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Factors determining swimming efficiency observed in less skilled swimmers

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The dynamics of performance in professional sport requires a systematic improvement of the training process. Such activities should also include optimizing the children and youth training in these disciplines, where an early specialization operates. The main aim of this paper was to search for the relationship between swimmer's segmental kinematics (segmental velocities, stroke rate, stroke length, stroke index); the relationship between swimmer's technical skill level (in four competitive swimming techniques) and training overloads taking into consideration gender and age effect. The study group consisted of 121 swimmers (69 female and 52 male), of the Polish 12–15 age group swim team, volunteered to serve as subjects. Video-based methods and video equipment are being applied to assist qualitative and simple quantitative analysis for immediate feedback and research in swimming. Both technical skill level preparation and segmental kinematics of 12–15 year old swimmers proved to be highly conditioned by implemented training intensity ($p < 0.001$), as well as the volume of training (high and average trade at a level of significance $p < 0.001$). Implemented training overloads expressed by both volume and intensity of training showed high and very high correlation with the swimming efficiency, presented segmental kinematics and technical skill level, however, there appeared particularly pronounced relationship with the size of kinematic parameters taken into account in four competitive swimming techniques, components of the 100 m individual medley.

Key words: *training loads, swimming strokes, kinematics*

1. Introduction

The dynamics of performance in professional sport requires a systematic improvement of the training process. Such activities should also include optimizing the training of children and youth in these disciplines, where an early specialization operates [1]. Researchers are constantly trying to find and classify factors which determine the highest precision in the swimming performance. This huge research has given special emphasis to the energetic and biomechanical assessments as the major determinants in enhancing swimming performance. Barbosa et al. state that from all the determinants the biophysical factors are getting most attention in swimming science [2], [3].

Due to progressively decreasing age in obtaining the peak performance among swimmers, it has become significant to recognize the factors that influence performance of young boys and girls. Seifert et al. claim that there are few factors deciding about higher performance. They say that improvement in swimming performance has been explained in terms of better control of stroke rate and stroke length, in particular with regard to race paces [4], skill due to age [5], [6] and gender [7], [8]. Despite the factors Seifert listed, and many more studies which have been published discussing the anthropometric and characteristics of the performance among young swimmers [9]–[14], there is still a need to carry out further research.

Most of the studies mentioned above were conducted exclusively in selected areas. It is appropriate

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then to further classify and clarify research including both internal and external determinants of swimming efficiency with the focus on all the factors: technique, kinematics, age and gender.

The main purpose of this paper was to search for the relationship between swimmer's segmental kinematics (segmental velocities, stroke rate, stroke length, stroke index); the relationship between swimmer's technical skill level (in four competitive swimming techniques) and training overloads taking into consideration gender and age effect.

2. Materials and methods

2.1. Participant characteristics

The study group consisted of 121 swimmers (69 female and 52 male), of the Polish 12–15 age group swim team, volunteered to serve as subjects. The subjects were informed about the methods and aims of the study and gave their written informed consent to participate; parental consent was obtained for underage subjects. Figure 1 presents percentage age distribution by gender.

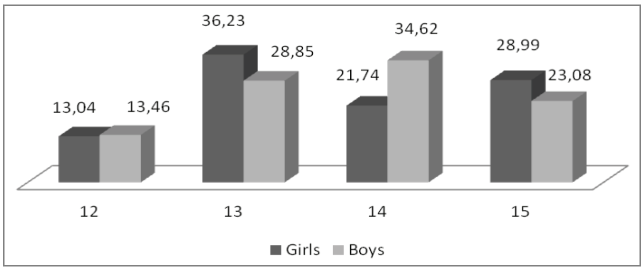

Fig. 1. Percentage age distribution by gender

The research was conducted over a period of one macrocycle lasting from 20 October 2008 to 25 January 2009, total 15 weeks. The purpose of this macrocycle was to prepare the swimmers to start in the Polish Championships. The macrocycle consisted of a preparatory period, the start-up and transition ones. The paper focuses on the special sub-phase, which aimed at the development of comprehensive features (speed, special strength) on the basis of work done in previous periods of training. Particular attention was paid to the improvement of swimming technique combining its implementation in parallel with the development of physical attributes. The authors have focused on two key areas: (i) quality of motor habit (forms and structure of the move) as the basis for the development of a speed development dispositions were improved, (ii) the swimmers worked on economics of movement techniques as the basis for the development of special strength.

This age group example shows a basic 15-week macrocycle, broken into 4 mesocycles. Competitions take place at irregular intervals within the macrocycle.

The recording and analysis of the data collected during the training session were based on the Excel spreadsheet database.

Computerized record workload of training was based on the following assumptions:

1. Training card subject to the appropriate formulations calculating both the duration of effort, and the volume and intensity in different areas of training both in the training unit statement, a daily, weekly and overall statements.

2. A card with the formula calculating the swimmer's Personal Best (PB) in particular areas of exertions and taking into account a series of measures

Table 1. Age group swim team – basic 15-week macrocycle with ascending loading sequence

Week	Mesocycle	Emphasis	Weekly Volume	Competition
1	1	Preparation week	45 kilometres	
2	1	Preparation week	50 kilometres	
3	1	Endurance week	55 kilometres	
4	1	Endurance week	60 kilometres	
5	2	Quality week	50 kilometres	Competition
6	2	Mixed week	60 kilometres	
7	2	Endurance week	55 kilometres	
8	2	Quality week	60 kilometres	
9	3	Mixed week	55 kilometres	
10	3	Endurance week	60 kilometres	
11	3	Quality week	55 kilometres	Competition
12	3	Mixed week	50 kilometres	
13	4	Mixed week	45 kilometres	
14	4	Taper week	40 kilometres	
15	4	Taper week	35 kilometres	Competition

used in the training of specialized and directed training. This was a key element in the diagnosis and prediction of individual level of the swimmer training tasks, and became a great predicator of functional possibilities during training units (to include minimum, maximum and average speed of swimming at the planned distances specifying their duration).

3. The classification system of exertion zones and their registration in the swimming training was created on the basis of the guidelines proposed by British Swimming Federation (www.whitedolphin.co.uk) [15]. Assumptions on the individual overload of training were implemented through the selection of the percentage of swimming speed in the exertion zones, calculated on the basis of the swimmers's Personal Best (PB) time for 200 m freestyle or style in which they specialized. In addition, the authors took into account the simulation of the speed of swimming with the designated time limit (maximum, minimum and average performance) for each exertion zone in the individual swimmers's personal best time. Simulation time limits were made individually for each swimmer.

2.2. Swim trial

The swimmers performed a 100-m individual medley trial (100 IM) with an individually specific speed in a 25-m pool. Each swimmer performed the test individually, on a separately marked lane, according to FINA rules. After each trial, all swimmers were informed of their performance time, which was estimated to be within ±2.5% of the Personal Best (PB), if not, the participant repeated the trial. The study was carried out twice before preparation period and afterwards. The participation in the examination of the swimmer was organized according to the Polish Swimming Association. During the startup the swimmer was recorded using the multi-camera motion techniques registration system. The Multi-camera Swimming Techniques Analysis System (Fig. 2) has been developed by the Swimming Technique Laboratory (www.l-t-p.pl) [16], and consisted of the following devices:

- Sliding platform on which the five camera system was installed: four overwater cameras and one underwater camera; the image recording speed was 25 frames per second.
- 1 m poles (tags) mounted along the line of the entire length of track-side of the swimming pool, at a meter, ranging from wall return basin, with special consideration to longer poles at the 5th and 20th meter of the swimming pool.
- Additional underwater camera recording the image in the exercise of relapse, mounted on the wall (on the opposite side of start bar).

The multi-camera motion techniques analysis system has facilitated a detailed record of the swimmers' movement techniques in the following areas:

- overwater side view – the whole distance of 100 meters,
- underwater side – view the entire 100 meters of distance,
- underwater view – front of the plane of relapse at 25 and 75 meter of the covered distance,

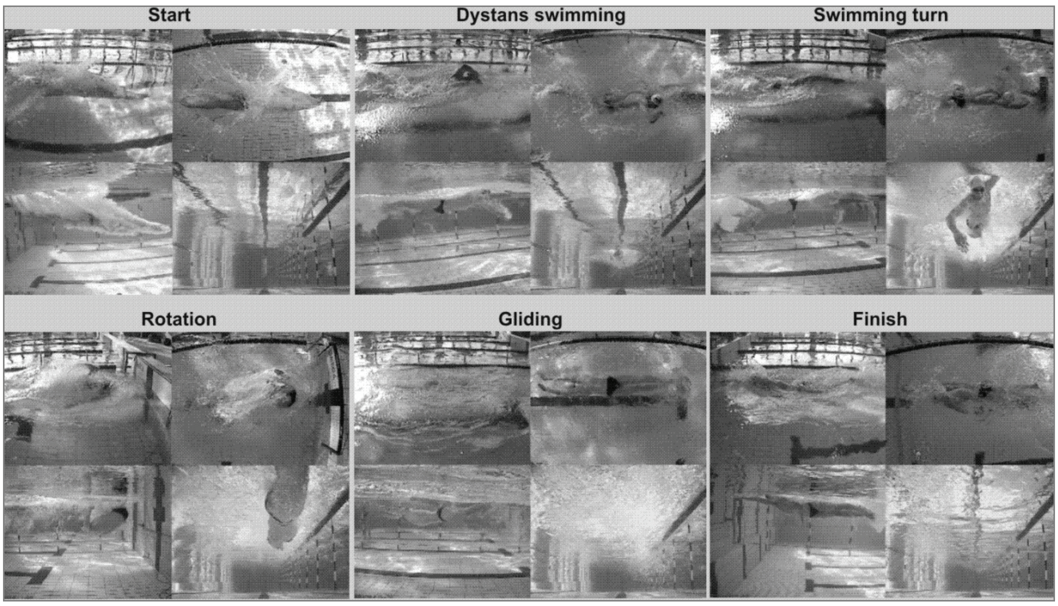

Fig. 2. The Multi-camera swimming techniques analysis system

- overwater view – front plane (top view) of the total distance of 100 meters.

A competitive swimmer tries to travel a given distance as fast as possible. So, mean swimming velocity (V) is the best variable to assess swimming performance [3]. The V values were obtained using the equation [5]

$$V = SL \cdot SR \tag{1}$$

where V represents mean swimming velocity, SL stroke length, and SR stroke frequency. Swimming velocity can be described by its independent variables: stroke length (SL) and stroke frequency (SR). SL is defined as a horizontal distance that the body travels during a full stroke cycle. SR is defined as the number of full stroke cycles performed within a unit of time (strokes.min^{-1}) or Hertz (Hz) [3]. The SR was measured with a crone-frequency meter (EZ430-Chronos) from three consecutive stroke cycles, in the middle of each 25 m lap. The SL was calculated by the equation [5]

$$SL = \frac{V}{SR \cdot V}. \tag{2}$$

High stroke index (INDEX) values were strongly associated with a low C [17], [18]. In this sense, INDEX can also be used as overall swimming efficiency estimation. INDEX was computed as

$$INDEX = SL \cdot V. \tag{3}$$

The research results were presented by the main statistical characteristics. Detailed analysis and development of the recorded material, obtained from five cameras was done by a computer program using VirtualDub. In this paper, an attempt was made at a complex quantitative analysis of quality. The attempt was based on the measurement of fair and rigorous analysis by experts, who have expertise in the swimming techniques being evaluated.

2.3. Statistical procedures

The normality of distribution was assessed on all data using the Kolmogorov–Smirnov test. Means, standard deviations, minimum and maximum values were calculated for all parameters. Partial correlation coefficients (rp) with age as control variable were used to determine the degree of association between assessment variables and swimming performance. Pearson's correlations coefficients were calculated in relation to swimming performance and between workloads. The level of statistical significance was set at $p \leq 0.05$ and $p \leq 0.01$. All statistical calculations were made using Statistica 8.1 (StatSoft Inc., 2009).

3. Results

The greatest impact on performance of 12–15 year old swimmers, expressed as sports result in all its forms in both sexes, is exerted by implemented training volume of a certain intensity of exercise (high correlation relationships at $p \leq 0.01$, as well as the measures of special effects (compounds and high average level ($p \leq 0.01$). Both technical skill level preparation and segmental kinematics of 12–15 year old swimmers, proved to be highly conditioned by implemented training intensity ($p \leq 0.01$), as well as the volume of training (high and average trade at a level of significance ($p \leq 0.01$).

Analyses were made with regard to the so-called division style: "long axis" (style and front crawl and backstroke) and "short axis" (butterfly, breaststroke). As is clear from the partial correlation analysis presented in Table 3 between segmental kinematics in crawl and backstroke and training volume implemented during the BPS (including the age control factor) there was no statistically significant correlation in majority of the cases analyzed. The only exception was the SL_4 parameter swimming, which showed a weak relationship to the level of significance ($p < 0.05$) with most of the signs included training loads, carried out in different periods during the training sessions.

Based on partial correlation analysis presented in Table 4 between segmental kinematics in butterfly and breaststroke and training volume implemented during the BPS (including the age control factor) it can be noted that the vast majority (with the exception of training used in the backstroke) implemented various training loads in the different subperiods of training had the greatest influence on the formation of all the parameters including the technical coordination and breaststroke. In most cases, the strength of the analyzed compounds ranged probability level ($p < 0.001$), and these relationships were the average o SR_3, SL _3, Index_3 and V_3 Showed quite a different impact loads. The fact was also that the means of training in different styles affect the development of kinematic parameters in these styles. And so, depending on the size of the most numerous of these parameters occurred with the measures the impact of comprehensive and targeted used in this styles: QK – quality kick, EP – endurance pull, RPW – race – pace work, S&D – skills and drills, D – distance in this technique.

Table 2. Partial correlation analysis between the swimming efficiency, expressed as the technical skill level preparation (in four competitive techniques) and training volume, implemented during the BPS (including the age control factor)

No.	Training loads	Points Butterfly	Points Backstroke	Points Breastroke	Points Front crawl	Points Individual medley
1	Quality week	.05	.07	.05	.10	.29
2	Mixed week	.23	.25	.17	–.01	–.10
3	Endurance week	.69**	.67**	.69**	.68**	.68**
4	Quality week	.73**	.74**	.73**	.73**	.70**
5	Mixed week	.71**	.69**	.71**	.69**	.70**
6	Endurance week	.34	.29*	.34*	.34*	.34*
7	Quality week	.30*	.30*	.38**	.29*	.32*
8	Mixed week	.29*	.32*	.32*	.28*	.30*
9	Mixed week	–.17	–.22	–.18	–.18	–.17
10	Taper week	–.01	–.07	–.02	–.04	.00
11	Taper week	–.10	–.10	–.10	–.11	–.09
Butterfly	QK_1	.38**	.45**	.43**	.22	.23
	EP_1	.38**	.45**	.43**	.22	.23
	RPW_1	.29*	.33**	.38**	.30*	.49**
	S&D_1	.29*	.33**	.38**	.30*	.49**
	D_1	.29*	.33**	.38**	.30*	.49**
Backstroke	QK_2	.37**	–.06	.09	.17	.12
	EP_2	.37**	–.06	.09	.17	.12
	RPW_2	.38**	.31*	–.18	.26	.22
	S&D_2	.38**	.31*	–.02	.26	.22
	D_2	.38**	.31*	–.12	.26	.22
Breastroke	QK_3	.08	.02	–.02	.11	.13
	EP_3	.08	.02	–.10	.11	.13
	RPW_3	.03	.03	.53**	.34**	.31*
	S&D_3	.03	.03	.53**	.34**	.31*
	D_3	.03	.03	.53**	.34**	.31*
Front crawl	QK_4	.01	.09	.17	.03	.02
	EP_4	.01	.09	.17	.03	.02
	RPW_4	.06	.14	.14	.15	.11
	S&D_4	–.06	.14	.14	.15	.11
	D_4	–.06	.14	.14	.15	.11
Individual medley	QK_5	.07	–.05	.19	.22	.24
	EP_5	.07	–.05	.19	.22	.24
	RPW_5	.11	–.09	.16	.16	.00
	S&D_5	.11	.09	.16	.16	.00
	D_5	.11	.09	.16	.16	.00

*: $p < .05$, **: $p < .001$
Abbreviations used in Table 2:
QK – quality kick
EP – endurance pull
RPW – race –pace work
S&D – skills and drills
D – distance in this technique
_1 – Butterfly
_2 – Backstroke
_3 – Breaststroke
_4 – Front crawl
_5 – Individual medley

Table 3. Partial correlation analysis between segmental kinematics in crawl and backstroke and training volume implemented during the BPS (including the age control factor)

No.	Training loads	Kinematics parameters in backstroke					Kinematics parameters in front crawl				
		T _2	V_2	SR_2	SL_2	Index_2	T_4	V_4	SR_4	SL_4	Index_4
1	Quality week	.05	.02	.10	–.05	–.03	.02	–.08	–.25	–.28*	–.22
2	Mixed week	–.04	.11	.16	.08	.08	.08	–.01	–.10	–.13	–.21
3	Endurance week	.05	.02	.10	–.05	–.03	.02	–.08	–.25	–.28*	–.23
4	Quality week	.02	.08	.17	.02	.01	.07	–.05	–.19	–.23	–.24
5	Mixed week	.06	–.06	–.01	–.11	–.08	–.05	–.10	–.26	–.28*	–.15
6	Endurance week	.06	–.01	.07	–.07	–.05	.00	–.09	–.26	–.29*	–.21
7	Quality week	.03	.07	.16	.01	.00	.06	–.05	–.21	–.24	–.23
8	Mixed week	.06	–.08	–.03	–.12	–.08	–.06	–.10	–.25	–.28*	–.14
9	Mixed week	.05	.02	.10	–.05	–.04	.02	–.08	–.25	–.28*	–.22
10	Taper week	.01	.09	.17	.03	.02	.07	–.05	–.19	–.22	–.24
11	Taper week	.07	–.05	.01	–.11	–.08	–.03	–.10	–.25	–.28*	–.16
Butterfly	QK_1	–.08	–.03	–.13	.04	.05	–.04	.06	.20	.22	.17
	EP_1	–.04	.13	.19	.11	.08	.11	.01	–.06	–.08	–.19
	RPW_1	.04	.01	.09	–.05	–.03	.01	–.09	–.26	–.29*	–.23
	S&D_1	–.07	.10	.12	.10	.10	.07	.01	–.05	–.07	–.17
	D_1	–.08	.08	.08	.09	.11	.05	.01	–.03	–.05	–.14
Backstroke	QK_2	.02	–.14	–.20	–.10	–.08	–.11	–.01	.06	.09	.19
	EP_2	–.05	.14	.18	.12	.10	.11	.02	–.03	–.05	–.17
	RPW_2	–.09	.05	.04	.06	.09	.02	–.01	–.06	–.08	–.14
	S&D_2	–.07	.10	.12	.10	.10	.07	.01	–.05	–.07	–.17
	D_2	–.08	.09	.10	.10	.11	.06	.01	–.03	–.05	–.15
Breastroke	QK_3	–.07	–.04	–.14	.03	.04	–.05	.06	.20	.22	.18
	EP_3	–.04	.14	.19	.11	.09	.11	.01	–.05	–.08	–.18
	RPW_3	.03	.03	.11	–.02	–.01	.03	–.08	–.24	–.27	–.24
	S&D_3	–.07	.11	.13	.10	.10	.07	.01	–.04	–.06	–.17
	D_3	–.07	.10	.12	.09	.10	.07	.00	–.05	–.08	–.17
Front crawl	QK_4	.07	–.11	–.08	–.14	–.10	–.08	–.10	–.22	–.30*	–.08
	EP_4	.07	–.02	.05	–.09	–.07	–.01	–.09	–.25	–.28*	–.17
	RPW_4	.05	.04	.13	–.03	–.03	.04	–.07	–.23	–.29*	–.22
	S&D_4	–.05	–.08	–.13	–.06	.01	–.09	–.05	–.09	–.10	–.04
	D_4	.06	–.01	.08	–.07	–.06	.01	–.09	–.25	–.28*	–.20
Individual medley	QK_5	.07	–.02	.05	–.08	–.07	–.01	–.09	–.26	–.28*	–.18
	EP_5	.08	–.03	.04	–.09	–.08	–.01	–.09	–.24	–.29*	–.15
	RPW_5	.07	.01	.09	–.06	–.06	.02	–.08	–.24	–.28*	–.19
	S&D_5	–.11	.04	–.01	.09	.11	.01	.04	.09	.08	–.01
	D_5	.07	–.01	.07	–.07	–.06	.00	–.09	–.25	–.28*	–.18

*: $p < .05$, **; $p < .001$
QK – quality kick
EP – endurance pull
RPW – race –pace work
S&D – skills and drills
D – distance in this technique
_1 – Butterfly
_2 – Backstroke
_3 – Breaststroke
_4 – Front crawl
_5 – Individual medley
T – time (s)
V – velocity – swimming speed (m.s^{-1})
SR – stroke frequency (rate) (ccl. min^{-1})
SL – stroke length (m)
Index – stroke index

Table 4. Partial correlation analysis between segmental kinematics in butterfly and breaststroke and training volume implemented during the BPS (including the age control factor)

No.	Training loads	Kinematics parameters in butterfly					Kinematics parameters in breaststroke				
		T_1	V_1	SR_1	SL_1	Index_1	T_3	V_3	SR_3	SL_3	Index_3
1	Quality week	.01	–.05	–.06	–.04	–.03	–.19	–.17	–.07	–.03	–.14
2	Mixed week	–.28*	–.29*	–.21	–.15	–.23	–.60**	–.60**	–.35**	–.45**	–.54**
3	Endurance week	–.06	–.14	–.11	–.07	–.09	–.38**	–.35**	–.18	–.17	–.31*
4	Quality week	–.23	–.29	–.21	–.16	–.23	–.59**	–.59**	–.35**	–.45**	–.53**
5	Mixed week	–.10	–.19	–.13	–.08	–.12	–.48**	–.46**	–.28*	–.29*	–.39**
6	Endurance week	–.33**	–.34**	–.28*	–.21	–.30*	–.58**	–.60**	–.40**	–.57**	–.57**
7	Quality week	–.26	–.22	–.23	–.17	–.25	–.61**	–.62**	–.38**	–.49**	–.56**
8	Mixed week	–.12	–.21	–.14	–.08	–.13	–.52**	–.50**	–.29*	–.28*	–.43**
9	Mixed week	–.33**	–.34**	–.27*	–.21	–.31	–.56**	–.59**	–.40**	–.57**	–.56**
10	Taper week	–.22	–.21	–.21	–.15	–.22	–.60**	–.60**	–.35**	–.44**	–.54**
11	Taper week	–.09	–.17	–.12	–.08	–.11	–.45**	–.43**	–.28*	–.28*	–.37**
Butterfly	QK_1	–.30*	–.33**	–.24	–.18	–.28*	–.60**	–.62**	–.39**	–.54**	–.57**
	EP_1	.14	.23	.12	.06	.13	.58**	.56**	.29*	.32*	.47**
	RPW_1	.08	.01	.01	.02	.04	–.14	–.10	–.01	.08	–.07
	S&D_1	–.24	–.30*	–.23	–.17	–.24	–.58**	–.59**	–.36**	–.46**	–.54**
	D_1	.04	.01	–.04	–.04	.00	.00	.01	.01	.06	.01
Backstroke	QK_2	.03	.02	–.04	–.05	–.01	.07	.07	.03	.06	.05
	EP_2	–.09	.00	–.01	–.03	–.05	.17	.13	.02	–.08	.09
	RPW_2	.12	.05	.03	.04	.07	–.05	–.01	.04	.15	.01
	S&D_2	–.04	–.02	–.10	–.10	–.08	.05	.04	–.02	–.04	.00
	D_2	.04	.01	–.04	–.04	.00	.00	.01	.01	.06	.01
Breaststroke	QK_3	.04	.03	–.03	–.04	.00	.04	.05	.03	.07	.04
	EP_3	.12	.22	.11	.05	.12	.57**	.55**	.28*	.30*	.46**
	RPW_3	.10	.02	.02	.03	.05	–.12	–.09	.00	.10	–.05
	S&D_3	–.20	–.23	–.20	–.15	–.21	–.56	–.55	–.32	–.40	–.50
	D_3	.05	.02	–.03	–.03	.01	.00	.02	.02	.07	.01
Crawl	QK_4	.03	.00	–.04	–.04	–.01	–.02	–.01	.00	.04	–.01
	EP_4	–.33**	–.32**	–.29*	–.20	–.30*	–.49**	–.53**	–.37**	–.56**	–.50**
	RPW_4	–.26	–.31*	–.22	–.15	–.25	–.62**	–.63**	–.38**	–.50**	–.56**
	S&D_4	–.17	–.25	–.17	–.11	–.18	–.58**	–.57**	–.31**	–.37**	–.50**
	D_4	–.23	–.14	–.20	–.21	–.22	.01	–.05	–.14	–.29	–.11
Individual medley	QK_5	–.29*	–.31**	–.21	–.15	–.28*	–.62**	–.62**	–.37**	–.48**	–.56**
	EP_5	–.28*	–.32**	–.23	–.16	–.29*	–.62**	–.63**	–.38**	–.51**	–.57**
	RPW_5	–.29*	–.31**	–.20	–.14	–.29*	–.61**	–.62**	–.37**	–.49**	–.55**
	S&D_5	–.21	–.28*	–.18	–.12	–.20	–.62**	–.61**	–.35**	–.43**	–.54**
	D_5	.09	.14	.03	–.01	.06	.38**	.37**	.18	.22	.39**

*: $p < .05$. **; $p < .001$
QK – quality kick
EP – endurance pull
RPW – race-pace work
S&D – skills and drills
D – distance in this technique
_1 – Butterfly
_2 – Backstroke
_3 – Breaststroke
_4 – Front crawl
_5 – Individual medley
T – time (s)
V – Velocity– swimming speed ($m.s^{-1}$)
SR – stroke frequency (rate) (ccl. min^{-1})
SL – stroke length (m)
Index – stroke index

Table 5 Partial correlation analysis between training intensity expressed such as energy zones system and swimming efficiency: technical skill level (in four competitive techniques), segmental kinematics (including the age control factor)

Training zone	A1	A2	A3	AT	CS	RP	Speed
Score Buterfly	.70**	.65**	.68**	.66**	.64**	.64**	.52**
Score Backstroke	.76**	.70**	.73**	.71**	.68**	.71**	.55**
Score Braststroke	.77**	.69**	.73**	.70**	.67**	.70**	.38*
Score Front crawl	.75**	.66**	.70**	.67**	.64**	.68**	.52**
Score Idividual medley	.76**	.70**	.72**	.71**	.66**	.73**	.65**
T_1	–.77**	–.72**	–.74**	–.73**	–.69**	–.73**	–.58**
V _1	.78**	.70**	.74**	.72**	.68**	.72**	.43**
SR _1	.72**	.58**	.65**	.60**	.56**	.60**	.48**
SL _1	–.73**	–.56**	–.65**	–.59**	–.55**	–.59**	–.54**
Index_1	.74**	.58**	.67**	.60**	.57**	.60**	.48**
T_2	–.72**	–.60**	–.67**	–.61**	–.59**	–.61**	–.59**
V_2	.76**	.60**	.70**	.62**	.62**	.59**	.57**
SR_2	.75**	.60**	.68**	.62**	.59**	.61**	.60**
SL_3	–.77**	–.68**	–.73**	–.69**	–.68**	–.68**	–.58**
Index_2	.77**	.67**	.73**	.68**	.67**	.66**	.50**
T_3	–.76**	–.65**	–.71**	–.66**	–.64**	–.65**	–.56**
V_3	.77**	.69**	.74**	.70**	.68**	.69**	.63**
SR_3	.77**	.69**	.74**	.71**	.68**	.70**	.63**
SL_3	–.79**	–.69**	–.75**	–.71**	–.69**	–.69**	–.29*
Index_3	.71**	.67**	.69**	.68**	.64**	.68**	.43**
T_4	–.75**	–.71**	–.73**	–.72**	–.69**	–.72**	–.34*
V_4	.73**	.56**	.67**	.58**	.59**	.55**	.44**
SR_4	.73**	.62**	.69**	.64**	.63**	.61**	.44**
SL_4	–.79**	–.69**	–.75**	–.71**	–.69**	–.69**	–.53**
Index_4	.52**	.47**	.50**	.48**	.46**	.48**	.56**

*: $p < .05$. **; $p < .001$
T – time (s)
V – velocity– swimming speed ($m.s^{-1}$)
SR – stroke frequency (rate) (ccl. min^{-1})
SL – stroke length (m)
Index – stroke index
_1 – Butterfly
_2 – Backstroke
_3 – Breaststroke
_4 – Front crawl
_5 – Individual medley
A1 – recovery work (to complement anaerobic and sprint work)
A2 – aerobic maintenance
A3 – greater aerobic stimulus to increase aerobic capacity
AT – anaerobic threshold
CS – high-performance endurance
RP – anaerobic (race pace training)
Speed – sprint

Further research activities undertaken to analyze training intensity were expressed as energy zones system and swimming efficiency: technical skill level (in four competitive techniques), segmental kinematics (including the age control factor). As is clear from the data contained in Table 5, describing the correlation between the intensity of the efforts deployed and the level of swimming performance shows that all energy zones considered exhibit very high and high-level relationships of significance ($p < 0.001$) with the efficiency of swim, degrees of technical training in all techniques and the size of the kinematic parameters included in all swimming techniques.

4. Discussion

Detailed analysis of training loads, both in the information and energy areas, during the immediate preparation for the winter Polish Championships allowed us to assess progress in implementing the training for individual swimmers in relation to the intended objectives. The analysis revealed differences in both the volume and intensity of training work in relation to the size of the training loads. Barbosa pointed out in his article [19] that during any swimming event, a swimmer spends most of his/her absolute or relative time in the swimming phase. Therefore, the swimming phase is the most (but not the only one) determinant moment of the swimming performance. In this sense, a large part of the biomechanical analysis of competitive swimming is dedicated to the four competitive swimming strokes: (i) the front crawl; (ii) the backstroke; (iii) the breaststroke, and (iv) the butterfly stroke. Front crawl is considered the fastest swim stroke, followed by butterfly, backstroke and breaststroke [5], [20]. Increases or decreases in V are determined by combined increases or decreases in SR (stroke rate) and SL (stroke length), respectively [21], [22]. Those are polynomial relationships for all swim strokes [23]–[25].

In our study, we are able to notice that kinematics parameters such as stroke rate (SR) and swimming speed (V), took the highest values during the competition period (relatively low intensity and volume). Stroke length (SL) has been optimized with respect to stroke rate and was observed to have substantial effect on an increase in swimming velocity in four competitive strokes. Additionally, we can give a possible clarification that the motor control and stagnation in the anthropometric characteristics could be the reason for a significant increase in SR and stagnation in SL. As a result we are able to observe that the training process was the main reason for V improvement, during the winter season. A very similar observation was made during the autumn season by Reis and Alves [26]. It seems that kinematics parameters, in both sexes, do not depend on training period. There was observed a phenomenon of adapting swimming technique in terms of volume and changing training loads. Kinematic parameters were relatively similar in analyzed periods. On the one hand, the state of the art as regards the area under discussion is supported by cross-sectional studies [27]. As swimming is a sport of multi-factorial nature, performance improvement does not only occur in response to one single domain (i.e., anthropometrics) [28]. It could be speculated that physical development (i.e., growth, maturation) could lead young swimmers to change their motor control strategies affecting the stroke mechanics and efficiency. Morais et. al. [28] show in their study that anthropometrics has the most important role in the sphere of performance improvement and stability, and kinematics, hydrodynamics and efficiency played minor role. Comparable consequences in relation to the stagnation in biomechanical parameters were reported for the period of a training season for young swimmers [29]. In swimming performance we are able to see a special kind of tendency used for a V increase during the winter season, what is more, the changes in biomechanical parameters, mainly in SR, can be the determinant aspect for this V improvement. On the other hand, an individual study should be considered to better explore the profit of the training process.

5. Conclusions

1. Implemented training loads expressed by both volume and intensity of training showed high and very high correlation with the swimming efficiency, presented as segmental kinematics and technical skill level. However, among boys and girls there appeared particularly pronounced relationship with the size of kinematic parameters taken into account in four competitive swimming techniques, components of the 100 m individual medley.

2. It seems that kinematics parameters, in both sexes, do not depend on training period. There was observed a phenomenon of adapting swimming technique in terms of volume and changing training loads. Kinematic parameters were relatively similar in analyzed periods.

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References

[1] BROKER J.P., CRAWELEY J.D., *Advanced Sport Technologies: Enhancing Olympic Performance*, [in:] J.R. Blackwell (ed.), Proceedings of the XIXth ISBS Symposium, San Francisco, 2001, 323–327.

[2] BARBOSA T.M., FERNANDES R.J., MOROUÇO P., VILAS-BOAS J.P., *Predicting the intra-cyclic variation of the velocity of the centre of mass from segmental velocities in butterfly stroke: a pilot study*, J. Sport Sci. Med., 2008, Vol. 7, 201–209.

[3] BARBOSA T.M., REIS V.M., MARINHO D.A., CARVALHO C., SILVA A.J., *Energetic and biomechanics as determining factors of swimming performance: Updating the state of the art*, J. Sci. Med. Sport, 2010, Vol. 13(2), 262–269.

[4] SEIFERT L., CHOLLET D., ALLARD P., *Arm coordination symmetry and breathing effect in front crawl*, Hum. Mov. Sci., 2005, Vol. 24(2), 234–256.

[5] CRAIG A.B., PENDERGAST D.R., *Relationships of stroke rate, distance per stroke, and velocity in competitive swimming*, Med. Sci. Sport, 1979, Vol. 11, 278–283.

[6] ARELLANO R., SANCHEZ-MOLINA J., NAVARRO F., DE AYMERICH J., *Analysis of 100-m backstroke, breaststroke, butterfly and freestyle swimmers at the 2001 European youth Olympic days*, [in:] J.C. Chatard (ed.), Biomechanics and Medicine in Swimming IX, Saint Etienne University, Saint Etienne, 2003, 255–260.

[7] GRIMSTON S.K., HAY J.G., *Relationships among anthropometric and stroking characteristics of college swimmers*, Med. Sci. Sports Exerc., 1986, Vol. 18, 60–68.

[8] PAI Y.C., HAY J.G., WILSON B.D., *Stroking techniques of elite swimmers*, J. Sports Sci., 1984, Vol. 2, 225–239.

[9] DUCHÈ G., FALGAIRETTE G., BEDU M., LAC G., *Analysis of performance of pre pubertal swimmers assessed from anthropometric and bio-energetic characteristics*, Eur. J. Appl. Physiol. Occup. Physiol., 1993, Vol. 66(5), 467–471.

[10] PELAYO P., WILLE F., SIDNEY M., *Swimming performance and stroking parameters in non skilled grammar school pupils: relation with age, gender and some anthropometric characteristics*, J. Sport. Med. Phys. Fitness, 1997, Vol. 37(3), 187–193.

[11] KJENDLE P., INGJER F., STALLMAN R., STRAY-GUNDERSEN J., *Factors affecting swimming economy in children and adults*, Eur. J. Appl. Physiol., 2004, Vol. 91(4), 473–480.

[12] KJENDLIE P.L., HALJAND R., FJORTOFT O., STALLMAN R.K., *Stroke frequency strategies of international and national swimmers in 100-m races*, [in:] J.P. Vilas-Boas, F. Alves, A. Marques (eds.), Biomechanics and Medicine in Swimming X, Portuguese Journal of Sport Science, Porto, 2006, 52–54,

[13] ZAMPARO P., *Effects of age and gender on the propelling efficiency of the arm stroke*, Eur. J. Appl. Physiol., 2006, Vol. 97(1), 52–58.

[14] JÜRIMÄE J., HALJASTE K., CICCHELLA A., LÄTT E., PURGE P., LEPPIK A., JÜRIMÄE T., *Analysis of swimming performance from physical, physiological, and biomechanical parameters in young swimmers*, Pediatry Exerc. Sci., 2007, Vol. 19(1), 70–81.

[15] PHILIPS G., *British Swimming Training Classification*, M. Peyrebrune, 2005.

[16] KUCIA-CZYSZCZOŃ K., DYBIŃSKA E., *Quantitative criterion of swimming techniques using multi-camera registration system on the exemple of individual medley among 13–14-year old girls*, [in:] K. Zatoń, M. Rejman, A. Kwasna (eds.), Science in Swimming III, 2011, 82–93.

[17] CRAIG A., SKEHAN P., PAWELCZYK J., BOOMER W., *Velocity, stroke rate and distance per stroke during elite swimming competition*, Med. Sci. Sports Exerc., 1985, Vol. 17, 625–634.

[18] COSTILL D., KOVALESKI J., PORTER D., *Energy expenditure during front crawl swimming: predicting success in middle-distance events*, Int. J. Sports Med., 1985, Vol. 6, 266–270.

[19] BARBOSA T.M, DANIEL A., MARINHO J., MÁRIO J., COSTA A., SILVA J. *Biomechanics of Competitive Swimming Strokes, Biomechanics in Applications*, [in:] V. Klika (ed.), ISBN: 978-953-307-969-1, 2011, InTech, Available from: http://www.intechopen.com/articles/show/title/biomechanics-of-competitive-swimming-strokes [22.10.2011].

[20] CHENGALUR S., BROWN P., *An analysis of male and female Olympic swimmers in the 200 m events*, Can. J. Sports Sci., 1992, Vol. 17, 104–109.

[21] TOUSSAINT H., CAROL A., KRANENBORG H., TRUIJENS M., *Effect of fatigue on stroking characteristics in an arms-only 100-m front-crawl race*, Med. Sci. Sports Exerc., 2006, Vol. 38, 1635–1642.

[22] KJENDLIE P.L., STALLMAN R., *Drag characteristics of competitive swimming children and adults*, J. Appl. Biomech., 2008, Vol. 24, 35–42.

[23] KESKINEN K.L., KOMI P.V., *The stroking characteristics in four different exercises in freestyle swimming*, [in:] G. de Groot P.A., Hollander P., Huijing, G. van Ingen Schenau (eds.), Biomechanics XI-B, Free University Press, Amsterdam, 1988, 839–843.

[24] KESKINEN K.L., LAURI J., KOMI P.V., *Maximum velocity swimming: interrelationships of stroking characteristics, force production and anthropometric variables*, Scand. J. Sports Sci., 1989, Vol. 11, 87–92.

[25] PENDERGAST D.R., CAPELLI C., CRAIG A.B., DI PRAMPERO P.E., MINETTI A.E., MOLLENDORF J., TERMIN I.I., ZAMPARO P., *Biophysics in swimming*, [in:] J.P. Vilas-Boas, F. Alves, A. Marques (eds.), Biomechanics and Medicine in Swimming X, Portuguese J. Sport Sci., 2006, 185–189.

[26] REIS J., ALVES F., *Training induced changes in critical velocity and V4 in age group swimmers*, Portuguese J. Sport Sci., 2006, Vol. 6 (Suppl. 1), 55–56.

[27] TAIAR R., TOSHEV J., LODINI A., ROUARD A., *Performance modelling of butterfly swimmers: links between morphometric, kinematic and hydrodynamic variables.* Acta Bioeng. Biomech., 2004, 6(2), 77–88.

[28] MORAIS J.R., SAAVEDRA J.M., COSTA M.J., SILVA A.J., DANIEL A. MARINHO D.A., BARBOSA T.M., *Tracking young talented swimmers: follow-up of performance and its biomechanical determinant factors*, Acta Bioeng. Biomech., 2013, 13(6), DOI: 10.5277/abb130316.

[29] MINGHELLI F., CASTRO F., *Kinematics parameters of front crawl stroke sprinting trough a training season*, Portuguese J. Sport Sci., 2006, Vol. 6 (Suppl. 1), 102–103.