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PHYSICAL ENDURANCE, SOMATIC INDICES AND SWIMMING TECHNIQUE PARAMETERS AS DETERMINANTS OF FRONT CRAWL SWIMMING SPEED AT SHORT DISTANCES IN YOUNG SWIMMERS

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Abstract

Introduction: Appropriate swimming techniques and anaerobic capacity have a strong influence on factors related to performance in young swimmers. This study evaluated the factors attributed to performance in sprint front crawl swimmers.

Aim of the study: To investigate the level of aerobic and anaerobic component of physical endurance, swimming technique and somatic indices, as well as to determine their influence on young swimmers' all-out sprint front crawl swimming.

Methods: The group of 26 swimmers (age: 16.1±1.09 years) was subject to anthropometric measurements including lean body mass (LBM), total body length (TBL) and arm span (AS). Each individual was subject to five laboratory tests and 2 swimming tests: alactic anaerobic test (vertical jump test – CMJ), incremental tests for assessment of arms ($\dot{V}O_2$max AR) and legs aerobic capacity ($\dot{V}O_2$max LG) in two different tests, one-minute anaerobic endurance tests for arms (60sAR) and legs (60sLG). Swimming include all-out tests at the distance of 25 and 100 meters.

Results: The biometric (TBL, AS) and body structure (LBM) indices level was in general determining swimming speed at high and average level. The maximal power obtained in anaerobic endurance test with legs (PmxLG) and total work in the CMJ (counter movement jump) test had the strongest influence on 25 and 100 meters swimming speeds. At both distances speed statistically significantly correlated also with the swimming technique parameters: stroke rate (SR), index of coordination (IdC) and propulsion phases (PL+PS).

Conclusions: Research on young swimmers confirmed essential influence of energy obtaining mechanisms from alactic, glycolitic and aerobic sources on swimming speed at short distances. Body size and swimming technique parameters had also significant influence on swimming results.

Key words: *front crawl, swimming technique, oxygen uptake, anaerobic capacity*

Introduction

Periodic monitoring of aerobic and anaerobic components of athletes' physical performance gives an opportunity to control and adapt training appropriately. This enables athletes to reach their peak performance. Athletes' physical loads in almost all sport disciplines, including swimming, include three main, overlapping, energy producing processes. The first one – anaerobic, the alactic path of gaining energy, is characterized by phosphocreatine (Pc) decomposition in muscle cells, which during short, intensive (explosive) exertions resynthesize adenosine-5′-triphosphate (ATP). This process is also referred to as the ATP-Pc system. The second process, also anaerobic – "lactic" –includes the catabolism of carbohydrates, mainly muscle glycogen. During exercise typical of a sustained sprint, muscle glycogen is decomposed into pyruvic acid and then lactic acid during anaerobic glycolysis. The third process – aerobic metabolic process – overlapping with the two mentioned before, includes the breakdown carbohydrates, free fatty acids and/or even protein oxidation. Together they enable ATP resynthesis, the highly energetic adenosine-5′-triphosphate reproduction, and reaches its highest level at the presence of phosphocreatine. Those biochemical processes allows skeletal muscles to develop large force quickly, right from the beginning of the physical effort. Knowledge of those effort metabolic processes is vital for training principles (1).

In laboratory practice, measurements of phosphagen component of swimmers physical endurance are rarely conducted. For instance Gerard et al. (2) showed statistically significant direct dependence between vertical jump results and type II fibers content in the *vastus lateralis* muscle with higher efficiency in short rather than long distance swimming. Keskinen et al. (3) noted significant dependence between explosive power measured in vertical jump test and swimming performance at the distance of 15 meters, including turn (7.5 m + turn + 7.5 m). Another example is in water polo players; their ability to increase swimming speed is co-dependent with the mass-center elevation height in the vertical jump test that was conducted on land and in water (4,5). The efficiency of the anaerobic glycolytic processes and power developed determine efficiency of the efforts lasting several dozen of seconds. The most popular test to assess anaerobic glycolytic processes is the 30-second long Wingate test (6). For this study, the Wingate was applied to both upper and lower muscle groups (7). Of note, some researchers suggest increasing the time of anaerobic test up to even 60–90 seconds (8-13). They claim that 30 or even 45 seconds long effort is too short for the maximal usage of anaerobic glycolitic potential, i.e. for the exhaustion of the energetic source.

According to Withers et al (14). and Carey et al. (15) in 60-second-long test assessing anaerobic capacity, during the last 30 seconds of physical effort, oxygen uptake amounts to 90.5% and 92% $\dot{V}O_2$max. Moreover, the percentage of power covered by aerobic source in this effort is high – 49% (14). In the light of this research, maximal minute oxygen uptake as an index of potential aerobic exertion abilities of the organism should also be used. $\dot{V}O_2$max assesses organism efficiency of swimmers specializing in short distance (duration of about 60 seconds) swimming.

There are various research protocols used to measure $\dot{V}O_2$max. Attempts to gradual increasing intensity are being used the most often, and rarely – continuous or interval efforts. Because of the specificity of swimming, swimmers' gradual tests on ergometers are often conducted in laboratories. They engage both upper (16) and lower (17,18) extremities. In laboratories equipped with a swimming flume such tests are conducted in water (17-19), and on swimming pool it is so called tethered swimming (18,20).

Also in case of young swimmers, early stage specialization occurs by the age of 13-14 years (21). In shaping swimming techniques according to style at sprint and resistance distances, somatic properties must also, or even above all, be taken into consideration. They include first of all total body length, arm span and lean body mass (23-27). These somatic attributes are largely inherited and together with anaerobic capacity potential they determine swimming technique to the highest degree.

In swimming technique parameters analyses, not only basic hydrodynamic rules but also movement patterns obtained from the world top swimmers are considered. In research of proficiency, professional swimmers are used as objective methods of technique assessment. They are based on the measurements of such parameters as: stroke length (SL – distance covered by a swimmers body during one cycle of arm movement) and stroke rate (SR). In case of various swimmers, depending on training status and distance covered, these parameters reach different levels. Mainly in youth groups, depending on training character, their impact on front crawl swimming speed may change. Coach opinions and some researchers reports prove that front crawl swimming results are most strongly correlated with stroke length (SL) (28,29). Proper Stroke length (SL) should be instructed first with young swimmers, because it is tightly bound to development of advanced technique, hydrodynamic excellence and higher swimming efficiency. However, such type of training may lead to oversight of other technique parameters, e.g. index of coordination (IdC), stroke rate (SR) (30) and to decreasing percentage of propulsion phases in arm movement cycles (31).

The purpose of this study was to investigate the level of aerobic and anaerobic capacity, described as the ability to resist fatigue (32). We will also research swimming techniques and somatic indices, as well as determining their influence on young swimmers' swimming all-out speed at short distances of 25 and 100m. Measurements and analysis of parameters discussed in the Introduction may be applicable to current researched athletes swimming results. Additionally, data analyzed in this work indices may be helpful in scheduling and verifying training assumptions for the coaches and members of the swimming community.

Materials and methods

Volunteers were recruited in sport oriented school signed a written informed consent. The research was approved by the Bioethics Commission in Cracow (No 292/KBL/OIL/2004 from 17th November 2004). The 26 swimmers were 16.1±1.09 years of age, 11 represented ectomorphic and 15 – mesomorphic body type (24).

On the basis of typical anthropometric measurements there were calculated e.g. somatotype using the method suggested by Carter-Heath (24), percent of fat (PF) and lean body mass (LBM) according to formula presented by Slaughter et al. (33). The total body length (TBL) was measured when lying back, from the tips of the fingers with the arms stretched up above the head down to the pointed toes. Arm span of abducted arms was measured between the arms from the fingertips. The measurements were completed using appropriate anthropometric instruments (Sieber Hegner Maschinen AG, Switzerland) and Harpenden-type foldmeter of constant pressure (10 g cm^{-2}).

Laboratory and swimming tests

Each individual in five days underwent five laboratory tests and two swimming tests:

1) alactic anaerobic test (vertical jump test – CMJ),
2) incremental tests for assessment of arms ($\dot{V}O_2$max AR) and legs aerobic uptake ($\dot{V}O_2$max LG),
3) one-minute anaerobic endurance tests for arms (60sAR) and legs (60sLG),

4) swimming all-out sprint at the distance of 25 meters,
5) swimming all-out sprint at the distance of 100 meters.

The arms tests ($\dot{V}O_2max$ AR and 60sAR) were performed in a sitting position, with the use of the 834E-Ergomedic ergometer, Monark (Sweden). The $\dot{V}O_2max$ LG legs aerobic capacity test was completed with the use of the ER 900 Jaeger cyclometer (Germany), and the 60sLG test on the 874E-Ergomedic cyclo ergometer, Monark (Sweden). The ergometer braking force was set for each individual at 7.5% BM in 60sLG and at 4.5% in 60sAR (6,34). Average power of arms and legs (PavAR and PavLG) as well as maximal power (PmxAR and PmxLG) were measured during these tests. The 60sAR, 60sLG, CMJ and swimming tests were preceded by 15-minute-long warm-up at intensity of 50% $\dot{V}O_2max$ with changeable movement rhythm. The incremental $\dot{V}O_2max$ LG test was preceded by a three-minute warm-up (WU) at intensity of about 45% $\dot{V}O_2max$, after which it was increased by about 30 W, every three minutes. The intensity of exercise during the warm-up was between 120 and 150 W, and in $\dot{V}O_2max$ AR 60 and 90 W depending on the age and physical endurance of the swimmer. In the $\dot{V}O_2max$ AR test the intensity was gradually increased every three minutes, for 12 or 18 W. The incremental exercises were performed at 70 rpm^{-1} in $\dot{V}O_2max$ LG and at 60 rpm^{-1} in $\dot{V}O_2max$ AR. The gas exchange indices were calculated, from one breath to another averaging it in 15 seconds periods, using the 919ER MEDIKRO meter (Finland).

Three minutes after both anaerobic tests and both swimming tests blood samples were drawn from the subjects' ear lobes in order to mark the lactate concentration (La), using the PLUS DR LANGE Miniphotometer (Germany). Maximal power and workload in single vertical jump (CMJ) were recorded using Opto Jump (Italy) apparatus. The elevation of the center of gravity during the vertical jump (CMJ) was assessed using the jump duration. Work during the jump (W) was calculated according to formula (2).

$$\Delta h = \frac{g t_l^2}{8} \quad (1) \qquad W = mg\Delta h = \frac{mg^2 t_l^2}{8} \quad (2)$$

where: WL – work during the jump [J]m – body mass [kg]
g – gravitational acceleration [$m\ s^{-2}$] t_l – jump duration [s]
Δh – elevation of the center of gravity [m]

The 100m and 25m swimming tests were carried out in a 50 meter-long swimming pool, with start in water. The 25 m swimming test was beginning with 5-meter-long start-up, and the time measurement started when the swimmer's head reached half of the swimming pool. Swimming parameters for 25m race were recorded once between the start line and the 20th meter of the distance, and for 100m race – twice between 5th and 25th meter and between 75th and 95th meter. The duration of the race and times of separate sectors were measured with a stopwatch with the accuracy of 0.01 s. The swimmers' movements were recorded using a GRV 9800 JVC underwater camera (Japan) from the side of the pool, 1m below the water surface, at 50 frames per second. Three full movement cycles were analysed.

As the arms movements during front crawl swimming are cyclic, the cycles were separated and divided into phases in the recording. The identification of the intracyclic phases was conducted according to Chollet et al. (30) method (fig. 1).

Cycles were divided into phases according to specific events during hand and arm movement (30). Each phase was specified according to its role in accelerating the swimmer's body (propulsion or non-propulsion

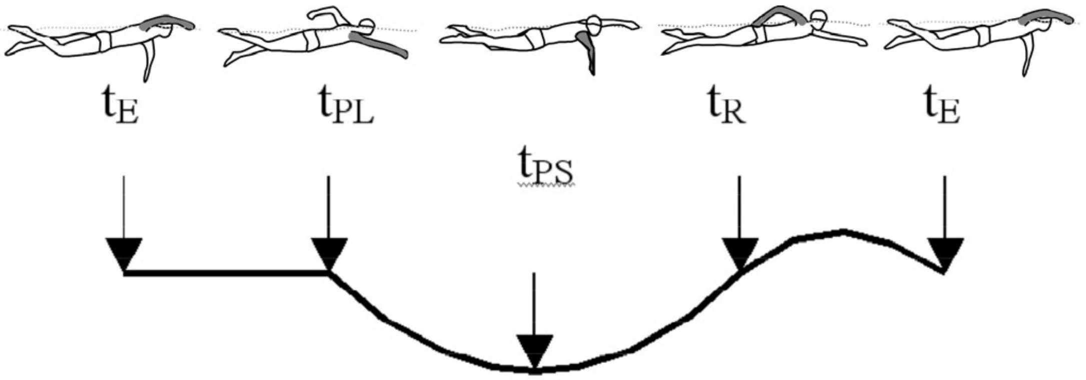

Fig. 1. *Front crawl upper extremity intracyclic phases division scheme (Chollet et al., 2000)*

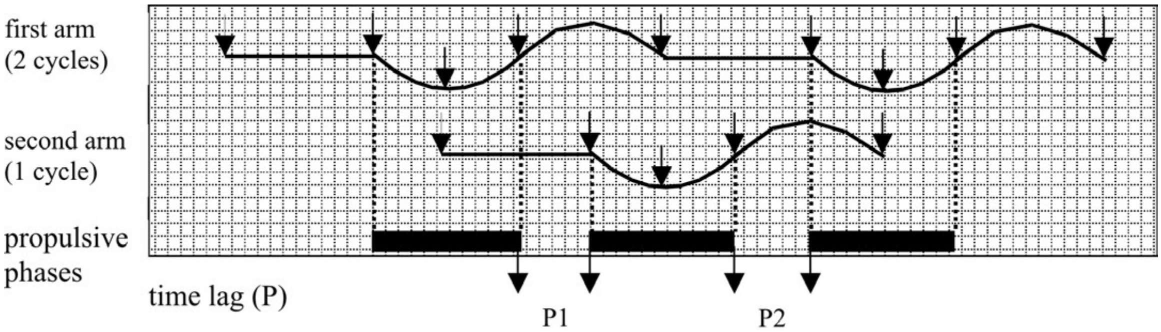

Fig. 2. *Arm movement coordination ("catch up")*

phase). The first is the entry phase (E – Entry, non-propulsion) – from the entry of the hand into the water till the beginning of its backward movement. Next is the first propulsion phase (PL – Pull) – from the end of the entry phase till the moment when the arm is vertically under the humeral joint. Third, the second propulsion phase (PS – Push) – from the vertical position of the arm till the arm release from the water. The cycle ends with the non-propulsion phase (R – Recovery) – from the hand's release from the water to its next entry into the water.

The following parameters were used to assess swimming technique during each analyzed 20m long swim (i=1,2,3,4):

1) Swimming speed: $V_i = 20\text{m} / \Delta t_i$, [$\text{m}\cdot\text{s}^{-1}$]
2) Stroke rate (SR_i), calculated as the reciprocal of the arithmetical average of duration of three analyzed swimming cycles: $SR_i = 1/T_i$, [$\text{ckl}\cdot\text{min}^{-1}$]
3) Stroke length (SL_i), calculated as the average speed to SR_i ratio: $SL_i = V_i/Sr_i$ [m].

The swimming cycles of both arms are typically phase-shifted. Depending on the chosen extremities coordination method, such a shift results in the occurrence of periods with no propulsion (when none of the extremities is in the propulsion phase) or periods with double propulsion (when both extremities are in the propulsion phase). Fig. 2 presents arm movement coordination ("catch up") with non-propulsive time lag (P) periods (IdC < 0) between the propulsive phases.

The index of coordination (IdC) has been used for the assessment of arm movement coordination. It is represented as percentage of the cycle length, similarly to all phases of the stroke cycle:

$$IdC_i = \frac{t_R^{k1} - t_{PL}^{k2}}{T_i} * 100\% \qquad (3)$$

where
IdC – index of coordination,

t_R^{k1} – start of the recovery phase (R) for the first arm,

t_{PL}^{k2} – start of the pull phase (PL) for the second arm,

T_i – total duration of the stroke cycle.

In case of overlapping phases IdC was positive, and in case of time lag between the phases it was negative.

Legs movement quantity (LQi), counted from the same shots as arms movements, were qualified as six-beat kick, corresponding to six complete alternating immersion and/or emersion movements in one upper extremities movement cycle, and four- and two-beat kick, for four and two leg movements in one arm movement cycle respectively.

Statistical analysis

To determine the relationship between *speed* and anaerobic or aerobic capacity and somatic or swimming technique variables, there were computed the partial correlations, controlling for age. Pearson correlations coefficients were calculated in relation to technique parameters of upper (SL, SR) and lower (LQ) extremities and between speed on 25 and 100 meter distances. Student's *t*-test for dependent groups was conducted to compare swimming results on two short distances analysed for one group of swimmers (2 dependent sets of results). Normal distribution of data was tested, confirm their formation similar to normal curve Gauss-Laplace. All tests were conducted with STATISTICA 6.1 software (StatSoft, Inc). The significance level was set at $P < 0{,}05$. Descriptive data were presented as mean ± standard deviation. Descriptive data is presented as mean ± standard deviation.

Results

Basic statistical descriptions of biometric and body structure indices as well as parameters of aerobic and anaerobic components are shown in table 1. Average power (PavAR) and maximal power (PmxAR) in the anaerobic endurance test using upper and lower extremities (PavLG) and (PmxLG) as well as maximal minute oxygen uptake ($\dot{V}O_2$max) in incremental test were the subject of detailed analysis. Moreover, total work index (CMJ) measured in a single vertical jump. In the examined group the level of the above-mentioned indices was diverse.

Table 1. *Swimmers' biometric, body structure and anaerobic and aerobic indices*

Parameters	BH [cm]	TBL [cm]	AS [cm]	BM [kg]	LBM [kg]	$\dot{V}O_2$max AR [l·min^{-1}]
$\bar{x}$ ± SD	177.5±8.07	245.5±12.98	182.4±10.28	65.4±9.40	58.7±8.05	3.14±0.54
Parameters	PavAR [W]	PmxAR [W]	PavLG [W]	PmxLG [W]	CMJ [J]	$\dot{V}O_2$max LG [l·min^{-1}]
$\bar{x}$ ± SD	284.4±55.36	349.9±83.04	468.8±76.75	655.3±115.01	281.1±61.75	3.82±0.53

Abbreviations used in Table 1.: BH – body height [cm], TBL – total body length when lying back [cm], AS – arm span [cm], BM – body mass [kg], LBM – lean body mass [kg], $\dot{V}O_2$max AR – maximal oxygen uptake of arms [l·min^{-1}], PavAR – average power of arms [W], PmxAR – maximal power of arms [W], PavLG – average power of legs [W], PmxLG – maximal power of legs [W], CMJ – work during the counter movement vertical jump [J], $\dot{V}O_2$max LG – maximal oxygen uptake of legs [l·min^{-1}].

Table 2. *Swimming technique parameters at 25 and 100m*

Distance	V[m·s^{-1}]	SR[ccl·min^{-1}]	SL[m]	IdC[%]	E[%]	PL[%]
25 m	1.73±0.12	54.9±4.26	1.90±0.16	3.3±5.91	23.6±7.09	21.0±4.53
100 m	1.63±0.10*	47.4±4.11*	2.00±0.19*	1.2±5.97*	26.6±7.84*	19.6±4.16*

Distance	PS[%]	R[%]	PL+PS[%]	E+R[%]	LQ2 [n]	LQ4 [n]	LQ6 [n]
25 m	29.6±4.03	25.8±3.38	50.6±6.38	49.4±6.38	5	6	15
100 m	28.0±3.82*	25.9±3.13	47.5±6.30*	52.5±6.30*	7	7	12

**P*<0.05 Statistically significant differences between groups

Abbreviations used in Table 2.: V – swimming speed [m·s^{-1}], SR – stroke rate [ccl·min^{-1}], SL –stroke length [m], IdC – index of arm movement coordination [%], E – entry; non-propulsion phase [%], PL– pull; propulsion phase PS – push; propulsion phase, R – recovery; non-propulsion phase, PL+PS – total of propulsion phases [%], E+R total of non-propulsion phases [%], LQ – legs movement quantity in one upper extremities movement cycle.

Table 3. *Selected partial correlations between swimmer's body morphological and functional indices, swimming technique parameters with age control and 25 and 100 meter swimming speed. Statistically significant correlations are marked with a star (P<0.05*, P<0.01 **)*

Parameters	TBL [cm]	AS [cm]	LBM [kg]	$\dot{V}O_2$max		PavAR [W]	PmxAR [W]	PavLG [W]	PmxLG [W]	CMJ [J]
				AR [l·min^{-1}]	LG [l·min^{-1}]					
V25 [m·s^{-1}]	0.58**	0.55**	0.39	0.37	0.53**	0.54**	0.44*	0.68**	0.81**	0.76**
V100 [m·s^{-1}]	0.61**	0.39	0.14	0.47**	0.53**	0.54**	0.45*	0.66**	0.75**	0.75**
SR25 [ccl·min^{-1}]	-0.07	-0.06	-0.19	0.18	0.13	0.32	0.38	0.27	0.55**	0.42$_{*}$
SR100 [ckl·min^{-1}]	-0.38	-0.33	-0.36	0.13	0.06	0.15	0.21	0.13	0.25	0.21
SL25 [m]	0.54**	0.51**	0.47*	-0.02	0.17	0.10	-0.07	0.16	0.14	-0.07
SL100 [m]	0. 61**	0.58**	0.57**	0.03	0.20	0.01	-0.24	0.11	0.01	-0.15
IdC25 [%]	-0.23	-0.32	-0.44*	0.07	0.39	0.47*	0.36	0.54**	0.69**	0.54**
IdC100 [%]	-0.27	-0.30	-0.29	0.09	0.20	0.22	0.10	0.29	0.25	0.32
PL+PS25 [%]	-0.05	-0.11	-0.12	0.12	0.26	0.35	0.26	0.30	0.53**	0.37
PL+PS100 [%]	-0.32	-0.32	-0.38	0.16	0.22	0.26	0.20	0.28	0.36	0.34
E+R 25 [%]	0.05	0.11	0.12	-0.12	-0.26	-0.35	-0.26	-0.30	-0.53**	-0.37
E+R 100 [%]	0.32	0.32	0.38	-0.16	-0.22	-0.26	-0.20	-0.28	-0.36	0.34

Abbreviations used in Table 2.: TBL – total body length when lying back [cm], AS – arm span [cm], LBM – lean body mass [kg], $\dot{V}O_2$max AR – maximal oxygen uptake of arms [l·min^{-1}], $\dot{V}O_2$max AR – maximal oxygen uptake of legs [l·min^{-1}], PavAR – average power of arms [W], PmxAR – maximal power of arms [W], PavLG – average power of legs [W], PmxLG – maximal power of legs [W], CMJ – work during the counter movement vertical jump [J] V – swimming speed [m·s^{-1}], SR – stroke rate [ccl·min^{-1}], SL –stroke length [m], IdC – index of arm movement coordination [%], PL+PS – total of propulsion phases [%], E+R total of non-propulsion phases [%].

Table 4. *Selected partial correlations between swimming speed and front crawl swimming technique indices at the distances of 25 and 100 meters. Statistically significant correlations are marked with a star (P<0.05*, P<0.01 **)*

Parameters	SR 25 [ckl·min^{-1}]	SL 25 [m]	IdC 25 [%]	PL+PS 25 [%]	E+R 25[%]	LQ 25 [n]
V 25 [m·s^{-1}]	0.66^{**}	-0.28	0.60^{**}	0.65^{**}	-0.65^{**}	0.33
Parameters	SR 100 [ckl·min^{-1}]	SL 100 [m]	IdC 100 [%]	PL+PS 100 [%]	E+R 100 [%]	LQ 100 [n]
V 100 [m·s^{-1}]	0.54^{**}	-0.20	0.51^{**}	0.63^{**}	-0.63^{**}	-0.15

Abbreviations used in Table 4.: V – swimming speed [m·s^{-1}], SR – stroke rate [ccl·min^{-1}], SL –stroke length [m], IdC – index of arm movement coordination [%], PL+PS – total of propulsion phases [%], E+R total of non-propulsion phases [%], LQ – legs movement quantity in one upper extremities movement cycle.

From data shown in Table 2 it follows that for front crawl swimming speed and swimming technique parameters were statistically significantly different at the distance of 25m than 100m, with the exception for the time percentage of hand's transposition above the water (R).

The biometric (TBL, AS) and body structure (LBM) indices levels were in general, determining of swimming speed at the distances at the high and average level excluding a weak correlation between LBM and V100. The interdependence between LBM and V25 or AS and V100 were of marginal statistical significance (*P*<0.08).

Average power in anaerobic endurance tests (PavAR and PavLG) had a substantial impact on swimming speed at the distance of 25 and 100m. Whereas maximal power (PmxAR) correlated with these indices to a lesser degree. The maximal power obtained in anaerobic test with lower extremities (PmxLG) and total work in the *vertical jump* test had a very strong influence on 25 and 100 meters-long swimming. All of the above-mentioned physical endurance indices strongly correlated, mostly statistically significantly (or of marginal statistical significance) with IdC at the distance of 25m (Table 3). Moreover, there was observed significant, or marginal significance, influence of $\dot{V}O_2max$ (in upper and lower extremities tests) on swimming speed at the distance of 25 and 100m. After anaerobic efforts using arms blood lactate concentration (LA) was on average about 12.6±1.73 mmol·l^{-1}, and in leg test 14.1±1.46 mmol·l^{-1} (*P*<0.01). In the 3rd minute after swimming test at the distance of 100m blood La concentration amounted to 12.2±1.89 mm·l^{-1} and was statistically significantly higher than after 25-meters-long test 7.8±1.96 mm·l^{-1}.

Swimming speed (V) at both distances strongly and statistically significantly correlated with front crawl swimming technique parameters (SR, IdC and PL+PS) (Table 4). Moreover, there was observed negative linear dependence between swimming technique indices LQ and SR (r = –0.47, *P*<0.01 for 25 m, and r = –0.43, *P*<0.02 for 100m). Leg movement number in one upper extremities movement cycle positively correlated with SL25 (r = 0.46, *P*<0.02) and SL100 (r = 0.50, *P*<0.01).

The dependence between swimming speed at both test distances was also measured. The connection was very strong, Pearson correlation index was r=0.96, *P*<0.001 (Fig. 3).

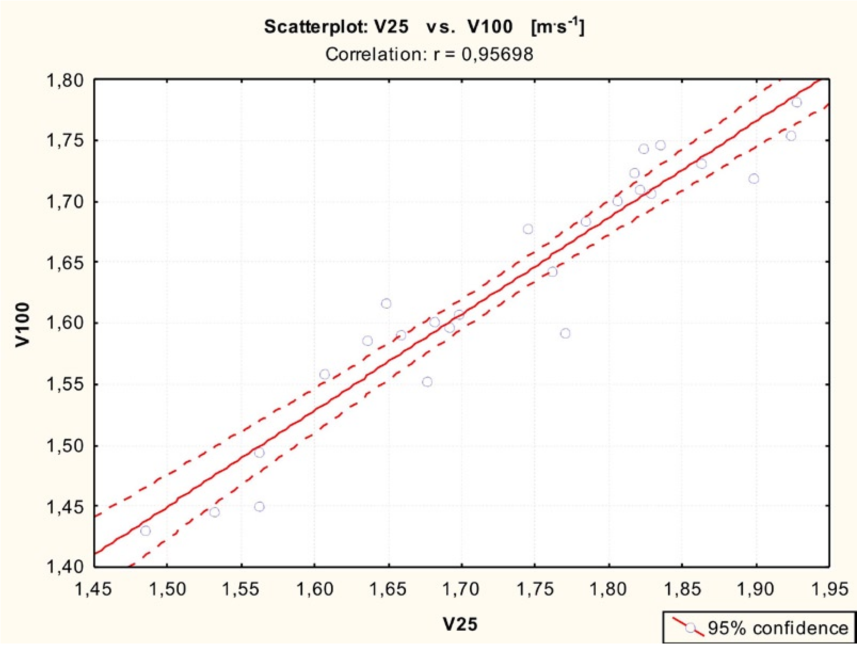

Fig. 3. *Regression line of the swimming speed at the distance of 25m versus swimming speed at the distance of 100m with 95% confidence interval marked with a dashed line*

Discussion

During swimming at the shortest distances the contribution of anaerobic glycolitic transformations in covering effort energetic cost is very high. In swimming sprint, from the muscle work energetics point of view, swimmer's motion speed in water depends mainly on organism's anaerobic metabolic transformations efficiency (35-39). It is also confirmed by the authors' research on young swimmers, whose maximal power obtained in one-minute anaerobic tests with arms (60sAR) and legs (60sLG) is highly correlated with swimming speed at the distances of 100 and 25m. Similar dependence on front crawl swimming speed at the distance of 100 and 25m showed CMJ index (positive correlations from r=0.75 to r=0.76).

A large contributor of anaerobic energetic transformations in those efforts shows high postexercise blood lactate concentration (La). For all examined athletes it was the highest after 100m front crawl race. After analyzing research results, considering metabolic profile, it may be argued that these young sprinters are highly efficient of anaerobic energy. Moreover, the observed statistically significant correlation between swimming speed at both distances and PavAR and PavLG results in one-minute tests is evidence of this conclusion. In practice, almost half of the power produced in the last 30 seconds of maximal one-minute work arises from aerobic source (40). The reflection of these observations were swimming tests results correlating with $\dot{V}O_2$max AR and $\dot{V}O_2$max LG at the level from r=0.37 at the edge of statistical significance ($P<0.08$) to r=0.53 ($P<0.01$). Prevailing influence of anaerobic efficiency indices (CMJ, PmxAR and PmxLG) on 25 and 100 meters swimming is indicated by a very high correlation (r=0.96).

Swimmers specializing in sprint have higher both body mass (BM) and lean body mass (LBM) as well as more favourable body length qualities than swimmers with endurance predispositions (23,27,38,41,42). In this research only the interdependence (of marginal statistical significance) between LBM and swimming speed at the distance of 25 meters was observed and there was no such dependence in the distance of 100 meters. Swimmers' body length indices TBL and AS had even stronger influence on 25 and 100m swimming speed, which is consistent with Kosmol's (43) observations. At the Olympic Games in Atlanta the average body height of the three medal winners in freestyle swimming at the distance of 100 meters was 198.33 cm, and for the finalists 194.00 cm. Athletes whose length body size are above average, reach usually higher kinetic energy than the smaller ones. However, water wave generated by movement of their bodies, which is of medium resistance, has lower amplitude than in case of their smaller competitors (44).

Furthermore, kinetic energy (dependent on speed) is partially changed into potential energy of the wave generated by the swimmer (dependent on the wave length and its amplitude). After reaching specific speed the wave generated has such properties that it practically obstructs further acceleration. To compare results of swimmers with different body lengths Froude number is often used,

$$Fr = \frac{v}{\sqrt{gl}} \qquad (4)$$

where
v – speed [$m \cdot s^{-1}$]
g – acceleration [$m \cdot s^{-2}$]
l – total body length [m]

For example, swimmers with similar body structure have the same Froude number, but the athlete with lower body length will reach lower swimming speed. According to Toussaint et al. (44) at swimming speeds above 1.5 $m \cdot s^{-1}$ the generated wave will be stronger limiting maximal body speed in water because it causes higher resistance. The observations of Vorontsov et al. (45) and Toussaint et al. (44) indicate that the longer body has more streamline properties because the zone separating boundary regions of high and low pressure is more at the back of the body, which causes generating smaller backwash and generates lower wave comparing to smaller body. Keeping in mind large influence of swimmer's body size on short distance swimming speed, in case of young swimmers it is relevant to predict the final body height. Body size forecasting besides considerations of genetics should also be based on comparison to growth charts in the frame of children and adolescent development – biological age control (21).

The results of the partial correlations between front crawl technique swimming indices and swimming tests results have shown that among swimming speed determinants at examined distances stroke rate (SR), index of coordination (IdC) and sum of propulsion phases in upper extremities movement cycle (PL+PS) played the strongest and the most statistically significant role. IdC strongly correlated with stroke rate (SR) which was also observed by Chollet et al. (30) and Potdevin et al. (46). Moreover, power indices and workload in anaerobic tests had the strongest influence on reaching high level of IdC and PL+PS at examined swimmers at the distance of 25 meters. The authors' research results and other researchers' reports (49,50) indicate that upper extremities movement's coordination, closer to so called "opposition", which does not show lag between propulsion phases or "superposition" with overlapping of these phases, was conductive to reaching higher swimming speed at both distances. Increasing swimming speed demands greater propulsion force by the swimmer through time-spatial structure of the arms movement cycle modification. It may be achieved by the shortening of the non-propulsion phases, especially arm transition above water (R), which is observed in case of the top swimmers (30) and gliding time shortening (E) in the phase of movement cycle beginning. Such action with stable SR level maintenance provides relative increase in propulsion generating in movement cycle and maintaining or increasing swimmer's swimming speed in spite of SL decrease in comparison with these parameters in long distance swimming. The authors did not observe significant influence of SL on swimming speed, although this parameter was in general strongly associated to swimmers' body size indices (TBL, AS, LBM),. Lack of such dependence might be caused by training specific parameter such as increasing stroke length. In researched swimmers group SL at the level of 94.3% and SR 91.5% of the parameters for Junior ME in Budapest finalists was noted. Meanwhile stroke rate increasing and upper extremities work synchronization facilitates the swimmer at short sprint distances to generate high mechanical power and to defy increasing front water resistance, which must be overcome by the swimmer using appropriate swimming technique. In this research it was observed that swimming speed increasing at short distances in comparison to long distances (42,47,48) is associated with increase in SR and IdC indices, which is consistent with the hydrodynamics theory assumptions (44). According to these assumptions arm speed determines resistance and lift. Finally, the greater the speed the higher the generated propulsion force.

Comparing authors' time-spatial front crawl swimming technique parameters at short distances of young swimmers to other researchers' results it was observed that obtaining high swimming speed is dependent on SR level and maintaining it on relatively stable level (26,46,49) and on higher and stable increase of SL level (26,31).

Results of research on young swimmers confirmed substantial impact of energy obtaining mechanisms (alactic, glycolitic and aerobic) on swimming efficiency at short distances. Significant influence on swimming results there had also body size, especially body total length (TBL), while the influence of an arm span (AS) and lean body mass (LBM) was smaller. These morphological indices significantly determined one of the essential swimming parameters – body transition during one movement cycle. Swimming technique level also significantly influenced the swimming efficiency. Some of its elements, for example, the sum of propulsion phases in arm movement cycle (PL+PS), SR and IdC have a strong relationship on front crawl swimming results at the distances of 25 and 100 meters.

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