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THE RELATIONSHIP BETWEEN 50m - FREESTYLE RESULTS AND CHARACTERISTICS OF TETHERED FORCES IN MALE SPRINT SWIMMERS: A NEW APPROACH TO TETHERED SWIMMING TEST

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Abstract. *This study tries to define the relationship between 50m freestyle competition velocity in swimmers (criterion variable) on the one hand, and basic mechanical characteristics of pulling force as F_{max} on the other, as well as impulse of force ($I_{mp}F$) and rate of force developement (RFD) measured by tethered swimming test ($Teth_{swim}$) at maximal intesity for 20 seconds (system of predictor variables). The sample consisted of 8 YU male freestyle sprinters, and the test was realised by a high-resolution tensiometric dynamometer (100 kHz) and a PC hardware-software system (ProIng). The recording of the realized pulling force yielded the averages of its maximal value ($avgF_{max}^{5\ to\ 20}$), its increment ($_{avg}RFD^{5\ to\ 20}$) and its impulse ($_{avg}I_{mp}F^{5\ to\ 20}$) for a single stroke in 5, 10, 15 and 20 s. The Backward Elimination criterion was used in Multiple Regression Analysis (MRA). The results of the MRA showed that the predictor system yielded a model structure of the variables $_{avg}I_{mp}F^{5}$, $_{avg}I_{mp}F^{10}$ and $_{avg}I_{mp}F^{20}$ and $_{avg}RFD^{20}$ that explained the criterion ($V50_{comp}$) at a very high level of 96.4% of the common variance ($F = 259.76$, $p = 0.000$). The results indicate that when $Teth_{swim}$ is used in top sprinters, it seems more adequate to analyze/observe the values of $_{avg}I_{mp}F$ and stroke RFD than F_{max}. They are mechanical characteristics and as such better describe sprinters' achievements.*

Key words: *tethered swimming, freestyle sprinters, pulling force, model*

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1. INTRODUCTION

Maximal swimming velocity, especially at sprint distances, depends on pulling force characteristics besides technical and energetic abilities of swimmers. The test most widely used to measure pulling force realized in swimming is the tethered swimming test (Оноприенко & Атаманов, 1973; Yeater et al., 1981; Keskinen et al., 1989; Sidney et al., 1996). Viewed kinematically, swimming is a series of cyclic movements performed by alternation of arm and leg strokes. Each stroke results in a characteristic force, which pulls the swimmer forward and is realized by contracting the muscles involved. When measured by tethered swimming, this force is defined as a pulling force and is represented by a characteristic sinusoid F-t curve (Figure 1) that describes its realization in time (Yeater et al., 1981; Dopsaj, 2000). Previous research has shown that the relationship between the pulling force realized during tethered swimming and the maximal swimming speed vary according to the swimmers' age and maturity (Vorontsov et al., 1999), their competitive level (Sidney et al., 1996), and the swimming distance (Yeater et al., 1981). Some previous research has focused only on the relationship between the maximal pulling force or the average of maximal pulling forces (F_{max} or $avgF_{max}$) of a single stroke realized in time interval of 10 seconds, and the swimming velocity achieved mainly at sprint distances (Keskinen et al., 1989; Sidney et al., 1996).

In terms of measurements, F_{max} or $avgF_{max}$ contains information solely about the force peak point or the average of such points achieved for the given single strokes realized by tethered swimming. On the other hand, force as a measurable value which is a product of muscle contraction is defined by at least two more dimensions, i.e., by its increment gradient/its increment in time (RFD – rate of force developement) and by the impulse of force ($I_{mp}F$) (Zatsiorsky, 1995), the realization of which can be reliably measured in water during tethered swimming (Dopsaj, 2000). If RFD and $I_{mp}F$ define the resultant force in time of its realization, it is disputable whether F_{max} that characterizes muscle force realized in only one point, that is, in a single stroke, can really be valid in describing the relationship between tethered swimming pulling force and the maximal velocity achieved.

Besides, the methodology of establishing the relationship and/or its quality between swimming velocity at a given distance and the characteristics of pulling force realized by tethered swimming requires that the test lasts at least approximately as long as the distance covered. In that way it is possible to adjust the observed occurrences, i.e., the characteristics of pulling force and the velocity of swimming (as criterion and predictor variables), also taking into consideriation the load exerted on the same energy system (Ring et al., 1996). This paper attempts to define the relationship between maximal velocity in 50m freestyle swimming (the level of competitor fitness) in senior swimmers, and the dimensions that mechanically define the area of pulling force realized by tethered swimming in the function of time/energy load simultaneous to the criterion observed. If statistically significant relationships are established, it will be possible to define a model structure that will enable better control over short- and long-term effects of the training process. This will then help improve training methodology and enhance the prognostic and diagnostic procedures that estimate the level of fitness in top sprinter swimmers.

2. METHODS

2.1 The sample examinees

The sample consisted of 8 YU male swimmers (3 on the national team). All the swimmers (24.6 ± 5.6 age; BM = 85.4 ± 8.3 kg; BH = 1.916 ± 0.062 m; s.b. 50 m free = 25.54 ± 1.15s) were freestyle sprinters (at 50 and 100m).

Pulling force characteristics were tested by the method of tethered swimming (Оноприенко, & Атаманов, 1973; Yeater et al., 1981; Keskinen et al., 1989; Sidney et al., 1996), according to the standardized procedure described previously (Dopsaj, 2000). Before the test, the swimmers warmed up swimming independently up to 1000 m. After a 10-minute rest the measuring started. On his turn, each swimmer put on a belted harness adjusting it to his body dimensions. Then he hooked a 1cm-thick PVC rope to the belt at the back hip region. The other end of the 5m rope was attached to a water-resistant high-resolution (100 kHz) tensiometric dynamometer placed on a metal support fixed on the side of the pool (Figure 1).

The dynamometer was connected to a PC. Having entered the pool, the swimmer did a 10-second trial of tethered swimming at medium intensity in order to get familiar with the equipment and the testing procedure. After a 1-minute rest the measuring commenced. The swimmers started tethered swimming (full technique – arms and legs stroke) at medium intensity and after two to three strokes, at the whistle of the time-keeper, they swam at maximal intensity for 20 seconds. At the whistle blow, the assistant timekeeper, who operated the PC, started the program for measuring and acquisition of data (ProIng, Belgrade). The raw data were processed by software specially designed by ProIng to analyze the parameters relevant to pulling force. After 21 seconds there was the second whistle blow as the signal to stop the measuring. This procedure yielded the entire recording of the pulling force during all 20 seconds of tethered swimming (Figure 2). The swimmers were told to follow the breathing pattern they would normally apply during a race. The test was done on the open swimming pool within the sports complex SRC Tašmajdan (Belgrade) in 2000, a week before the summer national senior competition.

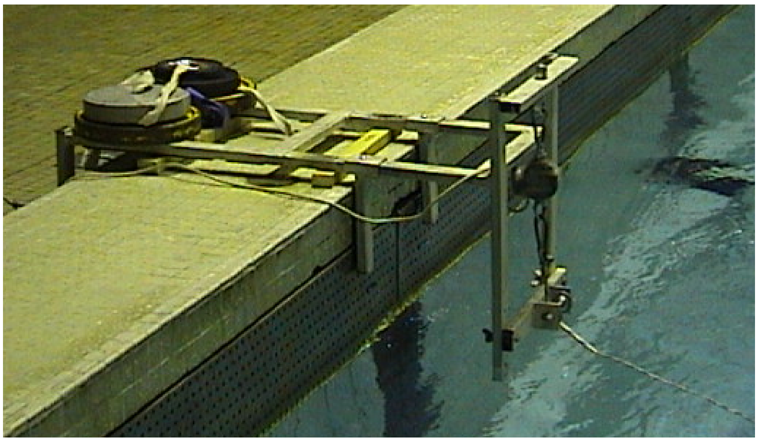

Fig. 1. The support with the dynamometer used to measure tethered pulling force

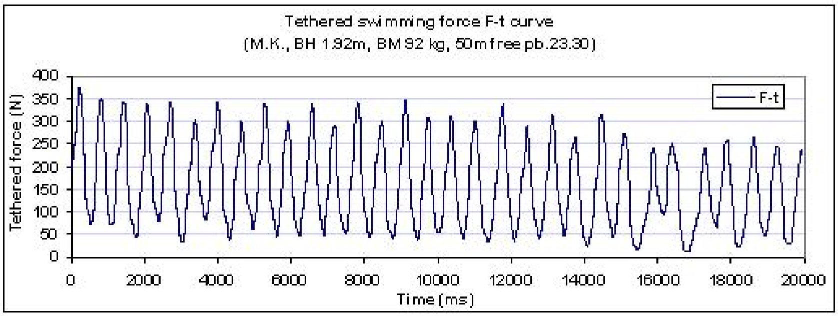

Fig. 2. An illustration of the recording of pulling force realized at the test

2.2 Variable sample

The criterion variable was the result at 50 m freestyle ($V_{comp}50$) accomplished at the summer national swimming senior competition in 2000, calculated as the average swimming velocity.

The prediction system had the following variables (N = 12) that covered the area of pulling force realized by tethered swimming (Figure 3):

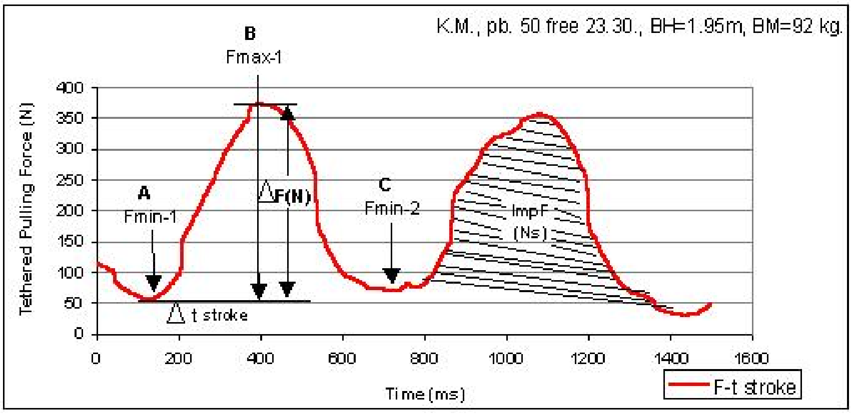

Fig. 3. A view of defining the mechanical characteristics of tethered pulling force

• the average value of maximal single-stroke tethered pulling force realized in 5, 10, 15 at 20 seconds - $avgF^{5}_{max}$, $avgF^{10}_{max}$, $avgF^{15}_{max}$ and $avgF^{20}_{max}$, obtained as the quotient of the sum of maximal values of single-stroke force peaks (B,...) and the number of strokes performed in the given time, expressed in N,

• the average value of single-stroke rate of force developement of tethered pulling force realized in 5, 10, 15 and 20 seconds - $avgRFD^{5}$, $avgRFD^{10}$, $avgRFD^{15}$ and $avgRFD^{20}$, obtained as the quotient of the sum of values of single-stroke rate of force developement of tethered pulling force ($RFD = \frac{\Delta F_{stroke}}{\Delta t_{stroke}} \bullet 1000$, where $\Delta t_{stroke} = t_{Fmax} - t_{Fmin}$ is expressed in ms, and $\Delta F_{stroke} = F_{MAXstorke} - F_{MINstroke}$ is expressed in N) and the number of strokes performed in the given time, expressed in N/s,

- the average value of single-stroke impulse of tethered pulling force realised for 5, 10, 15 and 20 seconds - $avgI_{mp}F^5$, $avgI_{mp}F^{10}$, $avgI_{mp}F^{15}$ and $avgI_{mp}F^{20}$, obtained as the quotient of the sum of values of single-stroke impulse of tethered pulling force ($I_{mp}F^{5,\ 10,\ 15,\ 20} = \int_{n=0}^{n} F_n \bullet t_n$) and the number of strokes performed in the given the given time, expressed in Ns.

2.3 Statistics

The results were first submitted to descriptive analysis in order to calculate the basic statistic parameters. The Backward Elimination criterion was used in Multiple Regression Analysis (MRA) to establish predictability of the predictor variables in relationship to the criterion. For the system of predictors that most accurately described the criterion there was calculated a formula for the equation of regression model prediction (Hair et al., 1998). Analyses were performed by the use of the software packages: SPSS for Windows (7.5.1) and STATGRAPHIC Plus (Win 3.0).

3. RESULTS

The results of descriptive statistics (Table 1) showed that the values of variation coefficients of all variables range between 4.20% for the criterion variable - $V_{comp}50$ and 25.66% for the average single-stroke rate of force development realized in 5 seconds - $avgRFD^5$. Since all the variations fall below the value of 30% and are within the range of rather homogeneous results, it is possible to claim that the results are reliable and can be validly used in further analysis, despite the small sample of swimmers.

The results of ANOVA regression showed that the system of predictor variables yielded a model of predictors that describe the criterion variable at a statistically high level of significance for F ratio - 259.76 and at the level of p value of $p = 0.00003$ (Table 2). The model describes the criterion with 99.72% of common variance ($R^2 = 0.9972$), or with 96.39% of variance adjusted to the sample total (adj. $R^2 = 0.9639$) and with the scope of standard error of estimation S.E.E. of 0.006417 m/s (±0.321s), and the scope of mean apsolute error M.A.E od 0.003 m/s (±0.143s).

MRA results showed that the set of predictors yielded a model structure of four variables, the first three of which represent the average values of single-stroke impulse of tethered pulling force realized for 5, 10, 15 and 20 seconds - ${}_{avg}I_{mp}F^5$, ${}_{avg}I_{mp}F^{10}$ and ${}_{avg}I_{mp}F^{20}$, as well as the average values of single-stroke rate of force development realized in 20 seconds - ${}_{avg}RFD^{20}$ (Table 2).

The results obtained were used to establish a prediction model for competitive level of fitness in top sprinter senior swimmers, which is expressed as the following formula:

$$V50_{comp} = 1.99025 - 0.0125504 \cdot avgI_{mp}F^{10} - 0.0243252 \cdot avgI_{mp}F^{20} + 0.0308284 \cdot avgI_{mp}F^5 + 0.000492702 \cdot avgRFD^{20}$$

Table 1. Basic descriptive statistics

Variable	MEAN	SD	Max	Min	cV (%)
$V_{comp}50$ (m/s)	1.96 (25.56 s)	0.08	2.08 (24.08 s)	1.84 (27.19 s)	4.20
$avgF^{5}_{max}$ (N)	271.37	59.18	332.81	158.57	21.81
$avgF^{10}_{max}$ (N)	261.99	52.39	324.69	161.05	20.00
$avgF^{15}_{max}$ (N)	254.22	48.87	317.10	160.27	19.22
$avgF^{20}_{max}$ (N)	247.16	45.93	303.31	156.85	18.58
$avgRFD^{5}$ (N/s)	716.04	183.75	899.14	398.32	25.66
$avgRFD^{10}$ (N/s)	685.93	156.90	873.81	401.61	22.87
$avgRFD^{15}$ (N/s)	668.29	139.84	852.27	402.96	20.93
$avgRFD^{20}$ (N/s)	643.65	126.39	802.18	394.15	19.64
$avgI_{mp}F^{5}$ (Ns)	93.88	18.51	112.81	60.05	19.71
$avgI_{mp}F^{10}$ (Ns)	90.80	16.76	108.93	57.72	18.45
$avgI_{mp}F^{15}$ (Ns)	88.43	15.72	106.49	57.57	17.77
$avgI_{mp}F^{20}$ (Ns)	86.46	14.92	102.78	57.11	17.25

Table 2. Results of ANOVA of regression and Multiple Regression Analysis

ANOVA of regression					
Source	Sum of Squares	Df	Mean Square	F ratio	p value
Model	0.047	4	0.012	259.76	0.000
Residual	0.000	3	0.000		
Total (Corr.)	0.048	7			

Multiple Regression Analysis - Backward Elimination Model				
Parameter	Estimate	Stand. Err.	t statistic	p value
CONSTANT	1.990	0.020	97.922	0.000
$avgI_{mp}F^{10}$	−0.013	0.002	−6.548	0.007
$avgI_{mp}F^{20}$	−0.024	0.002	−11.198	0.002
$avgI_{mp}F^{5}$	0.031	0.001	27.675	0.000
$avgRFD^{20}$	0.001	0.000	11.346	0.002

4. Discussion

It is obvious from the results of our research that the characteristics of tethered pulling force that the tested swimmers realized in 20 seconds define a 4-variable model that can estimate the level of competitive fitness with the reliability rate of 96.39%, and with error of estimation of ± 0.321 s (Table 2). The pulling force characteristics that best describe the level of competitive fitness, i.e., swimming velocity at 50 m distance are force impulse and rate of force development ($I_{mp}F$ i RFD). The average values of single-stroke pulling force impulse are statistically significant for the time of 5, 10, and 20 seconds, that is, almost in the entire tethered swimming test, while the average value of rate of force development is significant as a general indicator realized in 20 seconds, that is, as the value realized throughout the test (Table 2).

Force impulse, as a measurable physical characteristic, defines the given quantity of movement. In the case of tethered swimming, it represents the measure/quantity of the realized pull drive, and as such represents the working potential to be realized by non-tethered swimming i.e., free swimming. In other words, the more efficient a swimmer is in conveying to his body a greater potential of movement in the times of 5, 10, and 20 seconds of work, the faster he could swim in freestyle competition at the distance of 50 m.

The active phase of a stroke in freestyle sprint lasts approximately 400 ms and that is the time interval during which a swimmer realizes his own single-stroke pulling force (Kolmogorov, & Lyapin, 1999). Theoretically, the greater the level of RFD a swimmer is able to achieve in the time defined by active stroke phase, the faster he will move through water. This is also confirmed by the fact that the average value of single-stroke rate of pulling force development achieved in the entire testing time of 20 seconds entered the model as a variable that is statistically significant in defining swimming velocity at 50m.

5. Conclusion

In conclusion, the results show that when a tethered swimming test is applied to top sprinter swimmers, the achieved values of ${}_{avg}I_{mp}F$, as a measure of the quantity of movement conveyed, and stroke RFD, as a measure of estimating the achieved single-stroke force intensity, are more adequate to analyze/observe than F_{max}. Being mechanical characteristics of tethered swimming, these values obviously give a better model description of sprinter fitness at 50m, on condition that the test lasts for 20 seconds.

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POVEZANOST KARAKTERISTIKA SILE VUČE MERENE PLIVANJEM U MESTU I REZULTATA NA 50 m KRAUL KOD PLIVAČA: NOVI ASPEKT TESTIRANJA

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U istraživanju je pokušano da se definiše povezanost između rezultata na 50 m kraul stilom postignutog na takmičenju (kao kriterijske varijable) i osnovnih mehaničkih karakteristika sile vuče kao što je maksimalna sila (F_{max}), impuls sile ($I_{mp}F$) i gradijenta prirasta sile (RFD) procenjivanim metodom plivanja u mestu ($Teth_{swim}$) maksimalnim intenzitetom u trajanju od 20 sekundi (sistem prediktorskih varijabli). Uzorak ispitanika se sastojao od 8 YU plivača (3 reprezentativca) sprintera specijalizovanih za kraul tehniku, dok je merenje izvršeno pomoću tenziometrijske sonde visoke razolucije (100 kHz) i PC hardversko-softverskim (ProIng, Belgrade) sistemom. Iz zapisa realizovane sile vuče u funkciji vremena izračunato je sledeće: prosečna vrednost maksimalne sile vuče ($avgF_{max}{}^{5}$ do $avgF_{max}{}^{20}$), prirasta sile vuče ($_{avg}RFD^{5}$ do $_{avg}RFD^{20}$) i impulsa sile vuče ($_{avg}I_{mp}F^{5}$ do $_{avg}I_{mp}F^{20}$) pojedinacnog zaveslaja za 5, 10, 15 i 20 s. Statistička analiza je izvršena upotrebom Multiple Regresione Analize (MRA) primenom kriterijuma eliminacije unazad (Backward Elimination). MRA je pokazala da je iz sistema prediktora izdvojena modelska struktura varijabli $_{avg}I_{mp}F^{5}$, $_{avg}I_{mp}F^{10}$ i $_{avg}I_{mp}F^{20}$ i $_{avg}RFD^{20}$ koja je objasnila kriterijum ($V50_{comp}$) na vrlo visokom nivou od 96.4% zajedničke varijanse ($F = 259.76$, $p = 0.000$) . Rezultati ukazuju da je u slučaju primene testa plivanja u mestu kod vrhunskih plivača sprintera adekvatnije analizirati/posmatrati postignute vrednosti $_{avg}I_{mp}F$ i RFD zaveslaja, nego F_{max}, jer one kao mehaničke karakteristike bolje opisuju rezultatsku sprintersku pripremljenost.

Ključne reči: *plivanje u mestu, sprinteri krauleri, sila vuče, modelovanje*