

Integral indicators of the swimming techniques effectiveness of highly qualified crawl-stroke swimmers

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Abstract

Purpose:

It is known that prominent world-class swimmers are characterized by the manifestation of specific abilities. These abilities allow to constantly maintain a stable speed swimming of different segments of the distance. In this case, highly qualified swimmers can increase the maximum speed of swimming on a segment of a given length. They achieve this by increasing the total external mechanical power. In this case, swimmers keep, and in some cases even reduce the power of the stroke. It is implemented the phase-specific principle of creating driving forces during each phase. At the same time, the principle of creating driving forces is common to all swimming locomotion. The article gives a rationale for the effectiveness of the integral criterion application for evaluating swimming techniques. The integral criterion for evaluating the swimming technique was applied at remote speeds of the entire spectrum of the competitive front crawl swimming program.

Material:

The study involved 9 highly qualified crawl-stroke swimmers, members of Russia national team. The age of the participants ranged from 18 to 24 years. It is studied the kinematic and kinetic characteristics of the front crawl swimming technique of highly qualified athletes at various competitive distances. The studies applied video recording of swimmer's movements with OLYMPUS TG-5 camera (Vietnam) from a depth of 4.5 m. Three luminous markers located on the swimmer's hips were applied to record the dynamic parameters of swimmer's movements. The results of the swims were processed with Natatometry™ (Russia).

Results:

It was determined that swimmers demonstrated high indices of the intra-cyclic dynamic index (ICDI – Intra Cycle Dynamic Index) and the dynamic coordination index of the swimming cycle (DCI – Dynamic Coordination Index) at speeds in medium distances relative to speeds at sprint distances. Swimmers demonstrate the ability to generate a significant amount of promotional efforts at 100 m distance that ensure the achievement of high speeds. It is established that no general trends in ICDI changes in individual structural phases of the stroke. This indicates the demonstration of individual specific features in the swimming technique of each athlete.

Conclusions:

It is considered the feasibility of applying the integral indicators ICDI and DCI for a quantitative assessment of the intra cycle promotion forces interaction and hydrodynamic resistance forces arising at the level of an integral biomechanical system of the swimming cycle.

Keywords:

swimmers, high qualification, front crawl, performance indices, swimming technique.

Introduction

The modern crawl swimming competition program is very diverse. Swimmers cover a distance in a wide range of speeds. The change in speed applies different requirements to the athlete's body. These requirements should be specific to power supply mechanisms. Should affect the biomechanical characteristics of swimming technique [1].

For highly qualified world-class swimmers, the manifestation of specific abilities is characteristic only for a specific individual. [2]. Such abilities allow you to constantly maintain a stable swimming speed on the different segments of the distance [3]. In this case, highly qualified swimmers can increase the maximum speed of swimming on a segment of a given length. This is due to the increase in total external mechanical power [4]. Power of the stroke, in this case, may be maintained or even reduced. This phenomenon indicates the so-called hidden

possibilities of the individual [1]. These features can be realized in reaching the maximum swimming speed (CDP-phenomenon). The active hydrodynamic resistance of the swimmer is reduced in order to do that [5].

The basis of the propulsion mechanism of the stroke in swimming was determined in another study [6]. The basis is the strength of the hand cross. It includes the cumulative effect of hydrodynamic lifting force and frontal resistance (in the middle phases); hydrodynamic lifting force (at the end of the stroke). Hydrodynamic resistance increases due to the working movements of the athlete. The value of this increase in rowing is from 15 to 22%, and in swimming – up to 100% [7]. This characterizes the manifestation of individual technical skill.

This position has been confirmed in other studies [8, 9]. It stipulates further scientific research. The search should be aimed at developing an integral criterion for evaluating the effectiveness of swimming techniques. Such efficiency is determined at the remote speeds of the competitive front crawl swimming program. The

importance of solving this problem is manifested in evaluating the effectiveness of training exercises. The developed criteria allow to receive urgent information about the effectiveness of swimming techniques; make corrections to the training process.

In modern swimming, there is intense competition in every type of program. As a result, all-round swimmers appear. Such athletes show high results in the sprint and long distance. This is especially characteristic of the style "front crawl".

Studies of Kravcov [4] deal mainly with the kinematic characteristics of the swimming technique. Studies show that at submaximal speeds, highly qualified athletes achieve increased speed by unifying the technique's quality. Unification does not imply an increase in the power stroke and an increase in energy consumption [10]. Improvement of technology occurs due to the optimization of the tempo-rhythm structure of the stroke.

Therefore, it is necessary to supplement the kinematic analysis of the swimming cycle with experimental dynamic characteristics [11, 12, 13].

Hypothesis. The emergence of CDP-phenomenon is stipulated by the ability of athletes to select the biomechanical characteristics of the technique in accordance with the objectives for a particular competitive distance.

The purpose of the study is to analyze the abilities of "all-around crawl swimmers" to select the biomechanical characteristics of the technique in accordance with the objectives of a particular competitive distance.

Material and methods

Participants. The study involved highly qualified crawl swimmers ($n = 9$), members of Russia national Team. The age of athletes ranged from 18 to 24 years. The height of athletes ranged from 180 cm (5'11 ") to

191 cm (6'3"), weight - from 73 kg (160 pounds) to 82 kg (181 pounds). All athletes were informed of the purpose, objectives of the experiment and research procedures.

Design of the study.

Studies were conducted in a 25-meter indoor swimming pool of the Lesgaft National State University of Physical Education, Sport and Health.

All participants in the experiment were offered to crawl three 25 m distances. The distance competitive speed of each athlete is the same as in swimming 100, 200 and 1500 m. Each athlete performed the exercises individually with the choice of speed rate that is applied at rating competitions.

The studies applied video recording of swimmer's movements with OLYMPUS TG-5 camera (Vietnam) from a depth of 4.5 m. (Fig. 1). Three luminous markers located on the swimmer's hips were applied to record the dynamic parameters of swimmer's movements.

The following tasks were solved In the process of special research:

1. Development of an experimental method for determining the basic dynamic characteristics of front crawl swimming. It was studied the swimming cycle in athletes with various speed swimming techniques.

2. The study of swimming speed changes patterns and the dynamic structure of the swimming cycle.

For processing the results of the swims, the Natatometry™ program developed by us was applied [14]. The following kinematic and dynamic characteristics of swimming technique were obtained:

1. The average speed in the swimming cycle – v .
2. The distance covered by a swimmer in one swimming cycle – d .
3. Time of one swimming cycle – t .
4. The absolute amount of swimmer accelerations in a cycle – a .

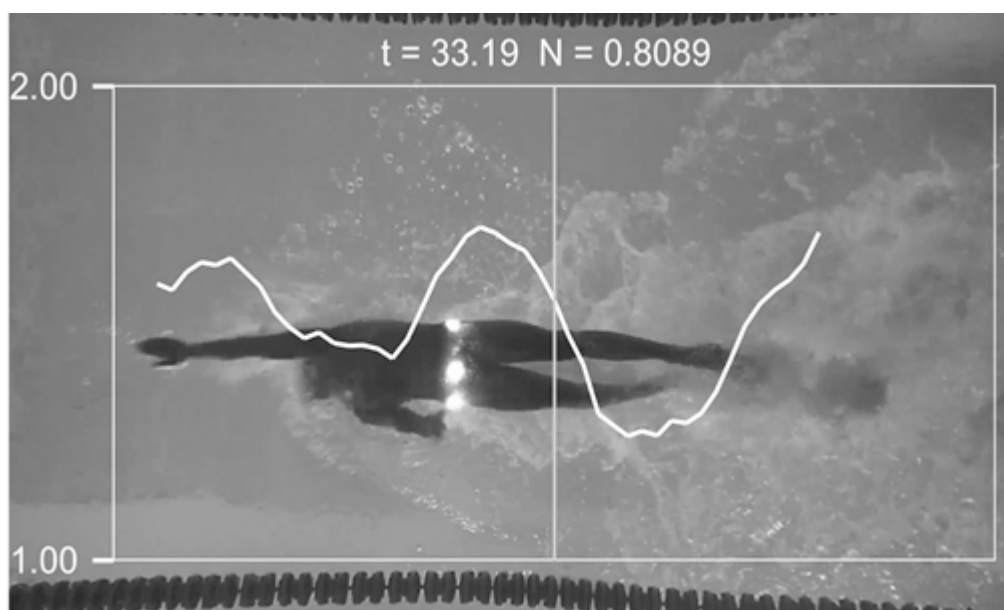


Fig. 1. An example of a shot of an underwater video recording with an overlaid graph of intra cycle speed. The ordinate axis is time, the abscissa is instantaneous speed (m/s). The vertical line in the center of the graph indicates the point on the graph that corresponds to this shot.

These parameters were also calculated for each dynamic phase of the stroke: the propulsive phase, the phase of slowdown and the phase of active slowdown [7].

In crawl, swimming athlete performs hand strokes in turn. Calculations were carried out for each hand separately.

To solve the research problems, the following integral indicators were calculated:

Intra Cycle Dynamic Index (ICDI):

$$ICDI = \frac{DV_{avg}}{|a|} \times 1000$$

D – the length of the swimming cycle (m);
 Vavg – average speed in the cycle (m/s);
 |a| – the sum of absolute values in the cycle.

2. The sum of the intra cycle dynamic indices (Σ) of each dynamic phase of the swimming cycle. For a crawl – 6 phases, 3 phases with the right hand, 3 phases with the left hand:

$$\Sigma = \Sigma(r) + (l),$$

where,

$\Sigma(r)$ – sum of right hand dynamic phases ICDI;

$\Sigma(l)$ – sum of left hand dynamic phases ICDI.

1. Dynamic Coordination Index of the swimming cycle (DCI – Dynamic Coordination Index).

Dynamic Coordination Index (DCI):

$$DCI = \frac{ICDI}{\Sigma}$$

The measurement results are presented in table 1.

For the convenience of data analysis, Vavg speeds were divided into three ranges;

1) Average (1.4 ÷ 1.6 m/s) – speeds at a distance of 1500 m crawl;

2) Submaximal (1.7 ÷ 1.8 m/s) – speeds at a distance of 200 m crawl;

3) High (1.9 m/s and above) – speeds at a distance of 100 m crawl.

The results of the swims were processed by Natatometry™ program [14]. The kinematic and dynamic characteristics of the swimming technique were calculated by Natatometry™ program.

The following integral indices were calculated:

1. Intra Cycle Dynamic Index (Intra Cycle Dynamic Index – ICDI);

2. The sum of the intra cycle dynamic indices (Σ) of each dynamic phase of the swimming cycle. For a crawl – 6 phases, 3 phases with the right hand, 3 phases with the left hand;

3. Dynamic Coordination Index of the Swimming Cycle (DCI – Dynamic Coordination Index) Dynamic Coordination Index (DCI).

Statistical analysis.

The intra cycle dynamic index, the sum of the intra cycle dynamic indices (the sum of right and left hands) and the dynamic coordination index of the swimming

cycle were obtained during the study. These characteristics were calculated using the SPSS.20 program.

The results of the swims were processed by Natatometry™ (program Russia).

It was conducted correlation analysis of the swimming speed and the intra cycle dynamic index, the swimming speed and the dynamic coordination index for a more in-depth study.

Results

Integral indicators should be developed based on the interrelated biomechanical and hydrodynamic characteristics of the swimming cycle. Therefore, the position was formulated in the course of applying new research methods with modern technology and computer technique. Such equipment can operate in the aquatic environment.

The correlation diagram of the average swimming speed Vavg and the Intra Cycle Dynamic Index (ICDI) is presented in Figure 2. The correlation diagram of Vavg and Dynamic Coordination Index (DCI) is presented in Figure 3.

The average speed in the swimming cycle (Vavg) ranged from 1.3 to 2, 1 m/s.

For the convenience of data analysis, we have divided Vavg speeds into three ranges:

1) Average (1.4 ÷ 1.6 m / s) – speeds at a 1500 m distance crawl;

2) Submaximal (1.7 ÷ 1.8 m / s) – speeds at a 200 m distance;

3) High (1.9 m / s and above) – speeds at 100 m distance crawl.

It was performed the analysis of the diagram. All selected athletes showed high ICDI and DCI indices at medium distances' speeds, relative to sprint distances' speeds.

This demonstrates the ability of all-around swimmers to reduce significantly the energy expenditure at the stayer distances.

At the same time, they demonstrate the ability to generate a significant amount of promotional effort. These efforts allow you to reach high speeds at a 100 m distance.

It should be noted that in the course of research we did not establish general trends in ICDI changes in individual structural phases of the stroke. This indicates the manifestation of individual specific features in the swimming technique of each athlete.

Some swimmers achieve a speed increase by increasing the power of the stroke or the correct distribution of physical effort during the second phase (propulsion). Other swimmers achieve the same results by reducing the forces of hydrodynamic resistance in the 1st slip phase and the 3rd phase of active resistance.

All athletes were characterized by very high indices of integral coefficients when swimming at submaximal speeds corresponding to 200 m distances (1.7 ÷ 1.8 m/s).

Swimming at such speeds requires the maximum mobilization of anaerobic glycolytic abilities and is accompanied by heavy feelings of fatigue.

Table 1. Integral characteristics of the swimming cycle of crawl-stroke swimmers participated in the research

№	Swim	left hand phase ICDI				right hand phase ICDI				Σ	ICDI	DCI (%)
		Iph	IIph	IIIph	Σl	Iph	IIph	IIIph	Σr			
1	pp_100	40.3	87.1	131.1	258.5	36.6	99.3	55.7	191.6	450.1	210.1	0.46
2	pp_200	24.3	67.4	83.4	175.1	60.4	132.2	30.8	223.4	398.5	311.3	0.78
3	pp_1500	45.7	99.3	59	204	40.3	118.5	21.4	180.2	384.2	250.4	0.65
4	kl_100	24	133.4	59.5	216.9	65.8	78.8	43.5	188.1	405	191.3	0.47
5	kl_200	82.4	59	40.1	181.5	75.4	195.1	0	270.5	452	367.1	0.81
6	kl_1500	46.1	60.9	82.3	189.3	58.5	89.9	95.1	243.5	432.8	241.9	0.6
7	sv_100	60.4	120.2	70.2	250.8	57.7	59.3	33.4	150.4	401.2	212.9	0.47
8	sv_200	58.8	123.5	35.4	217.7	62.4	204.2	0	266.6	484.3	401.8	0.82
9	sv_1500	45.2	45.5	40.9	131.6	80	120.4	90.5	290.9	422.5	321.5	0.76
10	iv_100	38.9	88.7	29	156.6	31.8	67.1	10.8	109.7	266.3	177.3	0.66
11	iv_200	79.9	67.7	68.2	215.8	77.1	203.2	0	280.3	496.1	398.8	0.80
12	iv_1500	85.9	88.3	91.4	265.6	54.1	86.4	26.1	166.6	432.2	300.9	0.69
13	pr_100	55.4	10.5	28.4	94.3	54.6	90.8	35.4	180.8	275.1	159.4	0.57
14	pr_200	81.2	110.2	40.4	231.8	60.1	112.2	29.4	201.7	433.5	321.7	0.74
15	pr_1500	50.8	51.2	28.4	130.4	39.1	135	46.2	220.3	350.7	209.6	0.59
16	sp_100	61.4	87.1	38.3	186.8	28.7	70.4	12.2	111.3	298.1	130.8	0.43
17	sp_200	106.2	73.4	100.2	279.8	45.8	109.9	66.5	222.2	502	420.2	0.83
18	sp_1500	57.8	65.1	63.2	186.1	61.7	89.3	50.4	201.4	387.5	288.1	0.74
19	ba_100	19.4	40.7	88.6	148.7	35.2	58.4	18.7	112.3	261	157.7	0.60
20	ba_200	77.5	95.4	61.3	234.2	52.2	81.4	20.9	154.5	388.7	304.3	0.78
21	ba_1500	53.9	55.6	45.9	155.4	45.3	71.7	33.1	150.1	305.5	206.6	0.67
22	ka_100	30.4	60.4	11.2	102	27.1	60.9	10.1	98.1	200.1	109.3	0.54
23	ka_200	56.1	88.4	78.3	222.8	73.2	110.1	14.8	198.1	420.9	350.9	0.83
24	ka_1500	82.1	68.3	28.2	178.6	49.9	68.1	10.3	128.3	306.9	228.3	0.74
25	db_100	40.3	33.2	22.4	95.9	35.1	54.2	12	101.3	197.2	100.8	0.51
26	db_200	98.7	51.1	33.2	183	36.3	125	64.8	226.1	409.1	360.1	0.88
27	db_1500	28.7	60.2	10.9	99.8	76	80.6	31.9	188.5	288.3	177.4	0.61

Note: pp_100 – certain athlete swimming a 100 m distance; left hand phase ICDI – intra cycle dynamic index in the left hand’s stroke phases; right hand phase ICDI – intra cycle dynamic index in the right hand’s stroke phases; Iph, IIph, IIIph – 1, 2, 3 stroke’s phases; Σl, Σr – the sum of the indices in the stroke’s phases of the right and left hands; Σ – the sum of the indices of the right and left hands; ICDI – intra cycle dynamic index; DCI – dynamic coordination index.

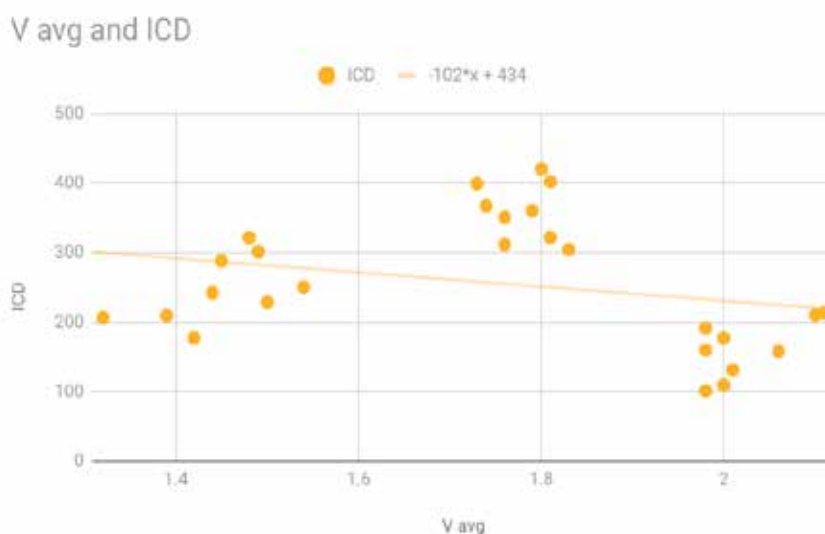


Fig. 2. Correlation diagram of Vavg (average swimming speed) and ICDI (intra cycle dynamic index).

Table 2. Correlation analysis of the integral characteristics of the swim cycle of crawl-stroke swimmers

	Vavg	ICDI	DCI
Vavg	1	-0,3616	-0,4623
ICDI	-0,3616	1	0,85808
DCI	-0,4623	0,85808	1

Note: Vavg – the average speed in the cycle; ICDI – intra cycle dynamic index; DCI – dynamic coordination index.

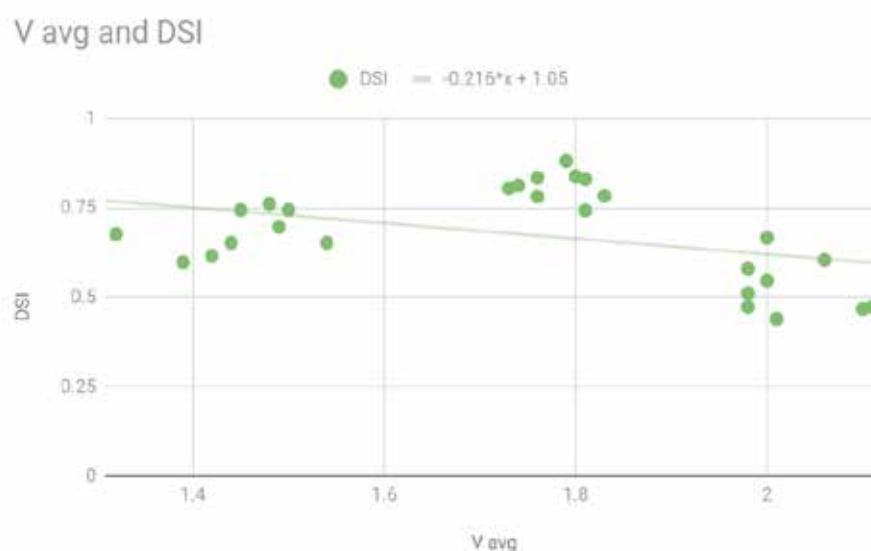


Fig. 3. Vavg and DCI Correlation diagram.

To achieve high levels of endurance, swimmers must have a very flexible, variable technique. This technique allows to achieve a specified level of swimming speed. At the same time, there are significant correlations in the dynamic and spatial-temporal characteristics of the motor actions.

It was determined that highly qualified swimmers achieve an increase in speed by increasing the power of the propulsive efforts while simultaneously reducing the forces of hydrodynamic resistance.

So, for three swimmers in swims No. 5, No. 8 and No. 11, the active braking phase is practically absent, that is, the propulsive phase continues until the end of the stroke.

Discussion

Issurin [6] conducted a metrological analysis of the swimmer motor actions' kinematics. This approach was applied in developing the method of recording and analyzing the intra cycle speed. It is based on computer processing of swimmer promotion parameters. It was performed with an underwater video camera. The widespread use of photographic registration in sports research determines the number of advantages of applying this method. The advantages of this method include: the autonomy of the object of study; the possibility of conducting research at some distance from the object; the possibility of simultaneous analysis of the kinematic parameters and the relative position of the segments of

the athlete's body; selection of kinematic characteristics along the coordinate axes [14].

In our studies, the video registration of the swimming technique allows to determine the kinematic characteristics of the swimmer's motor actions in each specific shot of the video. It gives the opportunity to assess the effectiveness of changes or correlations in the swimming intra cycle speed. The developed technique greatly expands the possibilities of photo registration and film cyclography. The technique allows to assess the effectiveness of the implementation of training exercises [9. 14]. The developed criteria provide an opportunity to receive urgent information about the effectiveness of swimming techniques and, accordingly, to make corrections into the training process [7].

Our study of the swimmer's translational motion kinematics provides an opportunity to analyze the main sources of error [11]. It also makes it possible to formulate general requirements for the implementation of training exercises and for the technique of a particular athlete.

It was defined that the kinematic phase structure of the stroke in swimming can only be considered in the complex with its dynamic characteristics. This allows to improve significantly the efficiency of swimming techniques in general.

Other studies argued [1, 3, 15-18] the need to determine the swimmer's speed as a constant value. Although it is not so. The magnitude of the speed

correlations greatly affects the efficiency of swimming techniques. Any random speed deviation during a single swimming cycle is a recognized fact [19]. Therefore, it is necessary to determine the indicators of propulsive efficiency, considering the non-stationary translational motion of the swimmer's body in the water. This allows you to make a video of the swimmers' motor actions by camera "OLYMPUS TG-5" (Vietnam) from a depth of 4.5 m. You must use the three luminous markers located on the swimmer's hips.

The study allowed: to expand the capabilities of the swimming techniques analysis; consider different swimming speed and power. The developed intra cyclic dynamic index (ICDI) and dynamic coordination index (DCI) have shown their effectiveness in assessing the kinematic characteristics of swimming techniques. The presented indices allowed to analyze the common factors of changes in the swimming speed and the dynamic structure of the swimming cycle. The study also allowed to identify the third dynamic phase of the stroke in the front crawl, as a phase of active slowdown. In this phase of the stroke, the speed of the rowing hand rises, and the

intra cycle speed begins to decrease. These studies were not conducted in the studied literature.

Conclusions

Integral indicators of the effectiveness' evaluation of swimming technique (ICDI – intra cycle dynamic index; DCI – dynamic coordination index of the swimming cycle) allows to quantify the interaction of intra cycle propulsive forces and hydrodynamic resistance forces. They arise at the level of a complete biomechanical system of the swimming cycle. These data confirm the results of our experimental studies.

The use of these indices makes it possible to compare the dynamic characteristics with key kinematic (intra cycle indicators of speed and acceleration) at competitive and training speeds. This will help improve the quality of technical training for highly qualified swimmers.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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