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Dynamics of Metabolic and Biomechanical Criteria of Preparedness of Elite Female Swimmers at 200 M Events within a Macrocycle

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Abstract: *The research aimed at improving the training process for medium-distance swimmers on the basis of regular and interconnected analyses of metabolic and biomechanical criteria of their preparedness. The study involved four elite female swimmers who specialized in different swimming techniques ata distance of 200 m (825-988 FINA Points). During the macrocycle of preparation for the 2017 World Swimming Championship, in the 8×200 m step-test with progressively increasing swimming velocity, a longitudinal shift of the metabolic curve was observed, the direction of which primarily depended on the completed training load. Based on the biophysical model of the process under study, the analysis of swimming velocity values at the last stage of the test showed that variations in the volume, intensity, and content of training work at different preparation periods result in targeted, strongly interconnected and, sometimes, significant dynamics of the level of preparedness. In the taper phase, quantitative (numerical) criteria of special preparedness of the three female swimmers who successfully performed at the World Swimming Championship were recorded within the range typical for that distance: metabolic power =1331–1491W, mechanical efficiency =0.059–0.063and propelling efficiency =0.71–0.73. Thus, the key factor for a swimmer's successful performance at the major competitions is the balance between the levels of functional, strength, and technical preparedness in the taper phase of the training program within the entire macrocycle.*

Keywords: *biophysical model, macro- and micro approaches, metabolic power, mechanical and propelling efficiency.*

1. Introduction

Proceeding from the available objective scientific information on energy supply and biomechanics of swimming, to work out and implement the individual training program for elite swimmers, practical coaches generally apply a *macro approach:* training impact →?→sports result. In other words, the principle of the 'black box' is used since the internal mechanisms for swimmer's energetic and biomechanical systems functioning are not sufficiently studied.

However, from the standpoint of the entire organism, between the energy supply, biomechanics, and the useful outcome of the swimmer's activity, there are functional relationships, formalized as biophysical models [1, 2, 3]. Evidently, the main outcome of an athlete's activity in water locomotion is swimming velocity at the competition distance, which predominantly contributes to the sports result. These are the biophysical models that make it possible to apply a more efficient *microapproach:* training impact → rationale→ outcome (swimming velocity).

With a swimmer's steady non-stationary motion in water performed with any sports technique, at the first stage, the produced metabolic power is transformed with losses into mechanical power, which, at the second stage, is transformed with additional losses into the athlete's swimming velocity. For sports swimming, this process is formalized as a corresponding biophysical model [4]:

$$v_0 = P_{ai} \times e_g \times e_p \times F_{r(\mathrm{fd})}^{-1} \quad (1)$$

where: v_0– average swimming velocity at competitive distance or training lap ($\mathrm{m \cdot s^{-1}}$); P_{ai}–metabolic power (power input) (W);e_g– mechanical efficiency(dimensionless): the ratio of total external mechanical power P_{to}(power output) to P_{ai};e_p– propelling efficiency(dimensionless),i.e., the ratio of useful external mechanical power $P_{uo}$to P_{to}, and $F_{r(\mathrm{fd})}$ –frontal component of active drag force in the steady non-stationary mode of body motion(N).

Therefore, taking into account the entire organism as a whole, in sports practice, the integral quantitative criteria of swimmer's *special* preparedness, worked out on the basis of the biophysical model, have recently been used (1): P_{ai} – the criterion of *functional preparedness; e_g*– the criterion of *strength preparedness; e_p* – the main criterion of *technical preparedness; $F_{r(\mathrm{fd})}$* – the additional criterion of *technical preparedness*[5].

Thus, **the aim of the study** was to increase the efficiency of medium-distance swimmers' training on the basis of regular and interconnected analyses of the main biophysical criteria from the standpoint of macro- and micro approaches.

2. Materials and Methods

The study involved four elite female swimmers (825-988 FINA Points) who specialized in different swimming techniques at a distance of 200 m. All the athletes were preparing in a 50 m pool for the 2017 World Swimming Championship (WSC)that took place on July 23-30 in Budapest (Hungary).

The strategic (general) plan of training for the WSC within the macrocycle (15 weeks, 17.04–30.07.2017) was worked out by the head coach of the team and approved by personal coaches, and it included four blocks: introductory block (2 weeks, 17.04–30.04.2017); aerobic and strength preparation block (4 weeks, 01.05–28.05.2017); specific preparation block (5 weeks, 29.05–02.07.2017); taper phase and major competitions (4 weeks 03.07–30.07.2017) [6].*Tactic (individual) plans* were worked out and implemented by personal coaches, and, hence, they differed essentially from each other.

To register the performed training load precisely, the Swim Planyzer"software was used (http://www.softconst.ru/sp; accessed in January 2017). This software allows one to plan (to create strategic and tactical plans), register, and analyze the training load of swimmers on the basis of the classification provided for by the International Center for Aquatic Research [7].

The aforementioned classification initially used the following training categories (intensity zones): Rec (recovery) – minimal aerobic metabolism at any unregulated swimming velocity; EN1 (endurance 1) – threshold of aerobic metabolism; EN2 (endurance 2) – threshold of anaerobic metabolism; EN3 (endurance 3) – maximum oxygen consumption; SP1 (speed 1) – anaerobic metabolism in the zone of tolerable lactate; SP2 (speed 2) – anaerobic metabolism in the zone of peak lactate production; SP3 (speed 2) – alactic metabolism. In the recent years, because of the regular application of the biomechanical breathing simulator[1] for better swimmers' recovery in the training process [8], the training category Rec was differentiated into two parts: Rec-F (recovery free) – the meaning stayed the same and entirely corresponds to the category Rec; and Rec-S (recovery with snorkel) – minimal aerobic metabolism at any unregulated swimming velocity using a biomechanical breathing simulator.

The experimental determination of the variables of the biophysical model (1) requires an interdisciplinary approach, which was implemented in the study. Standard testing was conducted at the final week of the first three blocks of training and at the beginning of the second week of the phase of tapering the training load. Each subject performed two intermittent step-tests with progressively increasing swimming velocity (from low to maximum): the first test was conducted in a swimming flume, and the second test was carried out 72 h later in a 50 m pool. The necessity of double testing is determined by the fact that, with similar P_{ai} values, a swimmer develops much lower

[1] The biomechanical breathing simulator is a snorkel with a low-frequency mechanical oscillation generator for the airflow ventilated by the swimmer.

velocity in the flume (by 8–14%) than in the pool[4, 9]. The test in the swimming flume consisted of repeated efforts of 8 × 2 min. In the pool, swimmers performed a set of 8 × 200 m trials. Rest intervals in both tests (regardless of the testing site) were: 3 min after the laps 1, 2, 3 and 4; 5 min after the lap 5 and 6; and 7 min after lap 7. Swimming velocities for each subject were previously calculated for stages 1–7 of both flume and pool testing (except for the last stage, which was performed at maximal intensity) using the Swim Planyzer"software. The calculated velocity gradually increased from stage 1 (category EN1) to stage 7 (category SP1).These calculations are based on the results of preliminary testing in the flume and pool and are performed by one of two computing units: the "USS Standard" and the "RUS Standard". The calculation method was individually chosen, taking into account the predominant type of energy supply–anaerobic or aerobic. During swimming pool tests, a visual light pacer was used for velocity control ("Virtual Trainer 2", Aqvaspeed, Italy). At the swimming flume, the flow velocity was controlled with a dedicated gauge.

During the flume tests, metabolic gas exchanges were continuously measured using the "MetaSwim" testing system ("Cortex", Leipzig, Germany). However, when testing in the pool, metabolic gas exchanges were measured during the first 2 min of each rest interval using a "MetaMax" mobile system ("Cortex", Leipzig, Germany). Basal values were obtained after 5 min of resting in an upright position immersed up to the neck in the pool in both tests, using the same instruments as for exercise measurements. Before each test stage and after performing in both conditions, blood samples were taken from swimmers' fingers for peak capillary blood lactate concentration assessment using a biochemical analyzer "Stat Fax 4500" ("Awareness Technology", Palm City, FL, USA).

To determine the total energy expenditure (E_{ai}) in both tests, the method of indirect calorimetry was used [3, 7, 10, 11].This approach is formalized as an equation for determining E_{ai}, consisting of the sum of three components: aerobic ($E_{ai(\mathrm{Aer})}$), anaerobic alactic ($E_{ai(\mathrm{AnAl})}$) and anaerobic lactic components ($E_{ai(\mathrm{Anl})}$) [4]. When testing in the swimming flume, at each stage of the test, all three components of E_{ai} were determined based on direct measurements. In the pool test, on the other hand, $E_{ai(\mathrm{AnAl})}$ and $E_{ai(\mathrm{Anl})}$ were also determined based on direct measurements from capillary blood lactate concentrations and recovery VO_2 values, but $E_{ai(\mathrm{Aer})}$ was calculated taking into account the individual values of $E_{ai(\mathrm{AnAl})}$ and $E_{ai(\mathrm{Anl})}$ obtained in the pool and the individual partial contributions of the main energy components to E_{ai} obtained earlier in the flume for the corresponding intensity step of the swimming pool test. The magnitude of metabolic power for each stage of the pool test was determined using the following equation:

$$P_{ai} = E_{ai} \times t^{-1} \tag{2}$$

where, P_{ai} is metabolic power (W) and t is the swimming time of the 200 m lap in test (s).

The rest variables of the biophysical model (1): P_{to}, e_g,e_p, and $F_{r(\mathrm{fd})}$, as well as the main indicators of the process under study: $C_{x(\mathrm{ad})}$ (the dimensionless coefficient of the active drag force) and $C_{x(\mathbf{sn})}$ (the dimensionless coefficient of the frontal component of the active drag force), were determined in the pool using a complex of specially oriented methods: a small perturbation method (standard variant SPM) [12] and a bio hydrodynamics method [4, 13]. The theory, technology, verification, and relevance evaluation of the used physiological, metabolic, and biomechanical methods are presented in detail in the works mentioned in this paragraph. All the testing procedures were naturally included in the subjects' individual training processes.

All experimental measurements and data collection were conducted in accordance with the CIOMS ethical guidance and standards, and all the subjects signed an informed consent form(Permission of the Ethics Committee of the Ministry of Sports, Tourism and Youth Policy of the Russian Federation dated December 15, 2016 No. 76).

3. Results and Discussion

The main results of the study in different periods of preparation in the macrocycle for a female front crawl swimmer F1 are presented in: Table 1A –the dynamics of the weekly swimming volume and its distribution by training categories; Figure 1– the dynamics of functional dependencies (metabolic curves) between $v_{0\exp}$ and P_{ai}(A) and between P_{ai} and P_{to}(B) in the 8 × 200 m step-test performed in the swimming pool; Table 1B–the experimental values obtained for biophysical model variables (1) of the P_{ai} into $v_{0\exp}$ transformation process in the last stage step-test. The analogous study data for a female butterfly swimmer F2 are presented in Table 2A, Figure 2and Table 2B; for a female back stroke swimmer F3 – in Table 3A, Figure3and Table 3B; forafemalebreaststrokeswimmerF4 – in Table 4A, Figure4and Table 4B. Table 5 represents the total swimming volume for all the subjects of the study and its distribution between the training categories for the entire training macrocycle.

Analysis of the dynamics of metabolic and biomechanical criteria of preparedness of the female front crawl swimmer F1 (age – 26 years, height – 1.82 m).The data of test 1, conducted during the *introductory block* (Figure1, Table 1B),reveal the initial level of the studied criteria of preparedness P_{ai}, e_g,e_p,$F_{r(\mathrm{fd})}$, and numerically explain the mechanism of achieving $v_{0\exp}$= 1.46m•s^{-1}by the subject at the final step of the test. Since the study was an integral part of the swimmers' training for the WSC, the following analysis was carried out strictly from the *longitude standpoint:* the experimental data in the analyzed period were compared to the similar data in the previous period.

Table1A. *The dynamics of the weekly swimming volume and its distribution by training categories in different periods of preparation in the macrocycle for a female front crawl swimmer F1.*

Periods	introductory block		aerobic and strength preparation block				specific preparation block					taper phase and major competitions			
Weeks	April 17	April 24	May 01	May 08	May 15	May 22	May 29	June 05	June 12	June 19	June 26	July 03	July 10	July 17	July 24
Total weekly volume, km	35.0	37.1	47.9	60.1	41.9	60.1	68.0	35.1	56.1	50.9	44.1	39.5	33.3	29.1	26.2
Rec-F, km	17.5	18.5	20.1	21.0	18.4	23.7	20.4	15.7	16.8	20.4	19.7	18.1	19.3	19.5	19.5
Rec-S, km	4.9	5.0	4.9	7.3	9.9	9.5	9.3	6.9	12.0	5.0	7.5	5.9	2.2		
EN1, km	9.3	9.3	12.6	12.8	8.5	10.7	13.6	4.6	12.2	11.9	5.3	4.9	5.1	2.4	2.8
EN2, km	2.6	3.1	8.3	14.6	3.3	10.8	18.7	5.4	11.3	8.1	8.4	6.1	3.1	5.2	1.4
EN3, km		0.2	1.1	2.1		0.5	2.1	1.0	0.8	2.3	0.5	1.7	1.2	0.6	0.4
SP1, km		0.2		1.2		0.4		0.6	1.4	1.1	0.6	1.3	0.9	0.4	0.5
SP2, km						0.4		0.4	0.9	1.5	1.2	0.6	0.4	0.4	1.2
SP3, km	0.7	0.7	0.9	1.1	1.8	4.1	3.9	0.5	0.7	0.6	0.9	0.9	1.1	0.6	0.4

Legend: *Rec-F – minimal aerobic metabolism at any unregulated swimming velocity; Rec-S– minimal aerobic metabolism at any unregulated swimming velocity using a biomechanical breathing simulator; EN1– threshold of aerobic metabolism; EN2– threshold of anaerobic metabolism; EN3 – maximum oxygen consumption;SP1 – anaerobic metabolism in the zone of tolerable lactate; SP2 – anaerobic metabolism in the zone of peak lactate production; SP3 – alactic metabolism.*

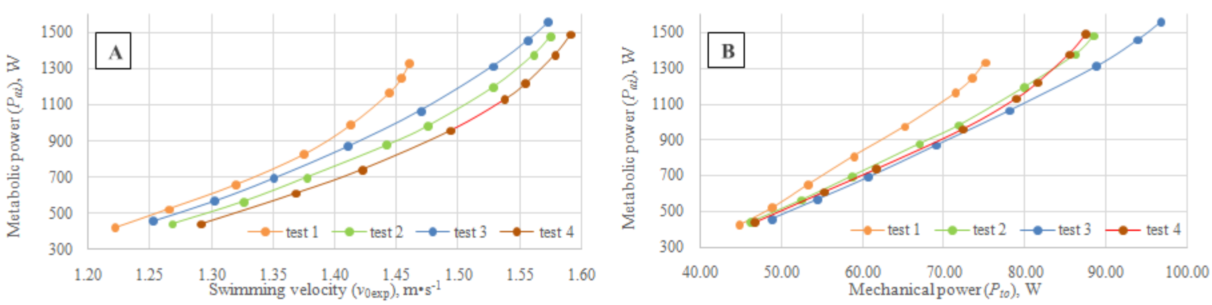

Figure1. *Dynamics of functional dependencies (metabolic curves)between $v_{0\exp}$ and P_{ai} (**A**) and between P_{to} and P_{ai} (**B**)for a female front crawl swimmer **F1**(26 years) in the step test 8 × 200 m over the periods of the training macrocycle. Legend: the introductory block(test 1, body mass–68.5 kg, $C_{x(ad)}$–0.288);the aerobic and strength preparation block(test 2, body mass–67.1 kg, $C_{x(ad)}$–0.274);the specific preparation block (test 3, body mass–67.8 kg, $C_{x(ad)}$–0.299);the taper phase and major competitions(test 4, body mass–67.4 kg, $C_{x(ad)}$–0.262).*

Table1B. *The experimental values obtained for biophysical model variables (1) of the P_{ai} into v_{0exp} transformation process in the last stage step-test in different periods of preparation in the macrocycle for a female front crawl swimmer F1.*

№ test	$v_{0\text{exp}}$ (m•s^{-1})	E_{ai} (kJ)	$E_{ai(\text{Aer})}$ (kJ)	$E_{ai(\text{AnAl})}$ (kJ)	$E_{ai(\text{Anl})}$ (kJ)	P_{ai} (W)	P_{to} (W)	e_g	e_p	$F_{r(\text{fd})}$ (N)	$C_{x(\text{sn})}$
1	1.46	179.46	106.90	34.01	38.56	1333	75	0.056	0.67	34	0.274
2	1.57	184.59	115.17	35.40	34.03	1481	88	0.060	0.69	39	0.267
3	1.57	194.91	113.18	40.72	41.02	1562	97	0.062	0.68	42	0.288
4	1.59	183.88	115.31	37.50	31.07	1491	87	0.059	0.71	39	0.255

Legend: *v_{0exp}– average swimming velocity at the test lap 200 m,E_{ai}– total energy expenditure, $E_{ai(Aer)}$–aerobic component, $E_{ai(AnAl)}$– anaerobic alactic component, $E_{ai(Anl)}$– anaerobic lactic component, P_{ai}– metabolic power, P_{to}– total external mechanical power,e_g– mechanical efficiency, e_p– propelling efficiency, $F_{r(fd)}$ – frontal component of active drag force in the steady non-stationary mode of body motion, $C_{x(sn)}$– dimensionless coefficient of the frontal component of the active dragforce.*

Training performed in the *aerobic and strength preparation block* (Table 1A) resulted in the shift of the metabolic curve to the right over the entire range of the developed velocities in the coordinates «$v_{0\text{exp}} – P_{ai}$» (test 2: Figure 1).In terms of the *macro approach*, most specialists and practical coaches interpret such changes as the positive dynamics of the level of subjects' functional preparedness [6, 14], since the same velocity values are achieved with lower P_{ai}in this test. Indeed, at the final step of the test,$v_{0\text{exp}}$ increased to 1.57m•s^{-1} (test 2: Table 1B), which was connected with the increase in E_{ai} and the corresponding increase in P_{ai}. This is the *first and most obvious factor* influencing the increase in swimming velocity. At that stage, changing E_{ai} was connected with a slight quantitative increase in the contributions of the aerobic component and the anaerobic alactic component, as well as a decrease in the contribution of the anaerobic lactic component, which resulted in the change of the partial contributions: $E_{ai(\text{Aer})}/E_{ai(\text{AnAl})}/E_{ai(\text{Anl})}$=62/20/18%[2].

However, a detailed analysis of the mechanisms of the observed increase in $v_{0\text{exp}}$ from the position of *micro approach,* based on the biophysical model (1), provides a more accurate and interrelated assessment of the influence of strength and technical preparedness. The metabolic curve shifted to the right in the «P_{to}–P_{ai}» coordinates, which explicitly indicated the growth of strength preparedness, since, with the same values, P_{ai} transformed more effectively into P_{to} over the entire velocity range. Determined under conditions of water locomotion and quantitatively reflecting the efficiency of the process, e_g is not a constant value since it is inversely proportional to$v_{0\text{exp}}$[4]. In the test, e_g gradually decreased from the value of 0.105 at the minimal v_{0exp} = 1.27m•s^{-1} to the value of 0.060 at the maximal v_{0exp} = 1.57m•s^{-1}. Therefore, the *second factor* for increasing $v_{0\text{exp}}$ is the increase in e_g, which, given the change in P_{ai}, leads to the increase in P_{to}.

The third, *not less significant, factor* for increasing$v_{0\text{exp}}$ is the increase in e_p (the main criterion of technical preparedness), which definitely indicates the high effectiveness of the individual technical training program used in this period.

The frontal component of the active drag force in the steady non-stationary mode of body motion ($F_{r(\text{fd})}$) depends not only on the kinematic and dynamic characteristics of the interaction of the swimmer's body and its movers with water but also largely on $v_{0\text{exp}}$. Therefore, an accurate assessment of changes in $F_{r(\text{fd})}$ = 39 N was made on the basis of the dimensionless coefficient of the frontal component of the active drag force ($C_{x(\text{sn})}$), which allowed to neutralize the influence of $v_{0\text{exp}}$ and the subject's body mass [4].Such a comparative evaluation of the results of tests 1 and 2 revealed the improvement of the additional criterion of technical preparedness (test 1: $C_{x(\text{sn})}$= 0.274; test 2: $C_{x(\text{sn})}$= 0.267), which is the *fourth factor* for increasing $v_{0\text{exp}}$.

Training performed in the *specific preparation block* (Table 1A) resulted in a slight shift of the metabolic curve to the left in the coordinate system «$v_{0exp} – P_{ai}$» (test 3: Figure 1, Table 1B), which is usually considered to be a negative process by the swimmer and the personal coach from the position of *macro approach*. In spite of increasing E_{ai} and P_{ai} at the final step of the test, $v_{0\text{exp}}$ remained at the same level = 1.57 m•s^{-1}. The observed change in E_{ai} was connected with a slight decrease in $E_{ai(\text{Aer})}$

[2] Further, in the text, the ratios of partial contributions are given in curly brackets in the same sequence without indicating the corresponding abbreviations.

and an optimal increase in $E_{ai(\text{AnAl})}$ and $E_{ai(\text{Anl})}$, which resulted in the corresponding change in the partial contributions of the main energy components {58/21/21%}.

However, analyzing the mechanisms of maintaining $v_{0\text{exp}}$ from the position of *micro approach* suggests a different interpretation of the process under study. In the coordinate system «P_{to} – P_{ai}», the metabolic curve shifted to the right over the entire velocity range, which indicated an increase in the level of strength preparedness and fully met the objectives of the training period. At the final step of the test, e_g increased to a value of 0.062. At that moment of training, a slight decrease in e_p and increase in $F_{r(\text{fd})}$ with the same $v_{0\text{exp}}$= 1.57m•s^{-1} was a temporary but natural process as a result of extremely «hard» training exercises in the SP1 and SP2 categories and the subject's participation in a series of official competitions [5]. In other words, the observed insignificant decrease in the main and additional criteria of technical preparedness during special training is a natural process that does not imply an urgent correction of the individual training program.

Training performed in the *taper phase* (Table 1A) resulted in a significant shift of the metabolic curve to the right in the coordinate system «v_{0exp} – P_{ai}» (test 4: Figure 1,Table 1B), which is usually treated quite positively by the swimmer and the coach from the position of *macro approach*. At the final step of the test, $v_{0\text{exp}}$ increased up to 1.59 m•s^{-1} with a simultaneous slight decrease in E_{ai} and P_{ai}. The change in E_{ai} was connected with a slight increase in $E_{ai(\text{Aer})}$, a slight decrease in $E_{ai(\text{AnAl})}$, and an optimal decrease in $E_{ai(\text{Anl})}$, which brought about the corresponding change in the partial contributions of the main energy components {63/20/17%}.

Analyzing the mechanisms of increasing $v_{0\text{exp}}$ from the position of *micro approach* similarly allows for an accurate and interrelated assessment of the influence of strength and technical preparedness. In the «P_{to} – P_{ai}» coordinate system, at most of the velocities, the metabolic curve didn't shift at all, except for shifting to the left only in the upper part of the range. Indeed, at the final step of the test, there was an optimal reduction in e_g, which brought about the corresponding reduction in P_{to}. Therefore, the two key factors for increasing $v_{0\text{exp}}$ were increasing e_p to a value of 0.71 and decreasing $F_{r(\text{fd})}$ to a value of 39 N ($C_{x(\text{sn})}$=0.255). Thus, it can be clearly stated that at the taper phase of the analyzed training macrocycle, the subject achieved the best criteria of technical preparedness.

From the analysis of the partial contributions of the main energy components during the *entire period of training macrocycle*, the athlete's metabolism can be classified as well balanced, without a predominating contribution of aerobic or anaerobic components to E_{ai}, compared to elite athletes' average results at the distance of 200 m [5, 7, 15].Due to the individual training program, optimally balanced levels of various aspects of preparedness were achieved on the eve of the WSC, which allowed the subject to set a personal record in the 200m front crawl in the final swim of the competitions.

Analysis of the dynamics of metabolic and biomechanical criteria of preparedness of the female butterfly swimmer F2 (age – 21 years, height – 1.80 m).

Table2A. *The dynamics of the weekly swimming volume and its distribution by training categories in different periods of preparation in the macrocycle for a female butterfly swimmer F2.*

Periods	introductory block		aerobic and strength preparation block				specific preparation block					taper phase and major competitions			
Weeks	April 17	April 24	May 01	May 08	May 15	May 22	May 29	June 05	June 12	June 19	June 26	July 03	July 10	July 17	July 24
Total weekly volume, km	32.8	33.6	42.3	52.5	40.7	52.7	60.2	35.0	50.2	46.0	40.8	37.8	32.0	28.5	21.6
Rec-F, km	16.5	16.5	18.4	18.0	17.4	20.7	18.4	14.1	14.3	16.2	16.6	17.50	19.3	19.5	16.3
Rec-S, km	4.5	4.9	3.9	6.5	9.3	7.1	7.3	7.6	9.6	5.2	7.7	5.1	1.7		
EN1, km	9.0	8.5	11.1	11.8	8.9	8.3	12.6	4.7	11.2	10.5	4.7	4.1	4.9	2.4	3.2
EN2, km	2.4	2.8	6.9	11.6	3.5	12.1	16.5	4.6	10.2	7.7	7.7	6.4	2.9	5.2	1.0
EN3, km		0.2	1.4	2.4		0.8	2.3	1.8	1.4	2.4	1.3	1.9	1.1	0.4	
SP1, km		0.2		1.6		0.4		0.7	1.2	1.4	0.8	1.5	0.6	0.4	0.3
SP2, km						0.4		0.6	1.0	2.1	1.3	0.7	0.2		0.5
SP3, km	0.4	0.5	0.7	0.6	1.7	2.9	3.1	0.9	1.3	0.5	0.7	0.6	1.3	0.6	0.3

Legend: *the abbreviations used Rec-F, Rec-S,EN1,EN2,EN3, SP1, SP2 andSP3 are identical to Table 1A.*

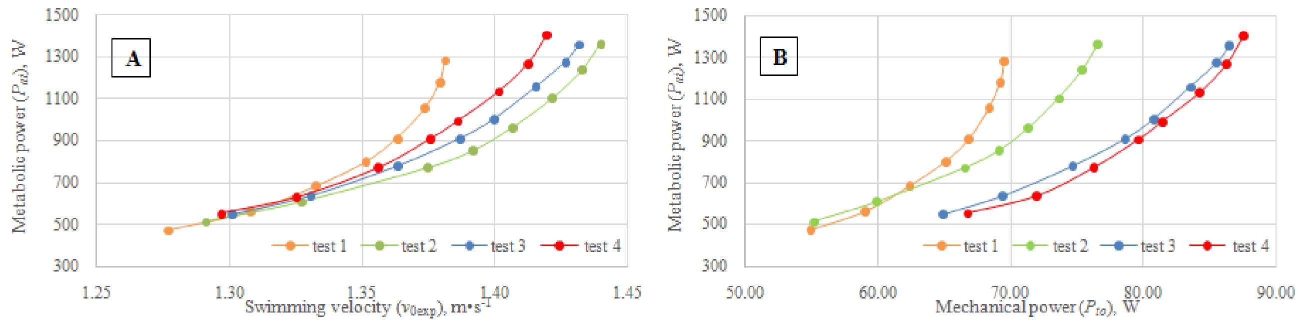

Figure2. *Dynamics of functional dependencies (metabolic curves)between v_{0exp} and P_{ai} (**A**) and between P_{to} and P_{ai} (**B**)for a female butterfly swimmer **F2**(21years) in the step test 8 × 200 m over the periods of the training macrocycle. Legend: the introductory block(test 1, body mass–60.8 kg, $C_{x(ad)}$–0.341);the aerobic and strength preparation block(test 2, body mass–59.8 kg, $C_{x(ad)}$–0.335);the specific preparation block (test 3, body mass–59.8 kg, $C_{x(ad)}$–0.385);the taper phase and major competitions(test 4, body mass–60.0 kg, $C_{x(ad)}$–0.399).*

Table2B. *The experimental values obtained for biophysical model variables (1) of the P_{ai} into v_{0exp} transformation process in the last stage step-test in different periods of preparation in the macrocycle for a female butterfly swimmer F2.*

№ test	v_{0exp} (m•s^{-1})	E_{ai} (kJ)	$E_{ai(Aer)}$ (kJ)	$E_{ai(AnAl)}$ (kJ)	$E_{ai(Anl)}$ (kJ)	P_{ai} (W)	P_{to} (W)	e_g	e_p	$F_{r(fd)}$ (N)	$C_{x(sn)}$
1	1.38	183.05	116.76	27.49	38.79	1285	70	0.054	0.65	33	0.307
2	1.44	186.23	123.53	28.09	34.61	1364	77	0.056	0.67	36	0.307
3	1.43	186.70	120.97	29.60	36.13	1360	86	0.064	0.64	39	0.337
4	1.42	194.79	119.25	32.08	43.45	1406	87	0.062	0.66	41	0.360

Legend: *the abbreviations used v_{0exp},E_{ai},$E_{ai(Aer)}$,$E_{ai(AnAl)}$,$E_{ai(Anl)}$,P_{ai},P_{to},e_g, e_p, $F_{r(fd)}$ and $C_{x(sn)}$ are identical to Table 1B.*

Training performed in the aerobic and strength preparation block (Table 2A) resulted in a rightward shift of the metabolic curve over almost the entire range of velocities in both coordinate systems (test 2: Figure2). At the final step of the test, v_{0exp} increased up to 1.44 m•s^{-1}, which was only partially due to the increase in E_{ai} and the corresponding increase in P_{ai} (test 2: Table 2B). The change in E_{ai} was connected with a slight increase in the contributions of the aerobic component and the anaerobic alactic component and a decrease in the contribution of the anaerobic lactic component, which brought about a change in the partial contributions: {66/15/19%}. The *microapproach* relates the change in v_{0exp} with a simultaneous increase in e_g, e_p, and $F_{r(fd)}$. The change in $F_{r(fd)}$ is treated as keeping the additional criterion of technical preparedness at the same level (test 1: $C_{x(sn)}$= 0.307; test 2: $C_{x(sn)}$= 0.307).

Training performed in the *specific preparation block* resulted in a shift of the metabolic curve to the left in the coordinate system «v_{0exp} – P_{ai}» within the last six steps (test 3: Figure2). In the «P_{to} – P_{ai}» coordinate system, the metabolic curve essentially shifted to the right throughout the velocity range. At the final step of the test, v_{0exp}slightly decreased to 1.43m•s^{-1}, which was not related to the change in E_{ai} and P_{ai} since their values remained at the same level. $E_{ai(Aer)}$ changed due to the decrease in $E_{ai(Aer)}$ contribution and the increase in $E_{ai(AnAl)}$ and $E_{ai(Anl)}$ contributions, resulting in the partial contributions change: {65/16/19%}.The *microapproach* relates this change inv_{0exp} with the multidirectional impact of the three factors: a positive one – a significant increase in e_g; and negative ones – a decrease in e_p and a significant increase in $F_{r(f.d.)}$, which, based on $C_{x(sn)}$, is estimated as an inadequately sharp deterioration of the additional criterion of technical preparedness. In other words, such a dynamic of the three factors at once (the decrease in $E_{ai(Aer)}$ and e_p contributions and the increase in $F_{r(fd)}$) is a negative process in this period of training, which demands a rapid correction of the further training program. Therefore, immediately after analyzing the results of test 3, the athlete's personal coach was recommended to make the urgently necessary adjustments to the tactical training plan: to increase the volume of exercises aimed at increasing the power of the aerobic system and to systematically use special exercises aimed at increasing e_p and reducing $F_{r(fd)}$.

Due to training performed in the *taper phase,* the metabolic curve shifted further to the left in the coordinates «v_{0exp} – P_{ai}» within the last six steps (test 4: Figure2). In the «P_{to} – P_{ai}» coordinate system, the metabolic curve shifted further to the right throughout the velocity range. At the final step of the test, $v_{0\text{exp}}$ decreased slightly to 1.42m•s^{-1} despite an increase in E_{ai} and P_{ai}.E_{ai} changed due to $E_{ai(\text{Aer})}$ contribution remaining the same and $E_{ai(\text{AnAl})}$ and $E_{ai(\text{Anl})}$ contributions increasing, which brought about the change in the partial contributions: {61/16/23%}.Again, the *microapproach* relates the change in$v_{0\text{exp}}$ with the multidirectional impact of the three factors: a positive one – an increase in e_p; and negative ones – a decrease in e_g and an increase in $F_{r(\text{fd})}$, which, on the basis of $C_{x(\text{sn})}$, is estimated as a further deterioration of the additional criterion of technical preparedness.

In the 200 m butterfly at the WSC, the subject's result was significantly inferior to her personal record. Based on the data on the main energy systems partial contributions during the *first three blocks of the training macrocycle,* the athlete's metabolism could be classified as aerobic. However, the training program in the last two weeks of the specific preparation block as well as in the taper phase caused an inadequate ratio between $E_{ai(\text{Aer})}/E_{ai(\text{AnAl})}/E_{ai(\text{Anl})}$,which is more typical for anaerobic-type swimmers.

In addition, the levels of the subject's strength and technical preparedness did not get optimally balanced despite the training program implementation in the taper phase: maxe_g = 0.064 was recorded in the specific preparation block, maxe_p = 0.67 was recorded in the aerobic and strength preparation block, and $C_{x(\text{sn})}$= 0.360 turned out to be the worst for the entiretraining macrocycle. Analyzing the training load within the final 5 weeks of the macrocycle (from June 19 to July 22) revealed the main reasons for the aforementioned phenomenon: an inadequately large volume of swimming in the categories SP1 and SP2; an excessive volume of special strength exercises on land and in water; a lack of special exercises aimed at increasing e_p and reducing $C_{x(\text{sn})}$. Thus, the practical recommendations to correct the training program based on the integral criteria of test 3, were obviously ignored by the athlete's personal coach.

Analysis of the dynamics of metabolic and biomechanical criteria of preparedness of the female backstroke swimmer F3 (age – 18 years, height – 1.81 m).

Table3A. *The dynamics of the weekly swimming volume and its distribution by training categories in different periods of preparation in the macrocycle for a female backstroke swimmer F3.*

Periods	introductory block		aerobic and strength preparation block				specific preparation block					taper phase and major competitions			
Weeks	April 17	April 24	May 01	May 08	May 15	May 22	May 29	June 05	June 12	June 19	June 26	July 03	July 10	July 17	July 24
Total weekly volume, km	36.1	36.8	50.7	61.8	44.1	63.7	71.8	40.8	62.2	57.9	48.3	43.4	36.7	31.3	29.5
Rec-F, km	18.9	18.9	17.6	19.8	16.8	20.1	21.6	13.9	16.5	19.2	20.1	18.5	21.5	21.5	21.7
Rec-S, km	5.1	5.2	6.9	5.3	9.1	10.5	8.3	8.1	13.6	6.3	7.9	6.5	0.2		
EN1, km	9.1	8.3	14.6	14.3	12.5	13.5	16.4	6.8	15.2	12.7	8.7	5.6	8.1	3.4	3.1
EN2, km	2.5	3.5	9.7	16.6	4.5	14.6	20.2	7.3	13.7	15.2	8.8	8.9	4.2	4.8	2.4
EN3, km		0.2	1.3	3.3		0.9	2.5	2.2	0.9	1.8	0.6	1.8	0.8	0.8	0.3
SP1, km		0.2		0.7		0.4		1.0	1.1	1.1	0.7	0.8	0.6	0.3	0.6
SP2, km						0.4		0.8	0.7	1.1	0.9	0.6	0.4		0.9
SP3, km	0.5	0.5	0.6	1.8	1.2	3.3	2.8	0.7	0.5	0.5	0.6	0.7	0.9	0.5	0.5

Legend: *the abbreviations used Rec-F, Rec-S,EN1,EN2,EN3, SP1, SP2 andSP3 are identical to Table 1A.*

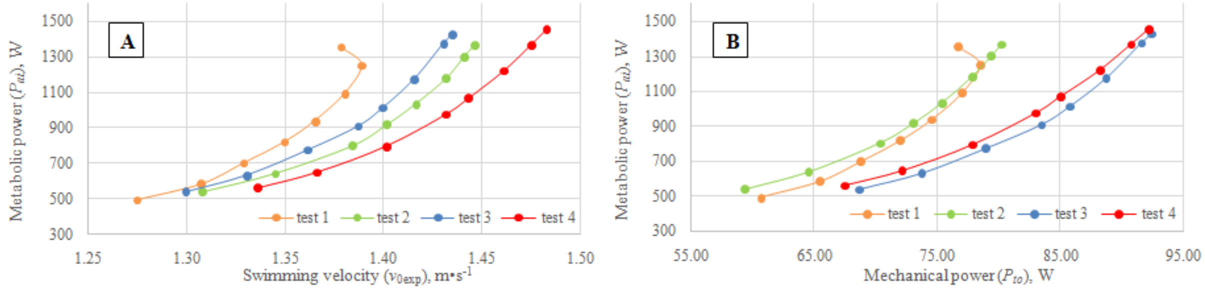

Figure3. *Dynamics of functional dependencies (metabolic curves)between $v_{0\text{exp}}$ and P_{ai} (**A**) and between P_{to} and P_{ai} (**B**)for a female backstroke swimmer **F3**(18years) in the step test 8 × 200 m over the periods of the training macrocycle.*

Legend: *the introductory block(test 1, body mass–68.1 kg, $C_{x(ad)}$–0.349);the aerobic and strength preparation block(test 2, body mass–67.1 kg, $C_{x(ad)}$–0.318);the specific preparation block (test 3, body mass–67.0 kg, $C_{x(ad)}$–0.381);the taper phase and major competitions(test 4, body mass–67.2 kg, $C_{x(ad)}$–0.342).*

Table3B. *The experimental values obtained for biophysical model variables (1) of the P_{ai} into v_{0exp} transformation process in the last stage step-test in different periods of preparation in the macrocycle for a female backstroke swimmer F3.*

№ test	$v_{0\text{exp}}$ ($m•s^{-1}$)	E_{ai} (kJ)	$E_{ai(\text{Aer})}$ (kJ)	$E_{ai(\text{AnAl})}$ (kJ)	$E_{ai(\text{Anl})}$ (kJ)	P_{ai} (W)	P_{to} (W)	e_g	e_p	$F_{r(\text{fd})}$ (N)	$C_{x\text{(sn)}}$
1	1.38	193.60	124.31	26.77	42.51	1357	76	0.056	0.67	37	0.305
2	1.45	186.02	127.05	29.38	29.59	1369	79	0.058	0.69	38	0.284
3	1.43	195.64	126.53	31.39	37.71	1428	93	0.065	0.69	45	0.341
4	1.48	193.03	131.51	31.37	30.14	1457	92	0.063	0.71	44	0.315

Legend: *the abbreviations used v_{0exp}, E_{ai}, $E_{ai(Aer)}$, $E_{ai(AnAl)}$, $E_{ai(Anl)}$, P_{ai}, P_{to}, e_g, e_p, $F_{r(fd)}$ and $C_{x(sn)}$ are identical to Table 1B.*

Due to training performed in the *aerobic and strength preparation block* (Table 3A), the metabolic curve shifted to the right in the coordinates «$v_{0\text{exp}} – P_{ai}$» practically over the entire velocity range (test 2: Figure3). At the final step of the test, $v_{0\text{exp}}$rose up to 1.45m•s^{-1} despite a decrease in E_{ai} and a corresponding decrease in P_{ai} (test 2: Table 3B). E_{ai} changed because of a slight increase in the contributions of the aerobic component and the anaerobic alactic component, as well as a decrease in the contribution of the anaerobic lactic component, which brought about a change in the partial contributions: {68/16/16%}.From the standpoint of the *microapproach*, the increase in $v_{0\text{exp}}$ is connected with an increase in e_g and $e_p$and an improvement of the additional criterion of technical preparedness (test 1: $C_{x\text{(sn)}}$= 0.305; test 2: $C_{x\text{(sn)}}$= 0.284).

Training performed in the *specific preparation block* resulted in a shift of the metabolic curve to the left in the coordinate system «$v_{0exp} – P_{ai}$» over the entire range of experimental velocities (test 3: Figure3). In the «$P_{to} – P_{ai}$» coordinate system, the metabolic curve significantly shifted to the right throughout the velocity range. At the final step of the test, $v_{0\text{exp}}$slightly decreased down to 1.43m•s^{-1}despite an increase in E_{ai} and P_{ai}. E_{ai} changed due to the $E_{ai(\text{Aer})}$ contribution remaining the same and the $E_{ai(\text{AnAl})}$ and $E_{ai(\text{Anl})}$ contributions increasing, resulting in a change in the partial contributions: {65/16/19%}.The *microapproach* suggests the multidirectional impact of the three factors for such a change in$v_{0\text{exp}}$: a positive one– a significant increase in e_g; a neutral one– keeping e_p at the same level; and a negative one – a significant increase in $F_{r(f.d.)}$, which, based on $C_{x\text{(sn)}}$**,** is estimated as inadequately drastic deterioration of the additional criterion of technical preparedness. In this respect, in order to improve technical preparedness, the athlete's personal coach promptly adjusted the further training program through the systematic use of special exercises.

Training performed in the *taper phase* brought about a significant shift of the metabolic curve to the right over the entire velocity range in the coordinates «$v_{0exp} – P_{ai}$» (test 4: Figure3). In the «$P_{to} – P_{ai}$» coordinate system, the metabolic curve slightly shifted to the left throughout the velocity range. At the final step of the test, $v_{0\text{exp}}$significantly rose to 1.48m•s^{-1}, which was only marginally related to the corresponding changes in E_{ai} and P_{ai}. The change in E_{ai} was connected with an increase in the contribution of $E_{ai(\text{Aer})}$, keeping the contribution of $E_{ai(\text{AnAl})}$at the same level, and a decrease in the contribution of $E_{ai(\text{Anl})}$, which resulted in a change in the partial contributions: {68/16/16%}.The *microapproach* relates such a change in$v_{0\text{exp}}$ with the multidirectional impact of the three factors: positive ones–an increase in e_p and improvement of the additional criterion of technical preparedness ($C_{x\text{(sn)}}$= 0.315); and a negative one– an insignificant decrease in e_g.

Analyzing the partial contributions of the main energy systems over the *entire training macrocycle* allows to classify the athlete's metabolism as aerobic. Due to the individual training program rapidly adjusted by the personal coach, the various aspects of the subject's preparedness on the eve of the WSC got optimally balanced, which allowed her to set a personal record in the 200m backstroke in the final of these competitions.

Analysis of the dynamics of metabolic and biomechanical criteria of preparedness of a female breaststroke swimmer F4 (age – 25 years, height – 1.78 m).

Table4A. *The dynamics of the weekly swimming volume and its distribution by training categories in different periods of preparation in the macrocycle for a female breaststroke swimmer F4.*

Periods	introductory block		aerobic and strength preparation block				specific preparation block					taper phase and major competitions			
Weeks	April 17	April 24	May 01	May 08	May 15	May 22	May 29	June 05	June 12	June 19	June 26	July 03	July 10	July 17	July 24
Total weekly volume, km	30.2	31.1	42.6	50.9	32.2	53.0	56.6	30.4	50.4	44.0	38.9	35.4	27.2	23.5	23.1
Rec-F, km	15.5	15.5	15.9	15.7	11.3	18.4	16.3	11.1	14.5	16.3	16.4	16.70	14.8	16.3	16.7
Rec-S, km	4.1	4.4	4.2	6.3	9.2	9.8	7.8	6.5	9.0	4.3	4.3	3.2			
EN1, km	8.5	7.8	12.6	14.8	6.7	9.2	12.7	4.7	12.1	10.8	5.8	5.9	7.1	2.4	3.2
EN2, km	1.8	2.1	7.9	10.6	2.9	10.1	15.7	5.1	11.1	7.9	9.4	5.8	3.3	3.2	1.1
EN3, km		0.2	0.7	1.3		1.2	1.5	0.8	1.2	1.9	0.8	1.5	0.7	0.6	
SP1, km						0.4		0.8	1.1	1.1	0.4	1.1	0.4	0.4	0.4
SP2, km						0.4		0.2	0.8	1.3	1.0	0.6	0.2		1.3
SP3, km	0.3	0.8	1.3	1.4	2.1	3.5	2.6	1.2	0.6	0.4	0.8	0.6	0.7	0.6	0.3

Legend: *the abbreviations used Rec-F, Rec-S,EN1,EN2,EN3, SP1, SP2 andSP3 are identical to Table 1A.*

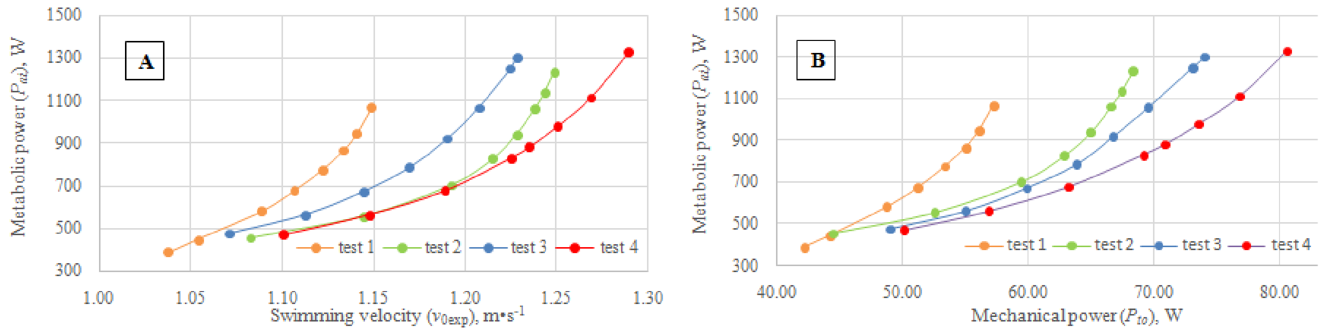

Figure4. *Dynamics of functional dependencies (metabolic curves)between v_{0exp} and P_{ai} (**A**) and between P_{to} and P_{ai} (**B**)for a female breaststroke swimmer **F4**(25 years) in the step test 8 × 200 m over the periods of the training macrocycle. Legend: the introductory block(test 1, body mass–68.5 kg, $C_{x(ad)}$–0.451);the aerobic and strength preparation block(test 2, body mass–67.9 kg, $C_{x(ad)}$–0.421);the specific preparation block (test 3, body mass–68.0 kg, $C_{x(ad)}$–0.479);the taper phase and major competitions(test 4, body mass–67.8 kg, $C_{x(ad)}$–0.452).*

Table4B. *The experimental values obtained for biophysical model variables (1) of the P_{ai} into v_{0exp} transformation process in the last stage step-test in different periods of preparation in the macrocycle for a female breaststroke swimmer F4.*

№ test	v_{0exp} (m•s^{-1})	E_{ai} (kJ)	$E_{ai(Aer)}$ (kJ)	$E_{ai(AnAl)}$ (kJ)	$E_{ai(Anl)}$ (kJ)	P_{ai} (W)	P_{to} (W)	e_g	e_p	$F_{r(fd)}$ (N)	$C_{x(sn)}$
1	1.15	183.53	126.65	26.48	30.39	1069	57	0.054	0.67	38	0.429
2	1.25	194.96	141.60	31.18	22.17	1236	68	0.055	0.69	38	0.358
3	1.23	208.74	139.32	30.29	39.12	1301	74	0.057	0.69	42	0.407
4	1.29	203.26	142.60	30.06	30.60	1331	81	0.061	0.73	46	0.406

Legend: *the abbreviations used v_{0exp},E_{ai},$E_{ai(Aer)}$,$E_{ai(AnAl)}$,$E_{ai(Anl)}$,P_{ai},P_{to},e_g, e_p, $F_{r(fd)}$ and $C_{x(sn)}$ are identical to Table 1B.*

Training performed in the *aerobic and strength preparation block* (Table 4A) resulted in a rightward shift of the metabolic curve over the entire velocity range in both coordinate systems (test 2: Figure 4). At the final step of the test, v_{0exp} increased up to 1.25m•s^{-1}, which was partly due to the increase in E_{ai} and P_{ai} (test 2: Table 4B). The change in E_{ai} was connected with a significant increase in the contributions of the aerobic component and the anaerobic alactic component, along with a decrease in the contribution of the anaerobic lactic component, which brought about a change in the partial contributions: {73/16/11%}.From the position of the *microapproach*, the increase in v_{0exp} is connected with an increase in e_g,e_p and a significant improvement of the additional criterion of technical preparedness(test 1: $C_{x(sn)}$= 0.429; test 2: $C_{x(sn)}$= 0.358).

Training performed in the *specific preparation block* made the metabolic curve shift to the left in the coordinate system «v_{0exp} – P_{ai}» and to the right – in the coordinate system «P_{to} – P_{ai}» over the entire velocity range (test 3: Figure 4).At the final step of the test, v_{0exp} slightly decreased to 1.23m•s^{-1}, despite a further increase in E_{ai} and P_{ai}. The change in E_{ai} was due to the $E_{ai(Aer)}$ and $E_{ai(AnAl)}$ contributions remaining almost the same and a significant increase in the $E_{ai(Anl)}$ contribution, which brought about a change in the partial contributions: {67/15/18%}. The *microapproach* relates such a change in $v_{0exp}$to the multidirectional influence of the three factors: a positive one–an increase in e_g; a neutral one –e_p remaining at the same level; and a negative one – a slight decrease in the additional criterion of technical preparedness.

Training performed in the *taper phase* resulted in a rightward shift of the metabolic curve only in the upper part of the velocity range in the coordinates «v_{0exp} – P_{ai}» (test 4: Figure 4). In the «P_{to} – P_{ai}» coordinate system, the metabolic curve significantly shifted to the left throughout the velocity range. At the final step of the test, v_{0exp}essentially increased to 1.29m•s^{-1}, which was only marginally related to the corresponding changes in E_{ai} and P_{ai}. The change in E_{ai} was connected with an increase in the $E_{ai(Aer)}$ contribution, keeping the $E_{ai(AnAl)}$contribution the same, and a decrease in the $E_{ai(Anl)}$ contribution, which brought about a change in the partial contributions: {70/15/15%}.From the position of the *microapproach*, the change inv_{0exp} is also connected with the multidirectional impact of the three factors: positive ones – increasing in e_g and e_p; and a neutral one– keeping the additional criterion of technical preparedness at the same level ($C_{x(sn)}$= 0.406). It should be noted that the simultaneous increase in e_g and e_p in the taper phase is extremely rare, because these indicators are negatively related [5, 6] and indicates a fine and professional balance of strength and technical training programs in the taper phase.

The athlete's metabolism can be classified as aerobic based on the analysis of the partial contributions of the main energy systems for the entire *macrocycle of training*. Due to the individual training program, the various aspects of the subject's preparedness got optimally balanced on the eve of the WSC, which allowed her to set a personal record in the 200m breaststroke in the final of the competitions.

Table5. *Total volume of swimming and its distribution by training categories for the entire analyzed macrocycle of preparation for the subjects F1, F2, F3 and F4.*

Subject	Total volume, km	Rec-F, km	Rec-S, km	EN1, km	EN2, km	EN3, km	SP1, km	SP2, km	SP3, km
F1	664 (100%)	288.6 (43.44%)	90.4 (13.61%)	126.0 (18.96%)	110.4 (16.62%)	14.5 (2.18%)	8.6 (1.29%)	7.0 (1.05%)	18.9 (2.84%)
F2	607 (100%)	259.6 (42.79%)	80.4 (13.25%)	115.9 (19.10%)	101.5 (16.73%)	17.4 (2.87%)	9.1 (1.50%)	6.8 (1.12%)	16.1 (2.65%)
F3	715 (100%)	286.6 (40.08%)	93.1 (13.02%)	152.3 (21.29%)	136.9 (19.14%)	17.4 (2.43%)	7.5 (1.05%)	5.8 (0.81%)	15.6 (2.17%)
F4	569 (100%)	231.4 (40.64%)	73.1 (12.84%)	124.3 (21.82%)	98.0 (17.21%)	12.4 (2.18%)	7.2 (1.26%)	5.8 (1.02%)	17.2 (3.03%)

Legend: *Rec-F – minimal aerobic metabolism at any unregulated swimming velocity; Rec-S– minimal aerobic metabolism at any unregulated swimming velocity using a biomechanical breathing simulator; EN1– threshold of aerobic metabolism; EN2– threshold of anaerobic metabolism; EN3 – maximum oxygen consumption;SP1 – anaerobic metabolism in the zone of tolerable lactate; SP2 – anaerobic metabolism in the zone of peak lactate production; SP3 – alactic metabolism.*

4. CONCLUSIONS

From the standpoint of the *macro approach*, the traditional final analysis of the subjects' sports results at the WSC compared to the completed training load during the entire preparation macrocycle (Table 5) doesn't give clear and precise answers to the number of simple questions which are extremely important for the athletes and their personal coaches in terms of further training. For instance, why did the subject F4, who completed the lowest total volume of swimming (569 km), achieve the best result (988 FINA Points)? Why did the subject F2,who performed the highest partial volume of high-intensity training in the EN3 (2.87%), SP1 (1.50%), and SP2 (1.12%) training categories, perform the least well (825 FINA Points)? A similar analysis from the perspective of the microapproach provides accurate individual answers to these and other questions. In general, the study showed that individual training programs of elite middle-distance swimmers in different strokes result in targeted, strongly interconnected, and, sometimes, significant changes in the numerical criteria of functional, strength, and technical preparedness in different periods of the macrocycle. The main factor for an athlete's successful performance in the main competitions is an optimal balance of individual values of metabolic power (P_{ai}), mechanical (e_g) and propelling (e_p) efficiency, and the frontal component of active drag force ($F_{r(\mathrm{fd})}$) in the taper phase.

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