

## Anthropometric predispositions for swimming from the perspective of biomechanics

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*Purpose:* Early identification of anthropological potential in swimmers is considered important to the recruitment and selection of children and adolescents to perform extensive and strenuous training. The aim of the research was a comparative analysis of the anthropometric parameters and indicators of adult, elite swimmers with people who had never trained for swimming. It was assumed that the specific characteristics of the swimmers' somatic composition referred to the laws of swimming biomechanics. *Methods:* Anthropometric measurements were taken in a group of elite male swimmers ( $N = 28$ ), aged 17–24. The same set of measurements was taken in a homogeneous control group of students of physical education. An anthropometric profile significantly differentiating swimmers from the control group was constructed. Next, a linear forward stepwise discriminant analysis was conducted to investigate which indices can be used to distinguish the two groups. *Results:* It seems significant that a specific somatic composition trait of swimmers in the form of a relatively long shank was observed, which had not been observed in earlier studies. Additionally, indices of relatively slim hand dimension, and indices describing a “reversed triangle” shape of trunk, were the most powerful discrimination variables between the two examined groups. *Conclusion:* The results obtained cannot be generalised to the entire population of swimmers, however referring them to the laws of biomechanics of swimming allows for the continuation of research into identifying the prognostic traits desirable for success among young swimmers.

*Key words:* swimming, anthropometric profile, biomechanics

### 1. Introduction

Preparing an elite swimmer is a long-term process that requires time and effort from both the athlete and the coach. There are many factors and relationships between them that determine success in swimming at the championship level. Therefore, early identification of anthropological potential in swimmers is considered an important aspect for recruitment and selection of children and adolescents to undertake extensive and strenuous training.

To identify individual, innate motor predispositions and swimming talent, one can be guided by reliable somatic composition traits [20].

In swimming, the most reliable prognostic traits include the skeletal dimensions [21]. Body height forecasting is the most commonly used tool in the selection of swimming talent [12]. In children, the predispositions for swimming at an initial stage of selection are low body mass with superior body height, wide hands, and long feet, as well as narrow ankles and wrists [20]. To determine the predispositions for swimming, a visual assessment and measurement of anatomical and morphological indicators of the upper and lower body parts are most often considered at the initial stage of selection [13]. According to Bompa [3], traits that are conducive to developing talent in swimming include long trunk, long upper limbs and feet, and a high aerobic and anaerobic capacity. Swimmers' anthropologi-

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cal characteristics (which are largely genetically determined) seem to be stable in the function of time (age) and remain related to swimming performance [13]. Therefore, somatic composition traits of elite adult swimmers can be treated as the pattern to identify the individual predisposition to succeed in swimming in youth.

The research area of the somatic physique and body composition of adult swimmers seems to be well explored. The analogy to current research of swimmers' anthropometric profiles has been estimated by Pietraszewska and Jakubowski [22] and Clarys [7]. The first authors demonstrated 17 traits statistically differentiating swimmers and non-training students. The second author presented a profile with 26 normalised traits of swimmers and students against a group of soldiers. A different scope of the research focused on determining differences in the anthropological composition between swimmers representing the different stroke specialisations [4]–[6]. The greatest scientific value in identifying specific somatic characteristics of swimmers was found as the result of longitudinal studies [14]–[20]. Nevertheless, further exploration of the aforementioned area seems to be justified by the acceleration of growth and the secular trend recognised in studies of swimmers [5]. The autonomy of researchers in the selection and quantity of variables examined (parameters and indicators) seems to be yet another argument for undertaking further research to identify the specific somatic traits that determine swimming efficiency.

Analysis of the body of knowledge and the resulting lack of certainty in identifying somatic traits conducive to developing talent in swimming, with continuous progression of results and ever-changing standards of recruitment and selection, give rise to a need for a multi-directional identification of individual predispositions in swimmers. One way to explain this identification is through the relationship between the body physique of swimmers and the biomechanical principles of swimming performance [14], [15], [20].

Assuming that the aim of swimmers' propulsive movement is a full and conscious use of their somatic and motor potential for efficient energy transfer onto the water, it should be clear that the difficulty of this process arises from the paradox based on the relationship between negative resistance that arises from the displacement of the swimmer's body through the water and the same resistance that is the source of generating positive drag on other body segments (mostly the hands, legs, and trunk). Therefore, this research concentrates on the identification of the specific somatic potential in high-level adult swimmers. It treats

their anthropometric characteristics and the biomechanical interpretation of these characteristics as justification for the need to identify prognostic traits for successful swimming already in young swimmers. Therefore, the aim of the study is a comparative analysis of the anthropometric parameters and indicators of highly skilled adult swimmers and physically active students, who had never trained in swimming, to identify intergroup differences in somatic composition while referring them to the laws of hydrodynamics, which determine swimming efficiency.

## 2. Material and methods

The research involved male swimmers with a preference for: freestyle swimming ( $N = 7$ ), breaststroke ( $N = 7$ ), butterfly ( $N = 7$ ), and backstroke swimming ( $N = 7$ ), aged 17–24. The criterion of selection for this experimental group was a high level of swimming proficiency, determined by the classification of the FINA (International Swimming Federation) [<http://www.fina.org/content/fina-points>]. The control group consisted of students of physical education ( $N = 28$ ) living in the same town, aged 20–25 years, who had never trained in swimming or other aquatic sports.

The study was conducted within the parameters of the Human Rights Declaration. The voluntary respondents and their parents or caregivers were informed of the objectives and procedures for the experiment, which was approved by the ethics committee. Informed consent for participation in the research was obtained.

A series of anthropometric measurements was taken for both groups. All measurements were taken by trained staff, in line with the standards developed by Martin and Saller [18]. Measurements were carried out using the following instruments: anthropometer (GPM, Switzerland), scale (Fawag, Poland), sliding calliper (GPM, Switzerland), spreading calliper (GPM, Switzerland), anthropometric tape (GPM, Switzerland), and skin-fold callipers (GPM, Switzerland). To determine the measurement error, it was repeated for every tenth respondent. Anthropometric measurements included: body height (B-v), body mass, symphision height (B-sy), knee height (B-ti), foot height (B-sph), arm span (daIII-daIII), shoulder breadth (a-a), upper body breadth (dl-dl), chest breadth (thl-thl), chest depth (xi-ths), biiliac breadth (ic-ic), hand length (sty-daIII), palm breadth (mu-mr), hand breadth (mu-mm), foot breadth (mtt-mtf), waist circumference, hip circumference, highest thigh circumference, foot length (pte-ap), trunk length (sst-sy), arm length (a-r), upper

limb length (a-daIII), thigh length (sy-ti), shank length (ti-sph), triceps skinfold thickness, and subscapular skinfold thickness. Moreover, the following anthropometric indicators were calculated: body mass index (BMI), trunk-to-height ratio ((sst-sy/B-v) × 100%), inter-limb index ((a-daIII/B-sy) × 100%), arm span-to-height ratio ((daIII-daIII/B-v) × 100%), hip breadth-to-trunk length ratio ((ic-ic/sst-sy) × 100%), hip-to-shoulder ratio ((ic-ic/a-a) × 100%), Rohrer index, Wertheimer index, palm breadth-to-hand length ratio ((mu-mr/sty-daIII) × 100%), hand breadth-to-hand length ratio ((mu-mm/sty-daIII) × 100%), foot breadth-to-foot length ratio ((mtt-mtf/ap-pte) × 100%), relative shank length-to-lower limb ratio ((ti-sph/B-sy) × 100%), relative shank length-to-thigh length ratio ((ti-sph/sy-ti) × 100%), and waist-to-hip ratio (WHR).

The differences in the means of the results of anthropometric measurements and indicators between the two groups were assessed using a Student's *t*-test for independent samples. An anthropometric profile was constructed based on the mean normalised values of the anthropometric parameters and indices significantly differentiating swimmers from the control group. Next, a linear forward stepwise discriminant analysis was conducted to investigate which indices can be used to distinguish between the two groups. Discriminant analysis included 11 combined indices, which previously exhibited significant differences between two groups assessed by the Student *t*-test. All analyses were carried out using the Statistica 13.1 (Dell Inc., 2016).

### 3. Results

In the group of swimmers (Table 1), knee height was significantly greater than in the control group. Body height and foot height were also greater in the group of swimmers, however at a lower level of significance. Compared to students from the control group, swimmers also had greater upper limb length, arm and hand length, arm span, and trunk length. Significantly longer shins in swimmers were also noticeable. Swimmers were characterised by upper body breadth and shoulder breadth greater than students in the control group. Another trait differentiating the subjects in both groups was thigh circumference, which was significantly smaller in the group of swimmers. Significantly lower values of the triceps and subscapular skin folds in the group of swimmers suggest that a lower fat component in the upper limb girdle is another trait differentiating this group of athletes from the control group.

Swimmers were characterised by physiques more slender than subjects in the control group (Table 2). The group of swimmers had higher WHR values, which suggests that the difference between waist circumference and hip circumference in swimmers was lower than in students from the control group. A comparison of the Wertheimer index value suggests that swimmers are characterised by greater trunk volume relative to the length of the lower limbs than those in the control group. The results indicate that in the group

Table 1. Results of morphological traits that statistically differentiated the examined groups (Student's *t*-test)

Variable	Swimmers		Control group		<i>t</i>
	$\bar{x}$	SD	$\bar{x}$	SD	
Body height (B-v) [cm]	183.45	6.01	179.92	4.27	2.619*
Knee height (B-ti) [cm]	50.28	3.05	48.28	2.13	2.945**
Foot height (B-sph) [cm]	8.73	0.92	8.28	0.59	2.276*
Arm span (da III-da III) [cm]	188.81	7.1	181.4	5.1	4.650**
Trunk length (sst-sy) [cm]	56.6	3.3	53.8	3.7	2.975**
Arm length (a-r) [cm]	35.3	2.4	34.0	1.6	2.462*
Upper limb length (a-daIII) [cm]	81.4	3.9	78.7	2.5	3.256**
Shank length (ti-sph) [cm]	41.6	3.3	40.0	2.2	2.152*
Hand length (sty-daIII) [cm]	20.0	1.0	19.28	0.8	3.067**
Shoulder breadth (a-a) [cm]	42.33	2.25	40.63	2.35	2.832**
Upper body breadth (dl-dl) [cm]	48.8	2.96	47.34	2.55	2.028*
Thigh circumference [cm]	56.47	4	57.93	4.78	-2.88**
Triceps skinfold [mm]	8.89	2.97	11.13	4.30	-2.297*
Subscapular skinfold [mm]	10.89	2.83	15.39	5.26	-4.024**

\* Statistical significance at  $p < 0.5$ .

\*\* Statistical significance at  $p < 0.01$ .

Table 2. Values of anthropometric indicators significantly differentiating the examined groups (Student's *t*-test)

Variables	Swimmers		Control group		<i>t</i>
	$\bar{x}$	SD	$\bar{x}$	SD	
Rohrer index (body mass [g]/body height [cm <sup>3</sup> ])	1.26	0.10	1.34	0.15	-2.140*
Wertheimer index (B-sy) / (((thl-thl) *(xi-ths)*(sst-sy))/1000)	25.36	3.60	27.77	4.81	-2.164*
Trunk-to-height ratio (sst-sy/B-v*100)	30.83	1.51	29.91	1.66	2.218*
Inter-limb index (a-daIII/B-sy*100)	86.38	3.69	84.56	2.26	2.307*
Arm span-to-height ratio (daII-daIII/B-v*100)	102.93	2.02	100.86	2.46	3.509**
Relative shank length-to-lower limb ratio (ti-sph /B-sy*100)	53.33	2.83	51.92	2.38	2.084*
Relative shank length-to-thigh length ratio (ti-sph /sy-ti*100)	115.04	13.02	108.46	10.12	2.180*
Hip breadth-to-trunk length ratio (ic-ic/sst-sy*100)	51.90	4.16	55.17	5.54	-2.539*
Hip-to-shoulder ratio (ic-ic/a-a*100)	69.27	5.04	72.87	5.15	-2.710**
Waist-to-hip ratio (WHR)	0.84	0.04	0.81	0.04	2.799**
Palm breadth-to-hand length ratio (mu-mr/sty-daIII*100)	43.16	2.37	45.31	2.06	-3.734**
Hand breadth-to-hand length ratio (mu-mm/sty-daIII*100)	54.29	2.89	56.12	2.34	-2.678*
Foot breadth-to-foot length ratio (mtt-mtf/ap-pte*100)	36.72	1.81	37.88	1.92	-2.389*

\* Statistical significance at  $p < 0.5$ .

\*\* Statistical significance at  $p < 0.01$ .

of swimmers a relative trunk-to-body height ratio was significantly higher than in the control group. A higher relative shank length-to-lower limb ratio and shank length-to-thigh length ratio determined in the group of swimmers suggest that a morphological trait differentiating swimmers from non-training students is the relatively long shank. Moreover, the distinct trait in this group of athletes may be the arm span-to-height ratio. Higher mean values of the inter-limb index recorded among swimmers indicate that the distinct trait in this group is the greater length of the upper limbs relative to the length of lower limbs. The swimmers also had lower relative hip breadth-to-trunk length ratio and hip-to-shoulder width ratio. Significant differences revealed that the distinct morphological traits of the swimmers' group are slim hands (smaller ratio of hand breadth-to-hand length and palm breadth-to-hand length ratio) as well as slender feet (smaller foot breadth-to-foot length ratio).

The anthropometric profile (Fig. 1) presents mean normalised values of the anthropometric pa-

rameters and indicators, significantly differentiating swimmers from the control group. A profile trait that most significantly differentiates swimmers from the control group is the arm span. In contrast, the smallest differences were found in the value of the Wertheimer index, Rohrer index, and the triceps skinfold thickness.

To identify which anthropometric variables studied were the best predictors of the traits differentiating the group of swimmers from the control group, the discriminant analysis was provided. The analysis, which included 11 combined indices, which previously exhibited significant differences between the two groups (assessed by a Student *t*-test; Tables 1 and 2) were carried out (Tables 3 and 4).

Canonical correlation, which accounts for 0.77, which seems relatively high, indicates the strong discriminating power (Table 3). The means of canonical variable for each group accounts for -1.24 and 1.12, for swimmers and controls, respectively.

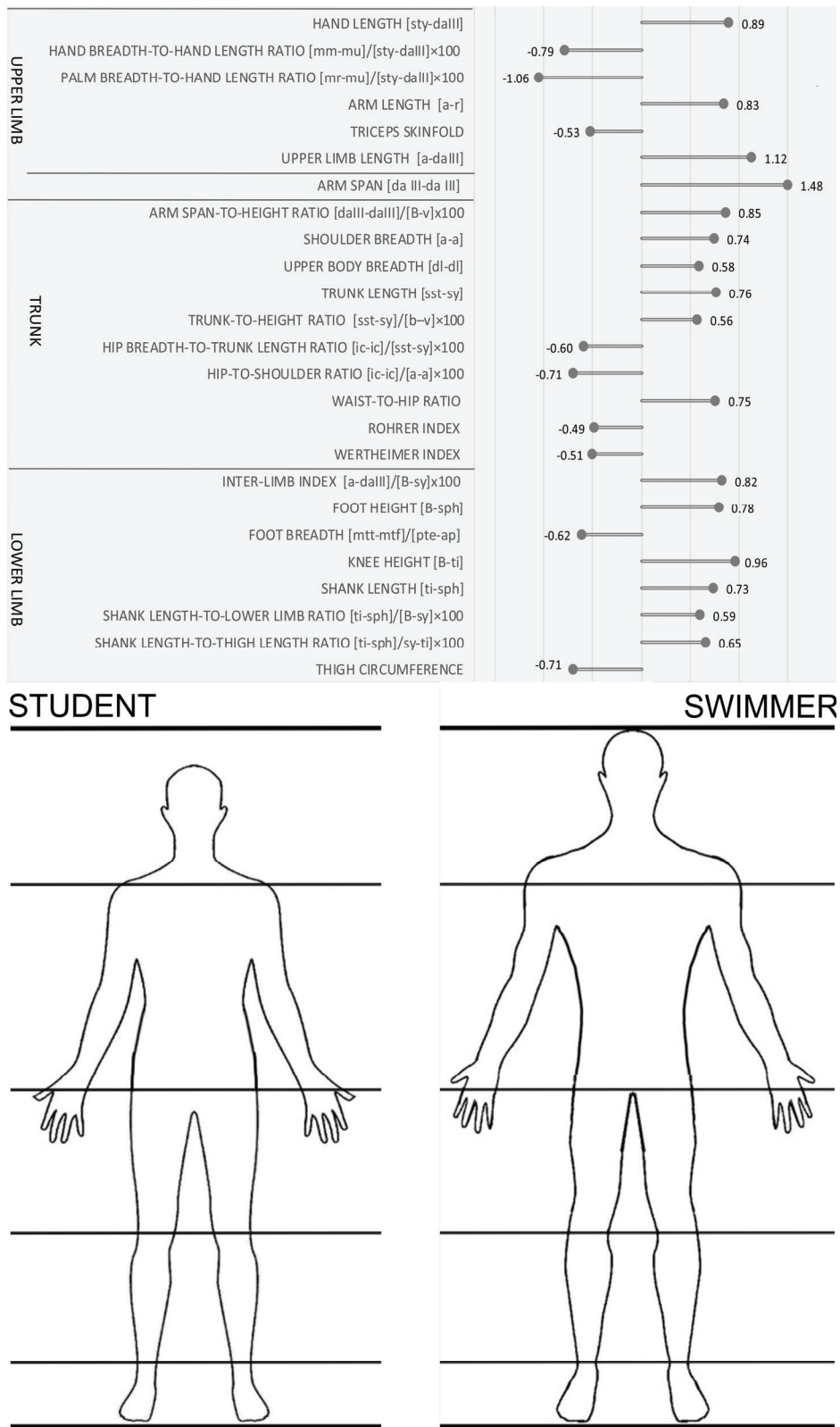


Fig. 1. Anthropometric profile of swimmers compared to students in the control group

Canonical loadings and correlations, each a discriminating variable, which significantly contributed to the discriminating function, are shown in Table 4. Among the variables contributing to the discriminat-

ing function are the traits describing the trunk's shape (hip-to-shoulder ratio and WHR), the shape of the hand (hand breadth-to-hand length ratio, palm breadth-to-hand length ratio) and foot, (foot breadth-to-foot

length ratio), and also the inter-limb index and arm-span. Significant correlation coefficients demonstrated that two indices of relatively slim hand dimension and two indices of relative “V” shape of trunk (waist-to-hip) were the most powerful discrimination variables in the two groups examined.

Table 3. Summary of the discriminant analysis (only one canonical variables was extracted)

Eigenvalue	Canonical R	Wilks' Lambda	CHI-Square	Df	P
1.445	0.769	0.409	47.837	7	< 0.001

Table 4. Canonical loadings and correlations with canonical variable for discriminating variables

Variables	Raw loadings	Standardised loadings	Correlations
Palm breadth-to-hand length ratio	0.471	1.041	0.411*
Waist-to-hip ratio (WHR)	-12.343	-0.512	-0.308*
Hip-to-shoulder ratio	0.121	0.616	0.299*
Hand breadth-to-hand length ratio	-0.127	-0.331	0.295*
Foot breadth-to-foot length ratio	0.219	0.410	0.263
Inter-limb index	-0.167	-0.504	-0.254
Arm-span	0.090	0.383	0.239

## 4. Discussion

The statistical range of the differences in the values of anthropometric parameters and indicators presented in swimmers' anthropometric profiles was in line with the aforementioned profiles constructed by other authors [22]–[26].

Baxter-Jones et al. [1] demonstrate that the average body height of swimmers aged 8–19 is significantly greater than in the population of their non-training peers. With this in mind, conclusions were derived by Clarys [7] that an above-average body height is a trait distinctive to this group of athletes, and it can be generalised to a wide range of ages.

A significantly lower value of the Rohrer index among swimmers tends towards a thesis that they are more slender in shape than the control group. The results of studies by Pietraszewska and Jakubowski [22] also pointed to a more slender physique for the swimmers. The swimmers examined had distinctively longer

trunks, calculated by taking both a direct measurement as well as by considering a greater trunk length-to-height ratio. The swimmers also exhibited a larger dimension of the shoulder width and lower values of the hip-to-shoulder ratio than the control group. In this respect, it seems that, in describing a distinct physique of a swimmer, one should make a specific compromise manifesting in the slenderness of a distinct athletic type. This result is in line with observations of other authors. Stragger and Babbington [26] describe the swimmer's somatotype as the ectomorph.

McLeod [19] points out that an activation of the abdominal muscles (particularly the oblique muscle group) during swimming, affecting development of the muscles around the waist, is likely to increase WHR values in swimmers. In the group of swimmers there is a significantly smaller thigh circumference recorded, as confirmed by the results of Pietraszewska [23]. The author explains this fact with a smaller share, compared with the upper limbs, of the lower limbs in generating propulsion in swimming and, consequently, less stimulation of these muscle groups in terms of their growth.

Pietraszewska and Jakubowski [22] highlight specific dimensions of the swimmers' trunk (a relatively long trunk, relatively narrow pelvis both in relation to the length of the trunk and shoulder width, and greater WHR value). A large shoulder width (and upper body width) corresponds to an above-average length of upper limb, a trait also noticed by Clarys [7] and Kjendlie et al. [12], determining a large arm span. Arm span-to-height ratio is recognised as a trait highly distinctive to swimmers [11], [12]. These results demonstrate that the traits differentiating swimmers from the group of non-training students are long slim hands and long slim feet. Above-average hand size is reported by Bixler and Riewald [2], Marinho et al. [17], and Rouboa et al. [25], and above-average foot size by Grimston and Hay [10], Keskinen et al. [11], and Toussaint et al. [27]. In view of the reasoning presented, the length of the hands and feet can be considered distinct physique traits of swimmers that become visible at a very young age [13].

The longer shank of swimmers indicated in this study has not been observed thus far. Therefore, there are no direct references of this characteristic in existing literature.

Although the interpretation of results is embedded in the scientific achievements of other authors, it is subject to limitations. The first of these is a small research sample (28 swimmers and the same number of stu-

dents). In contrast, however, Pietraszewska and Jakubowski [22] examined 33 swimmers and 36 non-training swimmers. In both of the aforementioned cases, however, the argument concerning the relatively small population of the elite swimmers seems to justify the relatively small study group. Another limitation is that the swimmers' specialisations in swimming stroke and distance were not taken into account. These differences have already been demonstrated in 12–13-year-old swimmers [21].

For the aforementioned reasons, from an anthropological point of view, the results obtained cannot be generalised for the entire population of swimmers, but it seems that they are useful for setting the direction of further research – increasing the size of the research group (research sample) and considering stroke and distance specialisation. Thus, validation of the results, considered according to the laws of hydrodynamics, which determine swimming efficiency, can be considered as an argument justifying the need for identifying prognostic traits in young swimmers for achieving success.

Understanding of the specific physique of swimmers represented by the results of discrimination analysis and main findings of the constructed profile, in terms of swimming efficiency, enables the comparison of slim hand dimensions with the shape of paddle blade (Fig. 2). Many studies based on the estimation of stroke rate and stroke length suggest a relationship between hand shape (i.e., hand length) and swimming efficiency [2], [16], [20], [21]. Its concave–convex shape forces a non-parallel water flow along the palm and dorsal surfaces of the hand during propulsive movements. Consequently, a greater lift force occurs, which is an important component of propulsive force [9]. Such reasoning is also confirmed in the design of fins, which significantly improve swimming efficiency [29]. Although Zamparo [30] did not indicate the differences in the efficiency and economy of swimming between long and hard fins and their short and soft counterparts, in both cases the length dimensions of the fins exceeded their width dimensions, in line with an as-

sumption that they would initiate water jets for as far as possible in the opposite direction to that of swimming. In this context, longer and narrower hands and feet (Fig. 2) of swimmers, compared to non-training students, can be interpreted as a trait that promotes swimming efficiency.

From a perspective of the biomechanics of human movement, the foot is the end of the biokinematic chain composed of lower limb segments [9]. Therefore, it acts as an effector, transferring muscle torque from the thigh and shank to the aquatic environment. Additionally, however small the range of movement in the hip joint determining the small role of this segment in generating propulsion, the movement of the shank and foot constitutes an important component (Fig. 2). In conjunction with the suggested role of the lower limb distal parts in generating effective propulsion, the elongated shank differentiating swimmers from students seems to be yet another distinct trait, justified from the biomechanics point of view. The torque can be increased by applying a longer arm [9]. By indicating shank as an element of the bone lever with the support point in the knee joint, it can be stated that swimmers are able to overcome greater hydrodynamic resistance with a relatively lower expenditure of energy because of the long shank. A longer shank results in a greater frontal area on which the thrust is generated. In addition, a longer shank implies a longer trajectory on which this positive drag can be generated. It seems, therefore, that this somatic trait of swimmers, not observed thus far by other researchers, can be considered a key finding of this study.

Another swimmer trait that helps to minimize negative resistance seems to be the specific, shape of the trunk. Among other things, this type of body shape can be viewed in the form of small pelvic width dimensions in relation to broad shoulders (Fig. 2). This determines the shape of the trunk, which can be compared to a reversed triangle with the base pointed in the swimming direction. By perceiving this shape as like a water droplet [16], it can be assumed that the trunk of a swimmer creates lower negative resis-

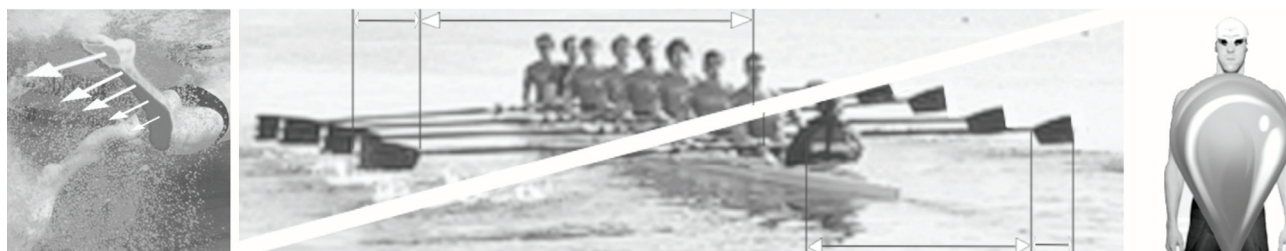


Fig. 2. Images demonstrating how the anthropometric traits (long shank, arm span and slim hand/slender feet, and “V” shape of elongated trunk) can affect the usage of the laws of hydrodynamics for efficient propulsion of swimmers

tance. Empirical evidence of this thesis has already been provided in [15] using the Particle Image Velocity (PIV) method to calculate the lowest drag coefficient in swimmers with an inverted triangle trunk shape compared with people with trunk shapes classified as an inverted trapeze, rectangle, and oval.

The distinctive shape of the trunk of examined swimmers is accompanied by greater length dimension of this segment of the body. Swimmers, compared to students from the control group, are distinguished by their longer trunks in absolute measurement and in relation to body height. The discussion is based on results of studies of the mechanisms of generating propulsion in swimming, referring to a search for models of swimming efficiency in nature among fish and marine animals. By 1999, Colman et al. [8] proposed a theory of human swimming propulsion established on a movement generated by tuna. Based on the same pattern of motion, a mechanism for generating propulsion while monofin swimming was developed [24]. In the cited and subsequent studies, it was pointed out that, by minimising the negative resistance and directing the water jets towards distal segments of the body, human propulsion movement became similar to that of fish. The noticeable length dimension of the trunk as a distinct characteristic of a swimmer's physique can also be considered in terms of utilising the positive drag as a source of propulsion. Ungerechts [28] found similarities in the mechanism of generating propulsion between a butterfly swimmer and a dolphin, indicating that a shorter human trunk is one of the obstacle to creating favourable hydrodynamic conditions in which the dolphin swims. Also, the body height of swimmers, clearly greater than in the control group, can be considered a trait conducive to minimising negative water resistance. Toussaint et al. [27] suggest that the body height of swimmers is negatively correlated with the magnitude of wave drag.

The arm span – longer than the body height – seems to be another trait distinctive for swimmers. Arm span is considered the main anthropometric parameter determining the efficiency of the generated propulsion because it correlates highly with the swimming velocity [11] and with biomechanical parameters of the swimming stroke: the stroke length, and stroke index [14]. The long segments of the upper limb go hand in hand with longer lever arms supported by the muscles, which, if properly trained, can generate greater propulsion [16] (Fig. 2). The elongated dimension of the upper limb is usually closely associated with the increase in its frontal area, allowing for more effective thrust.

## 5. Conclusions

The constructed profile indicated significantly longer shanks among swimmers. This trait has not been found in earlier studies. Other parameters, which have been found in this profile, corresponded to an existing somatic image of swimmers. They were taller than non-training students, they were characterised by specific trunk dimensions, namely a large length dimension of this segment of the body, accompanied by expanded width dimension and a relatively narrow pelvis. With a more developed upper trunk in terms of width dimensions, significantly longer upper limbs resulting in a large arm span, swimmers were characterised by slender hands. This tendency was exposed less significantly in case of the feet length.

The most powerful discriminating variables differentiating swimmers from the student group were the relative “V” shape of the trunk (hip-to-shoulder ratio and WHR) and the slim shape of the hand (hand breadth-to-hand length ratio, palm breadth-to-hand length ratio). Among the variables contributing to discriminating functions are the traits showing slender foot, (foot breadth-to-foot length ratio) and the inter-limb index, and arm span.

The intergroup differences in somatic composition of both research groups cannot be generalised to the entire population of swimmers, however referring them to the laws of biomechanics of swimming allows for the continuation of research into identifying the prognostic traits desirable for success among young swimmers. Further research should focus on reducing limitations of the current study: an increase in the sample size while considering swimmer stroke specialisation.

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