circumference and a variety of motor perfomance tests (Nevill et al. 2015; Sammoud et al. 2017). Statistical analyses were performed using SPSS 20.0 (SPSS, Inc., Chicago, IL, USA).

The multiplicative model:

Backstroke mean speed $(m.s^{-1}) = a \cdot (M)^{k_1} \cdot (S)^{k_2} \cdot \Pi\, (L_i)^{k_i} \cdot \exp(b \text{ biological age}) \cdot \varepsilon$ (Eq 1)

where 'a' is a constant, M is mass, S is stature and $\Pi\, (L_i)^{k_i}$ (i=3, 4,..., 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 somatic measurements paragraph).

The benefits of this model are to have proportional body size components. Note that "ε", the multiplicative error ratio, also assumes the error associated with mean swimming speed will increase in proportion to the athlete's body size. For example, see the relationship between mean swimming speeds and young swimmers' forearm girth measurements (Figure 1)

Figure 1 about here

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

Ln (backstroke mean speed ($m.s^{-1}$)) $= k_1.\log(M) + k_2.\log(S) + \Sigma k_i \cdot \ln(L_i) + a + b.\text{biological age} + \log(\varepsilon)$ (Eq 2)

Having fitted the saturated model with all available body size variables, an appropriate ''parsimonious'' model can be obtained using ''backward elimination'' (Nevill et al. 2015), in which the least important (non-significant) body size, limb segment length, girth, and breadth variables at each step are eliminated from the model. A parsimonious model is a model that achieves an acceptable level of explanation or prediction with as few predictor variables as possible. Further categorical or group differences in the experimental group (e.g., *sex*) can be explored by allowing the constant intercept parameter [e.g. ln(a) refers to natural logarithms in Eq 2] to vary for each group.

RESULTS

Table 1 shows somatic characteristics and swimming performance data of participants. Boys and girls age at peak height velocity was 12.56 ± 1.21 years and 12.20 ± 0.49 years, respectively. Table 2 indicates the parsimonious solution to the backward elimination regression analysis of ln(backstroke mean speed [$m.s^{-1}$]). The multiplicative allometric model exploring the association between 100-meter backstroke mean speed performance ($m.s^{-1}$) and the different somatic characteristics estimated that biological age, sitting height, leg length for the lower-limbs, and two girths (forearm and arm relaxed girth) are the main significant predictors of mean swim performance. Our allometric model detected that backstroke speed performance increases by 3.7% every additional year in young swimmers (within the age range of our observed data). The constant 'a' varied significantly by sex with females swimming 4.1% slower than male elite swimmers (Table 2). The adjusted coefficient of determination (R^2) was 75% with the log-transformed error ratio being 0.04 or 4%, having taken antilogs.

Table 2 near here

DISCUSSION

The present study used an allometric modelling approach to identify the most appropriate body size characteristics related to 100-m backstroke mean speed performance in boys and girls young swimmers. Our results revealed that stature and body mass did not significantly contribute to the allometric model, suggesting that the advantage of longer levers was limb-segment-specific rather than a more general whole-body advantage. These results are in accordance with previous recent studies (Nevill et al. 2015; Sammoud et al. 2017; Sammoud et al. 2018).

Additionally, the allometric model revealed that backstroke mean speed increases by 3.7% every additional year of the swimmers' biological age (see Table 2). Our results support previous researches demonstrating that biological age is a better predictor of performance than chronological age in various sport disciplines (Beunen, 1989; Beunen & Malina, 2008; Sammoud et al. 2018). Likewise, Sammoud et al. (2018) showed that breaststroke swimming performance mean speed increases by 2.5% every additional year of the swimmers' biological age. Based on this result, coaches should take into consideration the biological age rather than chronological age as a key factor in determining swimming performance.

Our findings are strengthened by the other results found in our model revealing that having a long torso (sitting height) affects positively the 100-m backstroke mean speed. It would appear that a longer torso allows the swimmers to cut the water with less water resistance and their long bodies give them an automatic edge. In his highly cited book, Charles, (2010) explained why, theoretically, a longer boat is faster than a shorter boat. He explained that the more relevant characteristic is actually the load waterline length (LWL) that is the most decisive factor in establishing how fast a boat can ultimately go. As a general rule the maximum speed of any displacement hull or hull speed (HS) is governed by a simple formula: $HS = 1.34 \times \sqrt{LWL}$; with

HS: Hull Speed expressed (knots)

LWL: Load Waterline Length (feet).

The analogy implied here to backstroke swimming performance is that the longer sitting-height component of the skeleton well reflects the benefits of a longer boat's hull when travelling through the water.

Additionally, results indicated that female backstroke mean speed performance is 4.1% less than male swimmers. Our findings are in line with those established by Geladas et al. (2005) who found that elite male 100-m front crawl speed performance is 3.8% faster than female elite swimmers. Likewise, Sammoud et al. (2017) showed that male butterfly mean speed performance is 5.6% greater than female swimmers. Kennedy et al. (1990) found that males usually swam faster (about 10% on average) than women in the four 100-m swimming events (backstroke, breaststroke, butterfly, and front crawl) during the Seoul Olympic Games (1988). East, (1970) 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.

Our results illustrated that leg length made a positive contribution to the 100-m backstroke performance. Our results extend the findings reported by Sammoud et al. (2018) who showed a significant positive contribution of leg length to 100-m breaststroke performance in young male and female swimmers. In backstroke swimming the upper and lower limbs move in a coordinated manner to produce a propulsive action. Even though the action of lower limbs is less effective than the arm stroke, its participation enables the achievement of 10% gain in swimming speed (Deschodt, Arsac, & Rouard, 1999).

Probably, the most important indicator from the allometric model provided in Table 2 is the advantage of having greater limb segment girth ratios [i.e., arm girth ratio = (forearm girth)/(arm relaxed girth)] on swimming backstroke mean speed. Our results illustrated that the forearm girth made a positive contribution to the 100-m backstroke mean speed performance, but having a greater arm relaxed girth impairs performance. The advantage of having a greater limb segment girth ratio [i.e., arm girth ratio = (forearm girth)/(arm relaxed girth)] could be explained by the ratio reflecting a measure of muscularity, i.e., with the muscularity component resulting from the flexed vs. non-flexed girth ratio. Similar results were reported by Sammoud et al. (2018) who showed that an increase in the forearm-girth or volume would improve 100-m breaststroke swimming performance. Sammoud et al. (2017) also revealed that an increase in a calf-girth or volume would increase the 100-m butterfly mean speed performance in adolescents male and female. Further support comes from Santos et al. (2012) who revealed a positive association between the arm muscle area and the propulsive force of the arm in young male swimmers. Finally, Geladas et al. (2005), showed a strong association between the handgrip strength and 100-m front crawl performance times in male swimmers (r= -0.73).

We recognise the current study has a number of limitations. Primarily, we did not assess the long term effect of the anthropometric characteristics on measures of backstroke performance. In addition, we were unable to assess the contributions of other variables such as, (1) functional fitness (e.g., muscular strength, muscular power 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), (3) biomechanical testing methods.

Conclusion

In summary, the present study revealed that the biological age, sitting height, leg length and girth ratio [(forearm-girth)/(arm relaxed-girth)] could be used as predictors for 100-m backstroke performance in swimmer athletes (adjusted R^2 = 75%; standard error is 0.04 or expressed as an error ratio of 4%, having taken antilogs). Therefore, these results highlighted the importance of considering somatic characteristics of young swimmers for talent identification (i.e., to help allocate swimmers in their most appropriate stroke).

Disclosure statement

No potential conflict of interest was reported by the authors.

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