Acta of Bioengineering and Biomechanics
Vol. 24, No. 1, 2022

Original paper
DOI: 10.37190/ABB-01964-2021-02

Study of talented young male swimmers – scientific approach to the kinematic and physiological predictors of 400-m front crawl race

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Purpose: The purpose of this study was to assess the influence of physiological and kinematic predictors on 400-m front crawl race in young male swimmers and to consider the interrelation between them. *Methods*: Nineteen male swimmers took part in this study (age: 13.5 ± 0.44 years, height: 168.6 ± 7.77 cm, body mass: 56.9 ± 10.57 kg). Measurements of physiological parameters were conducted using expired air analyzer (Start 2000 MES, Poland) during step-test in water flume. Kinematic indices were computed while analyzing video recording of 400-m front crawl race. To check for possible influence of biological age (*BA*) diversity in studied group, partial correlation with age control was computed. *Results*: Swimming to exhaustion in water flume defined as speed at maximum oxygen uptake and anaerobic threshold ($V_{\dot{V}O_2\max}$ and V_{AT}) occurred to be strongly positively correlated with 400-m race speed. Speed in surface swimming zones (V_{surface}) was related to ability of kinematics adjustment and significantly correlated with stroke index (*SI*). V_{surface} at the beginning and the end of the race, i.e., at 1st, 7th and 8th lap interplayed with stroke rate (*SR*) measured at corresponding laps. *Conclusions*: Our study showed that 400-m front crawl performance of young male swimmers is strongly dependent on swimming efficiency developed with aerobic conditioning. Significant role of proper pacing strategy was also identified, which indicates that race pace training should be implemented.

Key words: *adolescent swimming, front crawl, ventilatory thresholds, maximum oxygen uptake, kinematic indices, pacing strategy*

1. Introduction

Swimming performance of young swimmers is determined by the interaction of morphological, physiological, biomechanical and psychological factors, based on individual genetic endowment and continuously modulated by the training process [17], [29], [35]. Narrowing down, best performance in swimming depends on the amount of metabolic energy spent in transporting the body mass of the athlete and on the economy of aquatic locomotion over the unit of swimming distance [44]. Difference of swimming economy from one adolescent swimmer to another, also depending on competitive skill – swimming kinematics, physiological capacity or morphological development [12], [18], [36]. Metabolic energy related to physiological development of young athlete is influenced by growth and maturation, it was observed at both aerobic [24] and anaerobic [6] conditioning level. Appropriate level of aerobic conditioning of the talented young swimmer is a matter of great importance when our goal is to lead him to compete in the close and further future [31].

At the elite level, the best mid- and long-distance swimmers are expected to demonstrate high aerobic capacity with high enough anaerobic threshold, and competition usable aerobic power – $\dot{V}O_{2\max}$. Therefore, the level of these indicators, if possible, is periodically monitored during the training of age groups in order to further gradually improve endurance [20],

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Received: October 19th, 2021
Accepted for publication: January 11th, 2022

[39] and it is combined with proper technique skills development.

Interesting, however, is the relationship between morphological development and swimming performance kinematics – stroke rate (*SR*), stroke length (*SL*), stroke index (*SI*) including (or excluding) the influence of maturation state of young swimmers [1]. So far, measurements (free swimming) of oxygen consumption have been rarely carried out to assess the aerobic conditioning of young swimmers [22], [41], [43] but researchers have interest in this topic [3]. Indeed these valuable assessments of aerobic preparation, need to be performed during exercise that fully utilizes the aerobic metabolism. Interestingly, these tests include different procedures when swimming at least the 400 meters or during longer gradual speed increases [9], [31], [38]. The blood lactate or oxygen uptake outcome of all-out 400-m front crawl swimming could illustrate level of aerobic conditioning and aerobic maximal velocity [10]. Fernandes et al. [14] performed incremental test with the time limit at $\dot{V}O_{2\max}$ examination – time of maintaining swimming speed corresponding to maximal oxygen uptake – showing that it is possible that the maintaining of slow component of $\dot{V}O_{2\max}$ is very similar to 400-m front crawl race duration. In young swimmers however, it's complicated by the level of maturation which affect the aerobic conditioning, performance by enhancing those more advanced in puberty [24], [32].

In swimming, the aerobic condition is shaped during water training, along with the kinematic characteristics of locomotion related to both anthropometry and the persistence to technique building up [18], [22], [26]. Douda et al. [13] claim that when considering young swimmers performance there is no consensus about which determinants are the most important, but growth process (maturation) should be always considered. Morais et al. [28], after analyzing large number of literature, stated that in young swimmers talent identification could be characterized as multifactorial, holistic. Abbott et al. [2] indicate technique and anthropometric variables which in their opinion have the biggest influence on youth swimmers performance.

Morais et al. [29] stated that biomechanics is responsible for 60% of the young swimmers performance. Silva et al. [37] showed that, in age-group swimmers, technique training is crucial and the level of technique efficiency is influenced by maturation process. There are three the most frequently used indices which characterize swimming technique: stroke rate (*SR*), stroke length (*SL*) and stroke index (*SI*). The *SI* is considered as the one which explains the most a level of swimming efficiency [23], [27] but less experienced (especially they) young swimmers and also the others have often difficulties with saving energy, and/or consciously manipulating the *SR* and *SL* as fatigue inevitably increases with the race distance covered.

Taking the dependencies that result in the development of talented swimmers into account, we set ourselves the goal of examining: (a) physiological, biomechanical determinants of front crawl performance collected in aquatic motorized swimming flume during stage test and 400-m race, (b) the interplay between physiological and kinematic indices with swimmers maturity and 400-m freestyle race, (c) changes in kinematic indices through the 400-m freestyle race.

It is expected that kinematic and physiological indices associated with higher aerobic endurance (higher anaerobic thresholds), will be significant predictors of 400-m front crawl performance simultaneously with the ability to use appropriate kinematics along with the fatigue.

2. Materials and methods

2.1. Participants

Nineteen male swimmers (age 13.5 ± 0.44 years) participated in this study. They were recruited as the most talented swimmers from their age category from Kraków region, Poland. Participants presented swimming level which resulted in mean value of 352 FINA points for 400-m front crawl race. All of them were healthy and had licenses from the Polish Swimming Federation. Participants height (168.6 ± 7.77 cm, stadiometer – Sieber Hegner Maschinen AG, Switzerland) and body mass (56.9 ± 10.57 kg, Tanita BC-418, Japan) were measured and body mass index calculated (19.6 ± 2.28 kg/m^2). The study was approved by the Regional Medical Chamber in Kraków on 5 June 2020 (No. 94/KBL/OIL/2020). All participants and their parents provided informed consent for their participation in intensive physical effort during this study (parents of all participants became acquainted with the study program and with a short description of the tests).

2.2. Biological age

Biological age (*BA*) examination of participants was conducted by experienced anthropologist and was calculated as follows: BA = [(BHage + BMage)/2], where: BHage – age obtained from percentile charts on the basis of the participant's body height, Bmage – age obtained from percentile charts on the basis of the participant's body mass. Additionally, pubertal development was assessed. Tanner stages based on pubic hair scale were estimated [8].

2.3. Physiological indices measurements

Stage test in water flume (Fig. 1) in laboratory--controlled environment (temperature, humidity) was conducted. Sufficiently in advance, swimmers were asked to rest the day before the test and to maintain their daily diet. Before entering the water flume swimmers were instructed to testing procedure and went through 1000 meters in-water warm-up, as before the competition. Entering the test procedure swimmers fitted nose clip and were attached to respiratory/valve system with expired air analyzer (Start 2000 MES, Poland). Than placed own body in order to marker on the bottom of the flume (with eyesight controlling the position of the body relative to the marker through entire test) and to adjust proper valve system (attached to a rod-alike construction, just above a swimmers' head). One minute slow pace swim ensured to adjust to testing conditions. Whistle signal started (from –0.93 m/s), 2-minutes of 0.06 m/s speed increased steps. Breath by breath exhaled air was continuously sampled by expired air analyzer and saved for further analysis (Ergo2000M software MES, Poland). $\dot{V}O_{2\max}$, Aerobic Threshold (AT), Respiratory Compensation Point (RCP) were estimated according to Beaver et al. [5]. The test was terminated after complete exhaustion and inability to maintain required swimming pace reaching criteria of $\dot{V}O_{2\max}$ examination [19]. Time of test termination (t_{test}), speed of the water flow (V_{AT}, V_{RCP}, $V_{\dot{V}O_{2\max}}$) and oxygen uptake (VO_2AT, VO_2RCP, $\dot{V}O_{2\max}$) accompanying to occurring the ventilatory indices or were also assessed. Swimmers were also filmed through entire test duration (JVC GC-PX100BE, Japan) in order to calculate the kinematic indices of: SR, SL, SI at V_{AT}, V_{RCP}, $V_{\dot{V}O_{2\max}}$. Mentioned indices were calculated from 3 cycles at each step.

2.4. 400-m front crawl race

400-meter all-out test was carried out in a 25-m swimming pool that meets International Swimming Federation (FINA) requirements. Final results and split times of the race were measured with automatic timing device (Omega, Switzerland). Each one of the race series were performed by five to four swimmers, similarly, as in competition conditions. Participants reached 105.2% of their personal best time in 400-m front crawl while performing in our study. All trials were recorded with (JVC GC-PX100BE, Japan) camera with 50 Hz framing. Camera was placed at the tripod at the tribune, 6 metres above the water surface in the extension of the middle point of the pool. Starting from the block swimmers were asked to emerge until the 10th meter. To separate the areas of surface swimming, the pool was divided into zones. Markers were placed at the side of the pool to locate the line of 7 metres from each of the walls. For the first lap one marker was attached 10 metres from the starting block. Pool (excluding first lap) was divided to three zones: I – turn zone (7 m), II – surface swimming zone (11 m), III – turn zone (7 m). Including first 10 m start zone it resulted in: a) 227 meters for V_{STF} (start, turn,

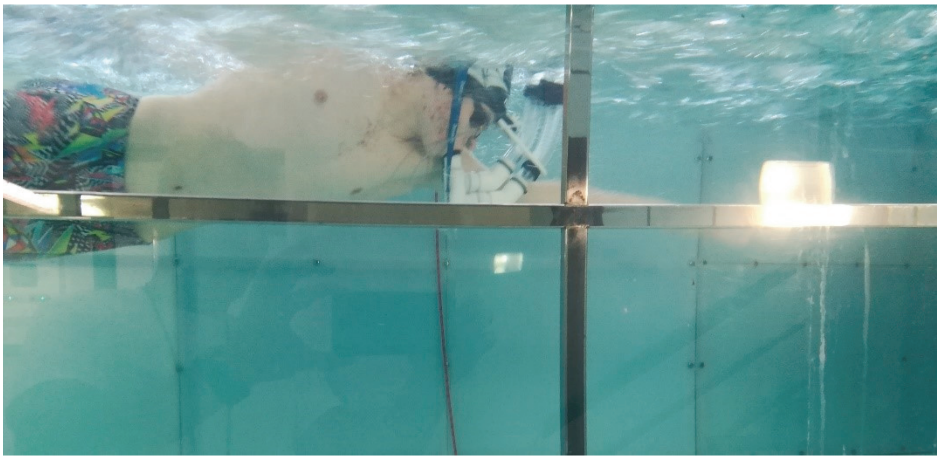


Fig. 1. Swimmer during stage test procedure in water flume

finish velocity) calculation, b) 173 meters for V_{surface} (surface swimming velocity) examination. Times for separate sectors were measured when swimmers head cross the imaginary line linking markers at the sides of the pool using program Kinovea – ver. 0.8.15. Stroke kinematic indices *SR*, *SL*, *SI* were calculated from surface swimming zones. The *SR* (cycle · min^{-1}) from each of surface swimming zones (extracted from 3 cycles). The *SL* (m) was estimated as: SL = $\frac{V_{\text{surface}}}{SR}$. Stroke index *SI* (m^2 · cycle · s^{-1}) was calculated as: $SI = V_{\text{total}} \cdot SL$. Kinematic results were averaged for every 50-m lap. Intraclass correlation (ICC) for *SR* calculation process was: ICC = 0.99, 95%CI = 0.990 – 0.999.

2.5. Statistical analysis

Standard statistical methods were used to calculate means and standard deviations (mean ± SD). The normality of the data assumptions were examined with the Shapiro–Wilks test. One-way ANOVA with repeated measures and Tukey HSD post-hoc test was carried out to detect and present differences between average velocities (V_{total}, V_{surface}, V_{STF}). Examination for relationship were computed between: a) stage test indices of: V_{AT}, V_{RCP}, $V_{\dot{V}O_{2\max}}$, $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2\max}$, b) kinematic indices (*SR*, *SL*, *SI*) of 400-m race or stage test and: (i) *BA* using Pearson's correlations; and (ii) V_{total} or V_{surface} using partial correlations controlled with *BA* factor. Partial correlations with *BA* control were also executed to show a relationship between V_{surface} and *SR*, *SL*, *SI* on the each lap of 400-m race and at last between kinematic indices of stage test *SR*, *SL*, *SI* and physiological indices of $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2\max}$.

Sphericity assumption of the data entered in one-way ANOVA repeated measures (V_{surface}, V_{turn}, V_{total}, *SR*, *SL*, *SI)* was examined with Mauchly's test. Assumption of sphericity was not met, than MANOVA Wilk's Lambda test was conducted to assess differences between the laps means of kinematic variables. Square or cubic trends were adjusted for the values of kinematic variables measured for each lap of 400-m front crawl race. The tests were conducted with STATISTICA 13.1 software (StatSoft, Inc). Significance level of $p \leq 0.05$ were established.

3. Results

A significant differences are shown between separated speeds of 400-m front crawl race: V_{total},

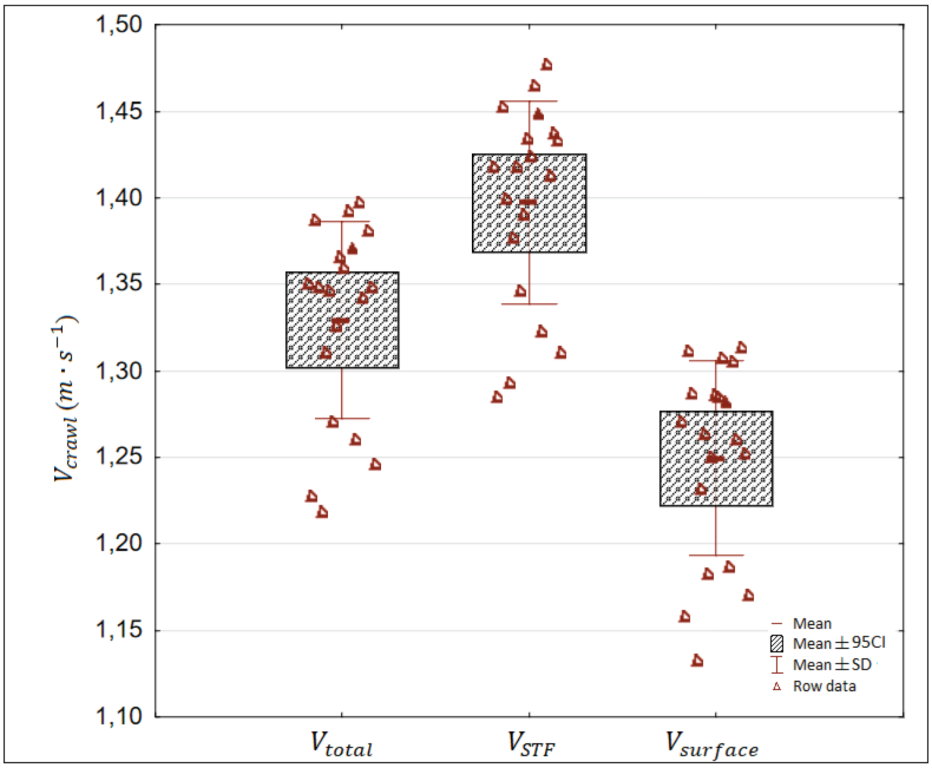


Fig. 2. Comparison between average speed values of: all of the distance (V_{total}), surface swimming zones (V_{surface}) and start, turn and finish zones (V_{STF}) measured during 400-m front crawl race

$V_{surface}$, V_{STF} ($F = 100.1$; $p < 0.001$). Post-hoc Tukey's (HSD) test confirmed significant differences among all of the measured averages ($p < 0.001$). In Figure 1, differences between analysed speeds are presented.

No significant but positive correlations were noted between biological age (*BA*) and V_{AT}, V_{RCP}, $V_{\dot{V}O_{2max}}$. Significant partial correlations controlled for *BA* were found between VAT, $V_{\dot{V}O_{2max}}$ and V_{total} (Table 1).

Table 1. Pearson correlations between *BA* and: V_{AT}, V_{RCP}, $V_{\dot{V}O_{2max}}$ (A). Partial correlations controlled with *BA* between *stage test* kinematics indices: V_{AT}, V_{RCP}, $V_{\dot{V}O_{2max}}$ and result of 400-m front crawl race (V_{total}) (B)

	Correlations	V_{AT} [m·s^{-1}] 0.89 ± 0.11	V_{RCP} [m·s^{-1}] 1.17 ± 0.06	$V_{\dot{V}O_{2max}}$ [m·s^{-1}] 1.24 ± 0.06
A	*BA* [years] 14.74 ± 1.82	0.01	0.26	0.12
B	V_{total} [m·s^{-1}] 1.33 ± 0.06	0.48 *	0.28	0.68 **

* Significant relationship between analysed indices with $p \le 0.05$; ** $p \le 0.01$.

There were strong, significant relationships between *BA* and $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2max}$. With *BA* control V_{total} did not significantly interplay with $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2max}$, although partial correlation between $\dot{V}O_{2AT}$ and V_{total} was close to significant (Table 2).

Table 2. Pearson correlations between *BA* and: $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2max}$ (A). Partial correlations controlled for *BA* between *stage test* physiological indices: $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2max}$ and result of 400-m front crawl race (V_{total}) (B)

	Correlations	$\dot{V}O_{2AT}$ [*l*·min^{-1}] 2.06 ± 0.46	$\dot{V}O_{2RCP}$ [*l*·min^{-1}] 2.85 ± 0.58	$\dot{V}O_{2max}$ [*l*·min^{-1}] 3.46 ± 0.71
A	*BA* [years]	0.63 **	0.71 **	0.57 *
B	V_{total} [m·s^{-1}]	0.43 $p = 0.07$	0.05	0.33

* Significant relationship between analysed indices with $p \le 0.05$; ** $p \le 0.01$.

Strong and significant correlations were found between *BA* and *SL*, *SI*. The kinematic indices of *SR* and *SL* showed no relationship with $V_{surface}$ when controlled for *BA*, but *SI* significantly interplayed with $V_{surface}$ (Table 3).

Table 3. Pearson correlations between *BA* and: *SR*, *SL*, *SI* (A). Partial correlations, controlled for *BA* between kinematic indices: *SR*, *SL*, *SI* of 400-m front crawl race and $V_{surface}$ (B)

	Correlations	*SR* [cycle·min^{-1}] 37.6 ± 3.62	*SL* [m] 2.01 ± 0.19	*SI* $\left[\frac{m^2}{s}\right]$ 2.51 ± 0.30
A	*BA* [years]	–0.44 $p = 0.06$	0.54 *	0.53*
B	$V_{surface}$ [m·s^{-1}] 1.25 ± 0.06	0.28	0.24	0.62**

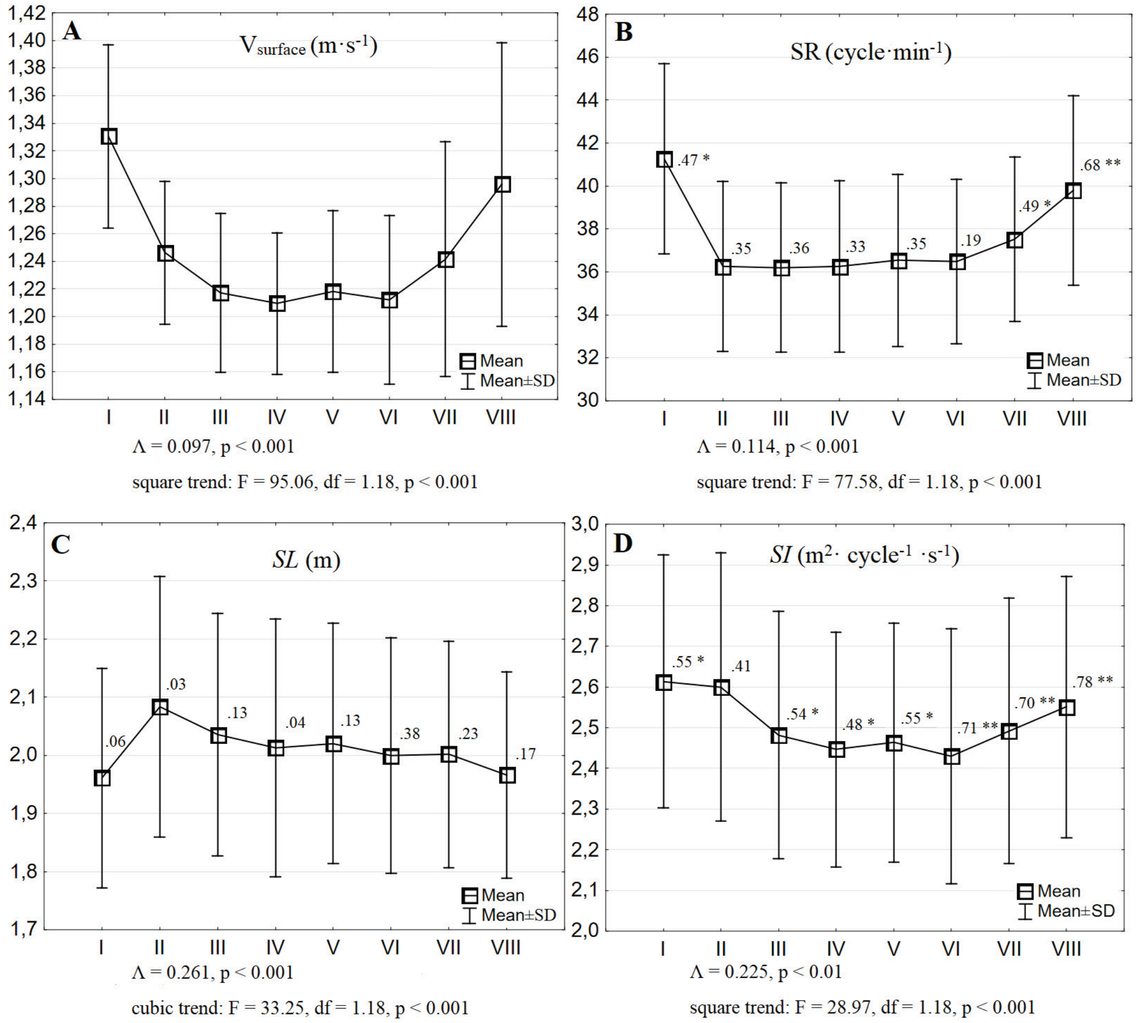
* Significant relationship between analysed indices with $p \le 0.05$; ** $p \le 0.01$.

In further proceedings, we decided to present the changes in kinematic variables and their interdependence to $V_{surface}$ also excluding the impact of biological age (these results are inserted close to squares of values averages in the graphs – Figs. 3B–D). We noted significant and high interrelation of *SR* and $V_{surface}$ on the first, seventh and the last lap (Fig. 3B), and also on the most laps between *SI* and $V_{surface}$ (Fig. 3D).

There were significant differences between 50-m laps speed ($V_{surface}$) in 400-m front crawl race ($\Lambda = 0.097$, $p < 0.001$) (Fig. 3A), stroke rate (*SR*) for each of 50-m ($\Lambda = 0.114$, $p < 0.001$) (Fig. 3B), stroke length (*SL*) ($\Lambda = 0.261$, $p < 0.001$) and stroke index (*SI*) ($\Lambda = 0.225$, $p < 0.001$). For $V_{surface}$, *SR*, *SI* curves square trend was established as the most suitable one (Figs. 3A, B, D). Cubic trend was established as the best fitted to *SL* curve (Fig. 3C).

For each of 50-m lap of average swimming velocity (V_{total}) ($\Lambda = 0.035$, $p < 0.001$) and velocity in turn zones (V_{turn} ($\Lambda = 0.157$, $p < 0.001$) significant differences were measured (Figs. 4A, B). Square trend was established as the most suitable one for V_{total} curve and cubic trend for V_{turn} curve.

Additionally, we decided to compute Pearson's correlation of stage test *SR*, *SL*, *SI* calculated at ventilatory thresholds and $\dot{V}O_{2max}$ with $V_{surface}$. We found that *SI* at *AT* was significantly correlated with $V_{surface}$ ($r = 0.48$, $p < 0.05$), when excluding *BA* in partial correlations it was nonsignificant.



* Significant relationship between analysed indices with $p \leq 0.05$; ** $p \leq 0.01$.

Fig. 3. $V_{surface}$ (A), *SR* (B), *SL* (C) and *SI* (D) indices on each 50-m lap of 400-m front crawl race. Wilk's test results (Λ) and trend's established for the curves (square trend, cubic trend). Partial correlations controlled for *BA* between $V_{surface}$ and *SR*, *SL*, *SI* at particular laps are presented in graphs B, C, D

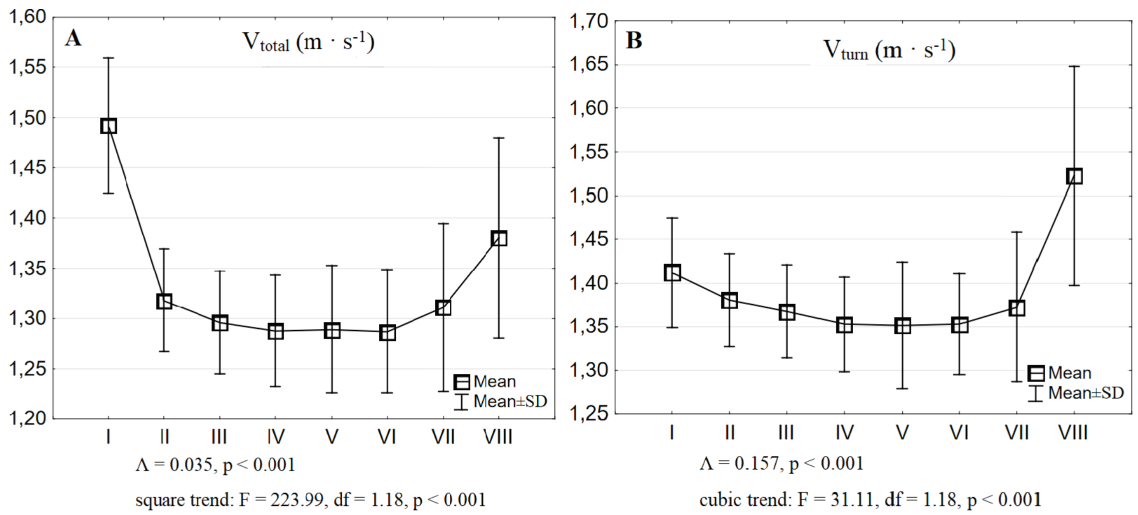


Fig. 4. V_{total} (A) and V_{turn} (B) values on each 50 m lap of 400-m front crawl race. Wilk's test values (Λ) and trend's established for the curves (square trend, cubic trend)

4. Discussion

These results show the rarely observed influence of physiological preparation and simultaneous kinematic-technical shaping on swimming results of young puberty male swimmers. In the presented study the result of 400-m front crawl race (V_{total}) was positively, significantly interrelated with physiological swimming efficiency – $V_{\dot{V}O_{2\max}}$ ($r = 0.68$, $p < 0.01$) and with V_{AT} ($r = 0.48$, $p < 0.05$). Furthermore, the V_{surface} interplayed strongly with 400-m *SI* kinematic ($r = 0.62$, $p < 0.01$) and was also significantly correlated to stage test – *SI* at *AT* ($r = 0.48$, $p < 0.05$). These studies also show the magnitude of the influence of maturation on the level of physiological and kinematic indicators. Thus, the physiological indices of oxygen uptake at metabolic thresholds – $\dot{V}O_{2AT}$, $\dot{V}O_{2RCP}$, $\dot{V}O_{2\max}$ did not interplayed significantly with results of 400-m front crawl race, when controlled for *BA*. On the other hand, interplay between $\dot{V}O_{2AT}$ and V_{total} (close to significant) shows the importance of a well-developed aerobic energy generation system in 400-m swimming, which was at the same time strongly dependent on *BA* (Table 2). Similarly, *BA* influenced on the shaping of kinematics, but their level and impact on V_{surface} we can state had to be mainly dependent by training (Table 3).

Considering these results, we can ask whether high oxygen uptake at the time of the appearance of subsequent metabolic thresholds is beneficial? Does higher oxygen uptake values at thresholds mean lower economy? It is possible to state that, the level of aerobic capacity represented by $\dot{V}O_{2\max}$ seems to influence the efficiency of aerobic system, but also enhance the anaerobic mechanisms of energy production used in 400-m front crawl race. Thus, higher $\dot{V}O_{2\max}$, supports the fast creatine phosphate reconstruction and the elimination of lactate [31]. These positive effect of high aerobic capacity level combined with the ability to swim fast using as much of oxidative energy as possible, could lead to later fatigue occurrence in 400-m front crawl race. Fernandes and Vilas-Boas [15] reported that best high level swimmers with great level of aerobic power are less likely to maintain the $V_{\dot{V}O_{2\max}}$ max for the longer time than the other talented swimmers who possess even higher aerobic capacity. The power of the former lies in the ability to use the entire oxygen potential supported-supplemented by a well-trained glycolytic component [33]. It could be also like that between different level or in more proficient swimmers with higher aerobic power but having smaller aerobic capacity the work will be not able to continue at the highest intensities [9].

Study of Jürimäe et al. [18] revealed that, among young male swimmers, *SL, SI* and $VO_{2\text{peak}}$ presented the strongest correlations with 400-m front-crawl results. Zacca et al. [42] reported that technique (*SR*, *SI*) showed the greatest influence on 400-m front crawl performance of age-group swimmers among others physiological, anthropometrical indices. Similarly to Abbott et al. [2] we found significant interrelation between *SI* and maturation level. In the study by Strzała et al. [40], the 400-m front-crawl performance was highly correlated with *SR*, propulsive phases of arm index of coordination (IdC) total body length and anerobic threshold assessed in arm-cranking. In the study by Mezzaroba and Machado [27], multiple linear-regression including only 1 variable of *SI* explained 89% of 400-m front crawl performance in young male swimmers. Similarly, in the study by Lätt et al. [23] stepwise regression analysis showed that *SI* was the best predictor of 400-m front crawl performance ($R^2 = 0.449$; $p < 0.05$) distinguished from the equation contained physiological, biomechanical parameters. It is similar to this study, where *SI* controlled for *BA* occurred to be strongly correlated ($r = 0.62$, $p < 0.01$) with V_{surface}. Our results also correspond to the other premises of care for shaping the appropriate kinematics of limb movements [16], [30].

In this study *SI*, reached at *AT* was significantly interrelated to V_{surface}. It could be explained by the fact that more efficient swimmers reached their *AT* later with respectively higher oxygen consumption, it means that their energetics was more supported by oxidative mechanisms. It means that swimming economy must be basically more dependent on the efficient oxidative mechanisms, always when the swimming distance is going to be longer. A valuable outcome of the presented study was that V_{surface} at first, 7th and 8th lap was significantly correlated with *SR* measured. It seems that ability to increase *SR* at the very end of the race is crucial for maintaining speed and to compensate drop of *SL*. It was shown by Mezzaroba and Machado [27], who stated that the not fully developed anaerobic mechanisms of adolescent swimmers could not provide enough energy for maintaining the proper coordination patterns (mainly increase *SR*) at maximum speeds at longer races. It is in accordance with the study of Dekerle et al. [11], where it has been shown that muscle fatigue leads to progressive increase in the energy cost in swimming and fall of kinematic parameters (also index of coordination highly related to *SR*). Zacca et al. [43] concluded that decrease in 400-m front crawl velocity after 4 weeks training cessation is caused by significantly lower *SR*. They stated that identification of $V_{\dot{V}O_{2\max}}$ is more applicable for evaluating energetics in age-group swimmers than $\dot{V}O_{2\max}$ or energy cost of swimming – C [kJ · m^{-1}]. It is because that in their study $V_{\dot{V}O_{2\max}}$ values were related to the individual 400-m front crawl performance. Our results are consistent with these observations because V_{surface} and $V_{\dot{V}O_{2\max}}$ in this study are almost identical. We could state that $V_{\dot{V}O_{2\max}}$ sets up the limit for the 400-m front crawl performance.

It was observed in our study that V_{surface}, V_{total}, *SR* and *SI* values change in a parabolic pattern and were parallel to each other (Figs. 3A, B, D, Fig. 4A), square trend suited for them the best. This pacing strategy was noted earlier by Robertson et al. [34]. It means that first lap of the race is the fastest, the middle ones are the slowest and the last one is close to the fastest ones from the beginning of the race, it is known also as fast-start-even strategy. The results presented in Fig. 4A are a good example of parabolic pacing strategy implication. Study by Mauger et al. [25] revealed that elite 400-m front crawl swimmers choose fast-start-even and parabolic pacing strategy most often. They claimed that these strategies are chosen because of their high effectiveness in terms of work-rate distribution. Bishop et al. [7] provided the physiological explanation for the fast-start-even pacing advantage, and showing the need of initial high intensity. It requires the use of phosphocreatine reserve resulting in a further greater oxidative contribution, which prevents swimmers from higher muscle fatigue level due to great anaerobic energy involvement and also saves the anaerobic pathway for the finish of the race.

Changes observed in our study in speed and *SL*, *SR* along 400-m front crawl race were similar to those presented by Laffite et al. [21]. They also noted drop of *SR* at the beginning of the second lap which ends at the final laps with the significant increase of *SR* and the progressive decrease of *SL* all along the distance. They also underline that *SL* decrease during all-out 400-m front crawl race seems not to be responsible for performance level, but the only way to sustain a high swimming velocity is increase of *SR*. It is in accordance with results of Aujouannet et al. [4], they found a relation between drop in swimming velocity in the middle-distance front crawl swimming and decrease of *SR* values.

5. Conclusions

The present study demonstrates result of significant interrelation between 400-m front crawl race (V_{total}) with physiological and kinematic swimming efficiency indices of young male swimmers. It was shown that swimming speeds and oxygen uptake at ventilatory thresholds has a great importance for swimmers' performance level and their swimming efficiency. We could also observe how maximal oxygen uptake and oxygen uptake at ventilatory thresholds as well as kinematic indices *SR*, *SL*, *SI* are strongly influenced by biological maturation. It gives a premise (information) for the implementation of sustainable training momently and in the long term.

This results can indicate that level of oxygen uptake influences the ability to maintain efficient stroke kinematic pattern, represented by the higher *SI* of young male swimmers. It could be explained by later fatigue occurrence and saving up anaerobic energy supplies for the last part of the race. Most of the swimmers used fast-start-even or parabolic strategy where *SL* decreased along covered laps and *SR* presented the U-shaped, square trend. Ability to increase *SR* at the final laps of the race in this study was crucial in 400-m front crawl race in young male puberty swimmers.

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