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Original research article

A COMPARISON OF KINEMATIC VARIABLES BETWEEN EUROPEAN ELITE, NATIONAL ELITE AND REGIONAL ELITE MALE 100M FREESTYLE SWIMMERS *

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Abstract. *The aim of this study was to compare kinematic characteristics of elite male swimmers i.e. to compare different groups of swimmers, participating in the 100m freestyle. The entire sample consisted of 24 swimmers divided into 3 groups of swimmers of different levels of performance: the European elite, Russian elite and Serbian elite. All of the races were recorded and analyzed with specialized software The Swim Watch Race Analyzer. The basic kinematic characteristics were calculated, including: the stroke index, stroke length, stroke rate, start dive length, start dive time, start dive velocity, turn dive length, turn dive time, turn dive velocity. In order to calculate the statistically significant difference for each variable between the groups, the one way ANOVA method and POST HOC (LSD) test were used. The results of this study have shown, that compared to the time on 100m freestyle, in competitive swimming there are different technical characteristics which determine the most successful swimmers compared to the less successful ones such as: the stroke length during 100m freestyle, with a particular emphasis on increasing differences in the fourth/last 25m of the race, stroke index, as a measure of specific stroke efficiency, with a particular emphasis on increasing differences in the third 25m of the race, start dive length and start dive velocity.*

Key words: *Stroke index, kinematical analysis, sprint swimming.*

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INTRODUCTION

Swimming races consist of three basic elements: the start, turn and swimming distance. The contribution of each of these stages to the final outcome of the race is significant and the magnitude depends on the length of the race. Performance analysis is an important step in devising training programs, and involves an evaluation of strategies used by elite athletes. A simple race analysis with a measurement of time during different phases of a competitive swimming event provides information about the effectiveness of a swimmer during the different phases of a race (Wakayoshi, Yoshida, Ikuta, Mutoh, & Miyashita, 1993). To assess those used by elite swimmers, several groups of researchers have analyzed technical and kinematic characteristics during international competitions to determine their relationship with performance. The analysis of swimmer competitive activities by analyzing the recorded race has progressed to the point that it has become a necessary tool for coaches, athletes, sport scientists (Jorgić, Okičić, Stanković, Dopsaj, & Thanopulos, 2011). In swimming, basic kinematical characteristics are represented by appropriate technique characteristics i.e. spatial temporal parameters such as stroke length (SL), stroke frequency (SR), stroke effectiveness (SE), stroke index (SI), start time up to 10m swim (STS10), absolute swimming velocity (ASV), turn time (TT) and other parameters (Okičić, 1999). A comparison of low-level swimmers with national team swimmers shows us which elements of the race (situational motor skills) should be improved in the training process. Thus, Seifert, Toussaint, Alberty, Schnitzler, & Chollet (2010), among others things, found that regional-level swimmers have a lower stroke index in comparison to the national level swimmers. Ludovic et al. (2007) compared different swimming speeds for the 100 meter freestyle, and concluded that faster swimmers make fewer oscillations in their stroke length compared to slower swimmers. By comparing the results of start performance between the best National swimmers and Europe's best swimmers at the European Championship "Budapest 2010", Dopsaj, Bošković, Beretić, Pejinović, & Kovačević (2010) concluded that Europe's top swimmers have a longer underwater gliding distance and statistically significant higher velocity of underwater gliding after the diving start. While it is noted that the underwater phase can be the longest in terms of time, the block and flight phases significantly influence the drag forces experienced by the elite swimmer in the glide phase (Mason, Alcock, & Fowlie, 2007). The analysis of a swimming race, or in other words, the parameters of situational motor skills allow the coach to make a situational model of a swimmer, or a model that enables them to achieve maximum sport performance. Such a model can be created for each swimming discipline (Mason & Formosa, 2011).

The aim of this study was to compare the kinematic characteristics of elite male swimmers i.e. to compare different groups of swimmers (regional elite, national elite and European elite, respectively), participating in the 100m freestyle.

THE METHOD

The sample of participants

The entire sample comprised 24 swimmers divided into 3 groups. The first group (regional elite) was compiled by analyzing the performances of 8 male 100-m event finalists of the 2012 Russian National Championship (mean standard 97.63% of the world record).

The second group (national elite) was compiled by analyzing the performance of 8 male 100-m event finalists at the 2012 Serbian National Championship (mean standard 95.58% of world record). Finally, the third group (European elite) was compiled by analyzing performances of 8 male 100-m event semifinalists and finalists at the 2012 Long Course European Swimming Championship (mean standard = 98.85 % of the world record).

Measuring procedures

One transverse video camera (Sony HDD, DCR-SR353E) with a frequency of 24 frames/s equipped with a wide angle to obtain a wider field of vision were positioned perpendicular to the long axis of the pool, at 25 m (half of the pool length). The lane buoys in the pool were used as distance markers. Each race was analyzed with specialized software The Swim Watch Race Analyzer, Version 2.23a (www.swimwatch.nl).

The sample of variables

The time for the 100 m freestyle (T100) was taken from the official race report. The 100 m freestyle race was divided in four parts, 25 m each. For the main indicator for the efficiency of the swimming technique, the value of the index of stroke efficiency was taken and calculated by the formula that is proposed by Costil, Maglischo, & Richardson (1992):

$$SI = \text{Stroke Length (0.01 m)} \times \text{Swimming Speed (m/s)}$$

- The stroke Index was calculated for each race segment (SI1-25), calculated at the 1^{st} 25m of the race, (SI2-25 m), the 2^{nd} 25 m of the race, (SI3-25 m), 3^{rd} 25m of the race (SI4-25m), and 4^{th} 25m of the race. The SI is expressed in arbitrary units.
- Swimming Speed (SS) for the second (SS2-25) and fourth (SS4-25) 25 m was calculated by the formula: D/T; where (D) was swimming distance and (T) swimming time at a long distance and is expressed in m/s. To calculate actual swimming speed in the first (SS1-25) and third (SS3-25) 25 m, the formula was: SS= (D-d1)/(T-t1); where (D) is the swimming distance minus the length of the underwater gliding (d1), (T) the swimming time at a distance minus time of the underwater gliding after the start and the turn (t1).

Stroke length and stroke rate values were obtained for each 25m section by the following procedure which is proposed Maglischo (2003):

- Stroke Length = D-d1/N, D-d1; swimming distance (D) minus the length of the underwater gliding (d1), N – the number of strokes per D-d1, SL is expressed in 0.01 m. This formula was used for stroke length calculation in the first (SL1-25) and third (SL3-25) 25 m, where the first and third length of underwater gliding were after start and the turn. The formula for calculating the stroke length of the second (SL2-25) and fourth (SL4-25) 25 m was: SL= D/N; where (D) is swimming distance and (N) the number of strokes.
- Stroke Rate (SR) = N/T-t1·60, T-t1= swimming time (T) at a distance minus the time of the underwater gliding after the start and turn (t1), N – the number of strokes per D-d1, 60 needed to obtain stroke frequency per minute. This formula was used for stroke rate calculation in the first (SR1-25) and third (SR3-25) 25 m,

where the first length of underwater gliding was after the start and in the third 25m after the turn. The formula for calculating the stroke rate for the second (SL2-25) and fourth (SL4-25) 25 m was: SR= (N/T)·60; where N is the number of strokes per 25m and (T) is swimming time at a distance.

Start dive lenght (SDL), Start dive time (SDT), Start dive velocity (SDV), Turn dive lenght (TDL), Turn dive time (TDT), Turn dive velocity (TDV) values were obtained by the following procedure which is proposed Dopsaj et al. (2010):

- Start Dive Lenght (SDL): Underwater diving phase after the start, which defines the distance from the start to the moment when the swimmer breaks the surface of the water with his head and moves into the swimming phase. SDL is expressed in 0.01 m.
- Start Dive Time (SDT): Time duration of SDL/underwater diving phase. SDT is expressed in 0.01 s.
- Start Time Velocity (STV): The average speed of underwater phase realization, which indirectly defines the technique efficiency of the start and underwater diving phase, expressed in m/s.
- Turn Dive Length (TDL): Underwater diving phase after the turn, which defines the distance from pushing the wall to the moment when the swimmer breaks the surface of the water with his head and moves into the swimming phase. TDL is expressed in 0.01 m.
- Turn Dive Time (TDT): Time duration of TDL/underwater diving phase after the start. TDT is expressed in 0.01 s.
- Turn Time Velocity (STV): The average speed of the underwater phase realization, which indirectly defines the technique efficiency of the pushing phase and underwater diving phase, expressed in m/s.

Statistical analyses

For all the variables, the basic parameters of descriptive statistics were calculated (Mean and Standard deviation). In order to calculate the statistically significant difference for each variable between the groups, the one-way ANOVA method and POST HOC (LSD) test were used. Statistical calculation was done by means of the Statistics software SPSS 15.0.

RESULTS

Table 1 presents the basic descriptive statistics for each variable, and the differences between three groups. A significant difference was found in the variable time of the 100m freestyle (F = 38.313, p=0.000). By using the post-hoc test, the significant differences were found between the first and second group (t=3.197, p=0.000), third and first (t=1.971, p=0.041) and third and second (t=4.140, p=0.000) group. The third group achieved significantly lower results at the T100 from the first and second group, and the first group achieved significantly lower results from the second group. The significant differences between the groups were found for the Stroke Length in each 25m distance (F=4.379, p=0.042; F=6.390, p=0.006; F=5.962, p=0.008; F=4.403, p=0.034), and significant differences in the Stroke Length for the first, second and third 25m were found between the first and second group, where in the fourth 25 m there was no significant differences between those two groups. The first group achieved significantly higher values of stroke length in the first (t=1.082, p=0.036), second (t=1.211, p=0.022) and third (t=1.451, p=0.018) 25 m than the second group, but in the fourth 25m significant differences were not observed. The third group achieved significantly longer stroke values than the second group in the first 25 m (t=1.98, p=0.038), second 25 m (t=2.492, p=0.021), third 25 m (t=2.231, p=0.015), fourth 25 m (t=1.871, p=0.027) and significantly higher values than the first group in the fourth 25 m (t=1.223, p=0.037) as well. Stroke rate value differences we found to be insignificant for each 25m between three groups of swimmers (F=1.102, p=0.351; F=0.207, p=0.815; F=0.075, p=0.993; F=0.482, p=0.628). There were significant differences in the stroke index variables values between the groups in each 25m (F=3.852, p=0.038; F=17.407, p=0.000; F=20.302, p=0.000; F=4.886 p=0.017). The first group achieved a significantly higher stroke index values than the second group at the first 25 m (t=3.788, p=0.012), second (t=2.721, p=0.001), third 25m (t=2.368, p=0.04) and fourth 25 m (t=1.69, p=0.047). The third group achieved significantly higher stroke index values than the second group at the first 25 m (t=1.875, p=0.035), second 25m (t=4.012, p=0.000), and significantly higher values on the third 25 m than the first (t=1.715, p=0.028) and second group (t=4.083, p=0.000), significantly higher values on the fourth 25 m than the second group (t=2.648, p=0.005) respectively.

Table 1. Comparisons of kinematic characteristics for different groups of elite swimmers.

Variable	1.Group (regional elite) Mean±SD	vs	2.Group (national elite) Mean±SD	vs	3.Group (European elite) Mean±SD	vs.	F	p
Time100 m (s)	49.682±0.967	2^{*}	52.880±1.381		48.740±0.323	$1^{*}, 2^{**}$	38.313	**0.000
Stroke Lenght 1-25m (m)	1.135±0.092	2^{*}	1.050±0.108		1.090±0.104	2^{*}	4.579	*0.042
Stroke Lenght 2-25m (m)	1.209±0.080	2^{*}	1.126±0.058		1.242±0.059	2^{*}	6.390	**0.006
Stroke Lenght 3-25m (m)	1.088±0.037	2^{*}	1.051±0.038		1.114±0.034	2^{*}	5.962	**0.008
Stroke Lenght 4-25m (m)	1.087±0.084		1.052±0.079		1.134±0.059	$1^{*}, 2^{**}$	4.403	*0034
Stroke Rate 1-25m (stroke/min)	110.15±5.645		113.01±9.476		107.21±7.873		1.102	0.351
Stroke Rate 2-25m (stroke/min)	93.52±5.815		94.90±5.422		93.24±5.350		0.207	0.815
Stroke Rate 3-25m (stroke/min)	92.21±5.850		92.56±9.089		92.54±4.825		0.075	0.993
Stroke Rate 4-25m (stroke/min)	97.80±5.348		96.27±5.736		95.24±4.626		0.482	0.628
Stroke Index1-25	2.368±0.321	2^{**}	1.989±0.228		2.124±0.271	2^{**}	3.852	*0.038
Stroke Index2-25	2.274±0.181	2^{**}	2.001±0.114		2.401±0.107	2^{**}	17.407	**0.000
Stroke Index3-25	2.085±0.109	2*	1.848±0.140		2.210±0.089	$1^{*}, 2^{**}$	20.302	**0.000
Stroke Index4-25	1.9230±0.198	2^{*}	1.772±0.166		2.032±0.129	2^{*}	4.886	*0.017
Start Dive Lenght (m)	11.262±1.679		10.250±2.381		12.250±0.963	$1^{*}, 2^{*}$	3.548	*0.047
Start Dive Time (s)	3.741±0.562		3.637±0.827		3.577±0.578		0.123	0.885
Start Dive Velocity (m/s)	3.029±0.394		2.821±0.136		3.464±0.327	$1^{**}, 2^{**}$	9.246	**0.001
Turn Dive Lenght (m)	7.337±0.881		6.450±2.677		6.875±0.640		0.566	0.576
Turn Dive Time (s)	2.633±0.425		2.250±0.994		2.656±0.406		0.936	0.408
Turn Dive Velocity (m/s)	2.810±0.238		2.949±0.426		2.612±0.212		2.423	0.113

vs. –LSD post-hoc test,
**The difference is significant at the ≤0.01 level,
*The difference is significant at the ≤ 0.05 level.

Significant differences between groups were found in the variable start dive length (F=3.548, p=0.047), and start dive velocity (F=9.246, p=0.001), where for the variable start dive length the third group achieved significantly better results than first group (t=1.560, p=0.047) and second group (t=2.062, p=0.029) and in the variable start dive velocity the third group achieved significantly better results than the first group (t=4.495, p=0.008) and second group (t=6.382, p=0.000) respectively. There was no significant difference between the groups for the variables start dive time (F=0.123, p=0.885), turn dive length (F=0.556, p=0.576), turn dive time (F=0.936, p=0.408) and turn dive velocity (F=2.423, p=0.113).

DISCUSSION

The parameters of situational motor skills can be used in two ways to compare swimmers with each other and to determine the effects of certain parameters on the swimming outcome (Jorgić et al. 2011). The aim of this study was to compare the kinematic characteristics of elite male swimmers, to compare and contrast different groups of swimmers participating in the 100 m freestyle. Elite Serbian swimmers were slower than elite Russian and elite European swimmers on the 100 m freestyle and at same time they achieved lower values of the stroke length during each 25m of the race than European and Russian swimmers, which determine the fact that stroke length is the best predictor of performance in the 100 m freestyle swim and agrees with the results of Chollet, Pelayo, Delaplace, Tourny, & Sidney (1997) who discovered that stroke length is important for achieving top results in swimming on a sample of 442 swimmers out of whom 40 were top swimmers. The differences in time for the 100 m between groups can be attributed to the differences in stroke length, a parameter that represents spatial characteristics. The data for this study corresponds to the results of Kennedy, Brown, Chengalur, & Nelson (1990) where the authors analyzed the biomechanical parameters of swimmers who participated in the 100 m freestyle at the Olympic Games; and also concluded that the stroke length is the most important factor in predicting success in swimmers. Strzala, Tyka, & Krezalek (2007) found that swimming velocity at different distances in the freestyle depends both on stroke length and stroke rate. In this study there were no significant differences between groups in stroke rates in each 25 m. The elite European and Russian swimmers raced at the same stroke rate as Serbian swimmers and during that time they managed to maintain longer strokes which may be a consequence of the better technical skill of Russian and European than Serbian swimmers and can be described as better motor effectiveness (Seiffert, Boulesteix, Carter, & Chollet, 2005). While it is assumed that three groups of swimmers were at a similar level of energy capabilities compared for stroke rate values, because stroke rates were more closely related to neuron motor and energy capabilities (Wakayoshi et al., 1993). The differences in the stroke index values can also be used as an indicator of the performance level because based on the results of study Sanchez (2000) the stroke index values among elite international competition swimmers was significantly greater than among elite national competition swimmers. This study has shown that during the glide phase after the start, high level swimmers presented a longer gliding distance and higher start dive velocity then top national elite and regional national elite swimmers, which, based on the results of the study of Elipot et al. (2009) can be explained by the fact that high level swimmers manifested a strong joint synergy between the shoulders, the hip and the knee and with this synergic action of those three joints, high level swimmers are able to hold a streamlined position during the whole glide phase. Hydrodynamic resistance is decreased and supra-maximal velocity is maintained for a longer period of time (Elipot et al. 2009).

CONCLUSION

The results of this study have shown that compared to the time on 100m freestyle, in competitive swimming there are different technical characteristics which determine most successful swimmers compared to less successful ones:

- Stroke Length during the 100 m freestyle, with a particular emphasis on increasing differences in the fourth i.e. last 25 m of the race, compared to less and medium successful swimmers.
- Stroke index, as a measure of specific stroke efficiency, with a particular emphasis on increasing differences in the third 25 m of the race, compared to less and medium successful swimmers.
- Start dive length compared to less and medium successful swimmers.
- Start dive velocity compared to less and medium successful swimmers.

Generally speaking, the results of this study define the strategy of competitive performance for the 100 m freestyle in top level male swimmers, which can be defined by the maximum use of start dive length (over 12 m); with a maximum start dive velocity (over 3.4 m/s); superior level of technical preparedness in terms of stroke efficiency and stroke length.

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KOMPARACIJA KINEMATIČKIH VARIJABLI IZMEĐU VRHUNSKIH EVROPSKIH, NACIONALNIH I REGIONALNIH PLIVAČA U DISCIPLINI 100M SLOBODNIM STILOM

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Cilj ovog istraživanja bio je da se uporede kinematičke karakteristike vrhunskih plivača, muškog pola, tj., d a se uporede različite grupe plivača, takmičara u disciplini 100m slobodnim stilom. Uzorak ispitanika sačinjavalo je 24 plivača podeljenih u tri grupe, različitih nivoa dostignuća sportskih rezultata: vrhunski evropski, vrhunski ruski i vrhunski srpski plivači. Sve trke su snimljene i upoređene korišćenjem specijalizovanog softvera The Swim Watch Race Analyzer. Izračunati su osnovni kinematički parametric: indeks zaveslaja, dužina zaveslaja, stopa zaveslaja, dužina startnog skoka u vodu, vreme startnog skoka u vodu, brzina startnog skoka u vodu, dužina okreta, vreme okreta, brzina okreta. U cilju utvrđivanja statistički značajne za svaku varijablu između grupa, korišćeni su metod one way ANOVA-e i POST HOC (LSD) test. Rezultati istraživanja su pokazali da u poređenju sa vremenom na 100m slobodnim stilom, u takmičarskom plivanju postoje različite tehničke karakteristike koje utvrđuju najuspešnije u odnosu na manje uspešne plivače: dužina zaveslaja tokom 100m slobodnim stilom, sa posebnim naglaskom na povećanje razlike u četvrtoj/poslednjoj 25m deonici trke, ineks zaveslaja, kao mera specifične efikasnosti zaveslaja, sa posebnim naglaskom na povećanje razlike u trećoj 25m deonici trke, dužina startnog skoka u vodu i brzina startnog skoka u vodu.

Ključne reči: *indeks zaveslaja, kinematička analiza, sprintersko plivanje.*