HUMAN MOVEMENT
2012, vol. 13 (3), 225–235

ADVISABILITY ON THE SHIFT FROM STANDARD FRONT CRAWL SWIMMING TECHNIQUE TO THE "KAYAKING" AND "LOPING" VARIANTS

doi: 10.2478/v10038-012-0026-1

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ABSTRACT
Purpose. The aim of this study was to analyze selected kinematics parameters of standard front crawl swimming technique and its variants, the "kayaking" and "loping", in order to estimate the differences that can determine swimming effectiveness and efficiency **Methods.** Eighteen swimmers, divided equally into three groups, took part in the research. The first group was composed of individuals who favored the standard technique, the second group used the "kayaking" variant and the third one swam in the "loping" variant. All swimmers were instructed to swim the 50 m freestyle with their technique of choice at maximum velocity. Analysis of kinematic parameters (time, average swimming velocity), swimming cycle parameters (stroke length, stroke rate), and the swimming efficiency coefficient (stroke index) was calculated using SIMI's 2D Reality Motion Systems software. **Results.** The Kruskal-Wallis test and Mann-Whitney U test found statistically significant differences in the studied parameters between the standard technique (S) and the "kayaking" (K) and "loping" (L) variants in the time to swim 25 m ($\bar{x}_S$ = 15.472 s, $\bar{x}_K$ = 13.540 s, $\bar{x}_L$ = 14.108 s), and between (S) and (K) in the 15 m swim time ($\bar{x}_{St}$ = 9.598 s, $\bar{x}_{Kt}$ = 8.593 s) and average swimming velocity ($\bar{x}_{Sv}$ = 1.562 m/s, $\bar{x}_{Kv}$ = 1.757 m/s). **Conclusions.** Analysis of the differences in the kinematic parameters that define front crawl swimming technique finds justification in the need to modify the standard technique of the propulsive movement used in swimming towards those that employ the "kayaking" and "loping" variants as they are more effective in affecting swimming velocity.

Key words: front crawl, "kayaking", "loping", stroke length, stroke rate, stroke index

Introduction

This study was rooted in the issues surrounding the use of more modern developed swimming techniques that attempt to optimize the front crawl. The aim of this study was to analyze front crawl swimming technique and the "kayaking" and "loping" variants as shown in Figure 1 [1–3].

The movement pattern of standard front crawl swimming technique was used as a reference point in order to identify the movement structure propulsive phase of the arm as well as its coordination with the "kayaking" and "loping" variants. All of the above-mentioned techniques are used in the freestyle sprint as well as a finishing sprint in medium and long distances. In the standard technique, arm movements occur alternately and maintain equal time intervals during the propulsive and recovery phases. The trajectory of the hand in the propulsion phase, in the frontal plane, resembles the shape of the letter "S" (where the hand moves in the direction of the long axis of the body, then it is straightened out towards the back and reaches towards the hip, Fig. 1a).

In the "kayaking" variation, the alternately-sided movements of the arms are also performed in uninterrupted coordination, in which the movement of one arm mirrors (in a general sense) the movement of the other arm. The distinguishing feature of "kayaking" in comparison to standard technique is the different arm movement structure in the propulsive phase. This limits elbow flexion in the stroke phase and reduces the adduction of the straightened arm when pointing to the torso during the push back phase, with the hand moving in the sagittal plane and resembling the shape of the letter "I" (Fig. 1b). When observed in its entirety, the shape of the movement is analogous to someone paddling in a kayak. The effectiveness of the "kayaking" variant has been confirmed in research studies by, among others, Kjendlie et al. [4, 5], while competitors such as Popov, Bernard and Cielo have applied the "kayaking" variant in international competition.

The "loping" variant of front crawl swimming technique does not feature equal time intervals of the arms during the propulsion and recovery phases, as is found

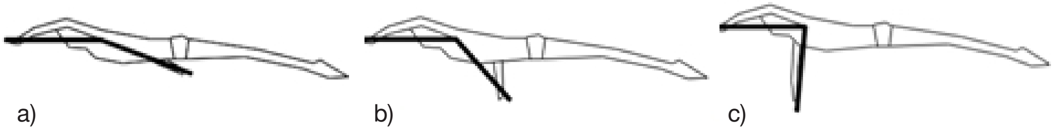

Figure 1. Illustration of the differences in upper extremity coordination in standard front crawl technique (a) and the "kayaking" (b) and "loping" (c) variants

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in the standard technique and "kayaking" variant (Fig. 1c). Mutual alignment of the arms is asymmetric during the different phases of the stroke cycle. Specifically, the arm's movement at the end of the preparatory phase, when straightened out at the elbow, is held in place for a slightly extended period of time, creating an impression of one arm "catching-up" to the other. While using "loping" variant, the arm movement structure as well as hand trajectory does not differ from the standard technique. However, there is a lack of research literature on the evolution of this stroke variant, but "loping" has been popularized by such swimmers as Bondi, van den Hoogenband, Lochte and Phelps.

It is well known that improving one's results in sport is based on the development of motor skills, movement techniques, and mental readiness to take part in competition [6]. Biomechanics study an athlete's movement processes in both time and space, creating a scientific basis to monitor the quality of movement structure (as a sign of improving technique) and monitor its coordination (as a manifestation of motor skills) [7]. Within the context of swimming technique, both of the abovementioned elements can be construed as the effective and efficient human propulsion in water [8]. It is assumed that movement coordination is the organized movement activity that results from a mutual alignment of all the elements that compose human movement when interacting with an environment [9]. These structural elements can be defined by using movement sequences, i.e., the division of movement as a biomechanical chain composed of the smallest elements of spatial displacement [10].

In sport activities composed of cyclic propulsive phases (such as swimming), the time (and velocity) used to cover a certain distance is a measure of the effectiveness and efficiency of an individual's technique; it provides an impartial criterion for evaluation [6]. The relationship between technique and race results is far more pronounced in swimming than in other sports due to the aquatic environment. The lack of physical support makes any attempt at stabilizing cyclic propulsive phases (with the exception of swimmers at the highest levels [11]) imperfect in nature. The power generated by a swimmer will vary from each motor sequence to the next and in each cycle phase and, therefore, due to water's active resistance, lead to intra-cycle changes in velocity [12].

These inrta-cycle changes in velocity are detrimental as the goal of competitive swimming is to obtain maximum velocity [12]. In addition, variable velocity results in rising energy expenditure. Thus, an increase in cycle velocity while minimizing inner-cyclical velocity fluctuations appears to be the basic criterion for effective [13] and efficient [14] swimming. Stabilizing inner-cyclical velocity variations is an especially important aspect of swimming technique in the front crawl as this is the fastest and, therefore, the most stabilized (due to velocity) swimming style. One of the ways in minimizing iinrta-cycle velocity changes in the front crawl is by having a high level of coordination abilities that allow one to perfectly perform propulsive arm movements [15]. Therefore it seems reasonable that the search for newer, more effective and efficient variations of the front crawl should focus on modifying the structure of the propulsive phase as well as overall movement coordination.

Research on the effectiveness and efficiency of various front crawl techniques has so far analyzed a variety of determinants that can cause an increase in swimming velocity and the ability to maintain it across various distances. These studies have defined and developed alternative coordination models ("opposition, "catch-up" and "superposition") [2, 3] and created a Coordination Index (IdC) to quantify the delays of various forms of arm motor coordination [3]. Other studies branched out to evaluate the energy costs of using various types of coordination structures in the front crawl [2, 16].

Based on the above premise, the aim of this study was to identify the factors that influence front crawl velocity variations by analyzing swimmers who have trained in competitive swimming at the highest levels. However, an original aspect of this study was the attempt to interpret the results in a practical context by objectively assessing the effectiveness and efficiency of swimmers who are high skilled in the swimming techniques here under analysis, and then determining the direction and size of these changes on swimmers just beginning to master various swimming styles and techniques. In this context, it is felt that an objective quantification of the differences in standard front crawl swimming technique and the "kayaking" and "loping" variants in experienced swimmers can justify the advisability of modifying the currently used standard movement algorithm in order to optimize technique and result in an increase in swimming velocity.

Therefore, the hypothesis of this study was to analyze recorded kinematic parameters of the standard front crawl technique and its "kayaking" and "loping" variants in order to determine their effectiveness and efficiency. With this in mind, the following research questions were examined: (1) Are the differences in time (and velocity) to swim a specific distance and the differences in the parameters that define cyclic propulsive movement (stroke length, stroke rate and the swimming efficiency coefficient) significant enough to objectively estimate the effectiveness and efficiency of standard front crawl technique and the "kayaking" and "loping" variants? (2) Does analysis of the differences in the kinematic parameters of the three analyzed swimming techniques by experienced swimmers create an objective basis on the advisability of using these modified techniques in the early stages of swimmers' training?

Material and methods

A total of 18 male swimmers voluntarily participated in the study. The subjects were divided into three groups, where the first group (N_S = 6) consisted of swimmers who preferred to swim the standard front crawl, the second group (N_K = 6) were swimmers who preferred to swim the "kayaking" technique, while the third group (N_L = 6) were those who swam the "loping" variant. Data on the participants' characteristics (Tab. 1) reflected the selection criteria that were originally selected in order to fulfill the study objectives. The subjects were randomly chosen according with the following criteria: (1) participants' age and career length were treated as a differentiating factor, (2) while a factor assessing their similarity was their skill level (i.e., each of the subjects had mastered their swimming technique at a similar level), which was determined by their fastest personal record in the 50 m freestyle. (3) Similarities of the swimmers' somatic parameters were used as an objective basis to compare their potential in terms of efficient and effective swimming (quantified by the kinematic parameters that characterize cyclical movement propulsion – stroke stride and stroke rate) [17].

It was decided that an objective assessment of the test groups' homogeneity would be assessed with a standard deviation of the mean values no larger than 10%. This was based on Bartlett's test, which is used to verify the equality (homogeneity) of variance in all subgroups of a population [18]. This test is based on asymptotic chi-square distribution and can be used for very small samples. The Bartlett test uses the relationships between the means and standard deviations of the sample to reflect the homogeneity of the results obtained from one individual (statistical significance at α = 0.05) with the results from the other swimmers. Bartlett's statistical formula was used only with decimal logarithms [18]. The results of the test found that the samples were homogeneous and met the assumptions that the selected group, in terms of skill level and the other selected parameters, should be characterized by a standard deviation of no more than 10% of arithmetic mean.

Swimming trials were conducted in a 25 m pool under the same conditions for all subjects. The task was to

Table 1. Characteristics of the swimmers participating in the study, in each research group

Group	Subjects	Swimming career (years)	50 m freestyle personal best (s)	Age (years)	Body height (m)	Body mass (kg)	($t_{2/1}$) (%)
Standard	X1	7	29.50	17	1.68	66.0	–1.12
	X2	9	29.61	19	1.92	84.0	–1.07
	X3	5	26.32	20	1.89	78.0	1.39
	X4	10	28.34	22	1.65	65.0	–2.21
	X5	8	29.80	21	1.83	74.0	–3.45
	X6	11	29.70	23	1.73	71.5	2.70
	$\bar{x}$	8.3	28.878	20.3	1.783	73.08	
	s	2.16	1.3624	2.16	0.1127	7.242	
Kayaking	Y1	8	27.12	18	1.73	74.5	3.50
	Y2	10	24.96	23	1.84	81.0	–0.60
	Y3	8	22.30	18	1.91	86.0	–2.83
	Y4	20	22.31	27	1.94	88.0	–0.24
	Y5	7	28.20	17	1.66	66.5	0.39
	Y6	13	24.27	23	1.77	78.5	–0.39
	$\bar{x}$	11.0	24.860	21.0	1.808	79.08	
	s	4.90	2.4363	3.95	0.1080	7.883	
Loping	Z1	8	24.01	18	1.68	66.5	1.06
	Z2	10	25.25	19	1.76	75.5	–2.45
	Z3	11	26.80	21	1.94	90.0	–1.49
	Z4	12	22.52	25	1.90	82.0	0.31
	Z5	5	26.36	29	1.82	81.0	–0.35
	Z6	9	24.90	21	1.84	79.5	3.44
	$\bar{x}$	9.2	24.973	22.2	1.823	79.08	
	s	2.48	1.5677	4.12	0.0942	7.781	
Total	$\bar{x}$	9.5	26.237	21.2	1.805	77.08	
	s	3.40	2.5903	3.40	0.1003	7.745	

($t_{2/1}$) – percent difference in the time to swim a distance in the first and second attempt, assuming that the swimmers' results do not differentiate more than 10% from their personal record swim 50 m in the front crawl at maximum velocity in two trails, with the time measured in order to verify if they performed at maximum capacity. It was assumed that the swimmers' times should differ –10% to 10% between first and second trails (equation #1) and that the results should not differ more than 10% than their personal best time (Tab. 1).

$$t_{2/1} = 100 - \frac{t_2}{t_1} \times 100. \qquad (\#1)$$

The need to swim at maximum velocity was dictated by the existing relationships between swimming velocity and the swimming cycle parameters (stroke length and stroke rate) [19]. Each trial was conducted after a 15 min warm-up, followed by a 5 min rest to stabilize heart rate. The swimmers then swam in their preferred swimming technique (standard front crawl or the "kayaking" or "loping variants). All of the athletes completed the trials in the prescribed manner mentioned above.

A solid basis for discussing the advisability of modifying the standard movement algorithm of the front crawl towards more optimal swimming technique needs to be based on the objective and normative selection of athletes as well as reliable and valid diagnostic tasks. This can stem from simulating starting conditions that accompany the swimmers during competition. At the same time, motivating the swimmers to achieve their maximum velocity (measured by a 10% tolerance of their personal best) can provide comparable results, determined at least in terms of their current fitness level.

Data on swimming technique were recorded during the first trial in the first 25-metre half of the 50 m distance the swimmers had to swim (by water start). The swimmers were timed with the Colorado Time system, an automated system that is composed of a tensometric starting platform, a touch plate and a stopwatch with a sampling frequency of 0.001 s. The remaining kinematic parameters were recorded for a distance of 15 m (excluding a 5-meter buffer at the end of the pool for flip turns) (Fig. 2).

The athletes were registered by two cameras filming at a frequency of 50 Hz. The first camera (DCR-TRV 22E, Sony, Japan) was placed under water at a depth of 1 m in the middle of the pool. The axis of the camera lens was perpendicular to the swimming direction in order to film the swimmer at the property angle possible, as this would allow for the filming of at least one full movement cycle. The measurement track was calibrated with a 2 × 2 m measurement frame that was placed vertically in such a way as to not adversely affect the swimmer. The swimmers wore markers in contrasting colors on the head and on the radial-axis of both limbs [20]. Video samples of the registered cycles were then randomly selected for direct measurement of swimmers' stroke length as well as to describe and verify the quality of the propulsive movement structure of the arms in each of the examined swimming techniques (Fig. 3).

Another camera of the same make and model was also placed in the middle of the pool but on top of the water. Video from this camera was used to record the swimmers' time in covering the 50 m distance (measured to nearest 0.001 s) and to calculate their average stroke rate and swimming efficiency ratio. The filmed data was then directly analyzed by 2D Motion Software System software (SIMI, Germany) according to the producer's guidelines and recommendations. Stroke rate was measured by the distance a swimmer covered in one movement cycle. This parameter was determined (Fig. 4) by the horizontal displacement of the marker placed on the swimmer's head from the time when the hand began "catching" the water (A) up to the moment when the hand completed the propulsion and preparatory phase and returned to the entry position (B) [11]. The mean stroke length was then calculated by using the equation [21]:

$$l(m/cycle) = \frac{d(m)}{c}, \qquad (\#2)$$

where: d – distance, c – number of movement cycles.

Stroke rate, as the average number of full movement cycles per time unit, was calculated by the formula [21]:

$$f(cycle/s) = \frac{c}{t(s)}, \qquad (\#3)$$

where: c – number of movement cycles, t – time to swim the distance.

An additional equation (#4) was used to calculate average swimming velocity. This parameter (whose diagnostic value is identical to the time spent in swim-

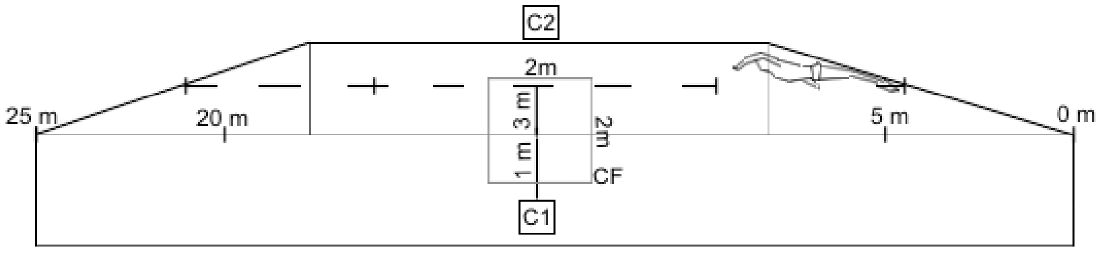


Figure 2. Schema of the measurement track

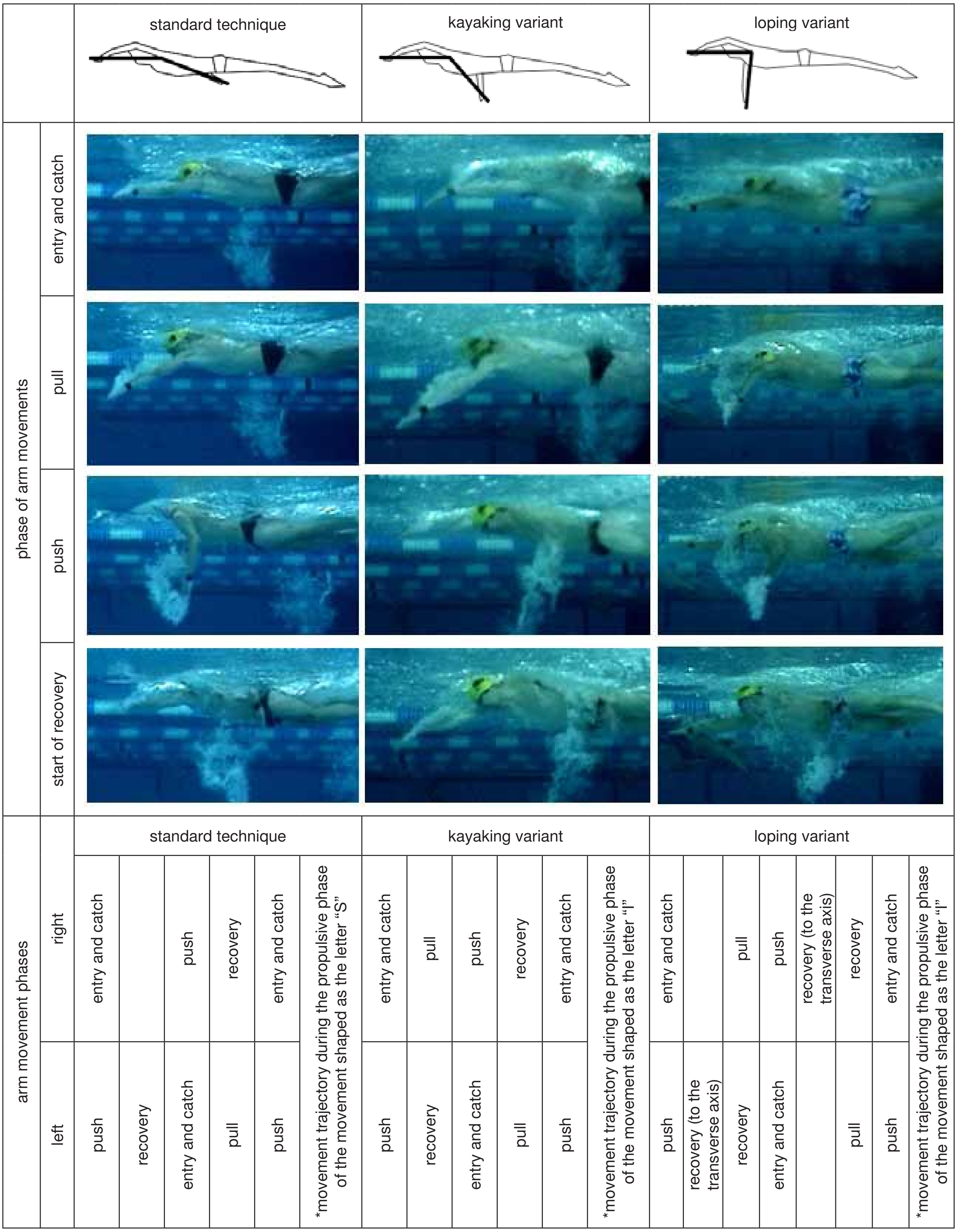
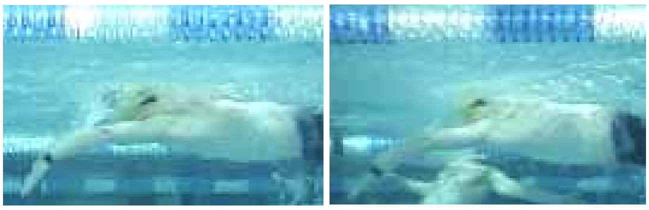


Figure 3. Illustration and explanation of the differences in the structure of the upper limb movements and their coordination phases of the standard, "kayaking" and "loping" front crawl techniques



A B

Figure 4. Illustration showing measurement of the stroke rate from the first sequence (phase A) to the last sequence (phase B) [11]

ming the total distance) was introduced only for hypothetical purposes:

$$v(m/s) = \frac{s(m)}{t(s)}, \qquad (\#4)$$

where: s – swim distance, t – time to swim the distance.

The swimming efficiency coefficient (stroke index) describes the ability to generate maximum swimming velocity using the minimum number of movement cycles (a longer stroke rate) and is expressed by [22]:

$$SI = l(m) \times v(m/s), \quad SI = (1/s), \qquad (\#5)$$

where: SI – stroke index, v – velocity, l – length of stroke rate.

Statistical analysis was performed with Statistica 9.0 (Statsoft, USA) software at a statistical significance level of α = 0.05. The Kruskal-Wallis and Mann-Whitney *U* test were used to test for statistically significant differences between the groups among all the measured parameters. They were used for the small sized groups under the assumption that the selected parameters do not show normal distribution [23]. In addition, ISO 9001:2009 standards were used for to standardize the recordings and to analise kinematic parameter of swimming cycle.

Results

Statistical analysis by the Kruskal-Wallis test found statistically significant differences in three of the analyzed parameters: the 25 m time, the 15 m time and the 15 m average swimming velocity (Tab. 2). These results point to the fact that only these specified parameters have a diagnostic value when comparing the three swimming techniques and, because of this, they were then subjected to the Mann-Whitney *U* test (Tab. 3).

Table 3. Results of the Mann-Whitney *U* test assessing the statistical significance of the parameters' differences between two swimming techniques

Parameter	Comparison of the front crawl swimming techniques		Significance level
25 m time (*t25*)	standard	kayaking	**0.004**
		loping	**0.038**
	kayaking	standard	**0.004**
		loping	0.503
	loping	standard	**0.038**
		kayaking	0.503
15 m time (*t15*)	standard	kayaking	**0.012**
		loping	0.058
	kayaking	standard	**0.012**
		loping	0.702
	loping	standard	0.058
		kayaking	0.702
15 m swimming velocity (*v*)	standard	kayaking	**0.014**
		loping	0.087
	kayaking	standard	**0.014**
		loping	0.623
	loping	standard	0.087
		kayaking	0.623

Statistically significant differences at α = 0.05 are marked in bold

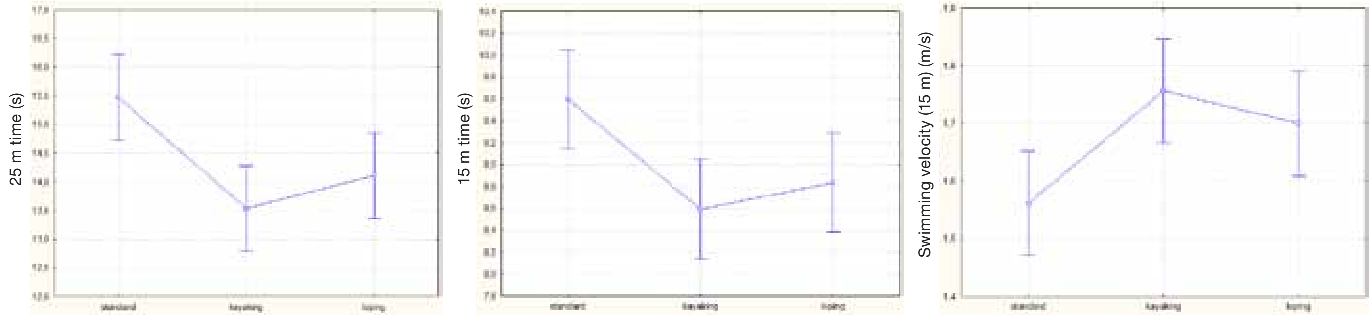
The Mann-Whitney *U* test (Tab. 3) indicated statistically significant differences in the time needed to swim 25 m in each of the front crawl swimming techniques. Significant differences were also found between the standard technique and the "kayaking" variant in the 15 m swim time (as well as the average velocity to swim this distance).

The 25 m distance was swum the fastest by swimmers who specialize in the "kayaking" variant of the front crawl ($\bar{x}$ = 13.5396 s), while those who used standard front crawl technique took the longest to cover the same distance ($\bar{x}$ = 15.4722 s) (Fig. 5). The average time of swimmers using the "loping" variant was $\bar{x}$ = 14.1080 s. Similar to the results in the 25 m distance, the shortest

Table 2. Results of the Kruskal-Wallis test evaluating the statistical significance of the differences across all measured parameters for each swimming technique variation

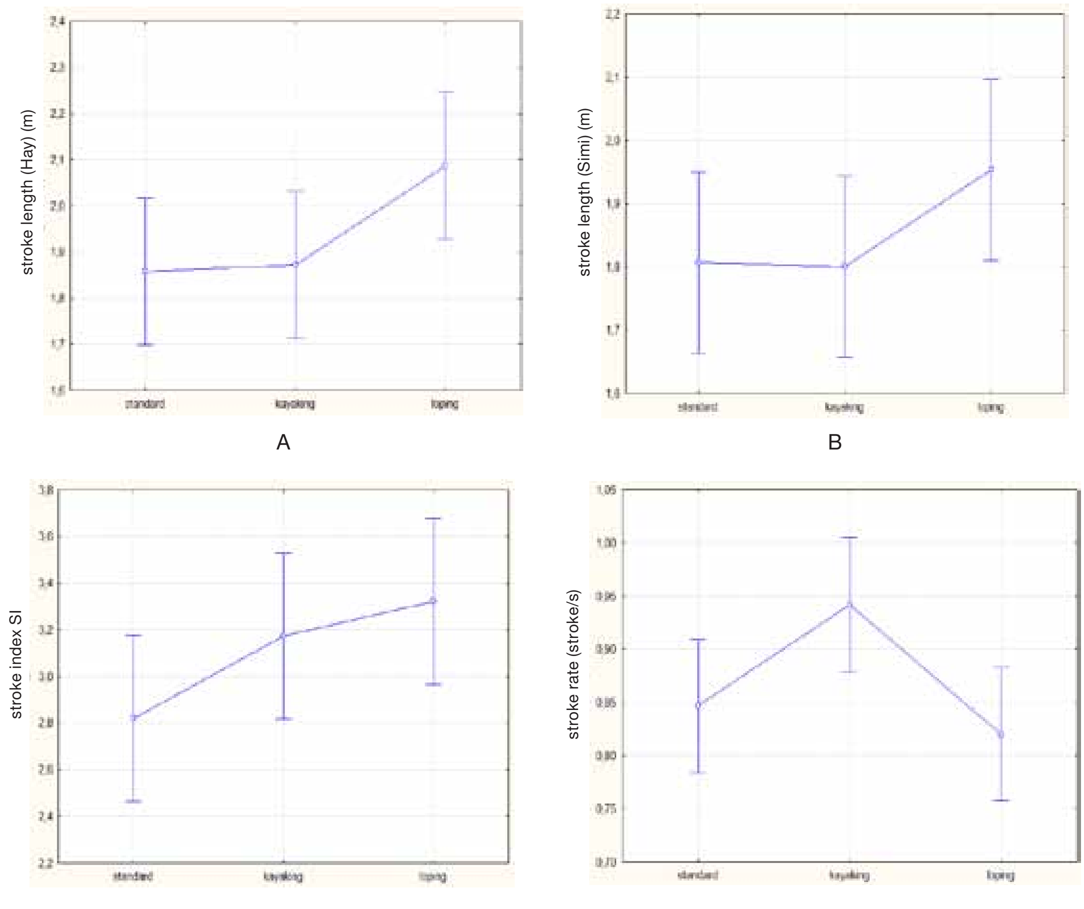
Parameter	*t25*	*t15*	*v*	*l* (Hay)	*l* (Simi)	*f*	*SI*
Chi-square	**6.587**	**5.769**	**5.789**	0.026	0	3.718	1.641
Degrees of freedom	**1**	**1**	**1**	1	1	1	1
Asymptotic significance	**0.010**	**0.016**	**0.016**	0.871	1.00	0.054	0.200

t25 – 25 m time, *t15* –15 m time, *v* – 15 m average swimming velocity,
l (Hay) – stroke length, *l* (Simi) – stroke length, *f* – stroke rate, *SI* – swimming efficiency coefficient (stroke index)
Statistically significant differences at α = 0.05 are marked in bold



A B C

Figure 5. Mean values of the parameters differentiating the front crawl swimming techniques:
A – 25 m time, B – 15 m time, C – 15 m swimming velocity



A B

C D

Figure 6. Mean values of the movement cycle parameters in the front crawl swimming techniques:
A – stroke length (Hay), B – stroke length (SIMI), C – efficiency coefficient (stroke index), D – stroke rate

time to swim the 15 m distance was by swimmers using the "kayaking" variant ($\bar{x}$ = 8.5927 s); the standard technique swimmers were the slowest ($\bar{x}$ = 9.5977 s) while those using the "loping" variant in the 15 m swim were in the middle ($\bar{x}$ = 8.8379 s). Similar results were also found in the average swimming velocity, although this was calculated only for hypothetical purposes. The fastest velocity in the 15 m distance was attained by the "kayaking" swimmers ($\bar{x}$ = 1.7568 m/s), while the slowest swimmers were those who used the standard technique ($\bar{x}$ = 1.5616 m/s). Swimmers who used the "loping" variant achieved an average velocity of 1.7000 m/s in the 25 m.

Time (and velocity) was treated as the key parameter in assessing the various swimming techniques due to it being singled out as a statistical diagnostic measurement. The remaining parameters of cyclic propulsive movements (Fig. 6), lacking a diagnostic character, were classified as additional forms of measurement in the assessment of swimming technique [22]. The results in Figure 6 illustrate that the values of the parameters that characterize the “loping” variant are significantly different from those values calculated for the standard and “kayaking” techniques. The “loping” variant is distinguished in terms of having the longest stroke length and smallest stroke rate. Consequently, the “loping” variant featured the highest swimming efficiency coefficient (stroke index) (Fig. 6).

Discussion

The objective of this study was to identify the differences in the kinematic parameters when swimming the standard front crawl technique and its two variations, “kayaking” and “loping” styles. The statistically demonstrated differences created a basis for analyzing the impact of modifying the standard front crawl technique in terms of time (and velocity). In addition, the deliberate selection of the groups of swimmers who specialize in each of the swimming techniques, aimed at forming a homogenous sample population in terms of skill and their ability to generate efficient and effectiveness propulsion, also provided an objective basis for this study.

Analysis of the parameters which determine the efficiency and effectiveness (stroke length, stroke rate and swimming efficiency) of the various swimming techniques did not confirm the supremacy of the standard technique over the other variations and if time (and average velocity) are taken under consideration, then the gap separating the standard technique is even smaller. Therefore, there is evidence to support the advisability of modifying the use of the standard movement algorithm in the direction of more optimized swimming techniques by focusing it on swimming velocity.

A puzzling difference was revealed in the times (and swimming velocities) between the two swimming techniques that maintain equal time intervals during the recovery and propulsive phases of both arms (standard technique and “kayaking” variant) and the technique, which due to an extended pull phase, features time intervals that are irregular and can lead to asymmetric arm positions during the phases of the cycle (“loping”). As was shown, the “loping” variant was characterized by the highest rate of swimming efficiency, probably stemming from holding out the hand after finishing the recovery stroke phase (an extended pull). Feature of this coordination pattern can be of importance in terms of economizing the propulsion movements in distances longer than the one in this study (50 m). This aspect has been confirmed by swimmers using this variant in the 100 and 200 m freestyle [24]. However, in shorter distances, the results point to “kayaking” as the most effective front crawl technique. “Kayaking” is also the most preferred style by top swimmers competing in shorter sprints such as the 50 and 100 m freestyle [24]. These results gained additional significance when coupled with the fact that these studies used fair and standarized tests on swimmers of different skill levels who also regularly competed against one another in international competitions.

As such, this raises the need for recognizing the need of modifying the techniques of swimmers who are just beginning to choose their swimming specialization. The search for efficient and effective swimming should go beyond the use of standard techniques; it should consider viable alternatives, as in this case (freestyle swimming), the use of the “kayaking” and “loping” variants. The differences in time (and velocity) by the swimmers using their preferred custom swimming techniques were found to be far smaller than the differences recorded for those that used the standard technique.

These results, based on the different movement structure of the hands during the propulsion phases when using the “kayaking” and “loping” variants, suggest that the shape of the hand trajectory (as the path that generates propulsion) is not the only determining factor in effective and efficient swimming when measured by time or velocity. In such a context, the advisability of modifying standard front crawl swimming technique appears to stem more from overall motor coordination of the arms than their structure.

Such quality control techniques can assist coaches and athletes in identifying which coordination variation pattern is best suited to their strength level and the distance they have to swim. The use of such a strategy can optimize swimmers’ performance in a race by taking into consideration their swimming pace distribution over a distance as well as being able to individually select what strategy would work best in a given situation [15]. As was previously mentioned, stroke length and stroke rate were the most objective measurements that determine the best-suited swimming technique [17]. Their distinct relationship with swimming velocity allow for the interpretation of the results in categories that can describe the effectiveness of swimming by using arm coordination algorithms (reflected by the relationship between stroke length and stroke rate). Based on the assumption that swimming velocity is directly proportional to stroke length (l) and stroke rate (f) (equation #6), it is possible to predict changes in swimming velocity over a certain distance depending on the swimming strategy and the distribution of its parameters [25]:

$$v = l \times f. \qquad (\#6)$$

Assuming that the relationship between the movement stroke parameters (stroke length and stroke rate) are compensatory (an increase in one parameter lowers the value of the second, equation #7), swimming velocity can only be increased if only one of the parameters change while the second remains unchanged (equation #8), or when one of the parameters increases while the second decreases, but the increase is so large that it offsets the reduction of the second parameter (equation #9):

$$(l - \Delta l) \times (f + \Delta f), \quad (\#7)$$

$$v + \Delta v = (f + \Delta f) \times l, \quad (\#8)$$

where (l ~const)

$$v + \Delta v = (l - \Delta l) \times (f + \Delta f); [(l - \Delta l) \times (f + \Delta f) > l \times f]. \quad (\#9)$$

The situation described in equation #9 illustrates the results attained when swimming the "kayaking" variant, which features a short stroke length (l) and high stroke rate (f) (Fig. 6) with a tendency to shorten the stroke length with an increase in stroke rate. In the case of the "loping" variant, a long stroke length (l) and low stroke rate (f) is observed with a tendency to increase stroke length while remaining at a constant stroke rate (equation #10):

$$v + \Delta v = (l + \Delta l) \times f, \quad (10)$$

where (f~const).

These dependencies illustrate the fact that high swimming velocity can be the effect of using different strategies in terms of coordination (by using strategies of different stroke length and stroke rate), but, regardless of the used strategy, the basic criterions of maximum swimming speed is to minimize intra-cyclic veliocity fluctuations – as an objective measure of efficiency and effectiveness. It is well known that fulfilling this criterion is only possible with a high level of coordination ability combined with a perfect propulsion movement structure [15]. High frequency arm movements (stroke rate) and a fixed time sequence during the propulsion phase of the "kayaking" variant suggests that it generates less intra-cyclic velocity variation than the "loping" technique. However, the "loping" technique was found to have the highest stroke index (swimming efficiency coefficient) both in this study as well as in the work of other authors [22]. On this basis, it can be assumed that the "loping" variants longer stroke length combined with a relatively low stroke rate compensates for intra-cyclic velocity fluctuations generated during the propulsion phase. In accordance to the results, an adequate explanation can be that the propulsion phases, interspersed with the period of an extended pull, do not result in an increase of water resistance [16] and therefore do not undercut the validity of the "loping" technique as an alternative to the standard technique.

The results of this study do not allow us to accurately judge which of the analyzed front crawl techniques is the most effective and efficient. Such a generalization is still being discussed by other authors. Costilla et al. [16] indicated that the superposition model (a variation of the "loping" variant) is the most economical in terms of energy expenditure. However, Chatard et al. [2] emphasize the relatively low energy costs of the "kayaking" variant. Nonetheless, in light of such a context, a rational basis on the modification of the standard technique in order to use other swimming variations lays more in the predisposed individual abilities of swimmers in terms of their coordination and physical abilities and their ability to adapt to new motor skills.

It is not the intention of this study's authors to relegate the use of the standard technique as a method at achieving success in sprint freestyle competition. Although it may seem inconsequential to be uncritical of the standard technique in the early stages of a swimmers' specialization, the role it plays once perfectly mastered in the preliminary stage of swimmers' technical training is undisputed. The acquisition of skills by novice swimmers that are consistent with the universally accepted standard technique, which was formed on the basis of swimmers' practical experience and existing knowledge, is both natural and necessary. However, improvement in technique, understood as expanding one's motor experience, should adjust towards the use of the standard technique in terms of the individual preferences of a swimmer (such as their somatic characteristics, style preferences, physical fitness level, etc.) in such a way as the allow a swimmer to take advantage of their full (unrestricted by standard principles) potential.

The implicational and cohesive character of this study goes along with the evolution of swimming technique as one that takes into consideration the "feel of the water", which is the specific sensitivity of a swimmer as an adaptive process built on gained experience. It is based on controlling and differentiating the "sensitivity" one feels from various receptors to sense motion in water [26]. In the generally standard technique, the "feel of the water" helps construct an image of movement, which itself determines the creation of a movement pattern program and whether it is correct when swimming in real-time conditions [8]. With individual techniques, as motor adaption developed by repeated stimuli, a swimmer becomes sensitive to motion and therefore increases his/her multi-sensory experience. This allows a swimmer to improve their motor skills in very complicated coordination sequences [27]. The collection of these types of experiences allow an individual to develop more precise movement control and, consequently, improve athletic progression [28], as well as in swimming [29, 30].

Inter-individual variability in one's kinesthetic differentiation levels and the speed at which one learns motor skills has been found to depend on individual predisposition [29, 30]. Therefore, the individualized technical training of young swimmers seems to be crucial in order to fulfill the idea of evolving one's technique, which is emphasized in this study. Hence, the need to accept the postulate of initiating a search for optimal variations of front crawl technique is the awareness that only through shaping a swimmer's standard technique based on stabilization of "kinesthetic differention level" [30], can justify the decision of using more advanced variant by towards modifying the structure and coordination of propulsive movements.

The original nature of the issues taken under consideration in this study do point to the fact that the results and their interpretations are not entirely exhaustive in terms of the complexity of the issues analyzed herein. However, it is hoped that the reliability of the scientific interpretation used in this study can contribute for further discussion and deeper exploration of this subject.

Conclusion

An objective interpretation of the differences between the kinematic parameters of front crawl swimming indicate that the standard technique was less effective and efficient than its "kayaking" and "loping" variants. At the same time, it was recognized that using the "kayaking" variant is an optimal technique in increasing effectiveness and may contribute to an increase in swimming velocity. However, the highly efficient nature of the "loping" variant makes it the optimal technique if energy-economical swimming is concerned.

Thus, the advisability of modifying the standard movement technique used in front crawl swimming towards its more optimal, in terms of efficiency and effectiveness, variants is applicable. The results that support such a statement were obtained in trials by swimmers who specialize in the techniques taken under consideration. The groups were all homogenous in nature in terms of their the body composition and their ability to generate similar levels of effective and efficient propulsion, with the swimmers differing only in terms of age and the length of their career as a swimmer.

Taking these facts into consideration when interpreting the results of this study, there is credence to the use of the front crawl "kayaking" and "loping" variations in the technical training of swimmers who are at the beginning of choosing their swimming specialization, as long as any changes in a swimmer's propulsive movement structure and coordination take place after fully mastering the standard technique. Modifications to a swimmer's standard technique seem to be even more reasonable when their arm coordination pattern in taken under consideration than as a change to their movement structure. The results do not offer a clear decision on which front crawl swimming techniques are more effective and efficient, but the study does point to the need for individualized technique training in order to fully exploit a swimmer's coordination and fitness abilities.

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Paper received by the Editors: November 15, 2011
Paper accepted for publication: March 21, 2012

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