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Original Article

Optimization of the process of technical fitness management of highly skilled swimmers

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Abstract
Purpose: to study the motion coordination structure of highly skilled swimmers during front crawl swimming. **Material & Methods:** 82 highly skilled swimmers (Master of sports) were examined. An original complex instrumental technique was used to obtain objective data. It included tensodynamography, electrogoniography, speedography, and photocyclography**. Results:** Objective and rather complete information about the spatial, temporal, spatiotemporal, and dynamic structure of swimmers' motions was obtained. Structural analysis of the athletes' motions during front crawl swimming was made. The cycle of motions was proposed to subdivide into periods I and III (*working*) and periods II and IV (*working and preparatory*). Working periods of the cycle are characterized by the presence of double hand support. In period I, the right hand performs support on the water, whereas the left hand performs an accentuated push-off. In period III, the left hand performs support and the right hand performs a push-off. A characteristic feature of the working and preparatory periods: while one hand performs a stroke (working motion), the other hand performs an overarm stroke (preparatory movement). In the cycle of motions, phases for the arms and legs are distinguished, which interact in a certain way in the periods of the cycle. It is determined that the ratio of periods in a cycle of motions constitutes 20%:30%:20%:30% or 1.0:1.5:1.0:1.5. The intra-cycle speed values are in the ratio 2.0:1.5:2.0:1.5. The hand support reactions during push-off and pulling are in the ratio 3:1. At the moment one hand enters the water, the other hand is at its maximum flexed position while performing a stroke. The moment the hand comes out of the water, the other hand assumes a "high elbow" position and is ready to start pulling. The athlete assumes the described positions (postures) twice per motion cycle. **Conclusions:** The model of motor action structure and the technique of designing individual models should be used in the period of swimming technique formation and in the process of improving the technical skills of swimmers. The universality of the technique consists in the fact that the rational structure contains a qualitative model (easily controlled by the athlete himself and managed by simple technical means), characterized by relative values, and a quantitative one - characterized by absolute values. The management process, in this case, is realized by systematic changing the absolute values of the motor action structure model with account for the athlete's individual data, but without alternating its relative values.
Keywords: highly skilled swimmers, technique, training management, swimmer's model.

Introduction

The task of managing the technical fitness of a swimmer reduces to the formation of his/her movement coordination structure. Coordination of movements provides efficient use of the athlete's functional potential to achieve the highest results at a competitive distance (Alptekin, 2014; Top et al., 2015).

Technical mastery improvement is associated with the receipt and use of two types of information - basic and additional. Basic information comes from the locomotor apparatus (receptors located in muscles, tendons, ligaments) and reflects changes in muscle length, degree of tension, direction, speed of movement, location of different body links, etc. It includes data on the structure of movements and the body interaction with the external environment (originated from the organs of vision and hearing, the vestibular analyzer, skin receptors). Additional information is addressed to the athlete's consciousness. It helps an athlete to form an estimate of the executed motions, errors that occur, the discrepancy between the actual state and the given one, and the performance of motor actions on the whole (Aspenes et al., 2009; Nasirzade et al., 2014).

In the process of managing the improvement of technical skills, only those motor actions are selected and reinforced that lead to a given result. These movements are reinforced and form solid skills because they are constantly repeated. Other movements are not reinforced due to their being inefficient (according to the generalized analysis of basic and additional information).

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The general mechanism of the process of managing the formation of a conditioned motor reflex was developed by P.K. Anokhin (1975). It is based on cyclicity that envisages the termination of each motor act by reafference, which signals the results of the action. The effect of cyclic management is based on two groups of afferent stimuli: circumstantial (pre-integrating) and starting afferentation, as well as memory. All three elements are united by afferentation synthesis, which is subordinated to the motivation that dominates at a specific moment. Afferentation synthesis leads to such selection of possible degrees of freedom in which excitations are selectively directed to the muscles performing the desired actions. No reflex actions occur in the effector apparatus until the synthesis of all afferent impacts on the body has been completed. This is followed by decision making, which is based on selecting and determining the degree of the component activity (which should ensure the motor action execution). P.K. Anokhin (1980) established that a special afferent apparatus is created in the effector part of the nervous system - an acceptor of action results. Formed on the basis of fine nerve mechanisms, this apparatus allows forecasting the signs of the necessary result at a given moment. In addition, it compares them with parameters of the real result, information about which comes to the acceptor of action results (due to reafference). This specific apparatus enables the body to correct the error of action or bring the imperfect motor acts to the perfect ones. Various “searches” and compensations may lead to optimal results through this kind of reafference evaluation. The circulatory development of these excitations during “recognition” and “search” may be so fast that each block of function consisting of components can develop within fractions of a second:
result→reafference→comparison and evaluation of the results in the acceptor of the action results→correction→new result.

The action acceptor (emphasized by Anokhin, 1980) is a permanent management factor, which establishes the correspondence of the performed action to the initial intention. It perceives afferent stimuli, compares the data of afferentation synthesis with the executed action. If the goal is achieved, the cycle is complete. If the goal is not achieved, a complex of new reactions is induced. These reactions should result in the motor action correspondence to its model in the action acceptor.

The realization of the mentioned theoretical provisions of motion management during the process of technical training of skilled swimmers should be based on the presence of specific knowledge about the main components of the motion rational structure and optimal models of sports technique.

Hypothesis - sports technique modeling will allow optimizing the process of management of swimmers’ technical training.

The objective of the study was to examine **the motion coordination structure of highly skilled swimmers during front crawl swimming**.

Material & Methods

Participants. 82 highly skilled swimmers (Master of sports) were examined.

Organization of study. An original complex instrumental technique was used to obtain objective data (Kolumbet et al., 2017-2019). It included tensodynamography, electrogoniography, speedography, and photocyclography**.**

Statistical analysis. Appropriate methods of mathematical statistics were used for factual material processing. Correlation analysis was applied to establish interrelations of the outlined elements of swimmers' motor action structure, as a result of which the dependence of the average swimming speed on the value of some kinematic and dynamic characteristics was revealed. Regression analysis was used to identify the minimum number of characteristics describing with a sufficient degree of accuracy the main parameters of motion technique, influencing sports results. The most significant parameters of technical skills were determined by the method of random balance (method of supersaturated plans), allowing to obtain an optimal mathematical model as a result of screening procedures (Monogarov & Bratkovsky, 1979).

While conducting complex pedagogical, biomechanical, and biological surveys with the participation of athletes, the legislation of Ukraine on health care, the 2000 Helsinki Declaration, Directive No. 86/609 of the European Society regarding people's participation in biomedical research were adhered to.

Results

Objective and sufficiently complete information about the spatial, temporal, spatiotemporal, and dynamic structure of swimmers’ motions was obtained (Table 1).

Structural analysis of the athletes’ motions during front crawl swimming was made. The cycle of motions was proposed to subdivide into periods I and III (*working*) and periods II and IV (*working and preparatory*). Working periods of the cycle are characterized by the presence of double hand support. In period I, the right hand performs support on the water, whereas the left hand performs an accentuated push-off. In period III, the left hand performs support and the right hand performs a push-off. A characteristic feature of the working and preparatory periods: while one hand performs a stroke (working motion), the other hand performs an overarm stroke (preparatory movement).

Table 1. Parameters for studying the coordination structure of swimmers' movements

	Coordination structure aspects	№	Parameters
1	Spatial	1	"Step" of motion cycle, cm
		2	Maximum flexion in elbow joint during stroke, degrees
		3	Maximum flexion in elbow joint during propulsion, degrees
		4	Elbow joint angle of the right arm at the boundary moment of the change of periods I and II (when the left hand leaves the water), degrees
		5	Elbow joint angle of the right arm at the boundary moment of the change of periods II and III (when the left hand enters the water), degrees
		6	Elbow joint angle of the right arm at the moment of its entering the water, degrees
		7	Elbow joint angle of the right arm at the moment of its leaving the water, degrees
2	Temporal	1	I period duration, s
		2	II period duration, s
		3	III period duration, s
		4	IV period duration, s
		5	Stroke duration, s
		6	Stroke first half duration, s
		7	Stroke second half duration, s
		8	Stroke density, s
		9	Support phase duration, s
		10	Pulling phase duration, s
		11	Push-off phase duration, s
		12	Stroke motion rate, cycles.min.$^{-1}$
3	Spatiotemporal	1	Average speed in a cycle, cm.s^{-1}
		2	Average speed in I period, cm.s^{-1}
		3	Average speed in II period, cm.s^{-1}
		4	Average speed in III period, cm.s^{-1}
		5	Average speed in IV period, cm.s^{-1}
		6	Speed variation in a cycle, cm.s^{-1}
4	Dynamic	1	The maximum value of hand support reaction at the first half of a stroke (during pulling), c.u.
		2	The maximum value of hand support reaction at the second half of a stroke (during push-off), c.u..
		3	The maximum value of hand support reaction in a cycle c.u.
		4	The maximum value of foot support reaction during kick c.u.

In the cycle of motions, phases for the arms and legs are distinguished, which interact in a certain way in the periods of the cycle (Fig.1).

This interaction results in the intra-cycle speed fluctuations, which depend on the value of other parameters registered during the change of periods and phases (Tables 2 and 3).

Table 2. Indices of swimming technique at the boundary moments of changing periods in a cycle

№	Arm	Elbow joint angle at the beginning of period, degrees X±σ	Elbow joint angle at the end of period, degrees X±σ	Duration, s **X±σ**	**in % to Δt of a cycle**	Speed, cm/s X±σ
1	Right	158±13.6	161±10.1	0.22±0.04	20	199±18.8
	Left	108±10.4	148±14.0			
2	Right	161±10.1	108±10.4	0.31±0.03	30	148±12.0
	Left	148±14.0	158±13.6			
3	Right	108±10.4	148±14.0	0.22±0.05	20	195±17.1
	Left	158±13.6	161±10.1			
4	Right	148±14.0	158±13.6	0.31±0.03	30	144±12.3
	Left	161±10.1	108±10.4			

Arm	*Periods and phases*			
	I period	*II period*	*III period*	*IV period*
Right	*1. Support* *2.Pulling*	*2.Pulling* *3.Transition from pulling to push-off*	*4.Push-off*	*5. Propulsion*
Left	*4.Push-off*	*5. Propulsion*	*1. Support* *2. Pulling*	*2.Pulling* *3. Transition from pulling to push-off*

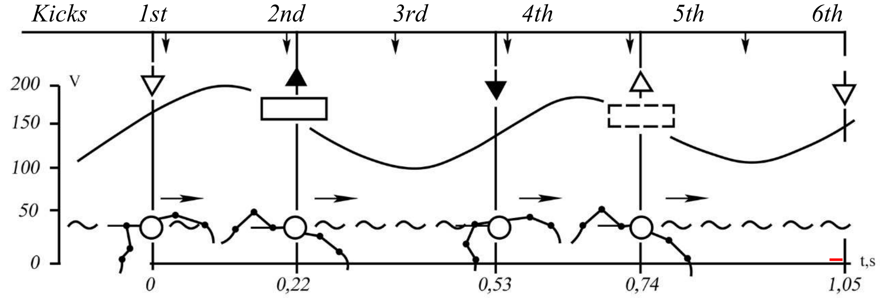

Fig. 1. Scheme of phase interaction in the periods of motion cycle. Postures assumed by the athlete at the moments of changing cycle periods and the dynamics of intra-cycle speed fluctuations. Legend:

▽△ right hand entering and leaving the water;	▭ inhale under left hand;
▼▲- left hand entering and leaving the water;	⬚ inhale under right hand;

Positive correlations of maximum values of intra-cycle speed in periods I and III (r=0.663 and r=0.515, respectively) and minimum values - in periods II and IV (r=0.436 and r=0.455, respectively) with average swimming speed were revealed. This indicates that intra-cycle speed increase in all four periods of the cycle leads to an increase in the average speed. Its increase will occur also at the expense of enhanced hand support reactions at pushing off the water (r=0.567), as well as at the cost of an increased rate of stroke movements (r=0.556). This is accompanied by an increased variation of intra-cycle speed (r=0.322).

Table 3. Indices of swimming technique at the boundary moments of changing phases in a cycle

№	Phases	Elbow joint angle, degrees X±σ	Duration, s **X±σ**	**in % to Δt of a cycle**	Value of hand support reactions, c.u. X±σ
1	Support	158±13.6	0.18±0.08	17.1	4.5±2.2
2	Pulling	161±10.1	0.15±0.08	14.2	9.5±2.5
3	Transition from pulling to push-off	135±12.7	0.18±0.06	17.1	1.9±1.8
4	Push-off	102±8.3	0.23±0.04	22.1	27.5±4.9
5	Overarm stroke	110±16.2	0.31±0.03	29.5	-

More complex associations are observed between the rate of stroke movements and intra-cycle speed values. The rate is in a positive relationship with maximum values of intra-cycle speed (r=0.690 and r=0.743) and in a negative with minimum ones (r=-0.407 and r=-0.426). This is due to the fact that with the increase in the rate of stroke movements, the maximum values of intra-cycle speed tend to increase faster than the minimum ones. Because of this, the variation of intra-cycle speed increases.

Significant speed variations in the cycle of movements reduce the economy of the technique. This becomes obvious when comparing the crawl with other swimming styles (breaststroke, butterfly). The difficulty in managing intra-cycle speed fluctuations should be noted. Management can be performed indirectly through changes in values of other parameters. The following regression equation was obtained:

$$\mathbf{V_{CD}=150.5+0.102X_1+7.2X_2+18X_3+0.008X_4-0.46X_5+0.01X_6-0.08X_7+0.03X_8,}$$

where: $\mathbf{X_n}$ – values are shown in Table 4.

It does not reflect the general picture of various factor influences. With its help, it is possible to calculate the expected sports result with an error of 10% according to the given values of the parameters included in it. Average statistical values of parameters, which were included in the regression equation, may serve as a guide mark in the capacity of model characteristics when achieving an average swimming speed up to 180 cm.s^{-1} (Table 4).

Table 4. The main parameters of the structure of athletes' motor actions during front crawl swimming

Xn	Parameters	X±σ
1	Elbow joint angle during hand entering the water, degrees	160.0±13.4
2	Duration of cycle II period, s	0.30±0.03
3	Duration of cycle III period, s	0.21±0.02
4	Elbow joint angle of one hand at the moment of other hand entering the water, degrees	105.0±11.3
5	Stroke motion rate, cycles/min.	58.0±5.2
6	"Step" per motion cycle, cm	185.0±14.7
7	Value of hand support reaction during push-off, c.u.	27.5±4.9
8	Maximum hand flexion during stroke, degrees	103.0±8.5

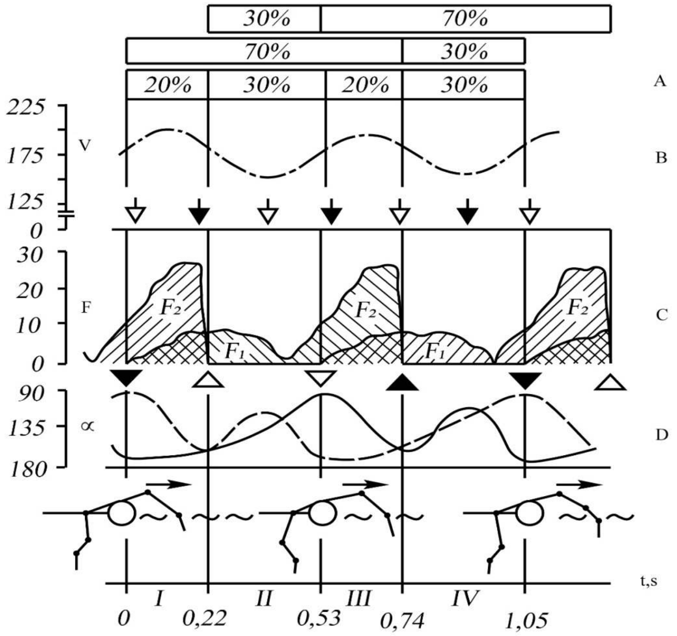

Fig. 2. Model of motor action structure of a sprinter (crawl).

Legend: *A* – rhythmic structure; *B* – spatiotemporal structure; *C* – dynamic structure; *D* – spatial structure; I-IV – cycle periods; F_1 – value of support reactions during pulling; F_2 – value of support reactions during push-off;

▽- left leg kick; △△ right hand entering and leaving the water

▼- right leg kick; ▲▲left hand entering and leaving the water;

———— - dynamics of right hand flexion in elbow joint;

– – – – – – - dynamics of left hand flexion in elbow joint;

-·-·-·-·-·- dynamics of speed intra-cycle fluctuations;

▧-right hand stroke; ▭ -overarm stroke;

▨-right leg kick; ▩ -moment of combined stroke motions;

Intra-cycle speed fluctuations have two maximal rises and two minimal drops in a cycle of movements. This is due to the fact that the swimmer (gradually accelerating hand motion during the stroke) creates sufficiently large support on the hand and forearm stroking surfaces. At the end of the stroke, body acceleration and hydrodynamic resistance are maximal. If the body is slightly raised in the water at this moment, its model decreases and the swimmer starts moving at a speed much higher than the average. In the motion cycle of an athlete during front crawl swimming, the possibility exists of creating two such moments during the I and III working periods of the cycle.

Maintaining optimal values of speed intra-cycle fluctuations at its minimal variations necessitates the application of symmetrical efforts in cycle periods, the correct position of assumed postures during the change, and a seamless rhythm in the alternation of working and preparatory periods. Only in this case will the athlete's movements be economical and efficient.

We have experimentally determined that the ratio of periods in the motion cycle constitutes 20%:30%:20%:30% or 1.0:1.5:1.0:1.5 (Fig. 2A). The intra-cycle speed values are in the ratio 2.0:1.5:2.0:1.5 (Fig. 2B), whereas those of the hand support reactions during push-off and pulling are in the ratio 3:1 (Fig. 2C). As one arm enters the water, the other arm assumes a maximally flexed position during the stroke. The moment one arm leaves the water, the other arm assumes a "high elbow" position and is ready to begin pulling. The athlete assumes the described positions (postures) twice per motion cycle.

Violation of one link of the motor structure results in significant shifts in its other links (Figs. 3A, 3B). In this case, the asymmetry of speed fluctuations is caused by the disturbance of rhythm in the cycle periods. An apparent asymmetry in the dynamic structure and the impaired positions of postures are observed when the cycle periods change, etc. All this inevitably leads to a significant increase in intra-cycle speed fluctuations and reduces the economy of swimming techniques.

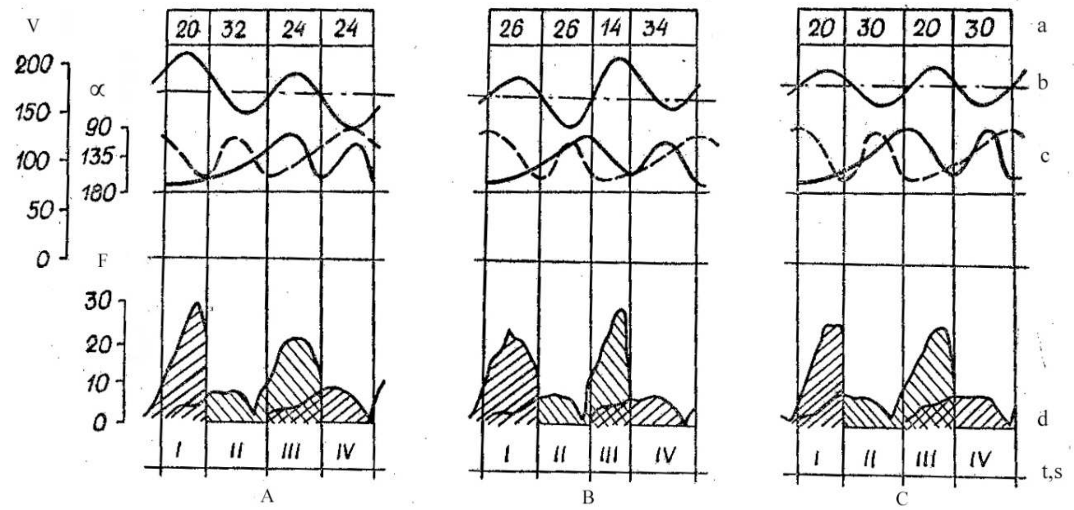

Fig. 3. Variants of swimmers' motor action structure (sprint)
Legend: *A*, *B* – variants with impaired motion structure; *C* – model variant; I-IV – cycle periods; *a* – rhythmic structure (percentage of periods in the cycle); *b* – spatiotemporal structure (intra-cycle speed dynamics); *c* – spatial structure (value and character of flexions in elbow joints); *d* – dynamic structure (value and character of hand support reactions in motion cycle)
▤of the right hand; ▨ -of the left hand;

Discussion

Model of motor action structure of sprinters (Fig. 2) in front crawl swimming (which we have obtained) reflects its most common and rational components, which we accept as a qualitative reference.

Identification of the degree of discrepancy between individual and developed model data represents the necessary condition for further improvement of swimming technique (Costa et al., 2010, 2013). Finding and developing methods and means of directed influence on elimination of the revealed discrepancies is the basis of technical mastery management of skilled athletes. However, models obtained in this way include a certain amount of subjectivity (Garsia-Hermoso et al., 2013). Individual data of athletes often differ so much that their reduction to the model fails to provide positive results. At the stage of higher sports mastery, the averaged, mathematical, qualitative models require individualization (Gurovic et al., 2015). The development of individual models is facilitated by the fact that the main regularities according to which the search should be conducted have already been established. In addition, a diagnostic technique has been developed, which is the basis for identifying individual data. A qualitative model of motor action structure is found. The reserve or prospective capacities of each particular athlete are determined (Moreira et al., 2014). As a consequence of this, it becomes possible to develop an individual regression equation, which will include technique parameters that are most significant for a given athlete only.

This approach is a specific example of the implementation of the management mechanism substantiated by Bernstein (1947, 1966) and further developed in the works of Donskoy (1971), Garrido et al. (2010), Marques et al. (2015).

One of the most important aspects of the process of managing the technical improvement of swimmers is the selection of a variety of special preparatory exercises that enable a forced manifestation of swimming technique individual elements (expedient for a given athlete). For instance, when covering a short segment (25 m), the athlete shows a speed that significantly exceeds the average speed at the main distance. By processing the motion cycle (in which the highest average speed was recorded), one may establish prospective values of the rate of stroke motions, "step" of a cycle, indices of support reactions during strokes and kicks, etc.

While stretching the rubber expander connected to the dynamometer, the athlete exhibits the maximum pulling strength by performing stroke movements at a certain rate (Macejkov & Putala, 2014). After several attempts, he/she empirically "finds" the time range of the stroke, in which he/she realizes his strength capacities to the maximum. That is, he/she demonstrates maximal pulling strength in the water. This is an optimal stroke rate for the given athlete. This is also where the increased values of support reactions are manifested, which are registered by the strain gauge indicators (West et al., 2011).

The rhythm of the movements is decisive in organizing the motion structure of the sprinter in front crawl swimming. Having determined the rate of stroke movements, one may easily calculate individual quantitative values of the period duration relative to the model (Morais et al., 2014).

When the maximum possible average speed is reached at a competitive distance, the optimal "step" per cycle of movements should be 20% longer than the athlete's body length. Only in this case, he will be able to assume the correct positions (postures) during changing the cycle periods and advance with minimal intra-cycle speed variations (Peyrebrune et al., 2014; Vantorre et al., 2014).

The individual model designed in this way is corrected in the process of changing the physical and anthropometric data of the athlete. As an example, here is the calculation of the individual model of a highly skilled athlete in comparison with the model and individual data (Table 5).

Table 5. Individual data comparison with the developed model data and individual model

№	Parameters	Model	Individual data	Difference from model, %	Individual model	Difference from individual, %
1	I period duration, s	0.21±0.02 (20%)	0.18 (15%)	-10.0	0.25 (20%)	+38.8
2	II period duration, s	0.30±0.03 (30%)	0.43 (36%)	+43.0	0.37 (30%)	-14.0
3	III period duration, s	0.21±0.02 (20%)	0.25 (21%)	+25.0	0.25 (20%)	0
4	IV period duration, s	0.30±0.03 (30%)	0.33 (28%)	+10.0	0.37 (30%)	+12.1
5	Stroke motion rate, cycles.min^{-1}	58±5.2	51	-12.1	48	-6.0
6	"Step" per motion cycle, cm	185±14.7	206	+16.7	225	+9.0
7	Value of push-off support, c.u.	27.5±4.9	22	-18.6	28	+27.0
8	Average speed, cm.s^{-1}	179.5±4.8	173	-4.0	183	+6.0
9	Elbow joint angle during stroke, degrees	103±8.5	90	-14.4	103	+14.4
10	Elbow joint angle during hand entering the water, degrees	160±13.4	134	-16.0	160	+16.0
11	Estimated result at 100 m distance, s	54.0	56.0	+4.0	53.0	-5.0

Conclusions

The model of motor action structure and the technique of designing individual models should be used in the period of swimming technique formation and in the process of improving the technical skills of swimmers.

The universality of the technique consists in the fact that the rational structure contains a qualitative model (easily controlled by the athlete himself and managed by simple technical means), characterized by relative values, and a quantitative one - characterized by absolute values. The management process, in this case, is realized by systematic changing the absolute values of the motor action structure model with account for the athlete's individual data, but without alternating its relative values.

Conflict of interest

The authors declare that there is no conflict of interests.

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