TECHNOLOGY FOR DECREASING ACTIVE DRAG AT THE MAXIMAL SWIMMING VELOCITY

Sergei Kolmogorov, Sergei Lyapin, Olga Rumyantseva and J. Paulo Vilas-Boas[1]
Centroconcept, Pomor University, Arkhangelsk, Russia
[1]Department of Physical Education, University of Porto, Porto, Portugal

The article describes the technology for decreasing active drag at the maximal swimming velocity. This technology can be used for both elite and sub-elite swimmers of different sex, age and qualification. It has been developed on the basis of optimal interaction between two functional systems of a swimmer (biomechanical and metabolic). The technology includes three components (training exercises; choice of training categories according to their international classification; use of special technical devices), as well as a set of concrete methods and technical procedures. The parameters, necessary for the research, have been measured by the method of small perturbations with the help of an additional hydrodynamic body.

KEY WORDS: technology, functional systems, active drag, CDP-phenomenon.

INTRODUCTION: Elite swimmers can increase their maximal swimming velocity ($v_{0\ lim}$) at a definite distance in different ways: not only with parallel increasing of the total external mechanical power (P_{to}), but also with conservation and even decreasing of this power (CDP-phenomenon) (S. Kolmogorov et al., 1997). The main reasons for the CDP-phenomenon are a) decrease in non-stationary frontal drag of a human body; b) increase in propelling efficiency at the account of purposeful change in dynamic and cinematic characteristics of a swimmer's movers; c) decrease in negative impulse of effective propelling force within motions cycle in butterfly and breaststroke (S. Kolmogorov and S. Lyapin, 1999).
This phenomenon brightly testifies to hidden capacities, which can be realized for decreasing a swimmer's active drag without prejudice to the final result – achieving the maximal swimming velocity. These capacities are finally connected with organization of the optimal interaction between two basic functional systems of a swimming human: a) the system of specialized biomechanical motions, necessary for forward movement of a swimmer's body, b) the system of energetic metabolism, providing swimming biomechanics and, in its turn, including aerobic and anaerobic mechanisms.
This or that character of these systems' interaction practically represents the *control system of upper level.* It is this system's *working mode* that determines the final efficiency of the two basic systems' interaction. At the same time the choice of the *optimal variant* of the control system's working mode, which is the main coaches' task, in essence, should be determined by orientation not to the local result but to the final goal of the training cycle: successful performance in the main season competition.
Realization of this methodological task presupposes creating the adequate training technology, specifying its basic components and working out the concrete methods, exercises and technical procedures for each of them.
In this connection the main tasks of the experimental research, which are described in this paper, were the following ones:
1. Defining the most effective ways of the maximal swimming velocity's increase by elite swimmers.
2. Analyzing the achieved results and on their basis working out the technology of active drag's decreasing for differently aged and qualified swimmers.

RESEARCH METHODS AND ORGANIZATION: The maximal swimming velocity at the distance of 30 m ($v_{0\ lim}$), active drag ($F_{r(a.d.)}$), dimensionless coefficient of hydrodynamic force ($C_{x(a.d.)}$) and total external mechanical power (P_{to}) were measured by the method of small perturbations with the help of an additional hydrodynamic body (S. Kolmogorov and O.Duplisheva, 1992; S. Kolmogorov, et al., 1997). The theory and technology of this method, as well as the technique of verification and evaluation of assumptions' relevance are described in these papers in detail.

The experiments were organized as five interconnected research projects. Each of them was devoted to solving definite tasks. The order of projects descriptions and their numbers is not chronological. It is connected with the logic of experimental material's presentation.

1. The first project was carried out during the period from September 1991 to August 1992. Three elite freestyle swimmers from the first 10 of the World ranking took part in the research. The changes in hydrodynamic characteristics of the sportsmen's swimming have been studied for the whole period of training for the Olympic games in Barcelona.
2. The second project contained four research cycles of 1 month duration in 1998. 11 girls and 13 boys, being eleven years old in the beginning of the research, took part in the projects. We studied the efficiency of different training exercises aimed at decreasing young sportsmen's active drag in different sports swimming strokes at the stage of preliminary basic training (age of 11–13 years).
3. The third project had the form of a longitudinal pedagogic experiment, conducted from December 1996 to May 1999. 8 girls and 13 boys aged 14 at the beginning of the project took part in the research. We studied aerobic and anaerobic training's influence on hydrodynamic characteristics of freestyle swimming at the stage of the specialized basic training at the age of 14–16 years.
4. The fourth project included mountain training in the Colorado-Springs camp (altitude 2200 m) since March 13 till April 2, 1995. 8 elite male swimmers from the first 25 of the World ranking, specializing in different swimming strokes, took part in the research. We studied the influence of training in the aerobic zone under conditions of middle-mountains on hydrodynamic characteristics of swimming.
5. The fifth research project was carried out in July-August 1995 during the period of direct training to the European Championship of 1995 in Vienna. 6 elite freestyle male swimmers from the first 25 in the World ranking took part in the research. In the course of the project we studied the influence of training with the help of the special technical devices in the tapering phase on hydrodynamic characteristics of swimming.

RESULTS AND DISCUSSION: Figure 1 shows three elite swimmers' individual hydrodynamic parameters taken in the ***first project.*** The sportsmen # 81 and # 121 became the Olympic champions. During the Olympic season of training they increased $v_{0\ lim}$ while P_{to} stayed unchanged or insignificantly decreased. At the start their hydrodynamic parameters were optimal. As for the sportsman # 52, his P_{to} increased together with $v_{0\ lim}$. His swimming technique at the start was not effective enough: hydrodynamic parameters of swimming motions' biomechanical system were energy-intensive. That is why this sportsman had bad results in the competition, though his absolute parameters of $v_{0\ lim}$ were higher during the season. This result was quite natural as the swimmer # 52 couldn't keep high swimming velocity for the whole competition distance under conditions of limited provision of metabolic energy though his parameters of metabolic power were the same as of the swimmer # 81.

Tables 1, 2, 3, 4 represent hydrodynamic swimming characteristics and sports results at the distance of 200 m by different swimming strokes before and after the research cycles of the ***second project.*** As a result of the research cycles there were revealed the most effective training exercises, decreasing active drag. They are listed in the conclusion. Systematic use of such exercises leads to decreasing $F_{r(a.d.)}$, $C_{x(a.d.)}$ and P_{to} and increasing of the maximal velocity in all swimming strokes. However, these differences are not always statistically significant. But they are sufficient for improvement of sports results in freestyle, backstrokes and dolphin ($P < 0.05$). In other words, during the period of research cycles it is possible to decrease the P_{to} parameters necessary for keeping one and the same velocity by a swimmer. In its turn, this leads to decreasing metabolic consumption for swimming velocity at a distance and allows to keep it longer without significant decrease. This brings to improvement of sports results.

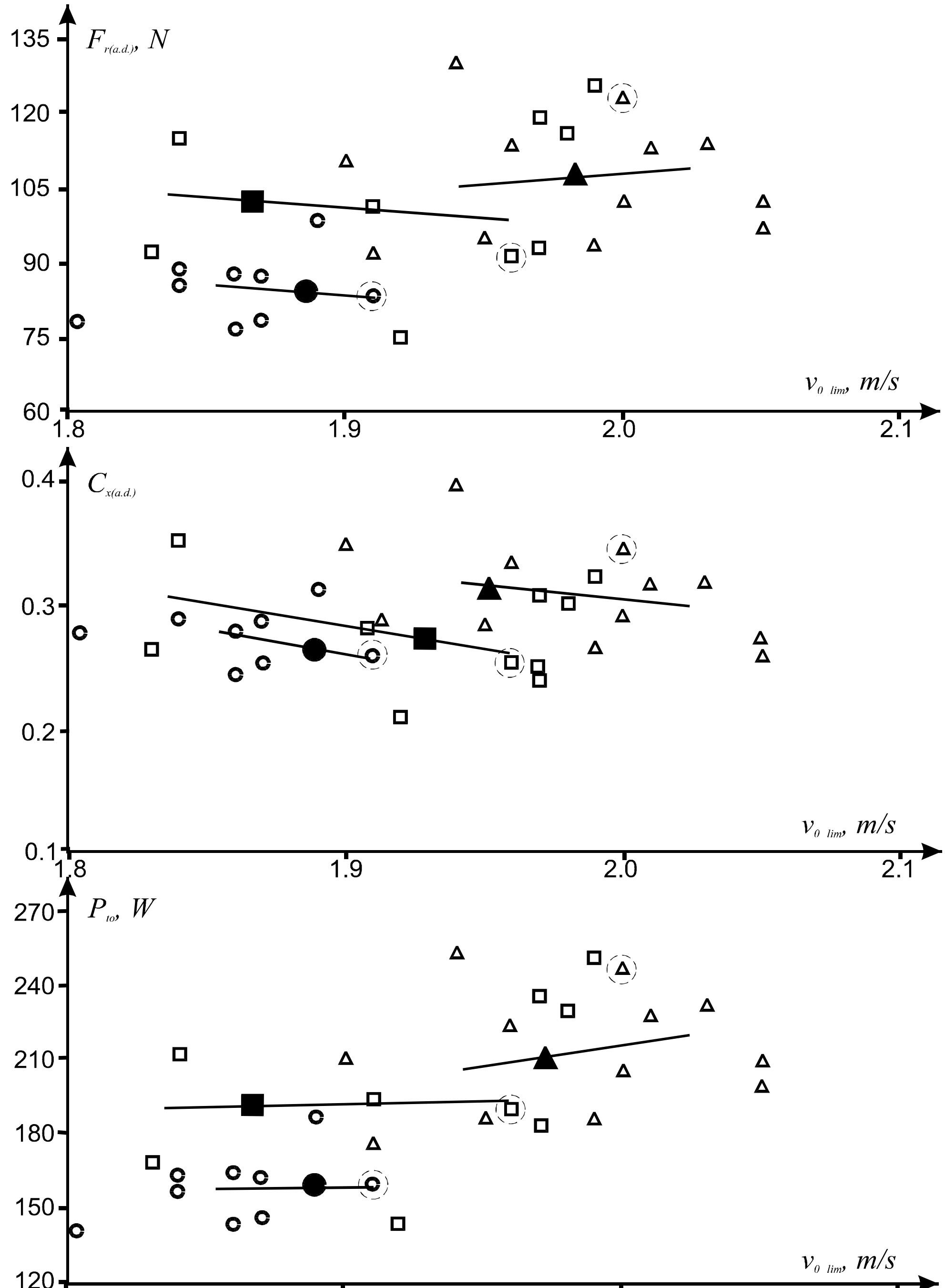

Figure 1 - The changes of individual hydrodynamic parameters of elite freestyle swimmers during the training period of 1991–1992: Δ – the subject # 52, □ – the subject # 81, ○ – the subject # 121. The data taken at the moment of start at the Olympic games in Barcelona, are in circles.

Table 1 Girls Freestyle (Project 2)

Testing date	Statistic data	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Result 200m {min:sec}
29-01.02.98	M	45.89	1.36	29.36	0.253	38.77	2:33.21
(1)	±m	1.64	0.02	1.19	0.015	1.66	0:01.39
Between	t			2.42	2.55		2.64
(1) and (2)	P			<0.05	<0.05		<0.05
28-29.03.98	M	46.09	1.38	25.73	0.211	35.65	2:28.68
(2)	±m	1.59	0.02	0.91	0.008	1.51	0:01.00

Table 2 Girls Breaststroke (Project 2)

Testing date	Statistic data	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Result 200m {min:sec}
26-27.09.98	M	48.99	1.07	24.89	0.325	26.75	3:18.07
(1)	±m	1.40	0.01	0.65	0.015	0.71	0:02.32
Between	t			2.44		2.18	
(1) and (2)	P			<0.05		<0.05	
25-26.10.98	M	49.18	1.09	22.70	0.288	24.72	3:13.09
(2)	±m	1.40	0.01	0.62	0.015	0.60	0:02.30

Table 3 Boys Backstroke (Project 2)

Testing date	Statistic data	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Result 200m {min:sec}
29-01.02.98	M	44.01	1.23	25.85	0.273	31.96	2:44.05
(1)	±m	1.07	0.02	0.89	0.007	1.33	0:01.96
Between	t				2.94		2.12
(1) and (2)	P				<0.01		<0.05
28-29.03.98	M	44.47	1.25	23.76	0.243	29.86	2:38.20
(2)	±m	1.01	0.02	0.76	0.007	1.15	0:01.95

Table 4 Boys Dolphin (Project 2)

Testing date	Statistic data	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Result 200m {min:sec}
26-27.09.98	M	47.80	1.31	34.73	0.311	45.52	2:40.84
(1)	±m	1.15	0.02	1.13	0.009	1.96	0:01.60
Between	t				2.30		2.09
(1) and (2)	P				<0.05		<0.05
25-26.10.98	M	47.65	1.33	32.68	0.283	43.54	2:35.77
(2)	±m	1.00	0.02	0.91	0.008	1.75	0:01.83

In the beginning of the ***third project*** the amount of swimming was 75–100 km and the volume of physical training on land was 28–30 hours per month depending on the level of subjects' individual qualification. In the end of the longitude pedagogic experiment the first parameter reached 150–180 km and the second one – 34–36 hours per month. The conceptual peculiarity of this research was significant varying of percentage correspondence between volumes of training exercises in different training categories and using of special programs of technical training. The training categories' classification, elaborated by the specialists of US Swimming, was used in the research. It is represented in Table 5. Tables 6, 7 represent hydrodynamic technique's characteristics and freestyle sports results at the distances of 100, 200, 400 m, obtained during the most effective period of the longitude experiment.

Table 5 Training Categories

Training Category	Description of the metabolism system	Pulse Rate	Work/Rest Ratio	Percent of Velocity	Lactate (Mm/L)
Rec	Any non-specific swimming velocity	< 120	Choice	80% Threshold Velocity	0-2
EN1	Min Aerobic Metabolism	120-140	10-30 sec's rest	90-95 % Threshold Velocity	1-3
EN2	Metabolism Anaerobic Threshold	130-170	10-30 sec's rest	Threshold Endurance Velocity	3-5
EN3	Metabolism at the level of Maximal O_2 Uptake	160-180	20 sec's rest to 1:1	107 % Threshold Velocity	4-8
SP1	Metabolism at the level of Lactate Tolerance	max	1:1 to 1:2	Inside 90 % Max Velocity at the competition distance	6-12
SP2	Metabolism at the level of Peak Lactate Production	max	1:2 to 1:8	Inside 95 % Max Velocity at the competition distance	10-18
SP3	Metabolism of Alactate Velocity/Power	n/a	1:2	100 to 110 % Max Velocity at the competition distance	2-3

It was revealed that a large amount of swimming exercises in the training categories EN3, SP1 and SP2 increases hydrodynamic characteristics of swimming technique. But these parameters are decreased in the categories EN1 and EN2. At the same time the optimal ratio between volumes of training load in different zones of energetic provision is necessary for achievement of sports result. In the most effective period of longitude experiment this ratio allowed to increase the maximal swimming velocity at the cost of insignificant decreasing of $F_{r(a.d.)}$, $C_{x(a.d.)}$ and P_{to}. These differences are not always statistically relevant. But they are the main reason for improvement of boys' and girls' freestyle sports results at different distances ($P < 0.05$). Such an optimal ratio of swimming volumes is the following one: in the beginning of the period – REC - 25%, EN1 - 30%, EN2 - 33%, EN3 - 8%, SP1 - 1%, SP2 - 0%, SP3 - 3%; in the end of the period – REC - 30%, EN1 - 34.5%, EN2 - 20%, EN3 - 10%, SP1 - 2%, SP2 - 1.5%, SP3 - 2%.

Table 8 represents hydrodynamic characteristics of swimming in the beginning and in the end of the period of mountain training within the framework of the ***fourth project***.

Table 6 Girls (Project 3)

Testing date	Statistic data	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Result 100m {min:sec}	Result 200m {min:sec}	Result 400m {min:sec}
19-23.09.97 (1)	M	55.26	1.49	39.93	0.237	59.63	1:06.17	2:22.58	5:02.64
	±m	1.55	0.03	2.06	0.012	3.96	0:00.57	0:01.33	0:03.18
Between (1) and (2)	t			3.08	3.90			2.30	2.60
	P			<0.01	<0.01			<0.05	<0.05
19-23.03.98 (2)	M	55.42	1.53	31.48	0.184	48.43	1:04.72	2:18.20	4:51.61
	±m	1.44	0.03	1.79	0.006	3.59	0:00.72	0:01.35	0:02.80

Table 7 Boys (Project 3)

Testing date	Stat. data	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Result 100m {min:sec}	Result 200m {min:sec}	Result 400m {min:sec}
20-23.09.97 (1)	M	59.38	1.58	46.55	0.244	73.75	1:00.74	2:11.75	4:38.03
	±m	2.07	0.02	1.50	0.007	3.06	0:00.86	0:01.63	0:03.82
Between (1) and (2)	t			2.51	2.65		2.35		2.49
	P			<0.05	<0.05		<0.05		<0.05
20-23.03.98 (2)	M	59.15	1.62	40.96	0.208	66.36	0:58.20	2:07.32	4:27.04
	±m	2.04	0.02	1.64	0.011	2.74	0:00.65	0:01.77	0:03.10

Table 8 Men

			March 17, 1995					March 29, 1995				
Stroke	#	Height {cm}	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}
free-style	121	187	78.00	1.78	76.45	0.266	135.71	76.40	1.83	60.34	0.200	110.51
free-style	116	196	85.60	1.76	111.03	0.367	195.94	86.20	1.82	97.78	0.304	177.57
free-style	567	184	73.10	1.72	94.71	0.368	162.46	73.40	1.75	75.39	0.282	131.72
dol-phin	137	187	81.50	1.69	94.51	0.353	159.37	80.00	1.75	80.59	0.284	140.81
back-stroke	152	183	73.90	1.67	94.13	0.385	156.88	73.10	1.69	82.04	0.328	138.81
back-stroke	16	189	77.50	1.67	91.62	0.363	152.61	75.80	1.68	70.62	0.281	118.82
breast-stroke	556	184	77.80	1.53	88.92	0.415	136.24	78.00	1.56	79.39	0.358	123.66
breast-stroke	564	183	67.00	1.42	68.68	0.414	97.37	65.20	1.48	57.20	0.323	84.54

The total amount of swimming for the period of training in the mountains was 294 km. Its distribution by training categories was as follows: REC - 45%, EN1 -44%, EN2 - 9.2%, EN3 - 0%, SP1 - 0%, SP2 - 0.5%, SP3 - 1.3%. The training program included training microcycles of 4 days each. The task of the first microcycle was adaptation to training under conditions of hypoxia. Therefore there were two trainings a day. The bulk of training load was executed during the next four microcycles. Their organization was the same. The first three days of a microcycle included three trainings a day, and the last day – one recovery training. The individual analysis of experimental results has shown that under conditions of hypoxia this training program leads to essential increase of efficiency of the subjects' biomechanical system in all sports swimming strokes, i.e. to decrease of $F_{r(a.d.)}$, $C_{x(a.d.}$ and P_{to} at the cost of insignificant increase of the maximal swimming velocity.

Table 9 represents hydrodynamic characteristics of swimming technique in the beginning and in the end of the tapering phase of the ***fifth project***. The functional training of this phase is aimed at the balanced increase of the power of aerobic energetic system and the volume of anaerobic energetic system. In the course of this period the amount of swimming in the training categoties SP1, SP2 increases. This leads to abrupt decrease in efficiency of biomechanical system of motions (S. Kolmogorov et al., 1994). That is why in this period we used the special technical devices which allowed to resist this process. They are described in detail in the conclusion.

Table 9 Men

			July 28, 1995					August 12, 1995			
#	Height {cm}	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}	Weight {kg}	$v_{0\ lim}$ {m/s}	$F_{r(a.d.)}$ {N}	$C_{x(a.d.)}$	P_{to} {W}
110	190	83.00	1.96	164.29	0.449	321.92	83.80	1.95	110.23	0.301	215.43
154	182	80.20	1.91	160.39	0.473	306.29	81.40	1.97	135.94	0.372	267.95
80	189	81.20	1.89	122.00	0.363	230.92	81.90	1.99	112.58	0.303	223.51
107	195	92.00	1.88	153.43	0.427	288.04	92.00	1.95	135.43	0.351	263.47
510	186	79.40	1.87	111.07	0.345	207.35	79.60	1.91	91.99	0.272	175.79
8	188	78.20	1.84	150.54	0.486	276.89	80.00	1.89	108.96	0.330	205.46

The analysis of experimental results has shown that applying special technical devices, which are aimed at increase of propelling efficiency and rational combination of training exercises in different training categories, allows to escape the negative influence of rigid anaerobic trainings, very necessary in the tapering phase.

CONCLUSION: The technology aimed at active drag's decrease of differently aged and skilled swimmers includes key methodological concepts and three main interconnected components: (a) training exercises, (b) training categories according to the international classification, (c) special technical devices.

The key methodological concepts of the developed approach are important for both scientific research and interpreting the training results. They are: a) the conscious distinction of a swimming human's two functional systems (the system of rational biomechanical motions and the system of energetic metabolism); b) treating of interaction between them as a *control system* of upper level (in relation to the basic ones); c) the choice of the control system's *optimal working mode* from the standpoint of the training cycle's final goal: successful performance in the main season competition.

After the corresponding analysis and the next relevant specification this methodological approach can be used for sportsmen's training in other cyclic kinds of sport.

The special components of the training technology, allowing a decrease in active drag of differently aged and qualified swimmers are as follows:

a) Training exercises.

1. Repeated swimming at high velocity in the training category SP3 at short distances (up to 25 m). Motions and phases' boundary moment in a swimming stroke have strict requirements and guidelines. Underwater video-recording for the purpose of quick obtaining and using of information increases

efficiency of such exercises.

2. Repeated swimming with fins at the competitive and higher velocities in the training category SP3 at short distances (up to 25 m) for the purpose of a swimmer's movers' adaptation to interaction with water environment (e.g.: legs in fins execute dolphin motions and arms execute breaststroke motions, etc.).
3. Repeated training series like 10x50 m, 6x75 m. They are executed with constant velocity in the training categories EN1, EN2. The number of strokes decreases from the first to the last distance.

These exercises should satisfy the main requirement: simultaneous improvement of cinematic and dynamic characteristics of movement.

b) Training categories.

1. Interval series like 6-60x100 m, 3-30x200 m. They are executed in the training categories EN1, EN2. The total amount of one training series should not exceed 2000 m for swimmers of 11–13 years old in the category EN1. It should not exceed 1000 m in the category EN2. For swimmers of 14–16 years old in the category EN1 this amount should not exceed 4000 m and 2000 m in the category EN2. For elite swimmers the requirements are 6000 m in the category EN1 and 3000 m in the category EN2. The range of training distances can be from 50 to 400 m.
2. At the stage of the specialized basic training of young swimmers aged 14–16 the optimal distribution of swimming amounts by training categories is: REC - 25-30%, EN1 - 30-35%, EN2 - 20-33%, EN3 - 8-10%, SP1 - 1-2%, SP2 - 0-2%, SP3 - 2-3%.
3. In order to increase efficiency of swimming motions' biomechanical system during the period of elite swimmers' mountain training under conditions of hypoxia the bulk of training work is rational in the training categories EN1 and EN2.

The processes of swimming technique's biomechanical economizing are the most effective if aerobic modes of energy provision are used.

c) Special technical devices

1. Fully controlled swimming with competitive and higher velocities at different distances in the device of non-contact hydrodynamic leading (swimming after the special hydrodynamic body badly streamlined, which is propelled by a pulling machine with the necessary velocity). This device decreases active drag of a sportsman's body itself, which allows one's movers to work with high velocities in unperturbed flow. This gives an opportunity to improve competitive technique with a lower level of metabolic power, i.e. without exhaustion of anaerobic energetic system's capacity of a human organism. For example, with the help of this device the subjects in the fifth project executed the repeated training series of 10x50 m freestyle at the higher velocity than their personal record with the pulse rate 150–165 strokes per minute.
2. Swimming at the competitive and higher velocities in the flume, in which the velocity of liquid flow's upper level (10–20 cm deep) is slow (10–15 %). The biomechanical sense of this process is analogous to 1.
3. Swimming at the competitive and higher velocities in the flume with a weight ($\approx$20N) attached to a swimmer by the blocks system. This weight horizontally pulls the swimmer forward in the same direction as the swimmer's propelling force. The biomechanical sense of this process is analogous to 1.

High efficiency of using these special technical devices is explained by the fact that a swimmer's mover is able to adapt to interaction with fast hydrodynamic flow, which is present under conditions of real competitive activity.

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