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The relationship between anthropometric characteristics and sports performance in national-level young swimmers

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Abstract: The main aim of this study was to verify associations between the anthropometric characteristics of young swimmers of different genders and different competitive levels with sports performance in 50m and 400m freestyle races at different levels (U-13 - Swimmers A and U-12 - Swimmers B). In addition, it was also intended to investigate the magnitude of the correlations between some specific variables (i.e., height, weight and wingspan) and the swimming performance. All participants were analyzed, regarding their anthropometric characteristics and their performance in the 50m and 400m freestyle swim. A total of 98 swimmers aged between 11-13 years old (mean ± standard deviation: 12.63 ± 0.76 years of age, 1.59 ± 0.08m height, 47.11 ± 7.82kg body weight) participated in the study. The results suggest that anthropometric characteristics have a positive relationship in the performance of swimmers when comparing genders (p< 0,01), furthermore positive linear correlations was found in height (r = 0.305 and r = 0.253, p <0.01), weight (r = 0.202 and r = 0.140, p <0.01), and wingspan (r = 0.227 and r = 0.203, p < 0.01) for 50m and 400m freestyle swim. The swimmers' efficiency of segmental movements was related to anthropometric characteristics and strongly associated with the length of the swimmers' segments. These results may be due to the fact that swimmers' maturational status may have played an important role, in the observed results. In addition, when comparing genders, the height and weight values of male swimmers tended to be higher. Furthermore, the differences observed in the 50m and 400m freestyle swimming events were related to the relationship that anthropometric characteristics have on the biomechanical parameters of swimming, which influence swimming performance. This study concluded that the improvement of performance of each young national-level swimmer is strongly related to the rate of growth, development and maturation

Keywords: physical demands; GPS, high-intensity actions; accelerations; decelerations.

1. Introduction

In pure sport swimming, young swimmers are subjected to intense training programs from an early age so that they can withstand competitive periods and achieve high sporting performance (Martínez et al. 2011). Pure sport swimming is characterized as an individual, cyclical, continuous, closed, and mixed activity that depends on genetic, contextual, psychological (Fernandes, R., Aleixo, I., Soares, S., & Vilas-Boas 2008), biomechanical, energetic (Barbosa et al.

2010), hydrodynamic (Morais et al. 2012), and anthropometric factors (Jürimäe et al. 2007). This type of swimming differs from other sports activities due to the nature of the environment in which it occurs (i.e. the aquatic environment), which requires particular spatio-temporal and energetic adaptations (Marinho et al. 2007). Since they constantly interact with the aquatic environment, swimmers seek the production of propulsive forces that maintain or accelerate their travel speed (Kwon and Casebolt 2006). Swimming performance depends on the ability to generate propulsive force and minimize the hydrodynamic drag that opposes displacement (Berger, Hollander, and De Groot 1997; Martínez et al. 2011), which can be stimulated by improving biomechanical patterns (Vantorre, Chollet, and Seifert 2014) and swimming technique (Scorţenschi 2019). Additionally, performance can also be affected by the variability of body composition (Charmas and Gromisz 2019) and anthropometric characteristics (i.e. weight, body mass index, height, and wingspan) (Morais et al. 2012; Zuniga et al. 2011).

The anthropometric characteristics of swimmers are closely related to each other and serve major roles in sports performance (Fernandes, Barbosa, and Vilas-Boas 2002a). Additionally, a previous study by Damsgaard et al. (2001) demonstrated that participation in sports competitions from a young age is directly related to the specific body composition and body proportions of each individual. Thus, the association between anthropometric characteristics and sports performance is a relevant indicator for identifying talent in the long-term development process of athletes (Sammoud, et al. 2018). Young male swimmers have been characterized as taller and heavier with a greater wingspan when compared to young female swimmers, and these characteristics contribute to differences in performance between genders (Schneider and Meyer 2005). Fat mass is an important body composition feature that seems to vary between sports. Typically, the lower the fat mass, the better the performance (Martínez et al. 2011). However, swimming seems to be an exception since advantages associated with a higher proportion of fat mass have been reported, such as greater buoyancy that results in lower energy expenditure (Fernandes et al. 2002a; Wells, Schneiderman-Walker, and Plyley 2006; Zuniga et al. 2011). Female swimmers seem to enjoy this advantage since—according to what has been reported in previous investigations (Fernandes et al. 2002a; Greco and Denadai 2005; Rodrigues et al. 2001; Wells et al. 2006)—they have a greater amount of fat mass compared to male swimmers.

A further investigation (Morais et al. 2013) has shown that anthropometric factors explain approximately 45.8% of the performance of 15-year-old male swimmers in 100m crawl tests, and 63.8% of the performance in freestyle swim tests among 13-year-old swimmers of both sexes (Bond et al. 2015). Anthropometric variables such as weight, body mass index, height, and wingspan seem to be strongly related to performance during swimming tests in young people and can thus potentially influence performance (Morais et al. 2013). On the other hand, young athletes of a high competitive level also present higher values of stature, and wingspan as well as conclusively higher values of gestural frequency (GF) (Craig and Pendeegast 1979), cycle distance (CD), and swimming index (SI) (Morais et al. 2013) (when these performance variables are used as performance indicators) (Craig and Pendeegast 1979; Lätt et al. 2009, 2010; Morais et al. 2012). According to Chollet et al. (2000) (Chollet, Chalies, and Chatard 2000), GF is defined as the number of stroke cycles per unit of time and is expressed as "cycles.seg-1 (Hz)". Variations in speed result from correlations between increases and decreases in GF and CD, respectively (Toussaint et al. 2006). According to Maglisho (1999), CD was characterized as the average horizontal distance traveled during the completion of a complete stroke cycle (m). A swimmer's transformation of muscle strength into propulsive force enables an increase in CD, which is derived from the physical capacity to produce strength and the technical capacity applied in segmental paths, with an emphasis on the orientation of the most propulsive surfaces. Therefore, variables such as wingspan and height can condition the achievement of higher CD values (Anderson et al. 2006; Franken, Pivetta, and Antônio De Souza 2007), which represents an indicator of propulsive efficiency. Swimmers with more representative wingspan values tend to have higher CD (Barbosa et al. 2009; Franken et al. 2007) and SI (Jürimäe et al. 2007) values, with CD having a significant correlation with performance (Morais et al. 2012). SI is expressed as a swimmer's ability to move at a certain speed with a greater or lesser number of strokes and essentially derives from the relationship between CD and speed (Caputo et al. 2000). It is measured in m/s and is an excellent performance indicator for young swimmers (Jürimäe et al. 2007) since a swimming speed with greater CD and less GF translates into an inefficient and ineffective technique (Caputo et al. 2000). Like the other variables referenced, SI also represents an excellent predictor of performance (Lätt et al. 2009, 2010).

Therefore, a range of performance variables is useful in training programming and control which, when related to athletes' anthropometric characteristics, seem to contribute to understanding and improving their performance through rigorous control and monitoring of training. Thus, the training of young swimmers must be regularly monitored so that the prescription is adequate for improving performance based on the particular characteristics of each swimmer (Marinho et al. 2011). Although the differences are not always significant in relation to anthropometric characteristics, growth, and maturation differences between genders at both prepubescent and pubescent ages (Malina, Bouchard, and Bar-Or 2004), it remains important to continue investigating this topic. The maturation of an athlete involves the organs and structures of the body and translates into morphological changes observed throughout the growth process, which reaches its peak during puberty. Thus, growth and development processes are strongly linked to the improvement of motor performance in children and adolescents (Beunen and Malina 2008). Therefore, based on this relationship, growth and physical development indicators should be considered because biological maturation does not start at the same age in both genders and does not have the same duration in all individuals (Erlandson et al. 2008). In fact, the literature has reported a strong association between anthropometric characteristics and performance in pure sport swimming. However, this relationship requires further investigation to clarify its impact on the performance of young swimmers of national level, both genders in a precise age range. Although some studies (Geladas et al. 2005; Jürimäe et al. 2007; Nevill, Oxford, and Duncan 2015; Sammoud, Alan M. Nevill, et al. 2018; Sammoud, Alan Michael Nevill, et al. 2018) have inferred about the importance of anthropometric characteristics for swimming performance in different age groups, knowledge about the effects of some variables (i.e., height, weight, Body mass index, wingspan, wingspan / height, GF, CD and SI) on performance remains to be investigated, particularly among genres of the competitive ranks of U-13 and U-12. In addition, few studies have made a specific comparison between swimmers of different genders and similar chronological ages who belong to different competitive levels. Thus, the present study aimed to verify associations between the anthropometric characteristics of young swimmers of different genders and different competitive levels with sports performance in 50m and 400m freestyle races at different levels (U-13 - Swimmers A and U- 12 - Swimmers B). In addition, it was also intended to investigate the magnitude of the correlations between some specific variables and the swimming performance.

2. Materials and Methods

Subjects

A total of 98 swimmers aged between 11 and 13 years old (mean ± standard deviation: 12.63 ±

0.76 years of age, 1.59 ± 0.08m height, 47.11 ± 7.82kg body weight) participated in the study.
All the swimmers belonged to the U-13 and U-12 level, with 48 females and 50 males. The female sample consisted of 25 of the U-13 (Swimmers A) - (12.48 ± 0.30 years of age; 1.60 ± 0.06m in height; 47.25 ± 7.95 kg of body weight) and 23 at the U-12 level (Swimmers) B) - (11.63 ± 0.28 years of age; 1.52 ± 0.04m in height; 42.76 ± 5.99 kg of body weight). While the male sample was composed of 26 belonging to the U-13 level (Swimmers A) - (13.62 ± 0.25 years of age; 1.64 ± 0.07 m in height; 52.08 ± 7.68 kg of body mass) and 24 belonging to the U -12 level (Swimmers B) - (12.69 ± 0.26 years of age; 1.58 ± 0.08m in height; 45.75 ± 6.70 kg of body weight).

Design

The present study consisted of a cross-sectional study that aimed to verify the impact of anthropometric characteristics on sports performance in national-level young swimmers (e.g., 12 -13 years), in the 50m and 400m freestyle swimming events. Additionally, we sought to determine whether differences existed between genders and between swimmers of the same gender at different competitive levels (U-13 - Swimmers A and U-12 – Swimmers B), and was also intended investigate the correlations between some fundamental variables (i.e., height, weight and wingspan) and the swimming performance The inclusion criteria established for the sample were; a) the swimmers must have been present in the last 3 calls of the Portuguese national swimming team b) the swimmers could not have episodes of injuries in the last 6 months. As an exclusion criterion, it was established that; a) swimmers with reports or episodes of indisposition or illness, in the days prior to the evaluation were excluded from the sample. All participants were analyzed with regard to their anthropometric characteristics (height, body mass, body mass index, and wingspan), 50m and 400m freestyle swimming performance, and biomechanical variables. All participants were fully informed verbally and in writing regarding the nature of the study. They were informed that they could withdraw from the study at any time, even after giving their written consent. All parents provided their informed consent allowing the voluntary participation of their children in the study, which had the approval of the Academy's Ethical Advisory Commission and was conducted in accordance with the Declaration of Helsinki.

Methodology

The evaluations were performed during the team internship period. All individuals were evaluated at the same point in the sports season (January). The evaluation sessions were spread over the two days of the internship and the tests were performed without the need for energy expenditure or the accumulation of fatigue (anthropometry) before the swimming performance tests. Sufficient rest was allowed between sessions to ensure that no fatigue was accumulated that would negatively influence performance. After arriving at the internship site on the day of the assessment, each subject was assessed after 5 minutes of rest with regard to anthropometric measures such as body mass, height, wingspan. Body mass index (BMI) was also calculated. They performed the 50m freestyle swim performance evaluation in the morning session and the 400m freestyle swim performance evaluation during the afternoon session.

Anthropometric Measures. All measures were assessed according to international standards for anthropometric assessment (Marfell-Jones et al. 2006) and were obtained before any physical performance test. Participants were barefoot and dressed in underwear or as little clothing as possible during the assessment. To measure body height (in m), a precision stadiometer with a scale of 0.001 m (meters) was used. BMI was obtained by dividing the body mass value by the square of height. Wingspan was determined by measuring the athletes with a tape measure placed on a precision wall with a scale of 0.001 m.

Swimming Performance Evaluation. The evaluation of specific swimming performance was performed through simulating the 50m freestyle and 400m freestyle swim. The 50m freestyle swim was performed in the morning, while the 400m freestyle was performed in the late afternoon to provide sufficient time for the participants to recover. After performing a 1000 m warm-up using the usual structure based on the protocols described by Neiva et al. (2014), each swimmer performed a simulated race (50 or 400m). The evaluation protocols were applied in a 25m covered swimming pool at an average temperature of 28º C and an average humidity below 70%, with departure from the block and official voices. The timing was recorded using a stopwatch (Finis 3x100 Stopwatch, Livermore, California). The swims were also filmed and subsequently analyzed using the program Kinovea® version 0.8.15. Biomechanical variables were evaluated for both simulations. Thus, the evaluation of GF was performed using a chronometer in three stroke cycles and later

converted to units of measurement in the international system (Hz). CD was measured by estimation using the following equation (Craig and Pendeegast 1979):

$$CD = v/GF \quad (1)$$

Where CD is the cycle distance ($m.c^{-1}$), v is the average speed of the swimmer (m.s-1), and GF is the gestural frequency of swimming. SI was then estimated using the following equation (Costill et al. 1985):

$$SI = CD \times v \quad (2)$$

Where SI represents the swimming index (m2 c^{-1} s^{-1}), DC is the distance per cycle ($m.c^{-1}$), and v is the average swimming speed $m.s^{-1}$). The speed variables, FG, DC, and IN were evaluated in the second 25m of each 50m (either in the 50m event or 400m event) and were used to determine the average measure in the 400m freestyle swim. To analyze these variables, the program Kinovea® (version 0.8.15) was used.

Statistical Analysis

Data analysis was performed using the statistical software IBM Statistical Package for Social Sciences (SPSS, version 24.0) for Microsoft Windows (Armonk, NY, EU: IBM Corp.). The significance level was set at 5%. The calculation of means, standard deviations, differences, and 95% confidence intervals (95% CI) was performed using standardized statistical methods. The normality of the distribution was verified using the Kolmogorov-Smirnov test (n>30) and not all data had a normal distribution. Thus, parametric (t-test) and nonparametric (Mann-Whitney test) tests were used for data analysis. For bivariate correlations, Pearson's coefficient was used for normal data, Spearman's correlation was used for non-normal data, and the determination coefficient (r2) was also calculated. Ratios were considered very high for values between 0.90 and 1.00, high between 0.70 and 0.90, moderate between 0.50 and 0.70, low

Table 1. Comparison between the mean values (± standard deviation) of the anthropometric variables of the Female Children belonging to the Swimmers A and to the Swimmers B. The significance values, confidence interval of the difference and the effect size are also presented.

Variables	Swimmers A (Female) (n=25)	Swimmers B (Female) (n=23)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
Height (m)	1,60 ± 0,06	1,52 ± 0,05	0,10	0,04	0,001**	1,44
Weight (kg)	47,25 ± 7,95	42,7 ± 5,99	8,61	0,37	0,003**	0,64
BMI (kg/m²)	18,31 ± 2,20	18,26 ± 2,08	1,30	-1,19	0,934	0,02
Wingspan (m)	1,63 ± 0,07	1,55 ± 0,06	0,12	0,04	0,001**	1.22
Wingspan / Height	1,01 ± 0.01	1.01 ± 0,02	0,82	0,80	0,808	0.01

Note: BMI= body mass index; CI= Confidence interval *p<0.05; **p<0.01

between 0.30 and 0.50, and very low between 0.10 and 0.30. The effect size was also calculated using Cohen's d for the comparison between analyzed groups (Cohen 2013). The magnitude of the effect was considered trivial (<0.2), small (0.2–0.59), moderate (0.60–1.19), high (1.2–1.99), or very high (>2.00) (Hopkins et al. 2009).

3. Results

Table 1 presents the mean values of the anthropometric variables for female

Swimmers belonging to the A and the B groups. Statistically significant differences were observed for height (p <0.01; d = 1.44), weight (p <0.01; d = 0.64), and wingspan (p <0.01; d = 1.22), with a high effect size for all variables.

Table 2 presents the mean values of the anthropometric variables for male Swimmers belonging to the A and B groups. Statistically significant differences (p <0.05) were observed for height and wingspan, with a high (d = 0.79) and very high (d = 3.88) effect size, respectively. Statistically significant differences (p <0.01) were also observed for weight and BMI, with a high effect size.

Table 3 presents the mean values of the anthropometric variables resulting from the comparison between male and female belonging to Swimmers A group. Statistically significant differences were observed for the variable's height and weight (p <0.05; d = 0.61), with a high effect size.

Table 4 presents the mean values of the anthropometric variables resulting from the comparison between male and female Swimmers B. Statistically significant differences were observed for height (p <0.01; d = 0.89) and wingspan (p <0.05; d = 0.65), with a high effect size.

Table 2. Comparison between the mean values (± standard deviation) of the anthropometric variables of Male Children belonging to Swimmers A and Swimmers B. The values of significance, confidence interval of difference and size of the effect are also presented.

Variables	Swimmers A (Male) (n=26)	Swimmers B (Male) (n=24)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
Height (m)	1,64 ± 0,07	1,58 ±0,08	0,01	0.10	0,019*	0,79
Weight (kg)	52,08 ± 7,68	45,75 ± 6,70	2,20	10,43	0,003**	0.87
BMI (kg/m²)	19,20 ± 1,81	18,10 ± 1,45	0,16	2,04	0,002**	0,67
Wingspan (m)	1,67 ± 0,10	1,60 ± 0,09	0,02	0,12	0,014*	3,88
Wingspan / Height	1,01 ± 0,02	1,01 ± 0,01	0,11	0,10	0,109	0,05

Note: BMI= body mass index; CI= Confidence interval *p<0.05; **p<0.01

Table 3. Comparison between the mean values (± standard deviation) of the anthropometric variables between genders of the children of Swimmers A. The significance values, confidence interval of the difference and the effect size are also presented.

Variables	Swimmers A (Male) (n=26)	Swimmers B (Female) (n=25)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
Height (m)	1,64 ± 0,07	1,60 ± 0,06	-0,01	-0,08	0,04*	0,61
Weight (kg)	52,08 ± 7,68	47,25 ± 7,95	-0,42	-9,22	0,03*	0,61
BMI (kg/m²)	19,20 ± 1,81	18,31 ± 2,20	0,24	-2,02	0,12	0,44
Wingspan (m)	1,67 ± 0,10	1,63 ± 0,07	0,02	-0,09	0,10	0,46
Wingspan / Height	1,01 ± 0,02	1,01 ± 0.01	0,73	0,71	0,71	0.01

Note: BMI: body mass index; CI: Confidence interval *p<0.05; **p<0.01

Table 4. Comparison between the mean values (± standard deviation) of the anthropometric variables between the gender of the Children in Grade B. The significance values, confidence interval of the difference and the effect size are also presented.

Variables	Swimmers B (Male) (n=24)	Swimmers B (Female) (n=23)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
Height (m)	1,58 ±0,08	1,52 ± 0,05	-0,02	-0,09	0,005**	0,89
Weight (kg)	45,75 ± 6,70	42,70 ± 5,99	0,75	-6,74	0,114	0,47
BMI (kg/m^2)	18,10 ± 1,45	18,26 ± 2,08	1,21	-0,88	0,755	- 0,09
Wingspan (m)	1,60 ± 0,09	1,55 ± 0,06	-0,01	-0,10	0,021*	0,65
Wingspan/Height	1,01 ± 0,01	1.01 ± 0,02	0.288	0,265	0,276	0.14

Note: BMI: body mass index; CI: Confidence interval *p<0.05; **p<0.01

Table 5. Comparison between the mean values (± standard deviation) of the swimming performance variables in the 50m freestyle and 400m freestyle, as well as the gestural frequency (GF), cycle distance (DC), swimming index (IN) and critical speed of female children belonging to the Swimmers A and B. Significance values, difference confidence interval and effect size are also presented.

Variables	Swimmers A (Female) (n=25)	Swimmers B (Female) (n=23)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
50m freestyle (s)	34,48 ± 2,34	36,52 ± 1,85	-0,80	-3,27	0,002**	-0,51
50m GF (5-20m) (Hz)	48,57 ± 4,13	50,07 ± 5,15	1,20	-4,20	0,271	-0,32
50m CD (m.c^{-1})	1,80 ± 0,19	1,65 ± 0,19	0,26	0,04	0,010*	0,78
50m SI (m^2 c^{-1} s$^{-1)}$	2,63 ± 0,38	2,27 ± 0,31	0,56	0,15	0,001**	1,03
400m frestyle (s)	330,75 ± 25,92	364,18 ± 26,36	0,001	0,001	0,001**	-1,12
400m GF (Hz)	37,20 ± 3,94	37,37 ± 4,53	0,92	0,91	0,918	-0,04
400m CD (m.c^{-1})	1,98 ± 0,23	1,80 ± 0,24	0,009	0,005	0,007**	0,76
400m SI (m^2 c^{-1} s$^{-1)}$	2,42 ± 0,36	1,99 ± 0,35	0,001	0,001	0,001**	1,21

Note: CI: Confidence interval; GF: Gestural frequency; DC: Cycle distance; SI: Swimming index; * p <0.05; ** p <0.01

Table 6. Comparison between the mean values (± standard deviation) of the swimming performance variables in the 50m freestyle and 400m freestyle, as well as the gestural frequency (GF), cycle distance (CD), swimming index (SI) and critical speed of male children belonging to Swimmers A B. The values of significance, difference confidence interval and effect size are also presented.

Variables	Swimmers A (Male) (n=26)	Swimmers B (Male) (n=24)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
50m freestyle (s)	31,08 ± 1,69	33,20 ± 1,98	-1,07	-3,17	0,001**	-1,15
50m GF (5-20m) (Hz)	54,68 ± 6,42	54,32 ± 6,32	3,99	-3,26	0,841	0,05
50m CD (m.c^{-1})	1,76 ± 0,21	1,68 ± 0,20	0,20	-0,03	0,170	0.39
50m SI (m^2 c^{-1} s$^{-1)}$	2,81 ± 0,43	2,53 ± 0,40	0,51	0.03	0,025*	0.67
400m freestyle (s)	310,52 ± 19,78	326,48 ± 16,94	0,001	0,001	0,001**	-0,86
400m GF (Hz)	38,74 ± 4,92	40,83 ± 5,37	0,24	0,22	0,229	-0.40
400m CD (m.c^{-1})	2,03 ± 0,27	1,84 ± 0,24	0.02	0,01	0,016*	0.74
400m SI (m^2 c^{-1} s$^{-1)}$	2,64 ± 0,39	2,25 ± 0,32	0,001	0,001	0,001**	1.09

Note - CI: Confidence interval; GF: Gestural frequency; DC: Cycle distance; SI: Swimming index; * p <0.05; ** p <0.01

Table 5 presents the mean values for specific swimming performance. Female Swimmers A registered better performance in the 50 and 400m freestyle swim ($p < 0.01$; $d = -0.51$; $p < 0.01$; $d = -1.12$) with a moderate and high effect size, respectively. Additionally, SI and CD were significantly higher, even without differences in GF ($p > 0.05$).

Table 6 presents the mean values of specific swimming performance for male children. Male Swimmers A registered better performance in the 50 and 400m freestyle swim, with a significantly higher SI. Significant differences in CD were also observed for the 400m freestyle swim.

Table 7 presents mean values of specific swimming performance for male Swimmers A compared to female Swimmers A. Male swimmers A registered better performance in the 50 and 400m freestyle swim with statistically significant differences ($p < 0.01$) and small effect sizes ($d = -1.66$ and $d = -0.87$, respectively). However, no statistically significant differences were observed with respect to GF, CD, and SI, except for the gestural GF of the 50m freestyle swim event, for which the male Swimmers A, exhibited a significant difference ($p < 0.01$).

Table 8 presents mean values related to the specific swimming income of male Swimmers B compared to female Swimmers B. Male Swimmers B registered better performance in the 50 and 400m freestyle swims with statistically significant differences ($p < 0.01$) and small effect sizes ($d = -1.73$ and $d = -1.70$, respectively). Additionally, statistically significant differences were observed for GFFG ($p < 0.05$; $p < 0.01$) for the 50m and 400m freestyle swims, respectively. Regarding the other analyzed variables, statistically significant differences ($p < 0.05$; $p < 0.01$) were observed for GF in the 50m and 400m freestyle swim as well as for SI ($p < 0.05$) in the 50m.

Table 9 presents the results of correlations between anthropometric variables and 50m and 400m freestyle swim times. The results revealed significant differences in positive linear correlations between height ($r = 0.305$ and $r = 0.253$, $p < 0.01$), weight ($r = 0.202$ and $r = 0.140$, $p < 0.01$), and wingspan ($r = 0.227$ and $r = 0.203$, $p < 0.01$) for the 50m and 400m freestyle swims, respectively (see Figures 1, 2, and 3).

4. Discussion

The objective of this study was to verify associations between the anthropometric characteristics (i.e. height, body mass, BMI, and wingspan) of young swimmers of different genders with the sports performance in 50m and 400m freestyle races of Swimmers A and B. In general, and based on the results presented, we can conclude that the studied anthropometric characteristics have positive associations with the performance of swimmers when comparing different genders. For both genders, there was also a tendency for Swimmers A to obtain better results when compared to Swimmers B. The results of this study support previous research indicating that anthropometry is strongly related to the performance of young swimmers (André et al. 2012; Geladas et al. 2005; Jürimäe et al. 2007; Nevill et al. 2015; Reis et al. 2010). Furthermore, positive associations were found between heigh, weigh and wingspan and the swimming performance.

The results of this study also indicate that the efficiency of swimmers' segmental movements seems to be related to the studied anthropometric characteristics, particularly the length of body segments. These results are in line with those of previous studies (Fernandes, Barbosa, and Vilas-Boas 2002b; Leone, Lariviere, and Comtois 2002), which found that the greater the length of the body segments, the faster the swimming and the lower the number of motor actions required to cover the same distance.

Additionally, the results of this study indicate that when comparing genders, the height and weight values of male swimmers tend to be higher, which is in line with a study by Malina et al. (2004) that emphasized the notion that body composition is a determinant of sports performance, particularly for swimmers (Malina and Geithner 2011). Based on the results exposed in this work, male swimmers have, on average, higher BMI values compared to women. It was also found that BMI increased with age, which is in line with the results of a previous study (Malina et al. 2004). The maturational state of swimmers can play a major role in the present study. According to Malina et al. (2004), maturation progress is directly associated with improved motor performance and is based on the skeletal and sexual maturation of individuals.

In the present study, it was found that the older swimmers (i.e. Swimmers A) were taller, heavier, and had a higher BMI, on average, when compared to the younger age group (i.e. Swimmers B). This allowed Swimmers A to have better results in most of the variables of performance analyzed. Also, according to Bohme (2004), maturation results in morphological changes that reach their peak during puberty. These changes involve most of the body's organs and structures. In this sense, the evolution of motor performance in children and adolescents is strongly associated with these stages of growth and development for children in the age group under study and appears to have a significant impact on performance in the 50m and 400m freestyle swimming events. Additionally, a previous study (Fernandes et al. 2002b) concluded that the variables under analysis (i.e. height, body mass, BMI, and wingspan) change from one step to the next, following the evolution of chronological age and influencing performance. Sports performance is affected by chronological age, which strongly correlates with swimmers' height and wingspan because the more expressive these measures are, the better their performance will be since these are presented as fundamentally important biomechanical factors for swimming (Cabral, Mansoldo, and Perrout 2008; Pacheco et al. 2009).

The relationship between anthropometric characteristics and performance in swimming has been a target of interest in previous research (Lätt et al. 2010; Morais et al. 2012; Negra et al. 2015) and the present work helps to emphasize the importance of this association in young swimmers, which can be an important factor in identifying talent and long-term development processes. A recent investigation (Morais et al. 2017) suggested that anthropometric characteristics were critical factors used as indicators to detect talent. Since anthropometry is fundamentally controlled by genetic markers (Issurin 2017), it will be less susceptible to training when compared to physical fitness attributes (Sammoud, Alan Michael Nevill, et al. 2018), which confirms its importance for talent detection. For this reason, anthropometric characteristics have been indicated as one of the most important factors allowing swimmers to achieve high levels of performance throughout their career from childhood to adulthood (Geladas et al. 2005).

This study aimed to analyze the impact of anthropometric characteristics (i.e. height, body mass, BMI, and wingspan) in young swimmers of both sexes on 50m and 400m freestyle swim performance. The results of the present study indicate that anthropometric characteristics have a fundamental impact on the performance of young swimmers. Male and female swimmers of a more advanced chronological age demonstrated more advantageous anthropometric characteristics that allowed them to achieve better results. Upon comparing athletes of the same gender, the observed differences indicate that a more advanced maturational state (following chronological age) translates into a trend of natural superiority among older swimmers compared to younger swimmers. Finally, the differences observed in the 50m and 400m freestyle swimming events seem related to the influence that anthropometric characteristics have on the biomechanical parameters of swimming, which are fundamental for swimming performance. Future studies could complement the present results and analyses with an accurate assessment of the maturational state of the sample under study. This study concluded

Table 7. Comparison between the average values (± standard deviation) of the swimming performance variables in the 50m freestyle and 400m freestyle, as well as the values of the gestural frequency (FG), cycle distance (DC), swimming index (IN) and critical speed between gender of Swimmer A. The values of significance, confidence interval of the difference and the size of the effect are also presented.

Variables	Swimmers A (Male) (n=26)	Swimmers B (Female) (n=25)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
50m freestyle (s)	31,08 ± 1,69	34,48 ± 2,34	4,55	2,25	0,001**	-1,66
50m GF (5-20m) (Hz)	54,68 ± 6,42	48,57 ± 4,13	-3,05	-9,16	0,001**	1,13
50m CD (m.c^{-1})	1,76 ± 0,21	1,80 ± 0,19	0,16	-0,72	0,457	0,19
50m SI (m^2 c^{-1} s$^{-1)}$	2,81 ± 0,43	2,63 ± 0,38	0,05	-0,40	0,131	0,44
400m frestyle (s)	310,52 ± 19,78	330,75 ± 25,92	0,002	0,001	0,001**	-0,87
400m GF (Hz)	38,74 ± 4,92	37,20 ± 3,94	0,285	0,262	0,270	0,34
400m CD (m.c^{-1})	2,03 ± 0,27	1,98 ± 0,23	0,656	0,631	0,642	0,19
400m SI (m^2 c^{-1} s$^{-1)}$	2,64 ± 0,39	2,42 ± 0,36	0,081	0,067	0,071	0,58

Note: CI: Confidence interval; GF: Gestural frequency; DC: Cycle distance; SI: Swimming index; * p <0.05; ** p <0.01

Table 8. Comparison between the mean values (± standard deviation) of the swimming performance variables in the 50m freestyle and 400m freestyle, as well as the gestural frequency (FG), cycle distance (DC), swimming index (IN) and critical speed between gender of the Swimmer B. The values of significance, confidence interval of the difference and the size of the effect are also presented.

Variables	Swimmers A (Male) (n=24)	Swimmers B (Female) (n=25)	Difference (CI 95%)		p- value	Effect size
			Higher	Lower		
50m freestyle (s)	33,20 ± 1,98	36,52 ± 1,85	4,44	2,18	0,001**	-1.73
50m GF (5-20m) (Hz)	54,32 ± 6,32	50,07 ± 5,15	-0,84	-7,64	0,015*	0,73
50m CD (m.c^{-1})	1,68 ± 0,20	1,65 ± 0,19	0,09	-0,13	0,706	0,15
50m SI (m^2 c^{-1} s$^{-1)}$	2,53 ± 0,40	2,27 ± 0,31	-0,05	-0,47	0,016*	0,72
400m frestyle (s)	326,48 ± 16,94	364,18 ± 26,36	0,001	0,001	0,001**	-1,70
400m GF (Hz)	40,83 ± 5,37	37,37 ± 4,53	0,008	0,004	0,008**	0.69
400m CD (m.c^{-1})	1,84 ± 0,24	1,80 ± 0,24	0,73	0,71	0,714	0,16
400m SI (m^2 c^{-1} s$^{-1)}$	2,25 ± 0,32	1,99 ± 0,35	0,01	0,008	0,013	0,77

Note - CI: Confidence interval; GF: Gestural frequency; DC: Cycle distance; SI: Swimming index; * p <0.05; ** p <0.01

Table 9. Results of the correlations between the different anthropometric variables and the different swimming distances (50m free and 400m free). The significance (p) values are also shown.

Correlated Variables	R	p-value	R square
Height - time 50m	-0,553	0,001*	0,305
Weight - time 50m	-0,450	0,001*	0,202
Wingspan - time 50m	-0,477	0,001*	0,227
Height - time 400m	-0,577	0,001*	0,253
Weight - time 400m	-0,434	0,001*	0,140
Wingspan - time 400m	-0,500	0,001*	0,203

Note: *p<0.01

that the improvement of performance of each young national-level swimmer is strongly related to the rate of growth, development and maturation. Consequently, it was found that the chronological age studied showed a strong relationship with the performance in the 50 and 400m events. The anthropometric characteristics are also related to the performance, and all this data must be taken into account by the coaches to enhance the effects of individualized training programs taking into account the age group and the

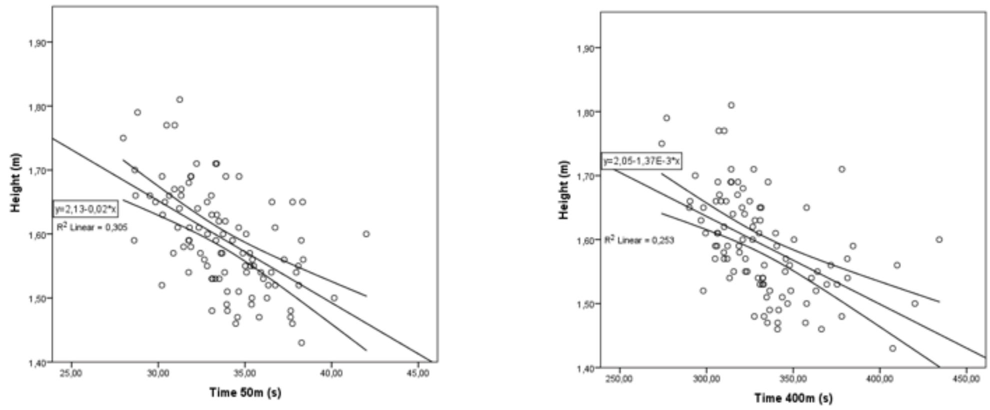

Figure 1. Graphical representation of the relationship between the height and time of the 50m free (left) or the time of the 400m free (right).

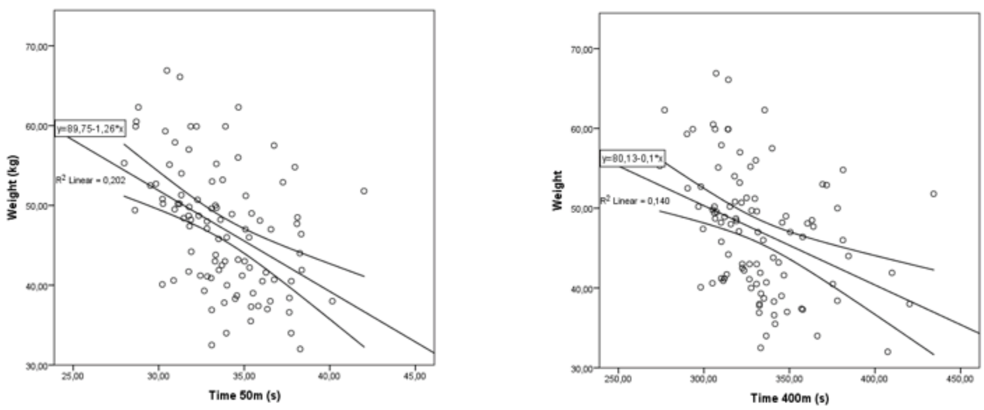

Figure 2. Graphical representation of the relationship between weight and 50m free time (left) or 400m free time (right).

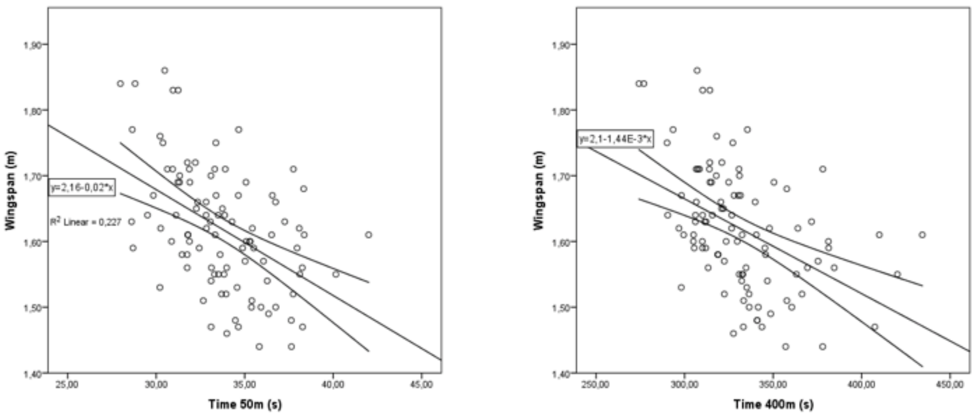

Figure 3. Graphical representation of the relationship between the wingspan and the 50m free time (left) or the 400m free time (right).

level of practitioners studied.

Supplementary Materials: The following are available online at www.jsc-cycling.com/xxx, Figure S1: title, Table S1: title, Video S1: title.

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References

Anderson, Megan E., William G. Hopkins, Alan D. Roberts, and David B. Pyne. 2006. "Monitoring Seasonal and Long-Term Changes in Test Performance in Elite Swimmers." *European Journal of Sport Science* 6(3):145–54.

André, Marcos, Marcos Santos, Marcos Lira, Barbosa Junior, Wilson Viana, Wilson Melo, Adalberto Costa, Manoel Costa, Marcos Moura, and Dos Santos. 2012. "Estimate of Propulsive Force in Front Crawl Swimming in Young Athletes." *Open Access Journal of Sports Medicine* 20123:115–20.

Armstrong, Neil. 2013. "Developing of the Elite Young Athlete." *Journal of Physical Activity, Sports and Exercise* 1(1):1–8.

Barbosa, Tiago, Vítor Lima, Erik Mejias, Mário Costa, Daniel Marinho, Nuno Garrido, António Silva, and José Bragada. 2009. "A Eficiência Propulsiva e a Performance Em Nadadores Não Experts." *Motricidade* 5(4):27–43.

Barbosa, Tiago M., José A. Bragada, Víctor M. Reis, Daniel A. Marinho, Carlos Carvalho, and António J. Silva. 2010. "Energetics and Biomechanics as Determining Factors of Swimming Performance: Updating the State of the Art." *Journal of Science and Medicine in Sport* 13(2):262–69.

Berger, Monique A. M., A. Peter Hollander, and Gert De Groot. 1997. "Technique and Energy Losses in Front Crawl Swimming." *Medicine and Science in Sports and Exercise* 29(11):1491–98.

Beunen, Gaston, and Robert M. Malina. 2008. "Growth and Biologic Maturation: Relevance to Athletic Performance." *The Young Athlete* 3–17.

Böhme, Maria Tereza Silveira. 2004. "Resistência Aeróbia de Jovens Atletas Mulheres Com Relação à Maturação Sexual, Idade e Crescimento." *Rev. Bras. Cine. Des. Hum. ISSN* 1415:8426.

Bond, Daisy, Laura Goodson, Samuel Oxford, Alan Nevill, and Michael Duncan. 2015. "The Association between Anthropometric Variables, Functional Movement Screen Scores and 100 m Freestyle Swimming Performance in Youth Swimmers." *Sports* 3(1):1–11.

Cabral, V., Antônio Carlos Mansoldo, and Jorge Perrout. 2008. "Maturação Sexual e Desempenho Físico Em Nadadores de 11 a 14 Anos de Idade." *Efdeportes (Revista Digital). A* 12.

Caputo, Fabrício, Ricardo Dantas de Lucas, Camila Coelho Greco, and Benedito Sérgio Denadai. 2000. "Características Da Braçada Em Diferentes Distâncias No Estilo Crawl e Correlações Com a Performance." *Rev. Bras. Ciênc. Mov* 8(3):7–13.

Charmas, Malgorzata, and Wilhelm Gromisz. 2019. "Effect of 12-Week Swimming Training on Body Composition in Young Women." *International Journal of Environmental Research and Public Health* 16(3):346.

Chollet, Didier, S. Chalies, and J. C. Chatard. 2000. "A New Index of Coordination for the Crawl: Description and Usefulness." *International Journal of Sports Medicine* 21(1):54–59.

Cohen, Jacob. 2013. *Statistical Power Analysis for the Behavioral Sciences*. Academic press.

Costill, D. L., J. Kovaleski, D. Porter, J. Kirwan, R. Fielding, and D. King. 1985. "Energy Expenditure during Front Crawl Swimming: Predicting Success in Middle-Distance Events." *International Journal of Sports Medicine* 6(5):266–70.

Craig, Albert B., and David R. Pendeegast. 1979. "Relationships of Stroke Rate, Distance per Stroke, and Velocity in Competitive Swimming." *Medicine and Science in Sports and Exercise* 11(3):278–83.

Damsgaard, R., J. Bencke, G. Matthiesen, J. H. Petersen, and J. Müller. 2001. "Body Proportions, Body Composition and Pubertal Development of Children in Competitive Sports." *Scandinavian Journal of Medicine and Science in Sports* 11(1):54–60.

Erlandson, Marta C., Lauren B. Sherar, Robert L. Mirwald, Nicola Maffulli, and Adam D. G. Baxter-Jones. 2008. "Growth and Maturation of Adolescent Female Gymnasts, Swimmers, and Tennis Players." *Medicine and Science in Sports and Exercise* 40(1):34–42.

Ernest W Maglisho. 1999. *Nadando Ainda Mais Rápido*. Manole.

Fernandes, R., Aleixo, I., Soares, S., & Vilas-Boas, J. P. 2008. "Anaerobic Critical Velocity: A New Tool for Young Swimmers Training Advice." *Physical Activity and Children: New Research* 211–23.

Fernandes, Ricardo, Tiago Barbosa, and João Paulo Vilas-Boas. 2002a. "Determinant Kinantropometric Factors in Swimming." *Revista Brasileira de Cineantropometria e Desempenho Humano* 4(1):67–79.

Fernandes, Ricardo, Tiago Barbosa, and João Paulo Vilas-Boas. 2002b. "Fatores Cineantropométricos Determinantes Em Natação Pura Desportiva." *Revista Brasileira de Cineantropometria e Desempenho Humano*

4(1):67–79.
Franken, Marcos, Felipe Pivetta, and Flávio Antônio De Souza. 2007. "Cinematica Do Nado Crawl, Caracteristicas Antropometicas e Flexibilidade de Nadadores Universitarios." P. 8 in *Cbce*. Vol. 15.
Geladas, N. D., G. P. Nassis, and S. Pavlicevic. 2005. "Somatic and Physical Traits Affecting Sprint Swimming Performance in Young Swimmers." *International Journal of Sports Medicine* 26(2):139–44.
Greco, Camila Coelho, and Benedito Sérgio Denadai. 2005. "Critical Speed and Endurance Capacity in Young Swimmers: Effects of Gender and Age." *Pediatric Exercise Science* 17(4):353–63.
Hopkins, William G., Stephen W. Marshall, Alan M. Batterham, and Juri Hanin. 2009. "Progressive Statistics for Studies in Sports Medicine and Exercise Science." *Medicine and Science in Sports and Exercise* 41(1):3–12.
Issurin, Vladimir B. 2017. "Evidence-Based Prerequisites and Precursors of Athletic Talent: A Review." *Sports Medicine (Auckland, N.Z.)* 47(10):1993–2010.
Jürimäe, Jaak, Kaja Haljaste, Antonio Cicchella, Evelin Lätt, Priit Purge, Aire Leppik, and Toivo Jürimäe. 2007. "Analysis of Swimming Performance from Physical, Physiological, and Biomechanical Parameters in Young Swimmers." *Pediatric Exercise Science* 19(1):70–81.
Keskinen, K. L., P. V. Komi, and H. Rusko. 1989. "A Comparative Study of Blood Lactate Tests in Swimming." *International Journal of Sports Medicine* 10(3):197–201.
Kwon, Young Hoo, and Jeffrey B. Casebolt. 2006. "Effects of Light Refraction on the Accuracy of Camera Calibration and Reconstruction in Underwater Motion Analysis." *Sports Biomechanics* 5(2):315–40.
Lätt, Evelin, Jaak Jürimäe, Kaja Haljaste, Antonio Cicchella, Priit Purge, and Toivo Jürimäe. 2009. "Longitudinal Development of Physical and Performance Parameters during Biological Maturation of Young Male Swimmers." *Perceptual and Motor Skills* 108(1):297–307.
Lätt, Evelin, Jaak Jürimäe, Jarek Mäestu, Priit Purge, Raul Rämson, Kaja Haljaste, Kari L. Keskinen, Ferran A. Rodriguez, and Toivo Jürimäe. 2010. "Physiological, Biomechanical and Anthropometrical Predictors of Sprint Swimming Performance in Adolescent Swimmers." *Journal of Sports Science and Medicine* 9(3):398–404.
Leone, Mario, Georges Lariviere, and Alain S. Comtois. 2002. "Discriminant Analysis of Anthropometric and Biomotor Variables among Elite Adolescent Female Athletes in Four Sports." *Journal of Sports Sciences* 20(6):443–49.
Malina, Robert M., Claude Bouchard, and Oded Bar-Or. 2004. *Growth, Maturation, and Physical Activity*. Human kinetics.
Malina, Robert M., and Christina A. Geithner. 2011. "Body Composition of Young Athletes." *American Journal of Lifestyle Medicine* 5(3):262–78.
Marfell-Jones, Michael, T. Olds, Arthur D. Stewart, and J. E. Lindsay Carter. 2006. *International Standards for Anthropometric Assessment*. Vol. 137.
Marinho, Daniel A., Rui A. Amorim, Aldo M. Costa, Mário C. Marques, José A. Pérez-Turpin, and Henrique P. Neiva. 2011. "'Anaerobic' Critical Velocity and Swimming Performance in Young Swimmers." *Journal of Human Sport and Exercise* 6(1):80–86.
Marinho, Daniel Almeida, Abel I. Rouboa, Francisco B. Alves, Nuno D. Garrido, João Paulo Vilas-Boas, Tiago M. Barbosa, Victor Machado Reis, António Moreira, and António José Silva. 2007. "Modelos Propulsivos: Novas Teorias Velhas Polémicas." *Universidade de Trás-Os-Montes e Alto Douro* 205.
Martínez, Sonia, Bruno N. Pasquarelli, Dora Romaguera, Cati Arasa, Pedro Tauler, and Antoni Aguiló. 2011. "Anthropometric Characteristics and Nutritional Profile of Young Amateur Swimmers." *Journal of Strength and Conditioning Research* 25(4):1126–33.
Morais, Jorge E., Nuno D. Garrido, Mário C. Marques, António J. Silva, Daniel A. Marinho, and Tiago M. Barbosa. 2013. "The Influence of Anthropometric, Kinematic and Energetic Variables and Gender on Swimming Performance in Youth Athletes." *Journal of Human Kinetics* 39(1):203–11.
Morais, Jorge E., Sérgio Jesus, Vasco Lopes, Nuno Garrido, António Silva, Daniel Marinho, and Tiago M. Barbosa. 2012. "Linking Selected Kinematic, Anthropometric and Hydrodynamic Variables to Young Swimmer Performance." *Pediatric Exercise Science* 24(4):649–64.
Morais, Jorge E., António J. Silva, Daniel A. Marinho, Vítor P. Lopes, and Tiago M. Barbosa. 2017. "Determinant Factors of Long-Term Performance Development in Young Swimmers." *International Journal of Sports Physiology and Performance* 12(2):198–205.
Negra, Yassine, Helmi Chaabene, Mehrez Hammami, Riadh Khlifa, Tim Gabbet, and

Younes Hachana. 2015. "Allometric Scaling and Age Related Differences in Change of Direction Speed Performances of Young Soccer Players." *Science&sport*.

Neiva, Henrique P., Mário C. Marques, Tiago M. Barbosa, Mikel Izquierdo, and Daniel A. Marinho. 2014. "Warm-up and Performance in Competitive Swimming." *Sports Medicine* 44(3):319–30.

Nevill, Alan M., Samuel W. Oxford, and Michael J. Duncan. 2015. "Optimal Body Size and Limb Length Ratios Associated with 100-m Personal-Best Swim Speeds." *Medicine and Science in Sports and Exercise* 47(8):1714–18.

Pacheco, A. G., T. Grossl, L. Mann, and J. Kleinpaul. 2009. "Variáveis Antropométricas e Sua Influência No Desempenho de Provas de 50 e 400 Metros Nado Livre." *EFDeportes. Com, Buenos Aires, Ano* 14.

Reis, Victor, Tiago Barbosa, Daniel Marinho, Fernando Barbosa, Antonio Reis, Antonio Silva, and Carlo Baldari. 2010. "Physiological Determinants of Performance in Breaststroke Swimming Events." *International SportMed Journal* 11.

Rodrigues, Maurício Nunes, Sidney Cavalcante da Silva, Walace David Monteiro, and Paulo de Tarso Veras Farinatti. 2001. "Estimativa Da Gordura Corporal Através de Equipamentos de Bioimpedância, Dobras Cutâneas e Pesagem Hidrostática." *Revista Brasileira de Medicina Do Esporte* 7(4):125–31.

Sammoud, Senda, Alan M. Nevill, Yassine Negra, Raja Bouguezzi, Helmi Chaabene, and Younes Hachana. 2018. "Allometric Associations between Body Size, Shape, and 100-m Butterfly Speed Performance." *Journal of Sports Medicine and Physical Fitness* 58(5):630–37.

Sammoud, Senda, Alan Michael Nevill, Yassine Negra, Raja Bouguezzi, Helmi Chaabene, and Younés Hachana. 2018. "100-m Breaststroke Swimming Performance in Youth Swimmers: The Predictive Value of Anthropometrics." *Pediatric Exercise Science* 30(3):393–401.

Schneider, Patrícia, and Flávia Meyer. 2005. "Avaliação Antropométrica e Da Força Muscular Em Nadadores Pré-Púberes e Púberes." *Revista Brasileira de Medicina Do Esporte* 11(4):209–13.

Scorţenschi, Dmitri. 2019. "Development of Speed Qualities by Improving Swimming Technique Elements Using Technical Means." *Ştiinţa Culturii Fizice* 1(33):79–82.

Toussaint, Huub M., and Peter J. Beek. 1992. "Biomechanics of Competitive Front Crawl Swimming." *Sports Medicine: An International Journal of Applied Medicine and Science in Sport and Exercise* 13(1):8–24.

Toussaint, Huub M., Arnoud Carol, Hilke Kranenborg, and Martin J. Truijens. 2006. "Effect of Fatigue on Stroking Characteristics in an Arms-Only 100-m Front-Crawl Race." *Medicine and Science in Sports and Exercise* 38(9):1635–42.

Vantorre, Julien, Didier Chollet, and Ludovic Seifert. 2014. "Biomechanical Analysis of the Swim-Start: A Review." *Journal of Sports Science and Medicine* 13(2):223–31.

Wells, Gregory D., Jane Schneiderman-Walker, and Michael Plyley. 2006. "Normal Physiological Characteristics of Elite Swimmers." *Pediatric Exercise Science* 18(1):30–52.

Zuniga, Jorge, Terry J. Housh, Mielke Michelle, C. Russell Hendrix, Clayton L. Camic, Glen O. Johnson, Dona J. Housh, and Richard J. Schmidt. 2011. "Gender Comparisons of Anthropometric Characteristics of Young Sprint Swimmers." *Journal of Strength and Conditioning Research* 25(1):103–8.