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FORCED INSPIRATORY VOLUME IN THE FIRST SECOND AS PREDICTOR OF FRONT CRAWL PERFORMANCE IN YOUNG SPRINT SWIMMERS

Original investigation

Saúl A. Noriega-Sánchez[1], Alejandro Legaz-Arrese[2], Luis Suarez-Arrones[1], Alfredo Santalla[1], Pablo Floría[1], Diego Munguía-Izquierdo[1]

[1]Department of Sport and Informatics, Section of Physical Education and Sports, Faculty of Sport, University Pablo de Olavide, Seville, Spain.

[2]Department of Physiatry and Nursing, Section of Physical Education and Sports, Faculty of Health and Sport Science, University of Zaragoza, Zaragoza, Spain.

Running head: FIV_1 determines front crawl performance in young swimmers

Corresponding author:
Diego Munguía-Izquierdo
Departamento de Deporte e Informática. Universidad Pablo de Olavide. Carretera de Utrera, Km. 1, s/n, 41013, Sevilla, España (Spain).
e-mail: dmunizq@upo.es
Phone: 0034954977589 22
Fax: 0034954348377

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ABSTRACT

The purposes of this study were to determine the extent to which specific anthropometric, conditional, and pulmonary function variables predict 100-m front-crawl performance in national swimmers and compare anthropometric, conditional, and pulmonary function variables between both genders. Two groups (male, n=8 and female, n=9) of sprint swimmers (mean age ± SD = 19.4 ± 0.7 and 16.9 ± 3.2 years, respectively) of national competitive level volunteered for this study. Swimmers performed an all-out 100 m front crawl swimming test. Physiological parameters of lung function were measured using portable spirometer. Basic anthropometry included body height, body mass and skinfold thickness. Lower limb strength was measured by countermovement and squat jump tests. Correlation and regression analysis were calculated to quantify the relationships between trial time and each variable potentially predictive. Differences between means of both gender groups were analyzed. Results showed that 100-m race performance correlated significantly with forced inspiratory volume in the first second (FIV_1) in male swimmers and with FIV_1 and forced vital capacity in female swimmers. Stepwise multiple regressions revealed that FIV_1 was the only predictor of 100-m race performance, explaining 66% of 100 m time trial variance in male swimmers and 58% in female swimmers. Gender comparisons indicated significant differences in anthropometric, conditional, pulmonary function and performance variables. The findings suggest that FIV_1 could be a good predictor of performance and it should be evaluated routinely and used by coaches in front-crawl sprint swimmers.

Keywords: pulmonary function, lower limb strength, anthropometrics, front crawl.

INTRODUCTION

Competitive swimming performance can be determined by anthropometrical, biomechanical, psychological, and physiological factors (30,36,38). The swimming performance is a multi-factorial phenomenon in which each factor probably plays a major role in the performance.

Competitive swimmers are dependent on physiological adaptations to enhance their performance. The physiology of all-out performance encompasses neuromuscular processes, cardiovascular components, intramuscular energy turnover, and respiratory elements (2). Swimming practice improves pulmonary function (24) and swimmers show higher lung volumes and pulmonary diffusion capacity compared with both nonathletic and athletic peers from other sports (6,8,35). These differences may be partly due to the restricted breathing (inhalation of elevated amount of air in limited time), water pressure on the thorax, and horizontal position of swimming. The respiratory muscle training has demonstrated improvements in swimming performance (17,20) and in pulmonary function (40). Despite this, the literature about pulmonary function parameters and swimming performance is limited (16,27). These evidences show the importance of the pulmonary function in swimmers, but it is unclear what specific pulmonary function characteristics influence sprint performance and hence what should be considered for talent identification of swimmers.

Some special anthropometric characteristics such as body mass, body height and arm span must be analyzed when swimming sprint determinants are studied (15,19,30,37). These parameters are inherent to swimmer performance and have high influence in swimmer's biomechanics and physiology. Actually, anthropometrical determinants as upper and lower extremity length characterized upper level swimmers. In young swimmers, anthropometrical factors could explain ~46% of 100 m front crawl variability (19). Velocity in sprint swimming performance can be compromised by total body length, lean body mass and upper extremity length in competitive young swimmers (10,37). However, data about these relationships among anthropometry and performance in young swimmers are scarce despite being essential in swimming performance.

Regarding conditional parameters, strength of the lower extremities is considered imperative in sprint swimming performance (18,41). In fact, mean force and velocity are related well with the four strokes and leg explosiveness can explain most of 100 m front crawl variability in young swimmers (10,28). Strength of lower extremities determines starts and turns that represent an important contribution in total swimming velocity (4,41). In spite of the evidence, the data is dispersed and more analysis is required in young swimmers.

There is no data available regarding the relationship between pulmonary function, conditional, and anthropometrics factors together with 100 m front crawl performance in young elite swimmers training and competing at high competitive level. In consequence, the main objective of this study is to determine the extent to which specific anthropometric, conditional, and pulmonary function variables predict 100-m front-crawl performance of national young swimmers of both genders. The secondary objective is to compare the anthropometric, conditional, and pulmonary function variables between young sprint swimmers of both genders.

Given the elevated respiratory capacity of the swimmers (6) the improvement of the swimming plus respiratory muscle training in swimming performance (17,20) and pulmonary function (40), and the importance of the proper inspiratory velocity in front-crawl stroke cycle we hypothesized the inspiratory parameters as possible determinants of front-crawl swimming performance. Based on previous findings we also hypothesized differences in pulmonary function (14), conditional (5), anthropometrics (body fatness) (23,42), and performance variables between young male and female sprint swimmers.

METHODS

Experimental Approach to the Problem

This study used a cross-sectional research design to determine the influence of some pulmonary function, conditional and anthropometrics variables in 100 m front-crawl sprint and to compare the aforementioned variables between young sprint swimmers of both genders. Correlation and regression analysis were calculated to quantify the relationships between trial time (dependent variable) and each variable potentially predictive (independent variables). Differences between means of both gender groups were analyzed. Tests were conducted over 2 sessions 48 hours apart. On the first session subjects were tested on anthropometric and vertical jump measurements. On the second session subjects were tested on pulmonary function and swimming performance measurements. All tests were performed in the same order and at the same hour of day (between 9:00 to 11:00 a.m.) to avoid a possible circadian effect.

Subjects

Seventeen national competitive swimmers volunteered to participate in our investigation, 8 male swimmers (19.4 ± 0.7 years) and 9 female swimmers (16.9 ± 3.2 years). All male swimmers were in absolute category (19 years old and older) and female swimmers were 5 in absolute category (17 years old and older) and 4 in junior category (15-16 years old). They were all swimmers sprinters and their personal records in 100 m for male and female group were 56.1 ± 1.7 and 65.2 ± 4.2 seconds, respectively (80.2% and 78.5% of world record, respectively). Swimmers were recruited from the Mairena del Aljarafe swimming club of Seville (Spain). Spanish national 1 level swimmers who had been able to maintain their level at least for the last for 3 years participated in this study. They had trained during 6 days per week during the last three years. Testing was conducted in the middle of the competitive season (January). All swimmers and their parents were informed of the purpose, nature, testing procedures, possible risks as well as their right to terminate participation at will, before they gave their voluntary written consent to participate. Written informed consent was obtained from participants over 18 years and from parents of minors before participation. There was a period of at least one week between the day when the information was provided to the swimmers and parents and the day when their informed consent was obtained. The study was approved by the Ethics Committee of the *University Pablo de Olavide* (Spain), and performed according to the Declaration of Helsinki 1961 (revision of Edinburgh 2000). All participants had normal spirometry and had no history of respiratory disease. Swimmers were instructed to avoid strenuous training the day before the tests and to maintain their normal diet, hydration and sleep routine. Moreover, subjects ate their last meal at least 2 hours before each test and were asked not to ingest any potentially ergogenic product (i.e., caffeine).

Procedures

After a standard warm-up, performance level was analyzed by 100 m all-out trial in 25 m swimming pool during simulated competitions. Time in 100m front crawl was adopted as performance measure. Starts were made from the starting blocks with a whistle as the starting signal. Participants were asked to perform 100 m front crawl as fast as possible and data were registered by video analysis (Panasonic SDR-H250) at a frequency of 50 Hz. The camera was placed perpendicular to the longitudinal axis of the pool in order to record the start and finish of swimmers. Sound was used to synchronise start signal and video camera. The software Dartfish (version 5.5, Lausanne, Switzerland) of video analysis was used to obtain total time of all-out test.

Physiological parameters of lung function were measured using portable spirometer (Microquark, Cosmed, Italy) according to American Thoracic Society recommendations (American Thoracic Society 1995). The pulmonary function technician and spirometer were the same throughout the study. Subjects performed one enforced spirometry by executing maximal inspiration followed by an enforced exhalation. This protocol was repeated three times (1 minute recovery between repetitions) and subjects were encouraged to continue exhaling until finish it. Participants were asked to do both the inspiration and the expiration “explosively”. Maximum Voluntary Ventilation test (MVV_{12}) was executed 2 min later. The data obtained by spirometry were: FVC = forced vital capacity, PIF = peak inspiratory flow, FIV_1 = forced inspiratory volume in the first second, FEV_1 = forced expiratory volume in the first second, FEV_1/FVC = relationship between forced expiratory volume in the first second and forced vital capacity, FEF_{25-75} = forced expiratory flow between 25 and 75% of forced vital capacity, and MVV_{12} = maximum voluntary ventilation (26). For each parameter, the best value was chosen from at least three consecutive maneuvers differing by no more than 5% (31)

Measurements of height, body mass and skinfolds were measured at the same time of day (i.e., the morning). The swimmer presented before training in a fasted state and all anthropometric variables were measured by a well-trained technician to avoid the interobserver coefficients of variation. Body height (to the nearest 0.1 cm), body mass (to the nearest 0.1 kg; Seca 780, Hamburg, Germany) was measured using standardized procedures and body mass index (BMI; $kg \cdot m^{-2}$) was calculated. Subcutaneous skinfolds (triceps, biceps, subscapular, suprascapular, abdominal, right thigh, right gastrocnemius, pectoral and axillary) were measured to the nearest 1 mm using skinfold caliper (Holtain, Crymich, UK) on the right side of the body (21). For each skinfold, three measurements were obtained, then the mean was calculated. The sum of the skinfold thickness was used as indicator of total body fat.

Conditional parameters of strength were measured using force platform (Quattro Jump®, Kistler Instrumente AG, Winterthur, Switzerland). All subjects were asked to perform both Squat Jump (SJ) and Countermovement Jump (CMJ). SJ started with leg on 90º flexion and hands on hips, and CMJ with leg on extension and hands on hips in order to go down to 90º flexion and jump immediately as high as possible. Each jump was performed 3 times and the best jump was used. 2 minutes rest was carried out between repetitions and a standard warm up of 10 min was performed before jumps trial (low intensity aerobic exercise, dynamic stretching and 5 submaximal jumps) (7,39). All subjects were verbally encouraged to jump with maximal effort. Only the best performance for each jump was retained for statistical analysis.

Statistical analysis

Normality of distribution and homoscedasticity of the data were verified by the Shapiro-Wilk and Levenne tests, respectively. Scatter plots were employed to examine linearity in relationship between dependent (100 m time performance) and independent variables potentially predictive to meet the assumptions of linear regression. Means and standard deviation values were calculated for all parameters (Table 1). Coefficient of variation of performance was calculated. The differences between means of both genders groups were compared by analysis of variance (ANOVA) of a single factor. Bivariate Pearson Correlation Coefficient was calculated to quantify the relationships between trial time and each variable potentially predictive. The relative contribution of independent variables on 100 m front crawl performance was calculated by stepwise multiple linear regression analysis (p of F for inclusion <0.05, p of F for exclusion > 0.1), including all variables showing a significant association with 100 m time after bivariate analysis as covariates in the model. Variables were included in order from the variable explaining the greatest to the least variance. The intraclass correlation coefficients were calculated for each dependent variable to determine test-retest reliability, obtaining values always greater than 0.95. A p-value <0.05 was considered to be statistically significant. SPSS for Windows, version 18.0, was used for all analyses.

RESULTS

Descriptive statistics for pulmonary function, anthropometric, demographic, conditional, and performance parameters and their differences between genders are presented in Table 1. The coefficient of variation of the swimming performance showed homogeneity of the male (3.0%) and female (6.5%) groups. Male swimmers were older, taller and heavier and showed less amount of adipose tissue than female swimmers ($P < 0.05$). Male swimmers showed higher level of performance in the trial time, higher height in SJ and CMJ test and higher values in almost pulmonary function parameters than female swimmers ($P < 0.05$), except for FEV_1/FVC and FIV_1, showing the last parameter a trend toward significance ($P = 0.061$).

Relationships between 100 m front crawl performance time and variables of male and female swimmers are presented in Table 2. Correlation coefficient analysis showed that FIV_1 was negatively correlated with 100 m front crawl time in male swimmers. FIV_1 and FVC were negatively correlated with time trial in female swimmers.

Multiple linear regression analysis results for male ($F = 9.53$, $R^2 = 0.66$, $P = 0.027$) and female ($F = 9.60$, $R^2 = 0.58$, $P = 0.017$) swimmers are presented in Table 3. In this regression were introduced all variables with significant relationship with time trial. Multiple linear regression analysis demonstrated that FIV_1 was the only significant determinant of 100 m performance and explained 66% of the variance in male swimmers. As in the analysis of male swimmers, FIV_1 was the only significant determinant of 100 m performance and explained 58% of the variance in female swimmers.

DISCUSSION

The main findings show that FIV_1 is the only predictor of front crawl performance among different anthropometric, conditional and pulmonary function parameters in male and female young sprint swimmers and that there are significant differences between both genders in anthropometric, conditional, pulmonary function and performance parameters.

This is the first study that determines the influence of FIV_1 in 100 m front crawl sprint in national-level competitive swimmers. According to our finding, FIV_1 is able to explain 66% of 100 m time trial variance in male swimmers and 58% in female swimmers. The high influence of FIV_1 in 100 m front crawl sprint can be partly explained because greater FIV_1 make it possible to achieve faster maximum inspirations and this is important for elite swimmers since this would allow them to increase the amount of air they can inhale in the limited time (0.3-0.5 seconds (40) their face is out the water (25). The expiratory phase can basically be executed at any time in the stroke cycle, while the appropriate inspiratory timing and velocity can affect swimming performance and must adhere to the stroke cycle as a whole (22). Swimmers with high FIV_1 may need less respiratory frequency, produce less inspiratory muscle fatigue, increasing active limbs blood flow and reducing fatigue in these limbs (33), and consequently may improve performance. Increases in FIV_1 may be a direct result of an increase in the velocity of shortening of the inspiratory muscles as a consequence of enhanced inspiratory muscle strength (25). Elevated lung volumes observed in swimmers have been suggested to be related to elevated inspiratory muscle strength (6). Consequently, we suggest evaluating pulmonary function parameters routinely and analysing them as swimming performance predictors.

Previous studies support that inspiratory muscle training improves performance in untrained subjects (11) and trained subjects of different endurance sports as athletics

(9) or rowing (12). To our knowledge, only two studies (17,20) evaluated young local-level competitive swimmers and showed that respiratory muscle training improves time trial. Another study (40) showed significant correlation between inspiratory muscle training and FIV_1 in adolescent national-level competitive swimmers. These findings indicate that the inspiratory muscle training may be an option to reach optimal level of swimming performance (17,20). A recent meta-analysis demonstrated that swimming performance showed inconsistent improvements in response to respiratory muscle training compared with control group (13). Small sample sizes (≤10 swimmers per group) and the facts that restricted breathing, prone position of swimming, and water pressure on the thorax during regular swim training already elicits effects upon the pulmonary system similar to those of isolated respiratory muscle training may explain these inconsistencies. Future studies to examine the optimal type of training to improve respiratory parameters and swimming performance in competitive swimmers are clearly needed.

In our study, anthropometric and conditional variables did not show significant correlation with swimming performance and consequently were not determinants in the performance prediction. However, another studies found that anthropometrical factors could explain ~46% of 100 m front crawl variability in young regional-level competitive swimmers (19). Strzała and Tyka (37) found that velocity in sprint swimming performance can be compromised by total body length and lean body mass in young swimmers. Geladas et al. (10) showed high correlation between upper extremity length and 100 m front crawl in adolescent swimmers. These discrepancies with our results may be due to our lack of assessments of important specific anthropometric variables (i.e., arm span, lean body mass) and to our small sample.

Strength variables as SJ and CMJ and their relationship with swimming performance have been poorly studied (3,29,41), although lower limb power may be determinant in sprint starts (4,41). West et al. (41) found high correlation between start crawl time and 1 maximal repetition strength, jump height in CMJ and peak and relative power in international sprint swimmers. Breed and Young (4) showed a correlation between CMJ performance and flight distance in swimming starts. The absence of correlation between strength variables and swimming performance in our data may be due to the lack of additional plyometric and dry-land strength training programs which enhance the development of the explosive strength of the swimmers and also to the small sample.

The results of the present study reveal significant differences between both genders in pulmonary function, anthropometric, and conditional parameters. Male swimmers show higher values than female swimmers in some pulmonary function such as FVC, PIF, FEV_1, FEF_{25-75}, and MVV. These differences were consistent with previous studies (14) and could be explained by reduced lung size, reduced airway diameter, decreased maximal expiratory flow rates and smaller diffusion surface in women. As expected, our female swimmers had greater fat stores, measured by skinfolds, compared with male swimmers. These findings were consistent with previous studies (23,32,42). In addition, weight, height, and BMI were decreased in female swimmers compared to male swimmers, as shown by previous studies (23,32). It has been suggested that female swimmers have greater fat mass and lower BMI compared with male swimmers because the latest have a greater proportion of muscle mass and therefore greater weight and BMI, given that BMI does not distinguish between fat and lean mass (23). Our female swimmers reached 75 and 83% of values obtained by males in SJ and CMJ height, respectively. It may be explained by elevated fat mass and reduced muscle mass in female swimmers, being these differences probably influenced by hormonal differences (e.g., higher production of testosterone in male swimmers).

The present study presents several limitations. Firstly, the lack of sample size minimizes the representativeness of the same, although Mairena del Aljarafe swimming club is the Andalusian club with the highest number of national level swimmers. Therefore it is difficult to find a homogeneous group with these characteristics in our region. Secondly, regarding anthropometric variables were not taken in consideration specific variables to swimmers such as hand and arm span or hand and feet surface (10,19). Thirdly, our study could have included upper strength variables in order to value the relation to final performance. And finally, it have not been taken into account biomechanics variables significant in swimming performance due to the large number of studies performed about this issue. Lätt et al. (19) found that biomechanics variables explain ~90% of 100 m swimming performance variance. Other biomechanics parameter as stroke length is a good predictor in the global competitive performance (34). Therefore, although biomechanics variables have not been measured in our study, it seems important to emphasize the value of a good technique teaching from the beginning of swimming learning. Despite all these limitations, it is observed for first time a relationship between swimming performance and FIV_1 in male and female homogeneous groups of front-crawl sprint swimmers. Further studies with higher sample size are needed to analyze relationship between swimming performance and pulmonary function parameters in all four competitive strokes and all race distances.

In conclusion, our study demonstrates that FIV_1 is the only predictor of 100 m front crawl performance of all anthropometrical, conditional and physiological variables measured in young national competitive swimmers. Other finding is that female swimmers present lower limb strength and pulmonary function parameters, and more body fat mass than male swimmers with better time trial.

PRACTICAL APPLICATIONS

It could be suggested that FIV_1 may be an important limiting factor for optimal front-crawl performance in young sprint swimmers. In this sense, FIV_1 value tested in the present study could be a good predictor of performance and it should be evaluated routinely and used by coaches for talent identification in front-crawl sprint swimmers. Therefore, it makes sense to include inspiratory musculature training exercises in swimmers training routines for sprint swimmers. Future research may analyse different inspiratory training exercises to help the coaches and swimmers to design those training stimuli more related to success.

This study provides a comprehensive profile of elite young sprint swimmers based on pulmonary function, conditional, and anthropometrics characteristics. The information in this study can be used by coaches to compare characteristics of their front-crawl swimmers with a group of male and female national level young sprint swimmers.

Differences between the male and female sprint swimmers were for anthropometrics, conditionals, and pulmonary function measures. These differences may adversely affect swimming performance and potentially explain gender differences in performance. These findings suggest that the swimming performance for female swimmers may be improved through training programs designed to reduce body fatness and increase parameters of strength of lower extremities and pulmonary function.

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Table 1. Means (Standard deviations) of demographic, anthropometric, conditional, pulmonary function and performance parameters in young freestyle swimmers

Variable	Male swimmers (n=8)	Female swimmers (n=9)
Demographic		
Age, years	19.4 (0.7)*	16.9 (3.2)
Anthropometric		
Height, cm	181.2 (4.4)***	165.5 (2.1)
Weight, kg	72.6 (6.5)***	55.0 (4.7)
Body mass index, km/m^2	22.1 (1.6)*	20.1 (1.5)
Skinfold thickness sum, mm	61.7 (11.2)**	93.4 (17.6)
Conditional		
Squat Jump, cm	41.7 (3.2)**	35.5 (3.9)
Countermovement jump, cm	45.4 (3.0)**	37.9 (5.3)
Pulmonary function		
FVC, L	6.0 (0.6)***	4.0 (0.5)
PIF, L	6.0 (0.6)**	4.8 (0.8)
FIV_1, L	5.2 (1.6)	4.0 (0.5)
FEV_1, L	5.4 (0.5)***	3.7 (0.4)
FEV_1/FVC, %	88.8 (6.0)	89.5 (5.9)
FEF_{25-75}, L/s	5.8 (1.0)**	4.2 (0.6)
MVV, L/min	186.7 (14.9)***	129 (22.4)
Performance level		
100m front crawl time trial, s	56.1 (1.7)***	65.2 (4.2)

FVC = forced vital capacity, PIF = peak inspiratory flow, FEV_1 = forced expiratory volume in the first second, FIV_1 = forced inspiratory volume in the first second, FEV_1/FVC = Relationship between forced expiratory volume in the first second and forced vital capacity, FEF_{25-75} = forced expiratory flow between 25% and 75% of forced vital capacity, and MVV = maximum voluntary ventilation; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 2. Correlation coefficients between 100 m front crawl time performance and demographic, anthropometric, conditional, pulmonary function in young freestyle swimmers.

Variable	Male swimmers (n=8)	Female swimmers (n=9)
Demographic		
Age, years	-0.66	-0.46
Anthropometric		
Height, cm	-0.28	-0.39
Body mass index, kg/m^2	-0.29	0.49
Skinfold thickness sum, mm	-0.44	0.50
Conditional		
Squat Jump, cm	-0.24	-0.09
Countermovement jump, cm	-0.43	-0.39
Pulmonary function		
FVC, L	-0.08	-0.72*
PIF, L	-0.16	-0.23
FIV_1, L	-0.81*	-0.76*
FEV_1, L	-0.50	-0.65
FEV_1/FVC, %	-0.45	0.42
FEF_{25-75}, L/s	-0.58	0.00
MVV, L/min	-0.17	-0.43

FVC = forced vital capacity, PIF = peak inspiratory flow, FEV_1 = forced expiratory volume in the first second, FIV_1 = forced inspiratory volume in the first second, FEV_1/FVC = Relationship between forced expiratory volume in the first second and forced vital capacity, FEF_{25-75} = forced expiratory flow between 25% and 75% of forced vital capacity, and MVV = maximum voluntary ventilation; * $p < 0.05$

Table 3. Regression analysis results that predict performance in male and female young freestyle swimmers.

	Beta male swimmers (n=8)	*Beta* female swimmers (n=9)
FVC, L		0.080
FIV_1, L	-0.81*	-0.76*
R^2	0.66	0.58
R^2 Corrected	0.59	0.52

FIV1 = forced inspiratory volume in the first second; FVC = forced vital capacity, FEV1 = forced expiratory volume in the first second; R^2 = coefficient of determination; * $p < 0.05$.