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ORIGINAL ARTICLE

Factors affecting children and adolescents 50 meter performance in freestyle swimming

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ABSTRACT

BACKGROUND: This study investigated which factors influence performance in a short distance swimming test (50-meters) in adolescent swimmers.
METHODS: Freestyle 50-meter personal best time (PBT) was registered for 67 swimmers (14.3±2.2 y; 46 males). Handgrip (HG), standing broad jump (SBJ), isometric knee-extension (KE), time to run 30 meters (V30m), maximal estimated oxygen-consumption (VO_2max), swimming-technique (CTE), height, weight, fat mass, body fat percentage (BF%) and fat-free mass (FFM) were measured. Variables that presented correlation with PBT were further examined using multiple linear regressions.
RESULTS: PBT was correlated with SBJ, VO_2max, HG, KE, CTE, Weight, Height, FFM, BF% and swimming hours per week (SHW). Multiple linear regressions showed that PBT was associated to Height, V30m, CTE and SBJ. Sex and age did not modify these associations.
CONCLUSIONS: PBT was found to be mainly associated with height and anthropometric variable. SBJ and V30m, both fitness-related variables, highly influenced by muscle fiber type were also predictors, suggesting that for short distances physiological factors might be determinant to performance. Age modified predictive values suggesting that this is also a key factor to performance, and thus competitions during adolescence should be organized according to year of birth rather than by age category.

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Swimming is a sport practiced by millions worldwide. Competitive swimming is becoming more popular and in recent years has become one of the most practiced sports around the world being the twelfth most practiced sport in Spain.[1] Nevertheless, the determinants that most influence swimming performance during adolescence are still unclear. Competitive swimmers are thought to have specific anthropometrical features compared with other athletes, but are nevertheless dependent on physiological adaptations to enhance their performance.[2]

In contrast to team sports like soccer or basketball, the selection of swimmers who may have the potential for competitive success is not based on the subjective opinion of coaches, but on their results. These results are dependent on psychological, morphological, physiological and technical factors, based on individual genetics and training. Although it is well known that these factors affect physical performance,[2] it is still unclear to what extent they affect adolescent swimmers' performance. Previous studies focusing on describing which variables affected performance in 11 to 14 year-old swimmers found that anthropometric variables (particularly in males) and specific fitness (aerobic speed and endurance), and technical domains (particularly in females) were determinant to performance in short distance swimming events.[3] However, as swimmers become older, these variables may change and new factors may become determinant to performance.

Handgrip has been associated with performance in young and adult swimmers,[4, 5] master swimmers [6] and talent detection models,[7] because it is considered a phenotype tool that reflects physical function in relation to hereditary genes.[8] However, handgrip only measures forearm strength that might not be the only relevant strength value for swimming performance. It would therefore also be interesting to assess swimmers strength with other tests such as isometric knee extension, which has demonstrated positive relations with performance in sports like soccer,[9] volleyball [10] and cycling.[11] Nevertheless, as previously stated, strength is not the only fitness-related value pertinent to performance. Other variables such as aerobic power, velocity and body composition have also been related to performance in adolescents.[3, 12, 13]

Regarding body composition, Siders *et al.* [14] found that fat mass and fat-free mass were negatively and positively associated respectively with performance only in females. The previous study was performed in collegiate swimmers and thus again, these associations could be different for adolescent swimmers than for collegiate swimmers.

Athletic performance is a multifactor term as it is determined by several different components such as physical fitness, anthropometry, psychological aspects and others. Nevertheless, the specific variables of these components that most influence performance still remain unclear. If the specific physical fitness tests that most influence swimming performance in short distances during childhood and adolescence are determined, a group of swimmers can be evaluated with these tests. If a swimmer performs poorly in one of these tests we can try to improve the performance of the swimmer in the specific test improving the physical fitness related variable and consequently improving swimming performance. Thus the present study uses assessment tools that most swimming coaches have access to and therefore can apply to their swimmers.

Therefore, the main aim of this study was to determine what fitness factors most influence performance of a short distance swimming test (50 meters) in adolescent swimmers. Taking into account previous studies, the main hypothesis was that anthropometric factors would be the most determinant factors related to performance in short swimming distances.

Materials and methods

The protocol and research presented in this paper are part of the Randomized Controlled Trial RENACIMIENTO. Full design of the project is explained elsewhere.[15]

Participants

Ninety-eight swimmers (52 males/ 46 females) agreed to participate in the study. However, those not meeting the following inclusion criteria were excluded *a posteriori*. Participants had to be between the ages of 11 and 18, Caucasian, healthy, with no chronic disease and free of musculoskeletal disorders (fibromyalgia, gout, osteoarthritis, rheumatoid arthritis, tendinitis), bone fractures, medication or habits affecting bone development (habitual smokers). Swimmers had to have a history of swimming and competing in regional tournaments for more than 3 years and training for a minimum of 6 hours per week. Tests were conducted on 3 different days. Swimmers first attended the laboratory to perform the strength and body composition tests [16] that were completed in 2 hours. On their second visit to the laboratory, on a weekend day, they performed the field tests (Standing Broad Jump, jump test, 30 meter run test and 20 meters shuttle run test). The third day needed to complete the study was the day swimmers competed, when personal best time (PBT) was obtained. All the PBT were recorded the same day. Nevertheless, due to space limitations laboratory measurements were performed in different days in a range of 4 weeks. By some swimmers the laboratory tests were performed 2 weeks prior to the swimming measurements while others performed the tests 2 weeks after.

Pubertal maturation was determined by self-assessment of secondary sexual characteristics according to the 5 stages proposed by Tanner.[17] This method has been reported to be both valid and reliable in assessing sexual maturity among adolescent athletes.[18]

Ethical committee

The study was aproved by the Ethics Committee of Clinical Research from the Government of Aragón (C.I.PI11/0034; CEICA; SPAIN), and followed the international rules for research with humans, following the Declaration of Helsinki (1964) as revised in 2000 in Edinburgh.

Parents or tutors and adolescents provided written consent. The present study is part of a Randomized Controlled Trial which is registered in a public database (www.clinicaltrials.gov) with the following register number: NCT02380664

Physical activity and general information

A structured questionnaire included information about aspects regarding training, number of years swimming (SYR), swimming hours per week (SHW) and other sports practiced, in addition to personal data such as birthdate, medical history, medication and injuries.

Laboratory tests

Body composition measurements

A portable stadiometer with 2.10 m maximum capacity and a 0.1 cm error margin (SECA 225, SECA, Hamburg, Germany) was used to measure height. A portable body composition analyzer with a 200kg maximum capacity and a±0.1 kg error margin (TANITA BC-418 MA; Tanita Corp., Tokyo, Japan) was used to measure body mass and estimate fat free mass (FFM) and body fat in kilograms (BFM) and body fat percentage (BF%). Individuals removed shoes, socks and heavy clothes prior to weighing. Coefficients of variation for the TANITA in our laboratory have been calculated for weight (0.09%) and body fat percentage (1.11%).[15] Body Mass Index (BMI) was calculated by dividing weight (kg) by squared height (m^2).

Strength measurements

Maximum isometric quadriceps extension strength by knee extension (KE) was measured using a strain gauge (MuscleLab, Force Sensor, Norway) after a 5 minute warm-up on a cycle ergometer (Monark 927E, Vansbro, Sweden) with a 45 watts resistance at 60 revolutions per minute. Participants were seated on a chair, with an anchorage placed on the distal third of the tibia. This anchorage was connected to a MuscleLab gauge that registered the Newtons generated by an isometric force during the 6 seconds that subjects were encouraged to perform maximum strength. Each subject performed two discontinuous maximal repetitions with each leg and a minimum of 3 minutes between attempts with the same leg. The best attempt with each leg was selected for further analysis. Maximum isometric forearm strength (HG) was determined with a digital handgrip dynamometer (Takei TKK 5401, Takei scientific instruments, Tokyo, Japan) in order to evaluate handgrip strength. The participants were instructed to exert their maximal grip with the upper limb in extension (right and left hand) in two trials, with brief pauses between each (3 minutes). Hand span to perform the test was different for each participant according to their hand size. The dynamometer was placed according to the optimal handgrip span suggested by Ruiz *et al*.[19] The best attempt for each hand was selected for further analysis.

Field tests

To perform the field tests, all swimmers who had trained the previous evening during 2 hours attended the laboratory in a fasting condition at 9 am. Blood samples were extracted in order to obtain bone markers, and a breakfast consisting of milk, cereals, bread, biscuits, juices and fruits was provided to all participants. An hour after breakfast, participants performed the field tests. All participants had performed all the tests in school previously and were therefore familiarized with all of them. In addition, all participants followed the same protocol (in the following order: 0. Five minute warm-up/ 1. Dynamic strength/ 2. Speed test/ 3. Cardiorespiratory fitness) that was performed at the same time of the day in order to control for diurnal effects that may influence experimental outcomes. Within the same test 2 minutes rest was allowed between trials. A five minute rest was allowed between the dynamic strength test and the speed test and ten minutes between the speed test and the cardiorespiratory fitness test. Therefore, including the test explication, development and rest periods nearly 2 hours passed from breakfast to the most physical demanding test (the 20 meter shuttle run test). For all field tests, the best attempt was selected.

Dynamic strength

The standing broad jump (SBJ) was performed in order to test explosive leg power. A two-footed take-off and landing were demanded of the participants, allowing them to swing their arms and bend their knees to provide forward drive. Three attempts were allowed. A rest period of 2 minutes was provided between the trials.

Speed: 30 m run test

Time to run 30 meters (V30m) was measured through time gates that were placed along an indoor football pitch. The followed protocol has been described elsewhere.[20]

Cardiorespiratory fitness: 20 meters shuttle run test

Five minutes of rest were allowed before starting the 20 meters shuttle run test. Maximum oxygen uptake (VO_2max) was estimated using the twenty meters shuttle run fitness test, which involves continuous running between two lines 20 meters apart in time to recorded beeps.[21] The Leger equation for children and adolescents between 6 to 18 years was used to estimate VO_{2max}.[21]

Swimming tests

Swimming personal best time

Fifty meters PBT was obtained for each participant in a 25 meter swimming-pool from the regional swimming championships. All swimmers started diving head first into the pool. Time spent to cover the 50 meters was determined by an expert referee with a touchpad chronometer system (Daktronics, USA).

Crawl technique

Crawl technique (CTE) was subjectively measured by a qualified swimming trainer with more than 10 years of experience. The trainer graded technique from 1 to 10, with 1 being a very poor technique and 10 a near perfect technique.

Statistical analysis

Data are presented as mean±standard deviation (SD) (otherwise stated). All the studied variables showed a normal distribution checked with Kolmogorov-Smirnov tests. Gender differences were evaluated with Independent student t-tests. Age adjusted partial correlations were applied between PBT and all the considered parameters (weight, height, BMI, CTE, KE, HG, VO_2max, V30m, SBJ, SYR, SHW, FFM, BFM and BF%). For the variables that showed correlation, hierarchical multiple linear regression models were computed. PBT was the outcome variable, and the variables that had previously shown correlations were entered in the model as predictor variables (Model 1). Model 1 was further adjusted by the following confounders: Sex (Model 2= Model 1 + Sex), Age (Model 3 = Model 2 + Age), SWH (Model 4 = Model 3 + SWH) and Tanner stage (Model 5= Model 4 + Tanner stage). Cook´s distance was calculated in order to detect highly influential cases that could bias the model, as no cases were above 1 all cases were included in the model. Model fit was determined from the adjusted R square. Multicolinearity was checked with the variance inflation factor (VIF) and the tolerance statistic both showin no colinearity within the data. Homoscedasticity and linearity were checked with residual plots (ZRESID *vs.* ZPRED), that showed a random array of dots randomly and evenly dispersed through the plot suggesting that the linear regression assumptions of linearity and homoscedasticity had been met. Normality of the residuals was checked with a normal probability plot that showed that residuals followed a normal distribution. One-way random intra-class correlation coefficient was calculated in order to determine the reliability of the tests. Finally, in order to explore the cross validity of the model and assess how well the model could predict the outcome in a different sample the Stein formula was applied.[22] The Statistical Package for the Social Sciences 15.0 software (SPSS Inc., USA), was used for all analyses and p value was set at $P<0.05$.

Results

Participants

A total of 82 adolescent swimmers of both genders met the inclusion criteria and finally participated in the study. However, some swimmers did not perform all the tests and therefore the final sample was reduced to 67 swimmers (mean age 14.3±2.2 years; 38 males, 29 females).

Descriptive characteristics

Descriptive statistics for the whole sample are summarized in Table I. Males were older, heavier, taller and presented higher values of BMI, KE, HG, VO_2max and SBJ, lower BF% and better times in V30m and in PBT than females (all P<0.05; Table I). No differences were found in CTE, BFM, SWY and SHW between genders (all p> 0.05; Table I). In addition, no differences were found for maturation status (P>0.05; Table I).

PBT was correlated with SBJ, VO_2max, HG, KE, CTE, Weight, Height, FFM, BF% and SHW (P<0.05; Table II).

Table I.—*Descriptive data.*

Variable	General (N.=67)	Male (N.=38)	Female (N.=29)
Age (y)	14.3±2.2	15.1±2.0*	13.4±2.0
Tanner $_{(I/II/III/IV/V)}$	2/11/13/35/6	0/4/8/20/6	2/7/5/15/0
Weight (kg)	55.6±13.2	61.7±12.0¥	47.5±10.1
Height, (cm)	164.2±12.1	169.7±10.2¥	157.1±10.7
BMI (kg/m²)	20.3±2.8	21.3±3.0¥	19.1±2.0
Crawl technique (1/10)	6.2±1.4	6.1±1.5	6.3±1.3
KE Isometric (N)	899.7±276.7	1035.2±270.7‡	722.1±161.6
Handgrip (kg)	55.0±17.8	63.9±17.6‡	43.2±9.4
VO_2max (l/min)	50.6±4.9	52.22±4.3‡	48.4±4.9
V30m (s)	5.2±0.5	4.9±0.3‡	5.5±0.4
SBJ (m)	1.9±0.3	2.1±0.3‡	1.7±0.2
PBT (s)	30.8±3.1	29.5±2.8‡	32.5±2.7
Swim years (y)	9.7±2.3	8.1±2.8	7.6±2.5
SHW (h)	7.9±2.7	1.0± 2.2	9.3±2.4
FFM (kg)	44.4±11.7	50.6±10.6¥	36.3±7.2
BF%	18.9±5.1	16.2±4.4¥	22.5±3.5

Data are presented as mean±Standard Deviation (SD).
*P<0.05; ‡P<0.008;
For body composition and fitness related variables Bonferroni corrections were performed to avoid Type I errors, and p values had to be below 0.01 and 0.008 respectively in order to be significant.
BMI: Body Mass Index; KE Isometric: knee extension isometric; V30m: velocity 30 meters; SBJ: standing broad jump; PBT: personal best time; SHW: swimming hours per week. VO_{2max}: Maximum oxygen uptake; FFM: Fat free mass; BF%: body fat percentage. *P<0.05 compared to female group.

Table III displays the association between PBT and fitness-related variables. As Tanner stage did not significantly modify associations and the adjusted r square decreased in model 5 suggesting that the extra predictor variable entered in the model decreased the model fit, only models 1, 2, 3 and 4 are explained bellow.

PBT was associated to Height, V30m, CTE and SBJ (r square: 0.789; Semip. Corr: 0.126-0.298). Additional

Table III.—*Personal best time.*

	SEE	B	r square	Change in r square	Adjusted r square	β^{δ}	Semip corre$^{\varphi}$	P
Model 1	1.48							
Height			0.608	0.608	0.602	-0.413	-0.298	**<0.001**
V30m			0.727	0.119	0.718	0.217	0.126	**0.035**
Crawl tec.			0.761	0.034	0.749	-0.207	-0.202	**0.001**
SBJ			0.789	0.028	0.775	-0.302	-0.166	**0.006**
Model 2	1.44							
Height			0.608	0.608	0.602	-0.424	-0.306	**<0.001**
V30m			0.727	0.119	0.718	0.278	0.155	**0.009**
Crawl tec.			0.761	0.034	0.749	-0.176	-0.167	**0.005**
SBJ			0.789	0.028	0.775	-0.371	-0.195	**0.001**
Model 3	1.43							
Height			0.608	0.608	0.602	-0.388	-0.266	**<0.001**
V30m			0.727	0.119	0.718	0.237	0.127	**0.028**
Crawl tec.			0.761	0.034	0.749	-0.177	-0.167	**0.004**
SBJ			0.789	0.028	0.775	-0.322	-0.161	**0.006**
Model 4	1.38							
Height			0.608	0.608	0.602	-0.348	-0.233	**<0.001**
V30m			0.727	0.119	0.718	0.253	0.135	**0.016**
Crawl tec.			0.761	0.034	0.749	-0.169	-0.160	**0.005**
SBJ			0.789	0.028	0.775	-0.217	-0.100	0.070
Model 5	1.38							
Height			0.608	0.608	0.602	-0.379	-0.223	**<0.001**
V30m			0.727	0.119	0.718	0.274	0.140	**0.016**
Crawl tec.			0.761	0.034	0.749	-0.164	-0.154	**0.005**
SBJ			0.789	0.028	0.775	-0.197	-0.089	0.070

Significant results in bold letters.
Model 1 (Includes all the selected fitness related variables by the stepwise regression).
Model 2=Model 1 + Sex.
Model 3=Model 2 + Age.
Model 4=Model 3 + Swimming hours per week (SWH).
Model 5=Model 4 + Tanner stage.
β is the estimated standardized regression coefficient; $^{\varphi}$Semi-partial correlation; SEE: Standard error of estimation of the model; Crawl tec: crawl technique; Swi h/w: swimming hours per week.

Table II.—*Correlations coefficients between 50m freestyle time and fitness and body composition variables.*

	SBJ	V30m	VO_2max	HG	KE	CTE	W	H	BMI	FFM	FM	BF%	SHW	SYR
PBT	-0.561*	0.538*	-0.435*	-0.511*	-0.267*	-0.322*	-0.440*	-0.602*	-0.114	-0.516*	-0.026	0.316*	-0.464*	-0.092

*P<0.05
SBJ: standing broad jump; V30m: velocity 30 meters; HG: handgrip; KE: knee extension isometric; CTE: crawl technique; W: weight; H: height; BMI: Body Mass Index; FFM: Fat free mass; BF%: Body fat percentage; SHW: swimming hours week; SYR: swim years; PBT: Personal best time.

TABLE IV.—*Intraclass correlation coefficient for the strength tests performed.*

Intraclass correlation coefficient	
Left knee extension	0.950
Rigth knee extension	0.924
Left handgrip	0.964
Rigth handgrip	0.942
Broadjump	0.924
V30m	0.963

sex adjustment did not change the model, as all the predictors stayed significant (r square: 0.803; Semip. Corr: 0.120-0.306). Age adjustment also increased the predictive value (r square: 0.809; Semip. Corr: 0.081-0.266). When SHW were added to the model the association between PBT and SBJ disappeared (P=0.138) although the predictive value of the model was increased (r square: 0.826; Semip. Corr: 0.066-0.223).

Table IV displays the test re-test intraclass coefficient results. All strength tests presented a high intraclass coefficient result (from 0.924 to 0.964) suggesting that they were reliable tests to perform in children and adolescent swimmers.

The Stein equation [22] with an r square of 0.78 indicates that the derived model (Model 4), is an applicable model if used with other samples of adolescent swimmers, as this adjusted r square value predicts that if this model was applied to completely different samples of similar trained adolescent swimmers it would account for 78% variance of PBT.

Discussion

The main finding of the present study is that height, technique and power are key factors that determine 50 meter performance in adolescent swimmers, independently of sex and age.

SBJ that might vary according to the type of muscle fiber that swimmers possess was an important predictor in models 1, 2 and 3. Therefore, PBT may vary depending on the type of muscle fiber that swimmers possess. Muscle contraction speed depends on the proportion of type II muscle fibers.[23] This research focuses on short distance (50 m) swimming events, where type II fibers are predominant [24] and particularly type IIb faster contraction fibers. Therefore, the association between 50-meter freestyle performance and SBJ could be due to the metabolic and physiological similitude of the effort that is determined by a similarity in muscle type (predominance of type II muscle fibers).

The fact that in a subject type I fibers or type II fibers predominate depends on his or her genetic inheritance. Therefore SBJ is partly related to genetics and having a larger number of type II muscle fibers could be the key to obtaining better performance in short-distance events. This hypothesis could be tested using muscular biopsies. However, this may imply ethical issues in a `population of this age range. Interestingly, V30m that is also influenced by muscle fibre type, proved to be an important factor affecting performance, reinforcing the previous idea that one of the most important factors regarding short distance performance at this age is physiological. Nevertheless, the present findings suggest that these physiological characteristics might be modifiable by training, as SHW deleted the effect of SBJ on performance suggesting that the number of training hours is key to performance. Although this is a well-known fact and is supported by many previous studies,[2, 25] it is an interesting finding and supports the idea that although there is a high genetic component to becoming an Olympic Champion training is also as important.

When age was included as a covariate the model r square increased but all the predictors remained similar suggesting that age might not be determinant to performance. Nevertheless, age is highly related to height that was the main predictor of PBT in all models. In addition, older children will have had a chance to improve their technique during more years than younger children which again was a significant predictor in all models. Therefore, age is an important predictor and as suggested by previous studies to minimize the influence of age on performance it would be better to organize competitions according to year of birth rather than by age category (two years of age together) as previously suggested.[3, 26]

Another factor affecting performance was height. Arm length has a linear relationship with height [27] being one of the main predictors of performance in previous studies.[28] This finding is in line with previous studies that evaluated short distance events.[29, 30] Although height is not a modifiable factor as it is mainly genetically determined, this is a key finding. If a coach trains a heterogeneous group of swimmers (regarding height), he might be able to start specializing these swimmers during adolescence, focusing the training of shorter swimmers on longer distances, in order to avoid failure of these swimmers in short distance events which might cause personal disappointment and might lead to withdrawal of the activity. This hypothesis is supported by non-published personal findings of the RENACIMIENTO Study,[15] in which we have followed adolescent swimmers during 4 years and found that swimmers that abandoned the activity were those that were performing the worse, therefore received more pressure from their coaches, faced personal disappointment and finally decided to abandon the swimming-club. If swimmers were well focused by coaches that choose the event that each swimmers was going to compete in, taking in to account their individual physiological and anthropological characteristics it is possible that they would perform better, improving their personal confidence and enjoying the activity. Therefore, reducing the withdrawal incidence and consequently increasing the prevalence of swimmers that might reach athletic success later in life.

Interestingly, technique, which is the pattern of movements to be performed and whose primary purpose is saving energy and optimizing the propulsive force, is usually identified as one of the determinant factors of athletic performance.[30-32] The results found in the present study are consistent with this, as technique was a predictive variable for PBT. In our sample technique did show a negative correlation with performance (the better technique the lower the time which was our performance indicator). Similar to our findings, Latt *et al.* [28] and Saavedra *et al.* [3] found that biomechanical factors were important variables related to performance in female swimmers. However, these findings were related to performance that was evaluated for longer distances. It is possible that technique might become a more relevant factor in longer distances allowing a more efficient movement. Nevertheless, in such short distances, it also seems important. The fact that technique is important in both short and long distances is of critical importance for coaches that should focus many training sessions on this parameter in childhood and adolescence as it is going to be a key parameter regarding athletic success. Growth anthropometric differences emerge during childhood and adolescence due to differences in pubertal development. These differences generally disappear at the end of puberty when the swimmer is fully developed. Although technique might have a smaller influence on performance than other anthropometric parameters during growth (PBT correlation with technique -0.322 and with height -0.602), this might partly be explained by the previously mentioned growth differences. Therefore, although it might become crucial later in life, it is still important to teach it and perfect it in previous stages,[32, 33] because it could become a crucial aspect in longer distances or in the future when the physical and fitness characteristics will be more equal among subjects.

Having a certain level of body fat has sometimes been suggested to present benefits to buoyancy [34, 35] and thereby to enhancing performance, but in this study no association was observed between BF% and PBT. Moreover, FFM was not a predictive value. We have to take into account that all swimmers in our sample were healthy adolescents who were in a normal range for both FFM and FM and that the PBT was measured for a short distance event. Perhaps over longer distances different effects would have been observed.

The fact that Tanner stage did not add any extra predictive value to the present model does not mean that it is not important for performance. Age and Tanner presented high correlations (Spearman r=0.643; $P \leq 0.001$) between them and both presented a high correlation with performance (-0.733 and -0.555 respectively; both $P<0.001$). Therefore, the fact that Tanner did not modify predictive values could be due to the order of the predictors introduced in the model, as if Tanner would had been included before age, it would had been a significant predictor for some variables (data not presented). Although in the present study maturational status did present a high correlation with chronological age, this is not always the case and therefore it is always necessary to take into account pubertal status when performing research studies in adolescent populations.

Limitations of the study

Some limitations deserve to be commented. Specific genetic or morphological aspects, related to muscle fibers were not measured and could help to explain some of the present findings. In addition, although swimming tests were performed during the same day for all swimmers, laboratory measurements were performed in different days for each swimmer. Therefore, some swimmers performed the strength tests prior to the swimming measurements while others performed them after. Moreover VO_2max was indirectly estimated by the 20m shuttle run test and therefore values might not be as accurate as possible. Body composition parameters were estimated by BIA, which is very sensitive to hydration status. Nevertheless, all the swimmers were also measured with dual energy x-ray (DXA) and therefore we also collected body composition values from DXA that showed a very high correlation with BIA body fat percentage (Pearson r=833) and lean mass (Pearson r=0.988). Although DXA is a more accurate and sensitive tool, we decided to use BIA values instead of DXA values as it is unlikely that coaches have an accessible DXA to perform body composition analyses to their swimmers. Another positive aspect of the present study is the large number of swimmers with high levels of training and with sophisticated methods of strength measurement as well as including a combination of body composition, anthropometric and physical fitness variables.

Conclusions

Short distance swimming performance during adolescence is mainly determined by fitness and anthropometry related qualities. Height was the variable that most influenced performance, and although it is a genetically determined variable and thus not modifiable, if coaches are conscious of the importance of this parameter on performance, they might be able to focus training sessions of shorter swimmers to longer distance events and therefore avoid personal disappointment and activity withdrawal. In addition SBJ and V30m, two fitness-related variables highly influenced by muscle fiber type were also critical to performance, suggesting that for short distances physiological factors might be determinant to performance. Nevertheless, training hours modified these associations suggesting that although genetically factors are important, environmental factor also make a difference. Moreover, technique was also associated to performance suggesting that coaches should focus many sessions on improving this parameter that is one of the most modifiable parameters of the present research and that could become even more important in more advanced stages of the athletic career. Age increased predictive values suggesting that it is also a key factor to performance and thus competitions during adolescence should be organized according to year of birth rather than by age category (two years of age together).

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