JOINT FLEXIBILITY AND STROKE EFFICIENCY IN RELATION TO SWIMMING PERFORMANCE OF JUNIOR SWIMMERS

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- shoulder rotation,
- stroke length,
- major stroke.

Abstract:
The purpose of the study was to determine the association between stroke efficiency and joint flexibility in relation to swimming performance. The sample consisted of 6 second-performance class junior swimmers (3 girls and 3 boys) aged 15 to 17 years, members of the swimming club ŠKP Košice. Boys specialize in freestyle sprint and middle-distance races. Contrary to boys, girls specialize in butterfly and individual medley middle-distance races. During 2013 mesocycle, swimmers participated in 5 measurements. Degree of flexibility was determined by administering shoulder rotation test and sit-and-reach test. Stroke efficiency was determined by 8x50 meters swim test performed in swimmer's major stroke. To determine correlation between particular variables in relation to swimming performance achieved in the swimmer's major stroke Kendall's non-parametric correlation was used. Results were analyzed intraindividually, according to gender and finally for an entire sample at $p < .05$. The results showed correlation between shoulder flexibility test scores and average distance per stroke 0.949 ($p < .05$) for swimmer C. M. There were no statistically significant correlations between other observed variables in relation to swimming performance of junior swimmers.

INTRODUCTION

Particular factors underlying swimming performance should not be analyzed separately due to existing relations between these factors. Swimming literature deals with determination of empirical structure of sports performance in most swimming events [26, 27]. Swimming performance is determined by the following factors: water resistance, energetics, aerobic-anaerobic performance, overall efficiency, stroke cycle efficiency and overall swimming mechanics. The contribution of particular factors to the structure of swimming performance has been studied by a variety of authors [16, 17, 21, 30].

Regarding the hierarchy of factors determining the structure of sports performance in swimming, first group includes the most genetically determined factors [20]. Swimming performance is primarily determined by anatomical factors such as body dimensions and proportions, body resistance in water determined by body cross-sectional area, adequate level of trunk and arm strength, explosive power (sprint races) and endurance (long-distance races). Among other determining factors are level of swimming technique and motor coordination. Another important factor is shoulder joint flexibility (backstroke, crawl and primarily butterfly), hip, ankle, and trunk flexibility [8]. Swimmers rely primarily on endurance which is closely related to the level of strength. The contribution of particular motor abilities to swimming performance changes depending on the swimming distance and stroke, respectively. All swimming events and competitive strokes are determined by muscular coordination and joint flexibility, which underlie achievement of maximum sports performance. Joint flexibility has decisive effect on correct stroke technique and is closely related to intermuscular and intramuscular coordination, which underlie stroke mechanics [13, 14, 18]. Greater degree of joint flexibility enhances performance in terms of greater range of motion in particular joints, which results in improved execution of stroke technique, increased balance of horizontal body position and decreased lateral body sway, lower degree of negative water resistance and lower energy expenditure leading to internal muscular viscosity against the executed movement. Individual competitive strokes require different degrees of joint flexibility especially in the shoulder girdle and ankle joints. Butterfly, crawl and backstroke swimmers need higher range of plantar flexion and internal rotation. Breaststroke swimmers rely on dorsiflexion and external rotation as well as above-average range of motion in hip and knee joints. Backstroke swimmers need greater range of motion in shoulder joints especially during initial arm stroke and the arm stroke itself. To crawl swimmers and butterfly swimmers, greater joint flexibility allows for ideal arm recovery above water surface without undue friction and to crawl swimmers for arm recovery without side arm swing, which induces lateral rotation of the entire body. Butterfly swimmers are required to have good level of spine flexibility [13]. Differences are evident also between male and female swimmers. Female pelvis differs from the male one by certain structural properties such as lighter pelvic bones, bigger pelvis volume, greater distance between hip joint sockets, wider and more flexed sacral bone). These factors confirm that female pelvis allows for greater range of motion than the pelvis of males [1]. Factors underlying technique together with other factors transfer into biomechanical characteristics of swimmer's motion. To externally evaluate swimming technique experts most frequently use the parameter of stroke length. Stroke length is the distance the swimmer's head moves during a complete arm cycle (stroke of right and left arm) [10]. Such distance is referred to as stroke length [12]. Foreign researchers use solely the term swimmer's 'distance per stroke'. Swimming velocity can be described by its independent variables: stroke length and stroke frequency. SL is defined as being the horizontal distance that the body travels during a full stroke cycle. SF is defined as being the number of full stroke cycles performed within a unit of time (strokes.min^{-1}) or Hertz (Hz). Increases or decreases in velocity are determined by combined increases or decreases in stroke frequency and stroke length, respectively [6, 15, 25].

THE AIM OF THE WORK

The aim of the study was to determine the association between stroke efficiency and joint flexibility in relation to swimming performance.

THE MATERIAL AND THE METHODOLOGY

A sample of 6 junior swimmers, 3 girls and 3 boys, who are members of the swimming club ŠKP Košice, participated in the study. Basic characteristics of the sample are presented in Table 1.

Five measurements were talen on 1 February, 9 March, 1 May, 13 September and 7 December 2013, respectively. Measurements were taken in the Diagnostic center of the Faculty of Sports, University of Prešov. During particular macrocycles flexibility of selected body parts, stroke efficiency and swimming performance were measured in each of the periods. Swimmers performed 2 tests of static joint flexibility and a stroke efficiency test.

Table 1. Basic characteristics of swimmers

Swimmer	Year of birth	Major stroke	Performance class	Training age
C. M.	1998	200 m butterfly 100 m butterfly	II.	9 years
E. B.	1997	100 m butterfly 200 m individual medley	II.	8 years
N. F.	1998	200 m individual medley 400m individual medley	II.	8 years
J. M.	1998	100 m freestyle 200 m freestyle	II.	9 years
R. T.	1998	50 m freestyle 100 m freestyle	II.	7 years
D. N.	1996	100 m freestyle 50 m freestyle	II.	9 years

1st test: *Sit-and-reach test*
Factor: Trunk flexibility
Test description: The test requires a box 35 cm long, 45 wide and 32 cm high. The dimensions of the bottom of the box is 55 cm in length by 45 cm in width. The top of the box exceeds the plane against which the tested person rests his or her legs by 15 cm. A measuring scale ranging from 0 cm to 50 cm is placed in the center on top of the box. The zero end of the ruler is at the front edge of the board. A 30 cm ruler is placed horizontally on top of the box. The tested person pushes the ruler using his or her hands. At the start of the test, the tested person rests his or her feet against the box, performs forward flexion movement, extends his or her legs with both hands touching the top edge of the box. The tested person pushes the horizontally placed ruler along the measuring scale. A better trial of the two is recorded. The tested person should extend his or her arms and reach forward as much as possible.
Scoring: Record the number of cm, percentage of standards determined according to gender and age (see Table 2)

Table 2. Trunk flexibility standards for boys and girls according to chronological age [22]

Age	Girls (cm)	Boys (cm)
14 years	26.11	21.7
15 years	28.93	23.8
16 years	27.47	24.12
17 years	27.21	23.46

2nd test: *Shoulder rotation*
Factor: Shoulder joint flexibility
Test description: With feet slightly apart, the tested person grabs a stick with both hands in front of the body. The purpose of the test is to bring the stick over one’s head and behind the back without changing the grip width. The tested person repeats the test with narrower grip during each of subsequent trials. The score of the test is the narrowest grip in centimeters.
Scoring: Percentage of transversal dimension: biacromial breadth (biacromiale, shoulder width).

Swimmers’ stroke efficiency was evaluated by 8x50 meter swim test performed in the swimmer’s major stroke. The test was individualized according to personal best, which was updated always on the measurement day. The start of every 50-meter swim was set at 2:30 min. Final 50-meter swim was calculated as personal best + 1 second, and each of the following swims equaled personal best + 2 seconds added to the previous 50-meter swim time. The swimmer starts from water and the parameter measured is the stroke count and the swim time. The swim time was used to calculate average swimming velocity and stroke count to determine the distance swum per single stroke cycle – stroke length [23]. Swimming performance was expressed as a point score according to actual FINA scoring tables.

Associations between particular variables in relation to swimming perfomance in the swimmer's major stroke were determined by non-parametric Kendall's correlation. The results were evaluated intra-individually according to gender and for the entire sample at $p < .05$.

RESULTS

Swimmer's forward motion is the result of two forces: propulsive and drag forces. Overall drag acting against the swimmer's motion depends on the swimmer's body constitution, joint flexibility of particular body segments, position of the head, arms, trunk and legs during the stroke cycle, on swimmer's body shape and body position, on body cross-sectional area and swimming speed. Among important elements of limb movement determining the efficiency of swimming propulsion are: angle of attack, limb speed and direction of motion [19].

Results of the stroke efficiency test such as distance per stroke at maximum velocity and average distance per stroke, flexibility test results – shoulder rotation and sit-and-reach test in relation to swimming performance showed positive correlation, which was statistically insignificant. At the same time, distance per stroke positively correlated with results of the flexibility tests. This correlation was statistically insignificant as well. There were no statistically significant correlations between observed variables in relation to swimming performance. For girls, flexibility test – shoulder rotation and distance per stroke positively correlated with swimming performance. For boys, both flexibility tests positively correlated with swimming performance, but distance per stroke correlated inversely with swimming performance. However, these results were statistically insignificant. Neither boys nor girls demonstrated significant relationship between flexibility test scores and distance per stroke.

In the particular stage of preparation, technical training is individually designed to adjust the technique of competitive strokes to individual specifics of the swimmer. During particular stages of preparation, swimmers fulfill specific tasks such as perfection of technique, error correction and maintenance. Perfection and technique stabilization are associated with development of motor abilities. Flexibility development makes part of the conditioning preparation (passive flexibility exercises in twos, body weight exercises, static exercises and active flexibility exercises).

The intra-individual assessment of swimmer C. M. showed that shoulder rotation test scores ranged from 101% to 244% of shoulder width with gradual increase nearing the competition period in the winter macrocycle. Sit-and-reach test score equaled 48% to 62% according to standards for gender and age. Average distance per stroke ranged from 2.344 to 2.470 meters, and the highest value was observed during the competition period in the winter macrocycle. Distance per stroke at maximum velocity was 2.27 to 2.5 meters, where the swimmer achieved the highest values during the competition period in the summer and winter macrocycle (2.38 m and 2.50 m). Swimming performance scores ranged from 594 to 614 points during the summer macrocycle with increasing values observed nearing the competition period. During the winter macrocycle, swimmer achieved similar scores and the highest score equaling 675 points achieved during the winter macrocycle was the highest score achieved during the entire period. At the same time, swimmer achieved the highest value of maximum velocity in the stroke efficiency test: 1.582 $m.s^{-1}$ (see Table 3) during this period.

Table 3. Values of performance parameters for swimmer C. M.

C. M.	Stroke efficiency test			Flexibility test		Swimming performance
	‘v’max ($m.s^{-1}$)	DPS ‘v’max (m)	xDPS (m)	1. (%)	2. (%)	(points)
2/1/2013	1.567	2.27	2.344	48	101	594
3/9/2013	1.577	2.27	2.395	62	160	610
5/1/2013	1.538	2.38	2.389	52	160	614
9/13/2013	1.582	2.27	2.458	59	236	675
12/7/2013	1.558	2.5	2.47	62	244	671

Note. ‘v’max ($m.s^{-1}$) - maximum velocity, DPS ‘v’max (m) - distance per stroke at maximum velocity, xDPS - average distance per stroke

There was a statistically significant correlation ($p < .05$) between flexibility test scores – shoulder rotation and average distance per stroke 0.949. There were no statistically significant correlations between remaining variables and swimming performance.

There were no statistically significant correlations between observed variables and swimming performance in the remaining swimmers. Shoulder rotation test, which is individualized according to shoulder width, appeared to be suitable for swimmer C. M., whose test scores increased in course of the monitored period. Regarding stroke efficiency, values of distance per stroke increased linearly. It should be noted that distance per stroke at maximum velocity observed during the final 50-meter swim was highest during the competition period in both summer and winter macrocycle, respectively.

As for butterfly stroke, main kinematic aspects are the trunk angle, the arm’s full extension during the upsweep and the emphasis in the second kick. Higher trunk angle with horizontal plane will increase the projected surface area and the drag force [2]. Butterfliers with increased velocities present a higher extension of the elbow at the upsweep, in order to increase the duration of this propulsive phase [24].

It was concluded that good flexibility is more important than single anthropometrical parameters. Increased velocity is achieved by a combination of increasing stroke rate and decreasing distance per stroke in all of the four competitive strokes. There are several biomechanical variables determining the competitive swimmer’s performance. For instance, some of those are kinematics variables (e.g. stroke length, stroke frequency, speed fluctuation, limbs’ kinematics), kinetics variables (e.g. propulsive drag, lift force, drag force) and neuromuscular variables.

Shoulder rotation test scores achieved by female swimmer E. B. ranged from 74% to 99% of shoulder width. Sit-and-reach test equaled 66% to 84% according to standards for age and gender. In the stroke efficiency test, average distance per stroke ranged from 1.95 m to 2.04 m, where the swimmer achieved the highest test score at the beginnning of the monitored period. Distance per stroke at maximum velocity ranged from 1.79 m to 1.85 m. Swimming performance during summer macrocycle equaled 490-533 points. The highest level of swimming performance in the competition period, during which the swimmer scored highest in the stroke efficiency test, maximum velocity parameter, distance per stroke at maximum velocity and shoulder rotation test, respectively. During winter macrocycle, highest value equaling 556 points was achieved during competition period and that was also the highest value observed during the entire monitored period (see Table 4).

Table 4. Values of performance parameters for swimmer E. B.

E. B.	Stroke efficiency test			Flexibility test		Swimming performance
	'v'max ($m.s^{-1}$)	DPS 'v'max (m)	xDPS (m)	1. (%)	2. (%)	(points)
2/1/2013	1.502	1.85	2.04	74	66	508
3/9/2013	-	-	-	-	-	490
5/1/2013	1.506	1.85	1.99	99	69	533
9/13/2013	1.420	1.79	1.95	90	84	466
12/7/2013	-	-	-	-	-	556

Note. 'v'max ($m.s^{-1}$) - maximum velocity, DPS 'v'max (m) - distance per stroke at maximum velocity, xDPS - average distance per stroke

The front crawl has the greatest stroke length and stroke frequency in comparison to remaining swimming techniques. Authors suggested similar behavior for the backstroke except that at a given stroke frequency, the stroke length and velocity were less than for the front crawl. At butterfly stroke, increases of the velocity were related almost entirely to increases in stroke frequency, except at the highest velocity. As for breaststroke, increasing velocity was also associated with increase in stroke frequency, but the stroke length decreased more than in other swim strokes [5]. Comparing the swim strokes by distance, there is a trend for stroke frequency and velocity decrease and a slightly maintenance of stroke length with increasing distances [4, 11]. Swimmer must have a high stroke length and, therefore, velocity should be manipulated by changing the stroke frequency [5].

Table 5 shows test scores of swimmer N. F. Shoulder rotation test scores ranged from 167% to 308% of shoulder width. Sit-and-reach test scores ranged from 8 to 69% according to standards for age and gender. Average distance per stroke ranged from 1.40 to 1.50 meters. Distances per stroke at maximum velocity, which were similar during the entire monitored period, equaled 1.09 m to 1.11 m irrespective of the training preparation stage. During summer macrocycle, swimming performance scores declined, where the highest point score equaling 658 was observed during preparation period of the summer macrocycle being the highest score observed within the entire period. During the winter macrocycle, the highest swimming performance point score equaled 631 points.

Table 5. Values of performance parameters for swimmer N. F.

N. F.	Stroke efficiency test			Flexibility test		Swimming performance
	'v'max ($m.s^{-1}$)	DPS 'v'max (m)	xDPS (m)	1. (%)	2. (%)	(points)
2/1/2013	-	-	-	-	-	658
3/9/2013	1.623	1.11	1.50	167	8	640
5/1/2013	-	-	-	-	-	581
9/13/2013	1.603	1.11	1.40	308	69	618
12/7/2013	1.667	1.09	1.43	277	52	631

Note. 'v'max ($m.s^{-1}$) - maximum velocity, DPS 'v'max (m) - distance per stroke at maximum velocity, xDPS - average distance per stroke

Velocity is the best variable to assess swimming performance. For a given distance, front crawl is considered the fastest swim stroke, followed by butterfly, backstroke and breaststroke [3, 6]. Hohmann and Seidel predicted 41% of girl's 50-m freestyle performance based on psychological, technique (i.e. stroke rate, swim velocity, limb's coordination), physical conditioning and anthropometrical variables. The relationship between swimming performance, biomechanics and energetics is displayed in Figure 2 [9].

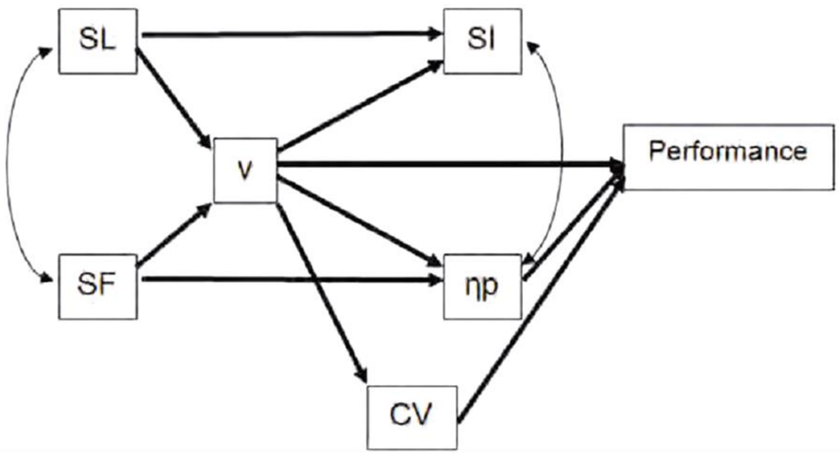

Figure 1. The final confirmatory model about the relationship between biomechanics, energetics and swimming performance.
Notes: SL - stroke length, SF - stroke frequency, v - swimming velocity, SI - stroke index, ηp - propulsive efficiency, CV - critical velocity

For swimmer J. M., there were no correlations between observed variables and swimming performance. Shoulder rotation test scores ranged from 45 to 53% of shoulder width. Sit-and-reach test scores equaled 18 to 44% according to standards for age and gender. Stroke efficiency test showed that average distance per stroke ranged from 1.51 m to 1.71 m. Swimmer J. M. achieved the highest value during the competition period of the winter macrocycle. Distance per stroke at maximum velocity ranged from 1.32 m to 1.52 m. The highest values of all observed parameters in the domain of flexibility and stroke efficiency were achieved at the end of the monitored period during the competition period of the winter macrocycle. During the entire period the highest point score of swimming performance equaling 606 points was recorded during preparation period of the winter macrocycle. During summer macrocycle, the highest point score equaled 566 points during the competition period (see Table 6).

Table 6. Values of performance parameters for swimmer J. M.

J. M.	Stroke efficiency test			Flexibility test		Swimming performance
	‘v’max ($m.s^{-1}$)	DPS ‘v’max (m)	xDPS (m)	1. (%)	2. (%)	(points)
2/1/2013	1.786	1.39	1.63	52	18	502
3/9/2013	1.838	1.35	1.53	45	32	478
5/1/2013	1.825	1.32	1.51	53	28	566
9/13/2013	1.825	1.47	1.61	51	44	606
12/7/2013	1.838	1.52	1.71	53	42	571

Note. ‘v’max ($m.s^{-1}$) - maximum velocity, DPS ‘v’max (m) - distance per stroke at maximum velocity, xDPS - average distance per stroke

Stroke mechanics variables, including the stroke frequency and the stroke length are dependent on limb’s kinematics. That is the reason why some effort is done to understand the contribution of the biomechanics of competitive swimming strokes limb’s behavior. For instance, at front crawl, observed a significant relationship between the hip velocity and the horizontal and vertical motion of the upper limbs was observed. As the upper limb’s velocity increased, the horizontal velocity of the swimmers increased as well. Therefore, it can be argued that upper limbs velocity has a major influence on swimming performance [7].

Table 7 shows scores achieved by swimmer R. T. Shoulder rotation test scores ranged from 54% to 73% of shoulder width. Sit-and-reach test scores equaled 13% to 29% according to standards for age and gender. In stroke efficiency test average distance per stroke ranged from 1.52 m to 1.82 m. Distance per stroke at maximum velocity equaled 1.52 m to 1.61 m. The highest value of swimming performance equaling 494 points during the entire period was achieved by the swimmer in the preparation period of the winter macrocycle. During this period the swimmer achieved highest scores in both flexibility tests and stroke efficiency test. During the summer microcycle, highest score equaled 488 points.

Table 7. Values of performance parameters for swimmer R. T.

R. T.	Stroke efficiency test			Flexibility test		Swimming performance (points)
	‘v’max ($m.s^{-1}$)	DPS ‘v’max (m)	xDPS (m)	1. (%)	2. (%)	
2/1/2013	-	-	-	-	-	449
3/9/2013	1.742	1.52	1.70	54	-13	461
5/1/2013	1.312	1.61	1.74	57	0	488
9/13/2013	1.852	1.61	1.82	73	29	494
12/7/2013	-	-	-	-	-	491

Note. ‘v’max ($m.s^{-1}$) - maximum velocity, DPS ‘v’max (m) - distance per stroke at maximum velocity, xDPS - average distance per stroke

Shoulder rotation test scores achieved by swimmer D. N. ranged from 43% to 49% of shoulder width. Sit-and-reach test scores equaled 29% to 46% according to standards efor age and gender. Average distance per stroke ranged from 1.71 m to 1.77 m. Distance per stroke at maximum velocity ranged from 1.35 m to 1.72 m. During the entire period, the swimmer achieved highest swimming performance score equaling 555 points during preparation period of the winter macrocycle. Highest shoulder rotation test scores, sit-and-reach test scores and maximum velocity achieved in stroke efficiency test were also observed during preparation period of the winter macrocycle. Swimming performance point score declined during summer macrocycle, and the highest value equaling 535 points was recorded during the preparation period (see Table 8).

Incorrect technique increases frontal drag and turbulent flow, decreases swimming velocity and increases energy expenditure. Incorrect technique may be caused also by low degree of joint flexibility. Greater joint flexibility in particular joints allows for improved stroke technique and decreased lateral body sway and negative water resistance resulting in lower energy expenditure [19].

Table 8. Values of performance parameters for swimmer D. N.

D.N.	Stroke efficiency test			Flexibility test		Swimming performance (points)
	‘v’max ($m.s^{-1}$)	DPS ‘v’max (m)	xDPS (m)	1. (%)	2. (%)	
2/1/2013	1.661	1.67	1.77	46	29	535
3/9/2013	1.639	1.72	1.72	43	33	485
5/1/2013	-	-	-	-	-	487
9/13/2013	1.838	1.35	1.71	49	46	555
12/7/2013	-	-	-	-	-	512

Note. ‘v’max ($m.s^{-1}$) - maximum velocity, DPS ‘v’max (m) - distance per stroke at maximum velocity, xDPS - average distance per stroke

Clean swimming speed (v; $m.s^{-1}$) equals the product of stroke length (the distance (m) covered during one stroke cycle) and stroke rate (the number of cycles per second). If different swimmers are compared, stroke length appears to be the single best predictor of swimming performance. Furthermore, Wakayoshi et al. found that after 6 months of aerobic swim training, an increase in maximal swimming speed was accompanied by an increase in stroke length during the last 150 m of a 400-m race, whereas no significant changes in stroke rate were observed [29]. Chollet et al. studied variations in stroking characteristics during 100-m races in male swimmers of different skill levels. They concluded that skilled swimmers are able to maintain a more constant stroke length throughout the race than less skilled swimmers. This would imply that the ability to maintain speed depends more on the ability to maintain stroke length over the course of the race than stroke rate [4]. Similar findings were reported by Vorontsov and Binevsky when studying stroking characteristics in 11- to 16-yr-old boys. The progressive decrease in velocity during a 100-m race correlated with the decrease of stroke rate but not stroke length, suggesting that stroke length remained constant during the race. Consequently, stroke length is more or less constant throughout the race [28].

CONCLUSIONS

Despite statistically insignificant correlations between observed variables and swimming performance, we may assume that swimmers' performances increased in course of the entire monitored period as a result of improved stroke efficiency determined by greater shoulder joint flexibility, i.e. joint flexibility.

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