Original Article

Contribution of anthropometric characteristics to critical swimming velocity and estimated propulsive force

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Abstract:

The aim of this study was to determine the anthropometric profiles of young male and female swimmers and to investigate the contribution of anthropometric characteristics to two determinants of swimming performance: critical velocity and estimated propulsive force. The study sample consisted of 25 female (age: 12.0 ± 0.9 years, height: 152.2 ± 8.3 cm, body mass: 42.0 ± 7.8 kg) and 25 male (age: 12.4 ± 1.2 years, height: 154.7 ± 11.3 cm, body mass: 49.1 ± 12.0 kg) swimmers. The swimmers were grouped in gender categories. For this study, the anthropometry was divided into 3 categories: length (cm), breadth (cm), and girth (cm) measurements. The critical velocity was estimated from 200-m and 400-m freestyle swimming performance. The estimated propulsive force was calculated using arm muscle area. Statistically significant correlation coefficients (ranging from 0.34 to 0.66) were found between the anthropometric characteristics (19 characteristics) and critical velocity for the female swimmers. Regarding swimming performance determinants, the highest correlations were between the hip girth and critical velocity ($r = 0.66$; $p < 0.05$) and between the flexed arm and estimated propulsive force ($r = 0.87$; $p < 0.05$). For the male swimmers, the highest correlations were between the transverse chest and critical velocity ($r = 0.81$; $p < 0.05$) and between the thoracic girth and estimated propulsive force ($r = 0.90$; $p < 0.05$). The somatotype analysis showed that the female swimmers were of the ecto-mesomorph type, and the male swimmers were of the endo-mesomorph type. The skinfold, length, girth and breadth could be used as predictors of critical velocity and estimated propulsive force in young swimmers. This study could help swimming coaches attain objective knowledge about the swimming performance of their athletes after basic anthropometric measurements and help them to benefit from this knowledge while monitoring the athletes' developmental process.

Keywords: body composition, force, somatotype, performance, swimming

Introduction

Swimming is a popular sport, and early starting specialization. Although performance and success in elite swimmers depend on various factors, physical parameters (i.e., body height, body mass and somatotype characteristics) are also determinants of swimming performance. In previous studies, physical properties, anthropometric characteristics and some of the strength parameters of swimmers were identified (Cochrane et al., 2015; Richardson, Beerman, Heiss, 2000), and the correlations between these parameters and swimming performance were investigated (Barbosa, Morais, Marques, Costa, & Marinho, 2015; Girold, Calmels, Maurin, Milhau, & Chatard, 2006; Kukolj, Ropret, Ugarkovic, & Jaric, 1999). Critical swimming speed (V_{crit}) is typically used as a determinant of swimming performance in the literature (Wakayoshi et al., 1992).

Various factors, such as physical fitness, motor skills, mental abilities, tactical training and anthropometric profiles affect the performance and success of athletes. Besides other factors, some physical parameters, such as somatotype components, body mass and body height are factors that influence competition success (Martín-Matillas et al., 2013). Somatotype properties yield descriptive and substantive information about the anthropometric profiles of athletes. Some prior studies only included descriptive information on general body properties (body height, body mass and body fat ratio [BFR] of young swimmers) in relation to the age group and gender (Bagnall & Kellett, 1977; Richardson, Beerman, Heiss, Shultz, 2000; Zuniga et al., 2011), whereas in other studies, the relation between various anthropometric characteristics (arm and leg lengths) of swimmers and their performance were identified (Avlonitou, 1994; Zuniga et al., 2011). In another study, upper extremity length, leg strength and grip strength were found to be determinants for 100-m freestyle swimming performance in male swimmers who were 12 to 14 years of age (Geladas, Nassis, & Pavlicevic, 2005). In general, these studies revealed that swimming performance is influenced by physical and anthropometric characteristics. In addition, some studies that investigated the arm muscle area (AMA), strength and swimming performance demonstrated that swimmers with a higher arm strength swim faster, which is an important performance-related

research finding (De Ste Croix, Armstrong, Welsman, & Sharpe, 2009; Hawley & Williams, 1991; Klika & Thorland, 1994; Santos, Barbosa, Melo, Veronese da Costa, & Costa, 2012).

Propulsive force is another factor that influences the swimming performance. Propulsive force is highly correlated with swimming speed and performance, according to prior studies (Geladas et al., 2005; Santos et al., 2012; Vitor & Böhme, 2010). Additionally, some anthropometric characteristics are crucial determinants of the estimated propulsive force (EPF) (Cochrane et al., 2015). Despite the existence of a relationship between the EPF and swimming performance, few studies have focused on the effect of the EPF on swimming performance, and there is a lack of sufficient studies on the somatotypes of young swimmers and the relationship between these somatotypes and the two most important swimming performance determinants (EPF and V_{crit}). Identification of these swimming performance-related variables in young swimmers could significantly contribute to the talent selection process. Therefore, the current study aimed to describe the anthropometric profiles of female and male young swimmers and determine the contribution of some of the anthropometric characteristics to EPF and V_{crit} .

Material and Methods

Participants

We tested male ($n = 25$) and female ($n = 25$) junior swimmers between the ages of 11 and 14 who volunteered to participate in this study. All subjects were from the same swimming club who were trained for two hours per day and six days a week. The participants had no injuries or health problems during the tests. This study was conducted in accordance with the Helsinki Declaration and was approved by the Medical Research Ethics Committee of Medical University Hospital (protocol no: 14-4/3), and all participants and their parents gave written informed consent.

Procedure

The swimmers were grouped according to gender. The measurements were performed in the Olympic indoor swimming pool and university laboratory. Swimmers attended all-out 200-m and 400-m freestyle swimming tests, and the results were used to estimate their V_{crit} using Equation 1, where $D1$ = swimming distance 1 (200 m), $D2$ = swimming distance 2 (400 m), $T1$ = the time for the 200-m swim in seconds and $T2$ = the time for the 400-m swim in seconds (Wakayoshi et al., 1992). The AMA was calculated using Equation 2, where AC is the arm circumference, SKF is the triceps skinfold and $\pi = 3.1416$. The calculation of the EPF is dependent on the AMA (Equation 3) (Cochrane et al., 2015; Santos et al., 2012).

$$V_{crit} (m \cdot sec^{-1}) = (D2 - D1) / (T2 - T1) \quad \text{Eq. 1}$$

$$AMA (cm^2) = (AC [cm] - \pi \times SKF [cm])^2 / 4 \times \pi \quad \text{Eq. 2}$$

$$EPF (kgf) = 0.643 \times AMA (cm^2) \quad \text{Eq. 3}$$

Anthropometry Measurements

The anthropometric measurements were divided into three categories; length (cm), breadth (cm) and girth (cm). Body mass and height were obtained when the swimmers wore light clothing and without shoes via a portable scale to the nearest 0.1 kg and a stadiometer to the nearest 0.1 cm, respectively (Seca, Germany). The measurements were taken according to Lohman et al. (1988). The circumference values were obtained using a single evaluator and a flexible tape measure with a precision of 0.1 cm. Skinfold measurements were taken using a skinfold calliper (Holtain Ltd, Crymych, UK) from 9 body locations (triceps, subscapular, axilla, chest, biceps, suprailiac, abdomen, thigh and calf). These data were used to estimate the body density using two different equations depending on the gender of the participant (Durnin & Rahaman, 1967). The BFR was calculated depending on this estimated body density using the Siri Equation (Siri, 1956). Two measurements were taken from each location on the body, and the mean value was used in the statistical analyses. The somatotype components were calculated according to the equation by Carter (Carter L, 1990). The Body Mass Index (BMI) was calculated as the body mass divided by the stature squared.

Statistical Analysis

The conformity of the data that had a normal distribution was tested using the Shapiro-Wilk Test and also checked using skewness, kurtosis and coefficient of variation (CV) values. As central tendency measures, the means and standard deviations were used for data that had a normal distribution, and the medians were used for those that had a non-normal distribution. To determine the significant difference between the female and male swimmers, an independent-samples t-test was used for the data that complied with the normal distribution, and the Mann-Whitney U test was used for the data that did not comply with the normal distribution. Moreover, absolute differences in dependent variables between genders were also included. For the regression analysis, a stepwise multiple regression model was used in which the anthropometric characteristics and somatotype components were the predictive variables and the V_{crit} and EPF were the outcome variables. An analysis program, SPSS for Windows release 20.0 (SPSS, Inc., Chicago, IL), was used for the statistical evaluation, and the level of statistical significance was accepted as $p \leq 0.05$.

Results

The descriptive characteristics of the subjects (age, body mass, height, BMI and BFR) and their anthropometric characteristics/body type (endomorph, mesomorph and ectomorph) are provided in Table 1. Table 1. Descriptive characteristics and differences, anthropometric/somatotype characteristics and freestyle swimming performance for the female and male young swimmers [mean $\pm$ SD (median)].

Variables	Female ($n = 25$)	Male ($n = 25$)	Difference
Age (years)	12.0 $\pm$ 0.9 (12.0)	12.4 $\pm$ 1.2 (12.0)	0.36
Body mass (kg)	42.0 $\pm$ 7.8	49.1 $\pm$ 12.0	7.06*
Height (cm)	152.2 $\pm$ 8.3	154.7 $\pm$ 11.3	2.44
Training Volume ($\text{h} \cdot \text{wk}^{-1}$)	12	12	-
BMI [$\text{kg} \cdot \text{m}^{-2}$]	18.1 $\pm$ 2.3	20.3 $\pm$ 2.7	2.16*
Body fat ratio (%)	13.5 $\pm$ 3.2	9.0 $\pm$ 3.9	4.56*
<u>Skinfolds (mm)</u>			
Triceps	11.4 $\pm$ 3.3 (11.3)	12.5 $\pm$ 4.6	1.15
Subscapular	8.4 $\pm$ 3.3 (7.2)	8 $\pm$ 2.9 (7.5)	0.34
Midaxillary	7.5 $\pm$ 2.9 (7.0)	8.9 $\pm$ 3.6	1.44
Chest	7.8 $\pm$ 2.2 (7.5)	8.5 $\pm$ 3.3 (8.0)	0.68
Biceps	7.6 $\pm$ 3.3 (6.2)	7.5 $\pm$ 2.6	0.08
Suprailiac	8.8 $\pm$ 4.0 (7.0)	14 $\pm$ 6.7	5.19*
Abdominal	12.6 $\pm$ 4.0	15.6 $\pm$ 6.3	2.98
Thigh	16.8 $\pm$ 4.8	16.5 $\pm$ 5.7	0.37
Calf	14.6 $\pm$ 3.7	13.1 $\pm$ 4.2	1.48
Sum of 9 skinfolds	97.1 $\pm$ 26.7 (93.7)	105.3 $\pm$ 34.3	8.23
<u>Lengths (cm)</u>			
Sitting Height	77.9 $\pm$ 5.0	77.5 $\pm$ 5.6	0.38
Arm Span	156.1 $\pm$ 9.3 (156.3)	159.5 $\pm$ 15.2 (151.5)	3.5
Arm	69.6 $\pm$ 4	69.8 $\pm$ 11.6 (69.6)	0.18
Forearm	21.1 $\pm$ 2.4 (21.4)	23.6 $\pm$ 6.5 (22.3)	2.51
Thigh	46.9 $\pm$ 3.0	47.0 $\pm$ 3.6	0.01
Lower leg	35.2 $\pm$ 2.7	36.0 $\pm$ 2.8	0.72
Total leg	89.5 $\pm$ 5.0	90.6 $\pm$ 6.5	1.06
Foot	23.3 $\pm$ 1.2	24.4 $\pm$ 1.9	1.09*
<u>Breadths (cm)</u>			
Biacromial	28.4 $\pm$ 1.8	28.8 $\pm$ 2.8	0.41
Transverse chest	22.8 $\pm$ 1.8	24.4 $\pm$ 2.8	1.58
Bideltoid	35.8 $\pm$ 2.3	37.7 $\pm$ 4.0	1.93*
Bitrochanteric	26.1 $\pm$ 2.6	26.7 $\pm$ 2.6	0.56
Biepicondylar humerus	5.9 $\pm$ 0.3	6.6 $\pm$ 0.5	1.1*
Styloid	5.0 $\pm$ 0.3	5.2 $\pm$ 0.3	0.25*
Hand	7.2 $\pm$ 0.4	7.7 $\pm$ 0.7	0.49*
Biepicondylar femur	8.4 $\pm$ 0.5	9.5 $\pm$ 0.5	1.1*
Foot	8.0 $\pm$ 0.7	9.1 $\pm$ 0.8	1.11*
<u>Girths (cm)</u>			
Shoulder	91.9 $\pm$ 6.5	98.0 $\pm$ 10.4	6.1*
Thoracic	77.6 $\pm$ 7.7	79.3 $\pm$ 9.4	1.67
Relaxed arm	22.8 $\pm$ 2.7	24.5 $\pm$ 3.1	1.76*
Flexed arm	24.3 $\pm$ 2.6	26.8 $\pm$ 3.6	2.54*
Forearm	20.8 $\pm$ 1.6	22.8 $\pm$ 2.2	1.92*
Wrist	13.9 $\pm$ 0.7	15.0 $\pm$ 1.1	1.10*
Hip	79.8 $\pm$ 7.5	82.3 $\pm$ 7.3	2.51*
Upper thigh	45.3 $\pm$ 5.1	47.5 $\pm$ 5.2	2.20
Calf	30.1 $\pm$ 2.8	32.2 $\pm$ 3.3	2.08*
Ankle	19.8 $\pm$ 1.5	21.0 $\pm$ 1.9	1.16*
<u>Somatotype</u>			
Endomorphy	3.2 $\pm$ 1.0	3.8 $\pm$ 1.2	0.58
Mesomorphy	3.7 $\pm$ 1.2 (3.4)	5.0 $\pm$ 0.9	1.32*
Ectomorphy	3.6 $\pm$ 1.4	2.5 $\pm$ 1.1	1.03*
<u>Swimming performance</u>			
200 m (sec)	173.4 $\pm$ 19.6	158.3 $\pm$ 20.1	0.23*
400 m (sec)	365.4 $\pm$ 44.5	333.4 $\pm$ 44.8 (326.0)	0.51*
V_{crit} ($\text{m} \cdot \text{sec}^{-1}$)	1.05 $\pm$ 0.13	1.16 $\pm$ 0.15	0.1*
<u>Propulsive performance</u>			
AMA (cm^2)	34.8 $\pm$ 7.8	41.0 $\pm$ 12.2 (39.3)	6.14
EPF (kgf)	22.4 $\pm$ 5.0	26.3 $\pm$ 7.8 (25.2)	3.95

Note: * $p \leq 0.05$; BMI: Body mass index; V_{crit} : Critical swimming velocity; AMA: Arm muscle area; EPF: Estimated propulsive force.

Correlations between the anthropometric characteristics, somatotype components, V_{crit} and EPF are summarized in Table 2.

Table 2. Zero-order correlations between the anthropometric/somatotype characteristics and the critical swimming velocity/EPF.

Variable	V_{crit}		EPF	
	Female	Male	Female	Male
<u><i>Skinfolds</i></u>				
Triceps	0.10	-0.10	-0.03	-0.16
Subcapular	0.25	0.13	0.25	0.26
Midaxillary	0.32	0.22	0.21	0.28
Chest	0.31	-0.08	0.14	-0.13
Biceps	0.34*	-0.02	-0.04	-0.12
Suprailiac	0.19	0.49*	0.20	0.39*
Abdominal	0.03	0.22	0.18	0.20
Thigh	0.21	-0.02	0.12	-0.14
Calf	0.42*	0.16	0.07	0.02
<u><i>Lengths</i></u>				
Sitting Height	0.54*	0.68*	0.75*	0.81*
Arm Span	0.40*	0.75*	0.67*	0.77*
Forearm	0.29	0.37*	0.19	0.24
Thigh	0.02	0.57*	0.62*	0.52*
Lower leg	0.47*	0.75*	0.45	0.48*
Total leg	0.23	0.73*	0.63*	0.59*
Foot	0.44*	0.78*	0.64*	0.68*
<u><i>Breadths</i></u>				
Biacromial	0.17	0.72*	0.52*	0.81*
Transverse Chest	0.55*	0.81*	0.68*	0.83*
Bideltoid	0.57*	0.80*	0.71*	0.84*
Bitrochanteric	0.57*	0.71*	0.71*	0.77*
Bipectondylar humerus	0.37*	0.73*	0.60*	0.75*
Styloid	-0.17	0.47*	0.42*	0.62*
Hand	0.03	0.69*	0.57*	0.74*
Bipectondylar femur	0.03	0.73*	0.38*	0.70*
Foot	0.19	0.79*	0.50*	0.82*
<u><i>Girths</i></u>				
Shoulder	0.64*	0.77*	0.77*	0.82*
Thoracic	0.60*	0.64*	0.82*	0.90*
Relaxed Arm	0.52*	0.63*	0.83*	0.73*
Flexed Arm	0.61*	0.65*	0.87*	0.80*
Forearm	0.49*	0.70*	0.82*	0.84*
Wrist	0.27	0.69*	0.69*	0.78*
Hip	0.66*	0.72*	0.81*	0.74*
Upper Thigh	0.61*	0.61*	0.79*	0.66*
Calf	0.50*	0.69*	0.60*	0.68*
Ankle	0.45*	0.70*	0.76*	0.64*
<u><i>Somatotype</i></u>				
Endomorphy	0.17	0.14	0.06	0.08
Mesomorphy	-0.24	0.18	-0.23	0.31
Ectomorphy	-0.55*	-0.16	-0.02	-0.31

Note: *r significant at $p \leq 0.05$. V_{crit} : Critical swimming velocity; EPF: Estimated propulsive force.

Statistically significant correlation coefficients (ranging from 0.34 to 0.66) were found between the anthropometric characteristics (19 characteristics) and V_{crit} for the female swimmers. The highest correlation was between hip girth and V_{crit} ($r = 0.66$; $p < 0.05$). The correlations between the anthropometric characteristics (24 characteristics) and EPF were also statistically significant (from 0.38 to 0.87). The highest correlation was between the flexed arm and EPF ($r = 0.87$; $p < 0.05$). While all girth (0.60 – 0.87) and breadth (0.38 – 0.71) measurements were significantly correlated with the EPF, none of the skinfold measurements showed significant correlations.

Additionally, for the male swimmers, statistically significant correlation coefficients (between 0.37 and 0.81) were found between anthropometric characteristics (27 characteristics) and V_{crit} . The highest correlation was between the transverse chest and V_{crit} ($r = 0.81$; $p < 0.05$). Correlations between the anthropometric characteristics (26 characteristics) and the EPF were also statistically significant (between 0.39 and 0.90). The highest correlation was between the thoracic girth and the EPF ($r = 0.90$; $p < 0.05$).

Regarding the somatotype component, a significant negative correlation was found between ectomorphy and V_{crit} only for the female swimmers ($r = -0.55$; $p < 0.05$).

The results of the stepwise regression analyses are shown in Tables 3-4. The V_{crit} ranged between 17.8% (calf skinfold) and 63.4% (bitrochanteric, styloid, biepicondylar humerus) for the female swimmers. Additionally, the EPF ranged between 51.3% (sitting height) and 76.2% (flexed arm).

For the male swimmers, the V_{crit} ranged between 40.5% (suprailiac, triceps) and 66.4% (transverse chest), and the EPF ranged between 51.3% (suprailiac, triceps, subscapular skinfold) and 91.2% (thoracic, flexed arm, upper thigh).

Table 3. Multiple regression equations used to predict the V_{crit} in the young swimmers

Outcome Variable	Female (n= 25)				Male (n= 25)			
	Constant (SE)	B (SE)	Predictor Variables	$R^2 \times 100$ cumulative	Constant (SE)	B (SE)	Predictor Variables	$R^2 \times 100$ cumulative
V_{crit}	0.83 (0.10)	0.01 (0.07)	<u>Skinfolds</u> Calf	17.8	1.12 (0.07)	0.02 (0.04) -0.01 (0.01)	<u>Skinfolds</u> Suprailiac Triceps	24.3 40.5
V_{crit}	0.37 (0.33)	0.02 (0.05) -0.02 (0.09)	<u>Lengths</u> Sitting Height Thigh	30.1 49.9	-0.33 (0.24)	0.06 (0.01)	<u>Lengths</u> Foot	61.6
V_{crit}	0.74 (0.32)	0.03 (0.07) -0.27 (0.06) 0.14 (0.05)	<u>Breadths</u> Bitrochanteric Styloid Biepicondylar humerus	33.0 51.9 63.4	0.87 (0.16)	0.44 (0.01)	<u>Breadths</u> T. Chest	66.4
V_{crit}	0.14 (0.21)	0.11 (0.03)	<u>Girths</u> Hip	43.7	0.06 (0.18)	0.01 (0.02)	<u>Girths</u> Shoulder	60.1
V_{crit}	1.54 (0.09)	-0.07 (0.01) -0.06 (0.01)	<u>Somatotype</u> Ectomorphy Mesomorphy	31.3 57.8	-	-	<u>Somatotype</u>	-

Note: V_{crit} : Critical swimming velocity; SE: Standard error; B: Unstandardized coefficients

Table 4. Multiple regression equations used to predict the EPF in the young swimmers

Outcome Variable	Female (n = 25)				Male (n = 25)			
	Constant (SE)	B (SE)	Predictor Variables	$R^2 \times 100$ cumulative	Constant (SE)	B (SE)	Predictor Variables	$R^2 \times 100$ cumulative
EPF	-	-	<u>Skinfolds</u> -	-	22.9 (3.81)	0.60 (0.21) -1.46 (0.37) 1.65 (0.59)	<u>Skinfolds</u> Suprailiac Triceps Subscapular	15.8 33.6 51.3
EPF	-35.9 (10.63)	0.74 (0.13)	<u>Lengths</u> Sitting Height	54.9	-61.4 (13.14)	1.13 (0.16)	<u>Lengths</u> Sitting Height	66.1
EPF	-31.72 (11.03)	1.51 (0.30)	<u>Breadths</u> Bideltoïd	51.3	-35.38 (8.12)	1.63 (0.21)	<u>Breadths</u> Bideltoïd	71.8
EPF	-18.66 (4.81)	1.68 (0.19)	<u>Girths</u> Flexed Arm	76.2	-26.56 (5.29)	0.58 (0.07) 1.79 (0.38) -0.87 (0.25)	<u>Girths</u> Thoracic Flexed Arm Upp. Thigh	81.8 86.3 91.2
EPF	-	-	<u>Somatotype</u>	-	-	-	<u>Somatotype</u>	-

Note: EPF: Estimated propulsive force; SE: Standard error; B: Unstandardized coefficients

Discussion

In this study, the mean ages of the female and male swimmers were 12.0 ± 0.9 and 12.4 ± 1.2 , respectively. Although the body mass and height measurements for the 12-year-old swimmers in the studies by Cochrane et al. (2015) and Ricardo (2011) were higher than those found in our study, the mass and height results in two other studies are consistent with our findings (Barbosa et al., 2015; Geladas et al., 2005; Marinho et al., 2009). However, the BFR measurements for the male swimmers in the current study was lower than that of a similar age group in the study by Cochrane et al. (2015).

Here, statistically significant positive correlations were found between the V_{crit} and various anthropometric characteristics (biceps, calf, sitting height, arm span, lower leg, foot, transverse chest, bideltoïd, bitrochanteric, biepicondylar humerus, shoulder, thoracic, relaxed arm, flexed arm, fore arm, hip, upper thigh, calf and ankle) in the female swimmers. In contrast, a statistically significant negative correlation was found between the V_{crit} and ectomorphy. These findings are consistent with the literature (Geladas et al., 2005; Grimston & Hay, 1986). In males, all lengths, breadths, girths and suprailiac skinfold measurements were significantly correlated with swimming performance (Table 2).

In particular, positive correlations between the swimming performance and sitting height, arm span, lower leg and foot lengths for both genders clarify the contribution of these lengths to swimming performance. In

agreement with these findings, the positive effects of extremity length on propulsive force, which is an important factor in swimming performance, were demonstrated in prior literature. (Geladas et al., 2005)

Significant correlations were found between the EPF and all anthropometric measurements (except for the skinfold, forearm and lower leg measurements) for the female swimmers. For the male swimmers, while all girths, breadths, and lengths (except for the forearm) were significantly correlated with the EPF, for the skinfold measurements, only the suprailiac showed a significant correlation. Positive effects of the long extremities and body segments on propulsive force generation have been previously reported in the literature (Grimston & Hay, 1986). Our results revealed that for male swimmers (V_{crit} : 0.68-0.78, EPF: 0.63-0.75) there was a higher correlation between swimming performance determinants and length measures than for female swimmers (V_{crit} : 0.40-0.54, EPF: 0.48-0.81). This trend was also valid for correlations related to girth and breadth measures (Table 2). These significant correlations between swimming performance determinants and length measures are also supported by similar results in another prior study (Grimston & Hay, 1986). Swimmers with long extremities have better pull, slide and performance characteristics (Grimston & Hay, 1986; Sharp, Troup, & Costill, 1982; Toussaint & Hollander, 1994), which could explain these significant correlations.

In this study, the higher correlations in males may have two possible reasons. 1) The mean age of male swimmers was 0.36 years greater than for the females, and the males had significantly shorter swimming times compared to the females (23 s and 51 s shorter for 200 m and 400 m, respectively). 2) For the anthropometric characteristics (foot length; bideltoid, styloid, hand, biepicondylar femur, and foot breadths and all girths except for the thoracic and upper thigh) that may have positive effects on the 200-m and 400-m swimming performances, V_{crit} and EPF were significantly greater for the males ($p < 0.05$).

The stepwise regression technique indicated that changes in the V_{crit} and EPF could be explained via anthropometric characteristics. A change in the V_{crit} was explained via the skinfolds, lengths, breadths and girths for both genders. For males, the same variables explained the change in the EPF. However, for the females, only the lengths, breadths and girths explained the significant amount of variance in the EPF.

For the females, the change in V_{crit} for the calf (skinfold) was 17.8%, for the sitting height and thigh combination (length), it was 49.9%, for the bitrochanteric, styloid, and biepicondylar humerus combination (breadth), it was 63.4% and for the hip (girth), it was 43.7%. For the males, the change in V_{crit} for the suprailiac and triceps combination (skinfold) was 40.5%, for the foot (length), it was 61.2%, for the transverse chest (breadth), it was 66.4%, and for the shoulder (girth), it was 60.1%.

For both the females and males, significant variances in the EPF for the sitting height (length) were 54.9% and 66.1%, respectively, and for the bideltoid (breadth), they were 51.3% and 71.8%, respectively. For the females, only the flexed arm (girth) explained the 76.2% of variance in the EPF; however, in males, this percentage increased up to 91.2% when the thoracic, the flexed arm and upper thigh combination was used. For the males, additionally, the suprailiac, triceps and subscapular combination (skinfold) explained the significant amount of variance (51.3%) in the EPF. The somatotype values in the females and males were 3.2-3.7-3.6 and 3.8-5.0-2.5, respectively. The males were significantly more mesomorphic and less ectomorphic than the females (Table 1). Ecto-mesomorphy was the dominant somatotype in the females, whereas endo-mesomorphy was dominant in the males. Ectomorphy (31.3%) and mesomorphy (26.5) were the best predictors that explained the variance in V_{crit} , which is consistent with the findings of Siders et al. (1993). However, no somatotype component explained the change in the EPF for both genders. Between the somatotype components, only ectomorphy had a moderate significant correlation ($r = -0.55$) with V_{crit} for the females. Other components had low level insignificant correlations with V_{crit} and EPF (ranging from -0.31 to 0.30). Lyttle et al. (1998) reported that slenderness makes a significant contribution to the hydrodynamic efficiency during swimming. In our study, the significant change in V_{crit} due to the ectomorphy and the relationship between these variables in females supports this opinion.

Conclusion

In brief, skinfold, length, girth and breadth measures could be used as predictors of the V_{crit} and EPF in young swimmers. The combination of ectomorphy and mesomorphy could only significantly explain the change in V_{crit} for females in terms of somatotype components. The girth measures were highly correlated with swimming performance for both genders. The practical advantage of this study is that basic and affordable anthropometric tests could be used to identify talented young swimmers by assessing the anthropometric characteristics that influence swimming performance. In addition, swimming coaches should focus on monitoring anthropometric characteristics that are important for swimming performance.

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