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CHANGE OF KINEMATICS OF THE STROKE AT EXHAUSTION OF SKELETAL MUSCLES

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Abstract. The purpose of the research consists in studying changes of kinematic parameters of the stroke at swimming by the crawl on the breast, caused by exhaustion of the skeletal muscles which produce the stroke movement of an arm. The sportsmen of 12–13 years having qualification of the first sport category and the candidate in the master of sport took part in experiment. On four pieces of a hundred-meter competitive distance, there were registered duration and average speed of movement, quantity of the stroke s, a step of the swimmer, and duration of one the stroke. According to abovewater and underwater video shootings, the biomechanical analysis of the stroke movements in the phases and the cycles, including determination of duration of phases and forms of a phase trajectory in joints was carried out. Model parameters of articulate angles and changes of kinematic characteristics of the stroke owing to exhaustion are determined.

Key words: model parameters of the stroke, phases of movement, angle of bending, elbow and wrist joints, hydrodynamic resistance.

INTRODUCTION

For qualitative growth of parameters in swimming, achievement of a new level of technical and physical readiness of sportsmen is necessary in view of principles of biomechanics of swimming. The technique of each swimmer is individual; therefore, one of questions of biomechanics of swimming is revealing basic features of the stroke. Perfection of technique of swimming by the crawl on the breast begins with statement of the rational stroke by arms. However at swimming a competitive distance under influence of exhaustion, there are changes in technique of swimming, in particular in the stroke movements of an arm.

The analysis of known publications shows that authors pay the big attention to features of kinematic parameters at passage of various distances and in the given question, the extensive volume of the information [1–11] is saved up. At the same time, in the scientific literature, there are no parameters of change of technique of movement depending on character of the general or local exhaustion in conditions of competitive activity.

The purpose of the present research was studying changes of kinematic parameters of the stroke at swimming by the crawl on the breast, caused by exhaustion of the skeletal muscles which produce the stroke movement of an arm.

TECHNIQUE AND THE ORGANIZATION OF RESEARCH

46 swimmers in the age of 12–13 years having sport qualification from the first sport category up to the candidate in the master of sport took part in the experiment. Research was conducted in 25-meter pool in the course of competition on a distance of 100 m by the crawl

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on the breast that excluded an opportunity of performance of competitive exercise not in full force and self-checking of technique of swimming under influence of exhaustion. On each of 25 m of the distance over pieces in length of 7.5 m (from sectoring of 12.5 m up to 20 m) there were registered: duration and average speed of movement, number of the strokes, a step of the swimmer, and duration of one stroke. Besides on pieces of 7.5 m with frequency 200 sequences/sec, video recording technique of swimming by three high-speed video cameras was made, two of which have been located in the sagittal plane (abovewater and underwater position) and one in the frontal (underwater position).

Based on abovewater and underwater video shooting, the biomechanical analysis of the stroke movements by arms in phases and cycles was carried out. The stroke is carried out by single movement with the acceleration started in the beginning of the output of an arm from water. The completed system of movements of the swimmer repeated many times refers to as a cycle. In the system of movements, one cycle is replaced by another. We allocate the beginning and the end of a cycle. The stroke cycle has conditionally been divided into 6 phases: 1) capture; 2) pulling up; 3) pushing away; 4) output from water (withdrawal); 5) movement above water (carrying out); 6) input in water (insertion). The phases are united in two periods 1) the basic working movements (the period of an active support); 2) finishing and preparatory movements. To the period of the basic working movements, there concern: a phase of the capture, a phase of pulling up and pushing away. To the period of finishing and preparatory movements, there concern: an output of an arm from water, movement above water (a phase of a carrying out), and an input in water (a phase of insertion). The analysis of the stroke movements included: duration of phases and the form of a phase trajectory in joints. The phase trajectory has allowed us to determine model parameters of articulate angles. In each of phases, we have been considered: an angle of bending in the wrist joint which has conditionally been denoted as an angle α and an angle of bending in the elbow joint – an angle β. Use of the given technique allows us to reveal changes of kinematic of the stroke on a background of exhaustion in comparison with model movement.

RESULTS AND DISCUSSION

The analysis of biomechanical characteristics of the stroke technique of young swimmers was based on studying of change of a range of articulate angles in kinematic pairs and positions of structural elements of kinematic chains (parts of the arm) concerning the body of the swimmer at the moment of the stroke performance. Besides, kinematic characteristics of passage 100-meter competitive distance (Table) have been determined.

The analysis of kinematic parameters of swimming testifies to heterogeneity of passage of a competitive distance. During all distance, the gradual increase in quantity of the strokes is marked. In the third quarter of a hundred-meter piece on a background of decrease of speed of movement and increase in a step of the swimmer, the quantity of the strokes corresponds to parameters of the first 25-meter piece. It is necessary to note that the third quarter is the weakest in all kinematic parameters of swimming. Dynamics of passage of a competitive distance testifies that in each subsequent 25-meter piece duration swimming increases and, accordingly, average speed of movement is reduced.

The data obtained in distances sites of 62.5–70 m testify to accumulation of exhaustion and, as consequence, change of structure of movement. In duration of one stroke and passage of a control site, last 25-meter site of the distance is more effective in comparison with the third piece of the distance. At the same time, the given advantage is determined by finishing acceleration, and the structure of movement differs from model one, losing in a step of the swimmer, quantity of movements during same sites of the distance and, that is the most important, in technical performance of the stroke movement.

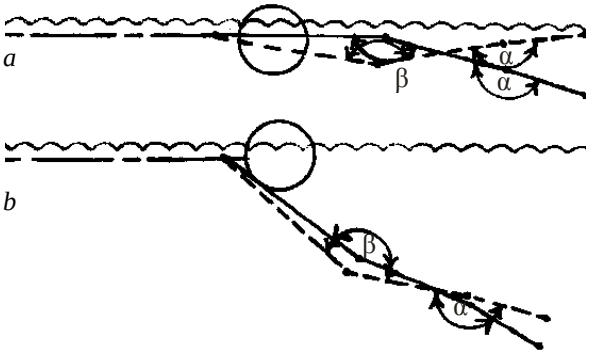

Fig. 1. A phase of the capture (the sagittal plane)

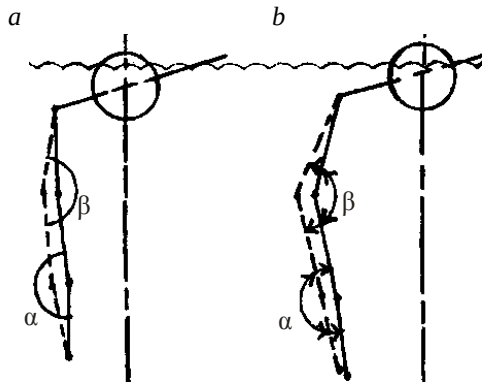

Fig. 2. A phase of the capture (the frontal plane)

Table

Kinematic characteristics of swimming in sites of a 100-meter distance

Parameters	In the piece of the distance of 12.5–20 m	In the piece of the distance of 37.5–45 m	In the piece of the distance of 62.5–70 m	In the piece of the distance of 87.5–95 m
Number of the strokes	10 ± 0.9	11 ± 0.4	10 ± 0.7	11 ± 1
Swimming time (s)	4.42 ± 0.21	4.91 ± 0.26	5.09 ± 0.19	5.04 ± 0.14
Average speed (s)	1.70 ± 0.12	1.53 ± 0.16	1.47 ± 0.14	1.49 ± 0.11
Step of the swimmer (m)	0.74 ± 0.06	0.72 ± 0.04	0.75 ± 0.07	0.69 ± 0.07
Duration of the stroke (s)	0.44 ± 0.02	0.47 ± 0.02	0.51 ± 0.04	0.46 ± 0.03

On the basis of the data of a high-speed video shooting there revealed model structure of the stroke movement in the beginning of the distance and change of kinematics of the stroke in its end on a background of exhaustion. Structural elements of the stroke in the beginning of the distance in the schemes of the stroke are presented in figures by a solid line, and changes of kinematics of the stroke under influence of exhaustion – by dotted line.

The phase of the capture of water begins right after immersing of an arm in water. This phase of the stroke is carried out most smoothly. The arm goes forward – downwards, the palm and the forearm actively rest on a counter stream of water. In the initial stage of the phase in the sagittal plane, the angle in the wrist joint (α) is equal to 172° ± 2°, and the angle in the elbow joint (β) is equal the 170° ± 3° (Fig. 1, *a*). For the frontal projection, the angle in the wrist joint (α) is equal to 172° ± 1° and in the elbow joint (β) – 173° ± 3° (Fig. 2, *a*). At the subsequent movement of the arm, the brush is a little bent and turns by the palm outside. The projection of the elbow joint is above the hand. Further, the hand quickly, but smoothly changes the direction and further goes «outside downwards – inside» under the longitudinal axis of the body.

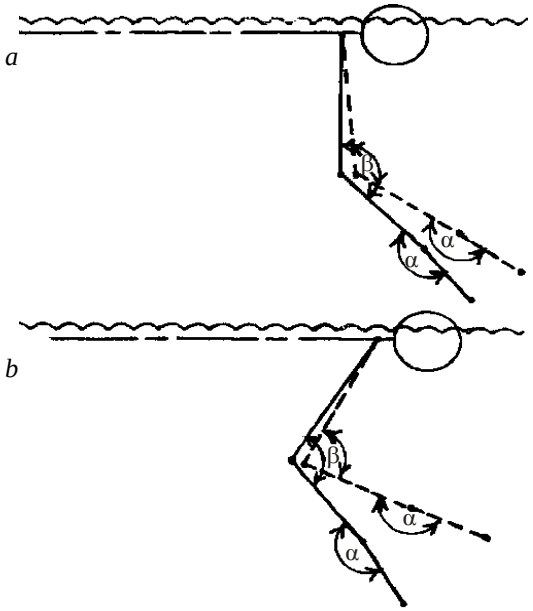

Fig. 3. A phase of pulling up (the sagittal plane)

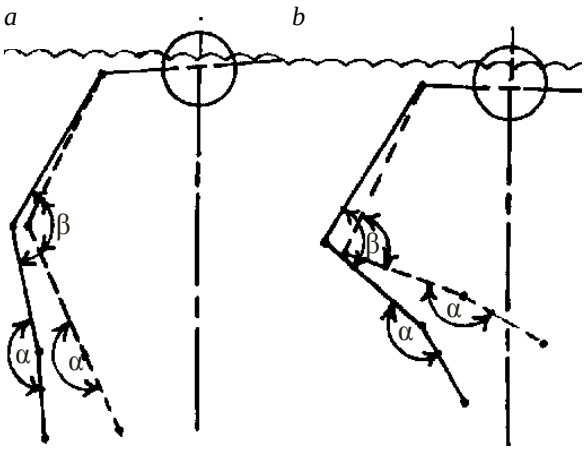

Fig. 4. A phase of pulling up (the frontal plane)

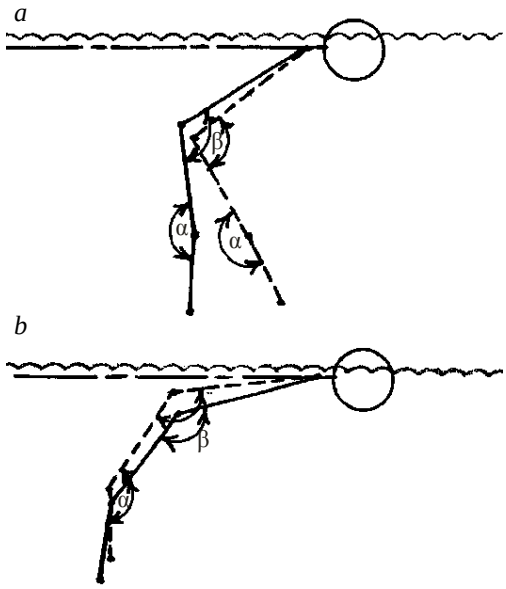

Fig. 5. A phase of pushing away (the sagittal plane)

At exhaustion, the angles of bending in the wrist and elbow joints change. The hand does not turn by the palm outside, and in some cases is directed inwards. Under pressure of water, it starts to lose a support on a counter stream. The angle of bending in the wrist joint increases and makes up 187° ± 1°. In the elbow joint, the reduction of the bending angle up to 163° ± 2° (Fig. 1, *a*) is observed. At supervision in the frontal plane, the turn of the hand a little inwards is marked and the angle α is equal to 180° ± 1°, and the angle β = 168º ± 2° (Fig. 2, *a*).

At model parameters of the stroke, the termination of the phase of the capture is carried out with high position of the elbow in relation to the hand. Movement of the hand in relation to the elbow is leading, and the elbow is kept in the top position and up to a level of the hand does not fall. The angle of bending in the wrist joint remains at the former level – 172° ± 2°, and in the elbow one decreases up to 165° ± 3° (Fig. 1, *b*). At the analysis of the stroke movements in the frontal plane, amplification of the capture of water by rotation and bending of the arm in the elbow (β = 153° ± 3°) is marked. The angle α makes up 176° ± 1° (Fig. 2, *b*). The category of swimmers at which at swimming by the crawl on the breast small turn of the forearm and the hand by the palm outside is consequence of high position of the elbow is revealed; other swimmers specially turn the arm in such position to keep the elbow above the hand.

At exhaustion, the movement of the hand changes in relation to the elbow. Rotary movement of the forearm is not carried out and the elbow falls from top to bottom. It makes the beginning of the stroke greased. The angle of bending in the wrist joint is equal to 178° ± 1°, and in the elbow one at visualization in the sagittal plane is equal to 150° ± 3º and in the frontal plane 155º ± 2° accordingly (Fig. 1, *b*, Fig. 2, *b*). In a percentage ratio, duration of the phase of the capture makes up 11% ± 3% of time from all cycle.

Upon termination of the phase of the capture, the phase of pulling up begins. Characteristic feature of the given phase is bending the forearm and the expressed rotation of the arm inwards. Movement of the hand and the forearm is carried out under the scheme «downwards – inside – back». In the beginning of the stroke, the hand keeps its leading position in relation to the elbow. Depending on features of the individual technique, the hand can deviate from the longitudinal axis of the body inwards or outside. At the moment of performance of the stroke movement, the smooth increase of effort that determines the basic direction of action – «acceleration of the trunk» is marked.

The kinematic chain in the sagittal planes is characterized by the angle of bending in the wrist joint of 176° ± 1°, in the elbow one – 135° ± 5° (Fig. 3, *a*). The analysis of position of parts of the arm in the frontal plane is characterized by the angle α =174°±2° and the angle β = 138° ± 5° (Fig. 4, *b*). Under influence of exhaustion in the phase of pulling up, it is marked the "coming down" of the elbow with reduction of the angle of bending up to 125° ± 5° in the sagittal plane and 130° ± 5° in the frontal plane.

By the moment of the basic part of the stroke, the swimmer gives to the body the high intracyclic speed. It is one of the primary goals of the phase of pulling up. Then, there is the most powerful part of the stroke – reduction and extension of the shoulder. Hence, the arm is more rigidly fixed in the wrist and elbow joints. The analysis of movement in the sagittal plane fixes the angle of bending in the wrist joint (α) as 173° ± 2°, and in the elbow one (β) – 110° ± 4° (Fig. 3, *b*). At the analysis of the stroke in the frontal plane, the angle α equal to 160° ± 2°, and the angle β – 100° ± 5° (Fig. 4, *b*). Some swimmers, trying to increase effort of the stroke movement, carry out this movement insufficiently smoothly. There is even such expression, that «the sportsman tears water». Hence, the phase of pulling up loses the "acceleration" function. Thus, intracyclic speed is lost.

As a result of exhaustion, the angle of bending in the wrist joint becomes equal to 178° ± 2°, and in the elbow one decreases up to 88° ± 3° in the sagittal plane and to 85° ± 2°

in the frontal plane (Fig. 3, *b* and Fig. 4, *b*). Duration of the phase of pulling up in a percentage ratio makes up 23% ± 3% from duration of all cycle of movements.

The phase of pushing away is a most vigorous stroke phase. During pushing away, vigorous unbending and reduction of the shoulder take place. In this phase, there is a powerful pushing away by the hand and the forearm from water, carrying out the stroke movement on a curvilinear trajectory under the stomach and the pelvis. The basic is movement «in front – back» which is combined with moderate rotation of the arm «back – outside». The loop-form trajectory of the stroke is depending on character of bending and rotations of the arm. The angle of bending in the wrist joint in the beginning of the phase is equal to 173° ± 2°, in the elbow one – 119° ± 3° (Fig. 5, *a*). In the frontal projection, the parameters of angles equal to α = 165° ± 2°, β = 118° ± 3° (Fig. 6, *a*).

At exhaustion in this phase, vigorous reduction and extension of the shoulder and powerful pushing away by the forearm and the hand from water disappear. As a result, the hand at once behind the elbow begins movement upwards and there is no end of the stroke . The angle of bending in the wrist joint is equal to 176° ± 2°, and in the elbow one – 100° ± 3° (the sagittal plane) (Fig. 5, *a*). In the frontal plane, the angle α is 175° ± 1°, the angle β is 110° ± 2° (Fig. 6, *a*).

In the course of almost all phase of pushing away, working planes of the hand and the forearm occupy the position close to a vertical. The swimmer gradually weakens the wrist, unbending thus the hand. It is carried out that the hand occupied the most favorable position. The stroke comes to an end by powerful sliding movement of the forearm and the hand «upwards – back». At the end of pushing away, the hand passes close about the hip, almost touching its by the big finger. Upon termination of the phase of pushing away, the angle α makes up 143° ± 2°, and the angle β – 150° ± 3° (Fig. 5, *b*). In the frontal plane, the angle of bending in the wrist joint makes up 178° ± 1, and in the elbow joint – 167° ± 2° (Fig. 6, *b*). On a background of weariness in this phase, the arm is taken out from water earlier, not reaching up to a level of the hip more often. In some cases, at strong exhaustion, the absence of the given phase was marked. Thus, powerful sliding movement by the forearm and the hand «upwards – back» vanishes. In Fig. 5, b, the angle α is equal to 150° ± 2°, the angle β – 130° ± 3°. The angle parameters of the wrist joint in the frontal plane are equal to 178° ± 1°, the elbow one – 155° ± 2° (Fig. 6, *c*). Duration of the phase of pushing away in percentage terms makes up 17% ± 3% under the relation to time of the full cycle.

The phase of the output of the arm from water begins with occurrence of the elbow above a surface of water. The hand leaves water behind a line of the pelvis or is little bit farther about the hip depending on individual technique of the stroke movement. Movement is carried out vigorously, but without jerks. The angle of bending in the wrist joint in the beginning of the phase is equal to 162° ± 2°, in the elbow joint – 133° ± 2° (Fig. 7, *a*). At the end of the phase, the angle α becomes 147° ± 2°, the angle β decreases up to 92° ± 2° (Fig. 7, *b*).

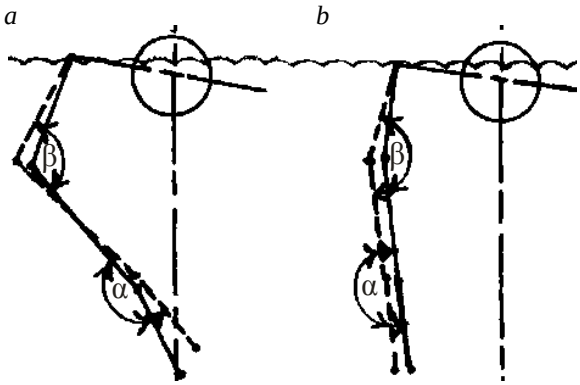

Fig. 6. A phase of pushing away (the frontal plane)

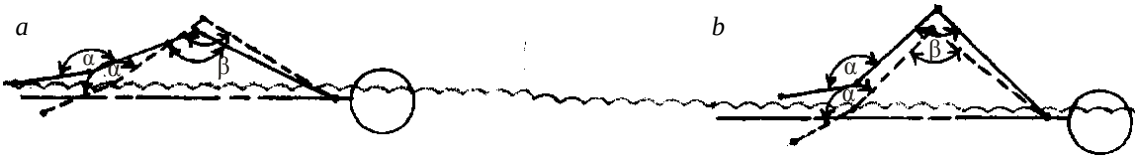

Fig. 7. A phase of withdrawal of arms from water

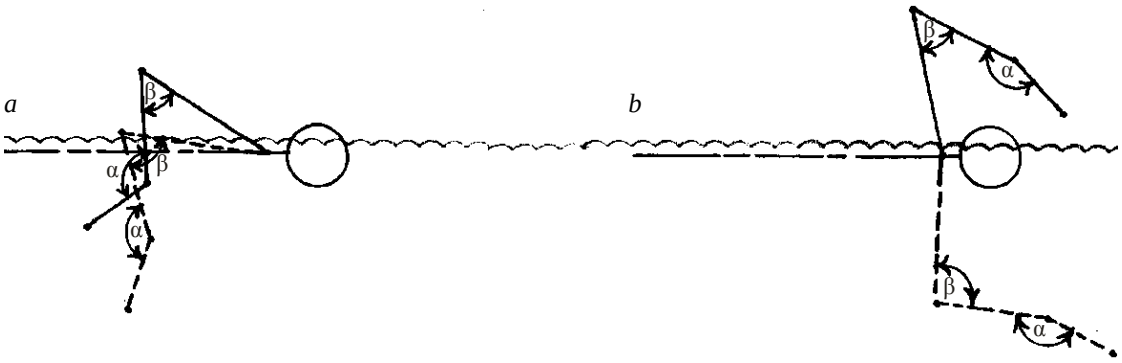

Fig. 8. A phase of a carrying of the arm above water

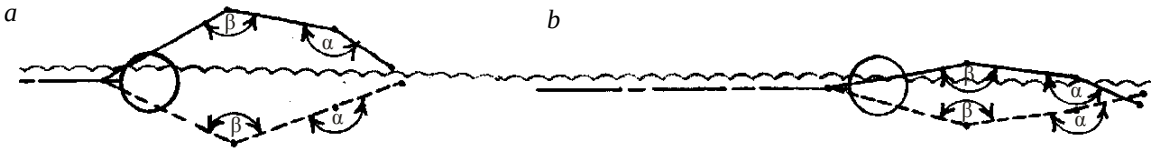

Fig. 9. A phase of the input of the arm in water

At exhaustion the hand does not reach a line of the pelvis, the stroke movement remains uncompleted. Therefore, at the output from water, the arm should overcome significant resistance. In comparison with model parameters, the angle in the wrist joint appears more on 10° and makes up 172° ± 1° while the angle in the elbow joint decreases up to 120° ± 3° (Fig. 7, *a*). The angle of bending in the wrist joint at the end of the phase at exhaustion reaches 160° ± 1°, in the elbow one – 95° ± 2° (Fig. 7, *b*). Sometimes, a swimmer, trying to execute the output of the arm from water more quickly and vigorously, makes this movement by "jerks". Duration of the phase in percentage terms makes up 6% ± 1% from time of a full cycle of movements.

Movement of the arm above water carried out by the majority of swimmers with high position of the elbow. It helps the swimmer to keep position of the body on the longitudinal axis. The arm is freely bent in the elbow. Muscles of the arm are weakened. The hand passes along the body, above a surface of water. The elbow goes almost above the body. In the middle of movement of the arm above water, the elbow a little slows down the movement, after that together with the hand and the forearm accelerates movement. The hand of the arm is weakened and turned by the palm back, it is a little outside. The angle α in the beginning of the phase is equal to 125° ± 1°, the angle β – 55° ± 2° (Fig. 8, *a*). At the end of the phase, the angle of bending in the wrist joint increases up to 160° ± 2°, and in the elbow one decreases up to 50° ± 2° (Fig. 8, *b*).

At exhaustion, the shoulder does not lift the elbow on sufficient height above a surface of water. The elbow passes away from the body and is lowered almost up to a level of the hand. The hand is stressed and is also turned by the palm downwards. In the beginning of the phase, there is a substantial growth of the angle in the wrist joint, making up 150° ± 2°, and also the angle in the elbow joint making up 70° ± 2° (Fig. 8, *a*). At the end of the phase the angle α increases up to 160° ± 2°, and the angle β – up to 95° ± 2° (Fig. 8, *b*). However, there are cases when the hand remains weakened, but because of the low position of the elbow

fingers can "cling" to water. Duration of movement of the arm above water makes up 30 ± 5% of all cycle of movements.

In the phase of the input of the arm in water (the phase of insertion) the hand is rigidly fixed in the wrist joint and a little bent. This phase finishes preparation for the following the stroke. It is carried out smoothly but fast. Consistently, the fingers, the wrist, the elbow and the shoulder are immersed in water. The palm is turned downwards – back and a little outside. Such position allows one to keep the head and the forward part of the body strictly on the longitudinal axis and to keep a high position of the elbow. During the input of the arm in water the elbow is directed to water aside and a little upwards. After the hand, the forearm and the shoulder enter into same «point» forward and downwards. The arm is almost completely straightened and begins the capture. The angle in the wrist joint is equal in the beginning of the phase to 160° ± 1°, and the elbow one – 137° ± 3° (Fig. 9, *a*). At the end of the phase, the angle $\alpha = 168° \pm 2°$, and the angle $\beta = 165° \pm 3°$.

At exhaustion in the phase of the input of the arm in water, the elbow does not rise highly enough. It is practically on the same level with the hand and there is not a smooth insertion of the arm in one «point», but impact by the hand and the forearm on water. The hand is not turned by the palm outside, and directed downwards. The angle in the wrist joint in the beginning of the phase reaches up 177° ± 1°, and the angle in the elbow joint makes up 134° ± 2° (Fig. 9, *a*). At the end of the phase, parameters of the angle of bending in the wrist joint are marked within the limits of 178° ± 1°, in the elbow one – 163° ± 2° (Fig. 9, *b*). Duration of the phase of insertion makes up in percentage terms 10 ± 2% from time of all cycle.

CONCLUSIONS

1. Heterogeneity of passage of a competitive distance in its various sites, namely, change of the basic kinematic parameters: duration of swimming, numbers of the strokes, average speed, a step of the swimmer, and duration of the stroke make an significant influence on result of competitive activity. The structure of movement in various pieces of a distance differs from model on, losing in a step of the swimmer; quantity of movements on same distances and, that is the most important, in workmanship of the stroke.

2. The exhaustion of skeletal muscles of the swimmer at passage of a competitive distance influences the kinematic parameters determining character of moving of an arm parts relative each other and a surface of water. On phases of movement, the following essential changes of kinematics are marked:

- In the phase of the capture, the hand is not turned by the palm outside and loses a support about a counter stream; there is no rotary movement by the forearm and the elbow falls downward.
- In the phase of pulling up, it is marked "coming down" of the elbow and decrease of traction effort of the pulling arm.
- In the phase of pushing away, vigorous reduction and unbending of the shoulder, and also powerful pushing away by the forearm and the hand from water disappears. In some cases, the given phase can be absent owing to early withdrawal of arms from water and impossibility to make force movement.
- In the phase of the output of the arm from water owing to uncompleteness of the previous phase, the arm should overcome significant resistance of water, and as consequence, the moment of braking appears.
- In the phase of carrying of the arm above water, the shoulder does not lift highly enough the elbow above its surface owing to what the elbow passes away from the body and is lowered almost up to a level of the hand;

- In the phase of the input of the arm in water, the elbow is practically on the same level with the hand and there is not a smooth insertion of the arm in one "point", and impact by the hand and the forearm on water.

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ИЗМЕНЕНИЕ КИНЕМАТИКИ ГРЕБКА ПРИ УТОМЛЕНИИ СКЕЛЕТНЫХ МЫШЦ

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Цель исследования заключалась в изучении изменений кинематических параметров гребка при плавании кролем на груди, вызванных утомлением скелетных мышц, осуществляющих гребковое движение руки. В эксперименте принимали участие спортсмены 12–13 лет, имеющие квалификацию первого спортивного разряда и кандидата в мастера спорта. На четырех отрезках стометровой соревновательной дистанции регистрировались длительность и средняя скорость движения, количество гребков, шаг пловца и длительность одного гребка. По данным надводной и подводной видеосъемок проводился биомеханический анализ гребковых движений по фазам и циклам, включающий определение продолжительности фаз и формы фазовой траектории в суставах. Определены модельные параметры суставных углов и изменения кинематических характеристик гребка вследствие утомления.

Ключевые слова: модельные параметры гребка, фазы движения, углы сгибания, локтевой и лучезапястный суставы, гидродинамическое сопротивление.

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