Impact of energetic-anthropometric features on 50-m and 100-m freestyle kinematic indices in young male swimmers

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Abstract

Purpose

The determinants of the sports results of young and adult swimmers differ, especially in sprint races (50-100m). Their identification can be used to assess the athlete's potential and to set appropriate requirements. The aim was to distinguish energy-anthropometric profiles (clusters) among young athletes and to characterize their kinematic indices in freestyle sprint races (50-100m). Kinematic variables from both distances were compared in each cluster.

Methods

Anthropometric indices and mechanical power of the upper limbs (arm-cranking) were determined in 43 subjects (boys, aged 12-13 years), which were used for cluster analysis. For the 50- and 100m races the following are determined: velocity (v), stroke rate (SR), stroke length (SL) and stroke index (SI). Comparative analysis was performed between clusters and between distances.

Results

The following clusters were distinguished: Large (LSP), Medium (MSP) and Small Size and Power (SSP), which differed due to anthropometric and power indices. Intergroup differences (LSP, MSP and SSP, respectively) were revealed in v50 (1.65m/s, 1.55m/s, 1.49m/s), v100 (1.52, 1.41, 1.34m/s), SL100 (1.92m, 1.77m, 1.72m), SI50 (2.92m/s2, 2.65m/s2, 2.54m/s2), SI100 (2.91m/s2, 2.51m/s2, 2.31m/s2). In all clusters differences were revealed between v50 and v100 and SR50 and SR100. Differences in SL50 and SL100 were noticed in LSP and MSP, while in SI50 and SI100 in MSP and SSP.

Conclusions

The evaluation of the technique should consider the energy-anthropometric profile of the athlete. The swimming technique need to be modified depending on the distance – also in races perceived as sprints.

Keywords

Kinematics, biomechanics, swimming, anthropometry, young athletes.

Introduction

The age of achieving maximum results in swimming is, on average, 22-27 years old [1] and is preceded by implementing a multi-year training plan. Such programs cover early childhood, adjusting the assumed effects of training to the capabilities of swimmers at a given stage of development. The effectiveness of training depends on many other factors, such as, among others, proper diet, appropriate recovery or psychological support from the close community [5]. All the above-mentioned determinants of sports results can be classified as environmental (nurture). It should be emphasized, however, that genetic factors (nature) also have a significant impact on swimming results [26]. In today's sports world, with large demands, athletes with insufficient potential in a given discipline, even with optimally conducted training, are not able to compete at the elite level. For this reason, many researchers and practitioners point to the important role of talent identification programs [23, 26, 41].

In swimming, structured training begins at an early age (on average 8-10 years old), which significantly complicates the accurate diagnosis of the athletes' potential [41]. In addition to the aforementioned environmental and genetic factors, sports performance in the early stages of a career is also dependent on the pace of biological development. It affects anthropometric, physiological and biomechanical indicators, which in turn determine swimming performance at a young age [18]. For this reason, it is important to accurately diagnose possible differences in sports performance among young athletes with different body builds and levels of energy properties. However, this type of analysis is hampered by the fact that all above mentioned determinants are interconnected [26]. Therefore, a commonly used approach is to attempt to distinguish different athlete profiles by assigning swimmers to groups, e.g. using cluster analysis [13, 26]. The criteria for differentiation here are the previously named anthropometric, physiological and biomechanical properties of swimmers.

In swimming, there are sprint (50-100 m), middle distance (200-400 m) and long distance (800-1500 m) events [21, 23]. Each type of race places different physiological, anthropometric and biomechanical requirements on the athlete [4]. For this reason, the determinants of sports results differ depending on the event. In sprint races, swimmers with large bodies, significant muscle strength and power, and anaerobic capacity have an advantage [8, 20]. Sports results also depend on the degree of mastery of the technique combining optimal movement efficiency (determined using stroke length) and movement frequency (measured by stroke rate) [10]. Establishing the determinants of sports success for different swimming events can be the basis for the identification of limitations to a given athlete's result and possible paths of career development.

It should be emphasized that high sports results at a young age do not unequivocally determine success at a later age. This applies especially to male swimmers, among whom, due to the later start of the puberty, the relationship between the results achieved at a junior and senior age is small [43]. It is particularly difficult to assess the potential of a young athlete in sprint competitions (50-100 m). In this case, the phase of achieving maximum results is shifted by an average of two years compared to other specializations (races of 200 m and above) [1]. Therefore, identifying the determinants of sports results at short distances at different stages of a sports career, especially among male swimmers, seems to be an issue worth taking up. An additional reason for undertaking this type of research is the opportunity to set more realistic goals, appropriate to the capabilities of adolescent swimmers.

The aim of the study was to distinguish energetic-anthropometric profiles of young swimmers, which are conducive to achieving high results in freestyle sprint races. It was decided to solve this type of problem based on cluster analysis. An additional aspect was the comparison of kinematic indicators in 50- and 100 m freestyle competitions, taking into account the distinguished clusters. It was hypothesized that athletes with different energy-anthropometric profiles would differ in terms of kinematic indices at both distances.

Materials and methods

Participants

The research involved 43 boys aged 12-14 years. The subjects represented a level corresponding to 299 ± 27 points on the World Aquatics scale for the 100 m freestyle (short-course pool). This corresponds to level 5 in the classification introduced by Ruiz-Navarro et al. [33]. The participants were volunteers recruited from among the best region swimmers in their age categories called up to the District Team. The subjects were active swimmers with a valid license from the national swimming federation, regularly competing in freestyle races. Each of them had 4-5 years of sports training in swimming.

The research was conducted in 3 sessions. The first session consisted of anthropometric measurements and a test of mechanical power of the upper limbs (arm-cranking), while the second and third sessions included participation in official swimming competitions in the 50- and 100 m freestyle races. Each session was planned in advance so that the coaches could adjust the training plans to the requirements of the study. All sessions were separated by approximately 3 days of rest, during which the subjects performed low-intensity training.

The study was approved by the Regional Medical Chamber in … on … (no. …). 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). All procedures contributing to the study complied with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Anthropometry

Body height (H) was determined using Martin's technique as outlined by Martin and Saller [19]. Arm span (AS) was measured as the distance between the *dactylion* points of the right and left hand, with the arms extended in a standing position. Both measurements were taken using an anthropometer (GPM, Switzerland) with a precision of 1 mm. Body mass (BM; accuracy - 0.1 kg), body fat percentage (BF; accuracy 0.1%), and active tissue mass (BMA; accuracy - 0.1 kg) were assessed utilising a Tanita BC-418 body composition analyser (Tanita, Japan).

Measurements of mechanical power of the upper limbs

To assess the mechanical power of the upper limbs, a 20-second maximal test was performed on an upper limb ergometer (834E-Ergomedic, Monark, Sweden). The device was operated using the MCE program (version 5v2, JBA Staniak, Poland). The study was conducted in accordance with the methodology of Strzala et al. [40].

Before starting the test, each participant undertook a two-stage warm-up. The first part consisted of 5 minutes of individual exercises covering mainly the upper body. The second stage consisted of 4 minutes of continuous work on an ergometer with a small load (1% of the subject's body weight) with a cadence of 90 cycles/min (imposed by the metronome). After starting the 2nd and 4th minute of arm-cranking, on the order of the person conducting the measurement, the subject's task was to perform 10-second bouts of crank rotations. After this time, on the command of the researcher, the subject was asked for return to rotations with a cadence of 90 cycles/min. After the warm-up and a few minutes' break, the participant began the actual test.

The load on the ergometer was 3% of the subject's body weight. The participant assumed a stable sitting position, placing their hands on the handles. Her/his task was to perform arm-cranking with the highest possible intensity for 20 seconds. During the test, the subject was encouraged to make a maximum effort. The researcher signalled the start and the end of the test. In order to avoid a sudden interruption of the effort, an integral part of the test was to encourage the subject to continue the rotations at a convenient rhythm for about a minute after the signal indicating the end of the test.

The following variables were subjected to further analysis:

- PP – peak power [W];
- PM – mean power [W];
- FI – fatigue index [%] – calculated as:

$$FI = \frac{WND}{WD} \cdot 100\%;$$

where:

WD – work that the athlete would perform if, after reaching PP, they developed maximum power until the end of the test;

WND – the difference between WD and the work that the subject actually performed.

50- and 100 m freestyle races

The next stage of the study was the analysis of the performance in swimming competitions held in a short-course (25 m) pool. The subjects took part in two regional events, swimming the 50- and 100 m freestyle distances. The competitions were conducted in accordance with World Aquatics swimming rules. Before the races began, the side edges of the pool were marked with distances of 5, 10, 15 and 20 m from the starting wall.

The races were recorded using a GoPro Hero Black 7 camera (Go Pro Inc., USA) in the “Linear” video recording mode at a frequency of 60 frames/s. The device was placed on a stable tripod about 8 m from the side wall of the pool at a height of about 5 m above the water surface, about 12.5 m from the starting wall. The described arrangement allowed recording of the middle 15 m of the distance. The lens was positioned perpendicularly to the direction of movement of the subjects.

The recordings were subjected to kinematic analysis using Kinovea software (version 0.8.15, Joan Charmant & Contrib, France). The values of velocity in the "clean swimming" (full-stroke) zone, stroke rate, stroke length and stroke index were calculated for the sections of 15-20 m, 40-45 m (50 and 100 m freestyle) and 65-70 m and 90-95 m (100 m freestyle). This was done as described by Wadrzyk et al. [42]. Based on the determined variables for the 50 m freestyle race, the average values were calculated:

- v_{50} – velocity [m/s];
- SR_{50} – stroke rate [cycle/min];

- SL_{50} – stroke length [m];

-SI_{50} – stroke index [m^2/s].

For the 100 m freestyle race the following averages were calculated:

- v_{100} – velocity [m/s];
- SR_{100} – stroke rate [cycle/min];
- SL_{100} – stroke length [m];

-SI_{100} – stroke index [m^2/s].

Statistical analysis

The obtained data were analyzed in Statistica (version 13, StatSoft, Poland). Descriptive statistics of the entire group were calculated. Box plots were generated for the designated variables to identify outliers. Among all participants, it was noticed that one subject was an outlier in several indicators (SL, SI, PP, PM). Thus, the sample was reduced by one case, therefore the final number of individuals included in the analysis was 42.

Then, a hierarchical Ward's method with squared Euclidian distance cluster analysis was performed [17]. The variables used for the analysis were anthropometric indices (H, BM, AS, BMA, BF) and power (PP, PM, FI). On this basis, a dendrogram was generated and agglomeration coefficients were determined to identify the potential number of clusters [6]. Then, using the same variables, non-hierarchical k-means clustering was performed several times (distance sorting and observations at a constant interval), each time changing the number of clusters (from 2 to 5). The size of the intra- and extra-group variance and the number of distinguished clusters were the basis for determining the final number of 3 clusters.

Basic descriptive statistics were performed for the distinguished clusters. The homogeneity of variance was assessed using Levene's test. For variables meeting this condition, ANOVA analysis of variance was performed with the F statistic and post-hoc between-group comparisons (test of the least significant difference). In the case of failure to meet the condition of homogeneity of variance, the Kruskal-Wallis between-group rank test was used with post-hoc multiple comparisons of mean ranks for all samples [7]. Partial eta squared (ηp^2) was considered as an effect size measure for ANOVA and interpreted in a way proposed by Ferguson [11]: no effect if $0 < |\eta p^2| \leq 0.04$; a minimum effect if $0.04 < |\eta p^2| \leq 0.25$; a moderate effect if $0.25 < |\eta p^2| \leq 0.64$; and a strong effect if $|\eta p^2| > 0.64$. A similar procedure was followed to compare the level of kinematic indicators (v, SR, SL and SI) between groups for the 50 and 100 m distances, respectively.

An additional part of the data analysis in each group was the identification of differences in v, SR, SL and SI on the 50- and 100 m freestyle distances. After assessing the normality of the distribution with the Shapiro-Wilk test, the Student's t-test for dependent samples was performed for the abovementioned variables [7]. For the entire statistical procedure, $p < 0.05$ was assumed as the level of significance.

Results

Energetic-anthropometric characteristics of clusters

Table 1 presents the descriptive characteristics of the clusters and the results of the variance analysis. Due to the average values of the indicators that were the basis for the analysis, the groups were named as follows:

- Cluster 1 - Large Body Size and Mechanical Power (LSP);
- Cluster 2 - Moderate Body Size and Mechanical Power (MSP);
- Cluster 3 - Small Body Size and Mechanical Power (SSP).

The table also includes the results of post-hoc comparisons: the least significant difference (BM, BF, BMA and FI variables) and the Kruskal-Wallis multiple comparison of mean ranks (H, AS, PP and PM variables) tests.

Table 1. Descriptive characteristics of anthropometric and power variables in clusters with the results of the analysis of variance and post-hoc tests

	Cluster 1 - LSP	Cluster 2 - MSP	Cluster 3 - SSP	p	F	ηp^2
Number of individuals [n]	10	19	13	-	-	-
~~H~~Body height [cm]	176.89 ± 6.31^{ab}	161.67 ± 3.45^{c}	151.16 ± 4.87	<0.001	85.14	0.81
~~AS~~Arm span [cm]	182.05 ± 8.19^{ab}	166.55 ± 4.41^{c}	155.31 ± 4.68	<0.001	64.79	0.77
~~BM~~Body mass [kg]	64.48 ± 9.63^{ab}	49.37 ± 6.05^{c}	38.97 ± 5.39	<0.001	39.00	0.67
~~BF~~Body fat [%]	16.19 ± 2.12	17.48 ± 4.35	15.22 ± 2.26	0.181	1.79	0.08
~~BMA~~Active tissue mass [kg]	53.98 ± 7.59^{ab}	40.59 ± 3.89^{c}	32.96 ± 3.83	<0.001	50.81	0.72

~~PP~~Peak Power [W]	337.18 ± 53.96[ab]	224.12 ± 42.06[c]	164.33 ± 20.50	<0.001	55.91	0.73
~~PM~~Mean Power [W]	286.28 ± 42.01[ab]	196.27[c] ± 34.42	144.03 ±15.86	<0.001	52.95	0.74
~~FI~~Fatigue Index [%]	12.85 ± 4.64[ab]	9.24 ± 3.21[c]	6.35 ± 4.02	<0.01	8.13	0.29

[a] - significant differences between LSP (Large Body Size and Mechanical Power) and SSP (Small Body Size and Mechanical Power), [b] - significant differences between LSP and MSP (Moderate Body Size and Mechanical Power), [c] – significant differences between MSP and SSP ($p<0.05$)

Table 2 presents the mean values of kinematic indices recorded for the entire group of participants and divided into clusters. The results of comparisons between clusters (the least significant difference) are also presented.

Table 2 Descriptive characteristics of kinematic variables of 50-m and 100-m freestyle races in clusters with the results of the analysis of variance and post-hoc tests

		All subjects	Cluster 1 - LSP	Cluster 2 - MSP	Cluster 3 - SSP	p	F	ηp^2
50-m race	Velocity [m/s]	1.56 ± 0.11	1.65 ± 0.10^{ab}	1.55 ± 0.09	1.49 ± 0.08	<0.001	9.45	0.33
	Stroke rate [cycles/min]	54.53 ± 5.13	56.46 ± 4.42	54.86 ± 5.70	52.56 ± 4.37	0.18	0.24	0.08
	Stroke length [m]	1.72 ± 0.12	1.76 ± 0.10	1.71 ± 0.15	1.70 ± 2.54	0.47	4.92	0.04
	Stroke index [m^2/s]	2.68 ± 0.29	2.92 ± 0.25^{ab}	2.65 ± 0.28	2.54 ± 0.21	<0.01	9.92	0.25
100-m race	Velocity [m/s]	1.42 ± 0.11	1.52 ± 0.12^{ab}	1.41 ± 0.11^{c}	1.34 ± 0.05	<0.001	9.52	0.33
	Stroke rate [cycles/min]	47.76 ± 4.16	47.69 ± 4.05	48.21 ± 4.76	47.15 ± 3.49	0.79	1.76	0.01
	Stroke length [m]	1.79 ± 0.17	1.92 ± 0.16^{ab}	1.77 ± 0.17	1.72 ± 0.11	<0.05	0.78	0.20
	Stroke index [m^2/s]	2.54 ± 0.39	2.91 ± 0.40^{ab}	2.51 ± 0.36	2.31 ± 0.18	<0.001	6.48	0.34

[a] - significant differences between LSP (Large Body Size and Mechanical Power) and SSP (Small Body Size and Mechanical Power), [b] - significant differences between LSP and MSP (Moderate Body Size and Mechanical Power), [c] – significant differences between MSP and SSP ($p<0.05$)

Figures 1-4 present a summary of the average values of kinematic indices recorded in the clusters. The differences between the kinematic indices recorded in both races were also noted, taking into account the division into clusters. ~~along with the results of post-hoc tests (comparisons between clusters and distances).~~

~~The subjects from the LSP cluster achieved higher velocity values over the 50 m distance than the swimmers from the other clusters (figure 1). At the same time,~~ $\cancel{v_{100}}$ ~~differed significantly only between the LSP and SSP clusters. In each of the clusters, the average values of~~ $\cancel{v_{50}}$ ~~and~~ $\cancel{v_{100}}$ ~~differed from 0.13 to 0.15 m/s.~~

~~In the case of SR (figure 2), for both the 50 m and 100 m competitions, no differences were noted between clusters. However, subjects from each cluster achieved different SR values depending on the distance covered – in the case of the 50 m race, the stroke rate was significantly higher than in the 100 m race (differences from 5.41 to 8.71 cycles/min).~~

~~The LSP group subjects achieved higher~~ $\cancel{SL_{100}}$ ~~values than the MSP swimmers (on average by 0.15 m) and SSP swimmers (on average by 0.20 m) (figure 3). In the 50 m race, no significant differences in stroke length were observed between the clusters. In the LSP and MSP clusters, significant differences in stroke length were observed depending on the distance covered – for the 50 m race, SL achieved lower values than for the 100 m. The described differences were not noted for the SSP cluster – the SL values observed in this group were similar in both races.~~

~~The stroke index was the highest in the LSP cluster (figure 4). In the case of the 50 m race, significantly lower values were noted in the clusters with medium and small body sizes. In the 100 m race, the stroke index was significantly higher in the LSP cluster compared to the SSP, but no differences were revealed in comparison with the MSP group. The value of the described index in the LSP cluster was similar in the 50- and 100 m races. In the MSP and SSP clusters, significant differences were noted in this respect – the stroke index reached higher values over the shorter distance.~~

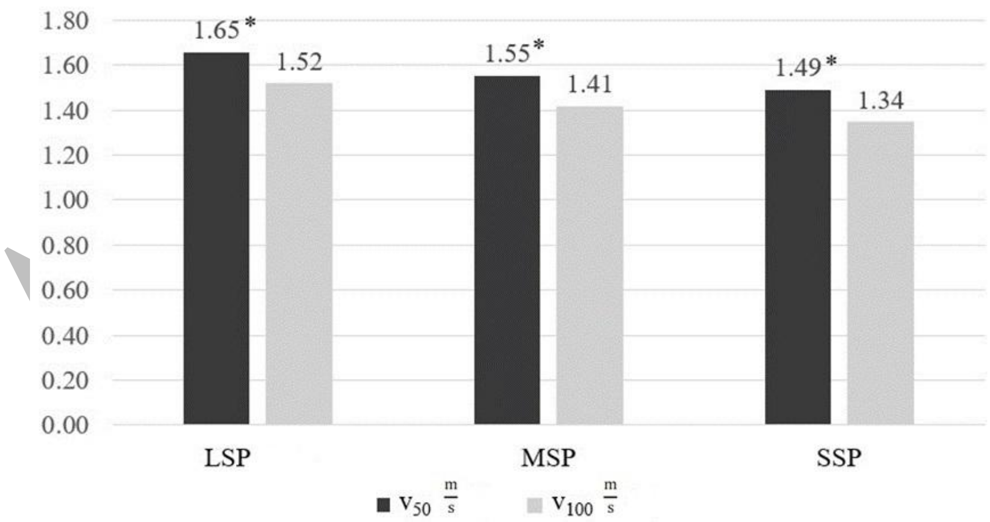


Fig. 1 Mean velocity (v50 for 50- and v100 for 100-m race) recorded in clusters. * - significant differences in v50 and v100 in cluster (p<0.05)

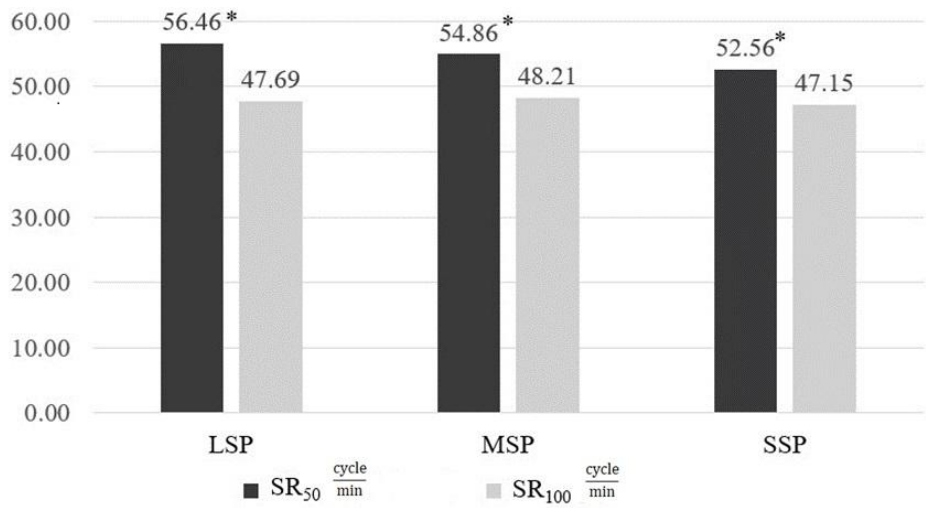


Fig. 2 Mean stroke rate (SR50 for 50- and SR100 for 100-m race) recorded in the clusters. * - significant differences in SR50 and SR100 in cluster ($p<0.05$)

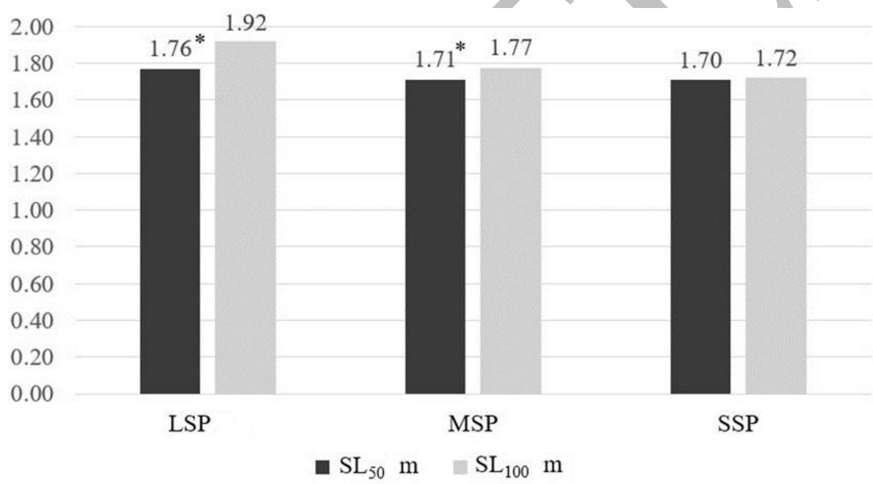
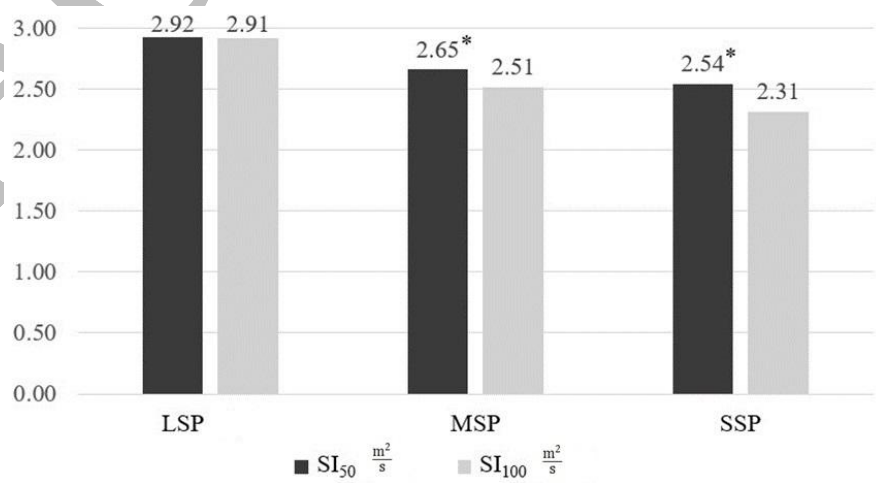


Fig. 3 Mean stroke length (SL50 for 50- and SL100 for 100-m race) recorded in the clusters. * - significant differences in SL50 and SL100 in cluster ($p<0.05$)



Mean stroke index (SI50 for 50- and SI100 for 100-m race) recorded in the clusters. * - significant differences in SI50 and SI100 in cluster ($p<0.05$)

The LSP cluster included athletes with the substantial body sizes – H and BM were larger than in the MSP and SSP groups. The subjects from this group were also characterized by a higher AS and BMA. The LSP cluster had similar BF values to the other groups. In terms of mechanical power indices, the LSP subjects achieved higher PP and MP values. They also noted a greater decrease in power, measured by the FI index.

In relation to kinematic indices, for both the 50-m and 100-m races, the subjects from the LSP cluster noted the highest velocity and stroke index values. Over the longer distance, the SL_{100} took on larger values than in the other groups. There were no differences in the SR_{50}, SR_{100} and SL_{50} indices compared to the MSP and SSP groups. LSP athletes significantly modified their technique depending on the distance covered – velocity and stroke rate were higher in the 50 m race, while SL was lower than in the 100 m event. The LSP cluster was the only one for which no differences were noted between SI_{50} and SI_{100}.

The MSP cluster athletes were characterized by an average body build compared to the other clusters. The H, AS, BM and BMA indices were lower than in the LSP group, but higher than in the SSP group. No differences were observed in the BF index compared to the other clusters. The power indices (PP, PM, FI) were lower than in the LSP group, but higher compared to the SSP group.

In the MSP group, the v_{50}, v_{100}, SI_{50} and SI_{100} indices were significantly lower compared to the LSP cluster. Comparing the results of the MSP group in regard to the SSP, only one significant difference was observed - the v_{100} variable was higher in the MSP cluster. The stroke length and stroke rate indices for both distances were similar to those recorded in the other groups (except for the previously mentioned SL_{100} in LSP cluster). A characteristic feature of this cluster was the significant modification of the technique depending on the distance covered – a similar kind of difference was noted as in the LSP cluster (variables v, SR, SL). At the same time, the stroke index took significantly lower values when covering a longer distance.

The SSP swimmers were characterized by small body size. This is evidenced by the lowest values of almost all anthropometric indices (H, AS, BM, BMA). The BF was similar to those recorded in the LSP and MSP groups. Subjects from the SSP cluster also recorded the lowest values of power indices (PP, PM) while experiencing the smallest decrease in power (FI). The SSP swimmers achieved the lowest values of v_{50}, v_{100}, SL_{100}, SI_{50}, SI_{100} compared to the LSP athletes, but only in the case of v_{100} was the difference significant in regard to the MSP cluster. SSP subjects achieved similar values of SR_{50}, SR_{100}, SL_{50} compared to the other groups. In the SSP cluster, differences were noted in v_{50} and v_{100}, as well as SR_{50} and SR_{100}.

As in the MSP group, the stroke index for the 50 m race was higher than for the 100 m event. At the same time, the SSP subjects were the only ones whose SL_{50} and SL_{100} values were similar.

Discussions

In this study, 3 energy-anthropometric profiles were distinguished. Swimmers were assigned to the following groups: LSP (Large Body Size and Mechanical Power), MSP (Moderate Body Size and Mechanical Power) or SSP (Small Body Size and Mechanical Power). Due to significant differences between swimmers from the LSP and SSP groups, the discussion focuses on comparative analysis primarily between these clusters. In previous studies involving young athletes, kinematic indicators were compared, among others, at sprint and middle distances, i.e. 100-, 200- and 400 m freestyle [9, 16, 22]. Due to the lack of reports on differences in sprint events, i.e. 50- and 100 m freestyle, this type of comparison was made in the distinguished clusters.

The determinants of sports performance in adolescent athletes may be different than in adults due to the fact that the level of performance and skills is dependent on age [32, 37]. Previous literature has also noted that the sports performance of boys and girls is determined by different factors [15, 25]. Therefore, obtained results are discussed primarily in the context of other research on males and a similar age range (12-14 years). Thus, the focus is mainly on works regarding sprint races (50-100 m), for which the determinants of sports performance are different than for middle (200-400 m) and long distances (800-1500 m) [23].

Differences in the somatic structure and mechanical power of the upper limbs

As is known, the somatic structure and mechanical power of muscles are interrelated [26]. Athletes with greater lean mass achieve better results in tests aimed at assessing power [30, 39]. Body mass, in turn, is positively associated with other morphological indicators (including body height) [32]. This means that the sports result is determined by many factors that interact with each other [24, 25, 27]. For this reason, this subsection provides a comprehensive description of the groups, without attempting to isolate individual indicators that affect the sports result.

The analysis of the obtained results indicates a large diversity in terms of body build and the ability to develop mechanical power of the upper limbs – in 7 out of 8 indicators, significant differences were noted between clusters. In most anthropometric variables, the LSP subjects achieved higher values than those recorded in the MSP and SSP groups. In terms of body height and arm span, the differences between the LSP and SSP athletes amounted to over 0.25 m. Due to the homogeneity of the subjects in terms of chronological age, it seems that this is related to differences in the level of biological development. As noted by Mezzaroba and Machado [22], the greatest changes in anthropometric indicators (body height, arm span) occur on average around the age of 12. This indicates that the subjects were probably in different stages of puberty. The same may be true for the variation of somatic build. The maturation process affects anthropometric variables, such as height and mass, active body mass, and arm span [2, 24]. It cannot be ruled out that the LSP group – with significantly larger H, AS, BM, BMA, could have consisted primarily of athletes with an accelerated pace of development.

Significant differences were also observed between the identified clusters in the arm-cranking results. Both maximum and average power were significantly higher in the LSP group compared to MSP and SSP. Also, in this case, the influence of biological age on the recorded results cannot be ruled out. Birat and Ratel [4] indicate that the maturation process increases the activity of enzymes responsible for anaerobic metabolism, as well as the body's capabilities in terms of neuromuscular conduction, and may also lead to changes in the functioning of fast- and slow-twitch muscle fibres. The fatigue index values recorded in own studies are consistent with the above observations. Athletes from the MSP and SSP clusters experienced a smaller decrease in power during the test compared to LSP swimmers. This is primarily due to achieving lower PP values. However, it cannot be ruled out that the MSP and SSP subjects, as presumably later developing, experienced peripheral fatigue to a lesser extent and relied to a large extent on the aerobic system even during short-term efforts [8]. The previously mentioned potential differences in the level of biological development could therefore have an impact not only on anthropometric variables but also on mechanical power [2, 24]. This also means that a larger body size may be beneficial not only in adulthood [20] but also in adolescence.

Differences between groups in 50 m kinematic indices

It is well-documented that elite adult sprinting races are dominated primarily by large-bodied athletes with significant muscle power [31]. A similar phenomenon has been observed in many studies of young swimmers in the 50 m freestyle races [3, 12, 27, 34]. In this study, no sports results (50 m time) were recorded. Due to the fact that v_{50} (full-stroke swimming velocity) is strongly associated with race time [42], it is not surprising that the LSP group achieved higher values of this indicator than those recorded in the MSP and SSP clusters.

So far, in the literature on young swimmers, the analyses of basic kinematic indices (SL, SR or SI) did not take into account the energy-anthropometric characteristics of the athletes. The SL_{50} values were higher in the LSP cluster (1.76 m) compared to the MSP and SSP (1.71 m and 1.70 m, respectively), but the differences were not significant. This fact is somewhat surprising because it is assumed that taller athletes with greater arm reach achieve higher SL values [26, 28]. A similar trend was observed for SR_{50} – in the LSP cluster, this variable reached higher values (56.46 cycles/min) than in the MSP and SSP (54.86 cycles/min and 52.56 cycles/min, respectively), although in this case, too, the differences were statistically insignificant. The currently observed SR_{50} values are similar to those reported in previous studies involving adolescent boys [12, 37]. However, among the best adult athletes, this indicator usually reaches higher values - about 60 cycles/min [10]. Therefore, it seems that the technique of young athletes, regardless of the somatic structure and mechanical power, is characterized by lower SR values than that of elite swimmers. Therefore, it should be checked whether modifying the swimming technique of young athletes to increase the stroke rate would allow for better sports results. This could prove to be an effective strategy provided that the appropriate length of the swimming stroke is maintained.

The SI_{50} reached higher values in the LSP cluster (2.91 m^2/s) compared to the MSP (2.65 m^2/s) and SSP (2.54 m^2/s). Athletes who can move by combining high speed and the length of the swimming stroke are classified as more technically efficient [28]. However, Mezzaroba and Machado [22] noticed that the greatest increase in the stroke index is noted in athletes around 14 years of age. In the case of the mentioned values, the potential effect of differences in biological age cannot be excluded. At the same time, it should be emphasized that the technique should be developed in all swimmers, regardless of their somatic structure and the level of mechanical muscle power.

Intergroup differences in 100-m kinematic indices

Swimming the 100 m freestyle, like the 50 m, is classified as a sprint event, in which a large share of energy comes from anaerobic metabolism [32], but the efficiency of the aerobic system is also important [38]. For this reason, similar intergroup differences in velocity were expected for the longer distance, although they could potentially be the effect of other physiological determinants. This assumption was based on the reports of Birat and Ratel [4], who proved that in young athletes, even in events classified as sprints, the share of aerobic processes can be significant. The results of this study are, therefore, consistent with the literature - subjects from the LSP cluster achieved higher v_{100} values than subjects from the MSP and SSP groups, but only in the latter case were the differences significant.

The SR_{100} recorded in all clusters had almost analogous values - no significant intergroup differences were shown in this indicator (change range from 47.15 to 48.21 cycles/min). The similarity of this indicator in groups with different performance levels on the 100 m distance was also noted in studies involving older competitors [29, 42]. This is probably due to the fact that the SR on distances longer than 50 m is primarily related to the intensity of effort [14]. In the case of competitions, when swimmers cover the distance with their maximum intensity, the SR values may be similar in groups with different performance levels. For this reason, this variable is usually not used as a determinant of technical efficiency on the 100-m distance [42].

Intergroup disproportions were also observed in the SI_{100} variable – subjects from the LSP cluster obtained higher values than those recorded in the SSP (no differences with respect to MSP). This observation should not be surprising, because LSP swimmers swam faster (v_{100}) and with a longer swimming stroke (SL_{100}) than subjects from the other groups. However, this study proves that the assessment of technical quality (for which this indicator is often used) using SI should also take into account somatic build. In this case, it would be worth expressing this indicator in relative values in future studies – e.g. in relation to body height or arm span.

Comparison of kinematic indices in groups on 50- and 100-m distances

An additional area of research was the comparison of kinematic indices in 50- and 100 m freestyle races. This characteristic was investigated in individual clusters, thus considering differences in somatic structure and the level of mechanical power of the upper limbs. So far, such analyses for these races have been performed only among groups with greater training experience, without taking into account the morphological and energetic diversity of the athletes [10, 35, 42].

Differences in full-stroke swimming velocity between the 50- and 100 m races were noted in all clusters. This is due to the specificity of the effort – as a result of the short duration of the 50 m event, athletes move with maximum intensity from the beginning to the end of the race [21]. In 100-m races, a similar strategy is probably ineffective. Due to the longer duration of the effort, potential severe fatigue could have a highly negative impact on the technique of the subjects [8]. Therefore, it should not be surprising that differences in velocity were noted in each group depending on the distance. Significant differences were also observed between SR_{50} and SR_{100} in all 3 clusters. This means that young athletes, regardless of their sports level and morphological-energetic profile, adjust SR to the requirements of a given competition. The same fact was noted in studies involving older athletes [42].

Subjects from the LSP and MSP clusters achieved higher SL values over the 100 m than over the 50 m race. Similar observations were made in the past in a group of elite male athletes [35]. It is assumed that the modification of SL depending on the distance length results from the need to adapt the movements of the upper limbs to the requirements of the race, which is documented in the literature using the index of coordination [36]. In the present study, no differences in SL were noted in subjects from the SSP cluster. Considering the higher v_{50} values in the LSP and MSP groups, it seems that athletes from these clusters adapted their technique in a more optimal way to the specifics of the 50-m race. This confirms the previously described fact of insignificant but noticeable differences in SR_{50} between the LSP, MSP and SSP clusters.

Among swimmers from the LSP cluster, the Stroke Index had similar values at the 50 m and 100 m distances (2.92 and 2.91 m^2/s). This indicates that the LSP group demonstrated similar technical efficiency at both distances, despite significant modification of SL. In the MSP and SSP clusters, SI_{50} was higher than SI_{100}. In previous studies involving athletes with a higher sports level (national), it was noted that the SI index in the 50 m race has lower values compared to the ones noted at the longer distance [10]. This difference indicates that younger athletes, unlike adults, have difficulty maintaining technical efficiency in the 100 m races. This may be due to shorter training experience and associated lower technical (movement stability) and tactical skills ("pacing").

Conclusions and practical implications

Among young swimmers, significant differences can be observed in terms of the somatic structure and mechanical power of the upper limb muscles. This, in turn, affects the level of kinematic indicators in freestyle sprint (50- and 100 m) races. The hypothesis that athletes with different energy-anthropometric profiles would differ in terms of kinematic indices in 50 and 100 m freestyle races was confirmed. For this reason, when assessing the technique, the energy-anthropometric profile of the athlete and the level of biological development should be considered. Talent identification systems should take these facts into account, facilitating the optimal development of swimmers with delayed maturation.

Sprint distances differ in terms of the demands placed on young athletes. This means that in order to achieve the best possible result, the swimming technique should be modified depending on the race. Athletes with larger bodies and greater mechanical power better adapted their technique to the requirements of the competition, achieving similar values of the stroke index in the 50- and 100 m freestyle. Athletes with smaller bodies and lower mechanical power achieved lower values of this variable over the longer distance. At the same time, regardless of the energy-anthropometric profile, athletes modified their stroke rate in a similar way depending on the distance covered. Therefore, technical efficiency in each competition should be monitored using primarily the stroke index.

Based on the research results, several practical implications can be distinguished. The most important of them is the indication that the training process of young swimmers should be focused mainly on the development of swimming technique. However, it is worth pointing out that the quality of performed movements, and consequently also sports results, are strongly determined by the morpho-functional capabilities of swimmers. This means that the progression of sports results of athletes during maturation is the effect not only of training, but also of changes occurring as a result of biological development. Therefore, changes in the energy-anthropometric profile should also be taken into account when monitoring the progress of young swimmers. This type of approach allows for a more accurate determination of the effectiveness of the training process and the athlete's susceptibility to training. This in turn increases the reliability of identifying swimmers predisposed to achieve high results at later stages of their sports career. Moreover, the presented results can be a premise for creating youth training groups based on the morpho-physiological capabilities of the organisms, and not the calendar age. Thanks to this, young athletes could successfully implement training more adequate to their current capabilities.

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