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RESEARCH ARTICLE

Sprint Performance Determinants in High-level Young Swimmers

Carolina L. Matos[1], Ana T. Conceição[1,2,3,*], Hugo G. Louro[1,2], Henrique P. Neiva[2,4], Pedro N. Sobreiro[1,3], Bárbara L. Viana[4] and Daniel A. Marinho[2,4]

[1]*Sport Sciences School of Rio Maior, Rio Maior, Portugal*
[2]*Research Center in Sports Sciences, Health and Human Development, CIDESD, Portugal*
[3]*CIEQV: The Life Quality Research Centre, Santarém, Portugal*
[4]*Department of Sports Sciences, University of Beira Interior, Covilha, Portugal*

Abstract:

Background:

Identifying and evaluating the variables that influence performance are essential for obtaining excellence in sport.

Objective:

This study aimed to identify which parameters have the most influence on the 50 meters freestyle time in young competitive swimmers.

Methods:

One hundred and eighty-four high-level swimmers (males, n=92: 14.60±0.56 years; females, n=92: 13.53 ± 0.54 years) with 468±66 FINA points in the 50 meters freestyle short course participated in this study. Age, height, body mass, wingspan, stroke rate, stroke length, stroke index, turning time (5 m + 10 m), horizontal jumping, and medicine ball throwing were assessed. The swimming performance was assessed in a 50 meters freestyle time trial at maximum speed in a 25 meters swimming pool. Multiple regression was performed to assess the relationship between one dependent variable (50 meters freestyle time) and independent variables.

Results:

The results showed significant differences between both the genders. In male swimmers, only the turning time and the horizontal jump were significant (r^2=0.8819; p<0.001), while females, besides the same variables, presented significant results in terms of height, body mass, stroke length, and stroke index (r^2=0.9013; p<0.01).

Conclusion:

In conclusion, in young male swimmers, the turning time and the horizontal jump contributed significantly to the 50 meters freestyle swimming performance, and in young female swimmers, the main contributors were the turning time, horizontal jump, height, body mass, stroke length, and stroke index.

Keywords: Swimming, Young swimmers, Performance factors, Freestyle, Stroke, Turning.

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1. INTRODUCTION

The identification and evaluation of the variables that influence performance are essential for obtaining excellence in sport [1]. In the 1970s, a study [2] reported that the form and body functions are closely related to each other and decisive in achieving high-level sports performance. For instance, in swimming, Persyn *et al.* [3] postulated that the shape and dimensions of the swimmer's body and upper limbs influence the amount of propulsive and hydrodynamic drag forces exerted in a swimmer at a given swimming speed. More recently, Fernandes *et al.* [4] found a high ratio between the biacromial and bicrystal diameters of elite swimmers, a decisive factor in promoting a lower drag coefficient. The same study verified the length and surface of the swimmers' limbs to be high and, therefore, positively affecting their propulsive

* Address correspondence to this author at the Sports Sciences School of Rio Maior, Polytechnic Institute of Santarém, Av. Dr. Mário Soares, 2040-413 Rio Maior, Portugal; E-mail: anaconceicao@esdrm.ipsantarem.pt

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capacity. These morphological characteristics play a major role in the young swimmers' performance because the proportions of the swimmer's body influence hydrodynamic drag and make a difference between the elite and the rest [5].

Competitive swimming is a cyclic sport that occurs in a highly constrained environment (as water density is approximately 800 denser than air), causing higher active drag than other aquatic activities [6]. It means that swimmers must strategically manage their stroke length and stroke rate to guarantee high swimming speed with few fluctuations [7, 8]. To better understand the biomechanical factors that influence competition, researchers have been carrying out analyses to provide crucial information on the management of the stroking parameters (*i.e.*, stroke length, stroke rate, and swimming speed) [7, 9, 10]. In a swimming race, the variation of the stroke rate is usually associated with the variation of the stroke length, as swimming speed is the product of stroke rate and stroke length. Thus, swimmers manage their swimming speed to minimize the race time by adjusting their stroke rate, stroke length, or both [11].

Besides the biomechanical factors, strength parameters have been recently proposed as being part of the multi-factorial phenomena that enhance swimming performance [7, 12]. The assessment of specific muscle power output of both arms and legs seems to be essential in swimming [13], but it is difficult to assess it in the aquatic environment [14]. It has been suggested that the shorter the race, the higher the role of strength when compared to technical variables [14 - 16]. For short swimming races, the power production capacity is considered a key variable, and physical characteristics, such as body height, arm span, body composition, and somatotype, can also contribute to the level of performance [17]. The morphological characteristics largely depend on genetic factors but might have a decisive impact on swimming performance [18]. Barbosa *et al.* [19] reported fastest swimmers in the 11 to 13 years age group to be taller, heavier and with longer limbs than the others. Those swimmers showed higher stroke rate, stroke length, speed, stroke index, and propelling efficiency, but lower speed fluctuations. Another study showed [20] the best predictor for the 50 meters freestyle as the stroke rate in both genders. In male swimmers, Silva *et al.* [21] found that only short distances with high intensity could be predicted through the stroke index, shoulder flexibility and intracycle velocity. Using an allometric approach, Dos Santos *et al.* [22] verified the percentage of body fat and arm propulsive force to be significant predictors in the young swimmers' 50 meters freestyle swimming performance.

Since each individual is ontogenically endowed with a *sui generis* personality, with a certain structure and which, to a greater or lesser degree, helps in the realization of his talent in a certain area or spectrum of activities, the better the conditions (structural and environmental) for its development, the greater the resulting expression, regardless of the scope of the chosen activity [23].

Knowing right at the beginning of the long-term preparation and development plan as to which are the necessary characteristics that enhance the possibility of becoming a high-level athlete and meet the demands of a sport or sporting specialty, such as swimming, promotes an initial advantage in the model of preparation as long as it is carried out properly throughout the preparation process [23].

Previous studies indicate that height, body mass, wingspan, stroke rate, stroke length, and stroke index can predict the performance of swimmers, but a few include other variables, such as the turning time and the strength of the upper and lower limbs. Therefore, the aim of this study is to identify which parameters have the most influence on the 50 meters freestyle performance of young swimmers.

2. MATERIALS AND METHODS

2.1. Participants' Characteristics

The study included 184 young swimmers, 92 male swimmers (14.60 ± 0.56 years old, 1.75 ± 0.07 m and 64.06 ± 6.49 kg) and 92 female swimmers (13.53 ± 0.54 years old, 1.63 ± 0.06 m and 53.37 ± 4.98 kg), whose best 50 meters freestyle performance was classified with 468 ± 66 FINA points (short course). These were high-level swimmers, selected to be part of the Portuguese National Swimming Team in the four sports seasons (Table **1**).

Table 1. Summary of the distribution of swimmers by season and age.

<table>
<tr><th></th><th>Season 1</th><th>Season 2</th><th>Season 3</th><th>Season 4</th><th colspan="2">Total</th></tr>
<tr><td>15 years female</td><td>11</td><td>15</td><td>10</td><td>10</td><td>46</td><td rowspan="2">92</td></tr>
<tr><td>14 years female</td><td>17</td><td>13</td><td>6</td><td>10</td><td>46</td></tr>
<tr><td>15 years male</td><td>18</td><td>14</td><td>14</td><td>7</td><td>53</td><td rowspan="2">92</td></tr>
<tr><td>16 years male</td><td>13</td><td>15</td><td>2</td><td>11</td><td>41</td></tr>
<tr><td>Total</td><td>59</td><td>57</td><td>32</td><td>38</td><td colspan="2">184</td></tr>
</table>

2.2. Experimental Design

2.2.1. Measures and Procedures

Data collection was conducted during the National training camp that is carried out once per season for two days. During these days, four evaluation sessions were implemented to assess anthropometric variables (first session), dryland strength (second and third sessions) and swimming performance (fourth session).

2.3. Data Collection

2.3.1. Anthropometric Evaluation

After the swimmers arrived at the pool, they rested for 5 minutes, and then their body mass, height and wingspan were evaluated. To measure the height (in meters), a digital stadiometer with a scale of 0.001m was used (SECA, 242, Hamburg, Germany). The body mass was measured with a digital scale (TANITA, BC-730, Amsterdam, Netherlands). For the measurement of the wingspan, a precision measuring tape with a scale of 0.001m was used on the wall in the horizontal position, and then the swimmers positioned themselves with their backs to the wall and their heels against it and, with the arms extended horizontally, the measurement was carried out from the end of the middle finger to the other middle finger [24].

2.3.2. Dryland Strength Evaluation

To evaluate the dryland strength of the lower limbs, three horizontal jumps were performed, with three minutes of rest interval. The swimmers were instructed to place the feet at shoulder width on the mark, being allowed to move the upper limbs before the impulse. The distance from the initial position to where the feet landed was measured [25]. The average value and the maximum value obtained in the three jumps were used for further analysis.

In a different session, the evaluation of the upper limbs' strength was performed by throwing a 3kg medicine ball. To perform the evaluation, each subject sat on the floor with his/her back against the wall and held the ball in front of him/her with both hands (close to the chest) to achieve the widest amplitude, speed and distance as possible and without rotating the torso and hip during the execution of the movements. The evaluator checked the throwing position as well as the obtained range. Three attempts were made with a rest period of one minute between each one, and the distance from the initial position to where the ball touched the ground was measured [25]. The average and maximum values in the three throws were recorded for further analysis.

2.3.3. Swimming Evaluation

In the following session, the swimmers' swimming performance evaluation was conducted after a typical warm-up [26]. Each swimmer performed a 50 meters freestyle simulation at maximum speed in a 25 meters indoor pool. All the time measurements were recorded using a chronometer (FINIS, 3x100, California, USA). The total time and turning time (5 meters + 10 meters) were recorded. The time and stroke rate were measured between 5 meters and 20 meters, and then the stroke length and the stroke index were calculated. The swimming speed (in m/s) was calculated by the time taken between 5 and 20 meters. The stroke length, in meters, was calculated by equation **1**.

Equation **1**: No. of strokes divided by the length of the pool.

The stroke index was calculated by the multiplication of the swimming speed by the stroke length [27], and the higher the value of this variable, the better the athlete's efficiency [28].

2.4. Statistical Analysis

The data were treated by gender. All the assumptions were guaranteed, using global validation of linear model assumptions, testing skewness, kurtosis, link function and heteroscedasticity [29] before the multiple regression was performed to assess the relationship between one dependent variable and several independent variables [30] (Table **2**).

The dependent variable was the time in the 50 meters freestyle. The independent variables used to predict the time were the age in years on test day; the height in meters measured by a digital stadiometer (SECA, 242, Hamburg, Germany); the body mass in kilograms measured by a digital scale (TANITA, BC-730, Amsterdam, Netherlands); the wingspan in meters measured with a precision measuring tape; stroke rate in cycles per minute measured with a chronometer, three strokes cycles; stroke length in meters calculated by equation 1; stroke index given by multiplying the swimming speed by the stroke length; the turning time in seconds measured 5 meters before turning, plus 10 meters afterwards; the horizontal jump, lower limbs in meters, given by the middle distance between the three executions; medicine ball throw, in meters, given by the middle distance between the three executions. All analyses were developed in R version 4.0.3, using the package gvlma30 version 1.0 for testing the Linear Model Assumptions, Stats [31] for the linear model, and dplyr [32] version 1.0.3 for data manipulation. Based on these variables, the researchers intended to predict the time of performers in 50 meters freestyle using equations described below in the paper.

3. RESULTS

Table **2** provides the descriptive data (mean (SD) of all variables analysed in both the genders.

Table 2. Variables analyzed for each subject of the sample and descriptive statistics.

Variable	Description	Min.	Max.	Mean (SD*)
Age	Age of the participants in years	12	16	14.08 (0.76)
Height	Height in meters	1.49	1.90	1.69 (0.08)
Weight	Weight in kilograms	42.70	82.60	58.86(77.85)
Wingspan	Wingspan in meters	1.47	1.98	1.73 (0.10)
50m freestyle	Time	25.91	36.35	29.43 (2)
50m Freestyle SR	50m freestyle Stroke rate (cycles/min) in the distance 5-20m	37.14	65.50	51.15 (4.73)
50m Freestyle SL	50m freestyle Stroke length (meteres)	1.35	2.96	1.97(0.22)
50m Freestyle SI	50m freestyle Stroke index	1.99	7.52	3.31(0.58)
Turning Time	Turning time from 5m to 10m (s)	6.45	11.28	8.81 (0.65)

Note: * SD-standard deviation.

After performing multiple regression, the researchers observed that in the male gender, the model that best explains the time in the 50 meters freestyle is composed of the variables: turning time and horizontal jump in dryland (r2=0.8819, residual standard error: 0.6936). These two variables explain 88% of the time in the 50 meters freestyle (Table **3**).

Table 3. Summary of the estimated parameters obtained from the stepwise regression analysis predicting the 50 meters Freestyle for male swimmers.

Coefficients (Male)	Estimated Parameters	Std. Error	*P-value*
Constant	12.59	1.75	<0.001
Turning Time 5m+10m (s)	2.28	0.15	<0.001
Horizontal Jump (m)	-1.36	0.26	<0.001

For female swimmers, the investigators found a model that explains 90% of the time in the 50 meters freestyle (r2=0,9013, residual standard error: 0.3954). This model includes the height, body mass, stroke length, stroke index, turning time and the horizontal jump in dryland (Table **4**).

Table 4. Summary of the estimated parameters obtained from the stepwise regression analysis predicting the 50 meters Freestyle for male swimmers.

Coefficients (Female)	Estimated Parameters	Std. Error	*P-value*
Constant	6.23	6.51	0.341
Height (m)	3.74	1.12	0.001
Body mass (kg)	-0.03	0.02	0.01
Stroke length (m)	11.27	3.04	<0.001
Stroke Index (m^2/s)	-6.04	1.06	<0.001
Turning Time 5m+10m (s)	1.64	0.15	<0.001
Horizontal Jump (m)	-0.63	0.26	0.01

Therefore, the equation established for males is represented as follows:

50 m freestyle time (s) = 12.60+(2.29×turning time) - (1.37×horizontal jump) + 0.69

Where, the turning time is measured in seconds and the horizontal jump in meters.

The equation determined for females is represented as follows:

50 m freestyle time (s) = 6.22 + (3.74×height) - (0.03×body mass) + (11.27×stroke length) - (6.04×stroke index) + (1.63×turning time) - (0.63×horizontal jump) + 0.40

Where, the height is measured in meters, the body mass in kilograms, the stroke length in meters, the stroke index in m2/s, the turning time in seconds, and the horizontal jump in meters.

4. DISCUSSION

The aim of this study was to identify which parameters have the most influence on the 50 meters freestyle performance in young swimmers. The main outcomes revealed turning time and the horizontal jump as the best predictors of the 50 meters time in male swimmers, and the turning time, horizontal jump, height, body mass, stroke length and stroke index as the best predictors of the 50 meters time in female swimmers.

The results obtained related to male swimmers partially agree with previous findings. Geladas *et al.* [33] refer, in males, the upper limbs length, the horizontal jump, and the grip strength ($r2= 0.59$, $p < 0.01$) as significant predictors of the 100 meters freestyle performance. Moreover, Barbosa *et al.* [19] suggested height, body mass, wingspan, stroke rate, stroke length and stroke index to be factors that influence the performance. In the current study, the wingspan and the stroke rate did not reveal to be relevant in the sprint swimming performance. These results are interesting, considering that previous research suggested that variables, such as height and arm span, positively correlate with 50 meters or 100 meters freestyle performance [33, 34]. Anthropometric variables are usually associated with the performance of swimmers; however, they could also have a concurrent effect on other domains related to swimming techniques and compromise results [35]. For instance, a larger trunk transverse surface and body surface area could result in higher drag [36]. Moreover, body changes caused by growth can take some time to benefit performance [37].

The current results could also be explained by the participants' characteristics. For example, the male swimmers were probably homogeneous in body size, body composition, upper limb muscle power, biomechanical variables (stroke length, stroke index, stroke rate) and performance. These factors together might have influenced the results, and thus, in swimmers with similar body size, body composition, upper limb muscle power, stroke length, and stroke index, the lower limb muscle power can be the differential factor in the 50m freestyle swimming. Furthermore, in the current study, horizontal jump was found to be a determinant variable for both male and female swimmers. This could highlight the influence of strength on swimming performance, regardless of gender. Indeed, a previous study indicated the strength and the power characteristics of the lower limbs as predictors of swimming performance that allow to distinguish swimmers with different levels of performance [38].

Regardless of the differences in the explanatory variables for males and females, both highlighted the influence of lower limbs power and turning performance on sprint swimming performance. Coaches, swimmers and researchers can therefore understand the importance of strength training programs focused on the development of lower limbs power, contributing to the improvement of swimmers' performance [39, 40]. Moreover, some specific actions, such as turns, assume a high relevance in the swimming sprint performance and should be part of the training programs. Considering that the turning phase is a great part of the 50 m swimming [40], it is expected that the turning time would influence sprint performance. However, these results highlight that the variance in 50 m performance could be explained by the variance in turning performance. Thus, turning actions should be emphasised during swimming training in these ages.

In the current study, some anthropometric variables, such as height and body mass, and biomechanical variables, such as stroke length and stroke index, were observed to be important for female swimmers' performance. This implies that performance within these participants might be primarily dependent on mechanical factors also. It has been suggested that some morphological characteristics, such as the ratio between the biacromial and bicrystal diameters, length and surface of the swimmers' limbs, play a major role in the performance of young swimmers [5]. The swimmer's body can positively change the thrust but, at the same time, increase the hydrodynamic drag [5]. Changes in an anthropometric profile affect the technique, which could influence swimming performance [41]. In the current study, variations in anthropometric variables and kinematics were observed to be determinants for performance.

Among the variables considered for analysis, *i.e.*, height, body mass, wingspan, horizontal jump, medicine ball throwing, stroke length, stroke index, and stroke rate, the variance in sprint performance of the male participants was explained by lower limbs muscle power and turning time. This does not mean that the other variables are not relevant. In fact, it was previously recognized that swimming performance is not exclusively dependent on a small set of determining variables but depends on the interaction of several factors [37]. Moreover, in female swimmers, the difference in performance was influenced by the variation in anthropometric variables (*i.e.*, height and body mass), stroke technique (stroke index and length), turning time and lower limbs muscle power. These differences would allow the coaches and swimmers to recognize the importance of lower limbs power (that can also influence turning time) for sprint performance. Furthermore, anthropometrics and the swimming technique could differentiate female swimmers of this age.

The fact that some of these variables were not significant should be contextualized to our sample and characteristics. It should be noted that other factors not assessed in the present study, such as aerobic and anaerobic capacity, and some anthropometric measures, might also have influenced the 50 meters performance. In addition, we should not disregard the importance of upper limbs power and/or swimming technique previously suggested to influence swimming performance [42]. Due to the limitations of the study (absence of gold standard assessments of upper and lower limbs muscle power, body composition, and biological maturation), the results should be interpreted with caution.

CONCLUSION

It may be stated that the time in 50 meters freestyle can be predicted by the turning time and the horizontal jump in male young swimmers, and by the height, body mass, stroke length, stroke index, turning time and horizontal jump in female young swimmers. Thus, the study's researchers conclude that some anthropometric characteristics, stroking parameters and strength, can serve as determinants for the young swimmers' performance.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All the procedures were approved by the institutional ethics committee from the course with the study no.160522051.

HUMAN AND ANIMAL RIGHTS

No animals were used that are the basis of this study. All the reported experiments on humans were conducted in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2008 (http://www.wma.net/en/20activities/10ethics/10helsinki/).

CONSENT FOR PUBLICATION

All subjects were informed of the risks and benefits of the study, and a signed informed consent was obtained from them.

AVAILABILITY OF DATA AND MATERIALS

The data and materials that support the findings of this research are available from the corresponding author [A.T.C] upon reasonable request.

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CONFLICT OF INTEREST

The authors confirm that this article's content has no conflict of interest.

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