Acta of Bioengineering and Biomechanics
Vol. 7, No. 1, 2005

Estimation of swimmers anthropometric parameters and surface areas in real swimming conditions

REDHA TAIAR*, ALAIN LODINI

Laboratory for Analysis of Mechanical Constraints (LACM), UFRSTAPS,
University of REIMS, France

ANNIE ROUARD

UFR CISM, Department STAPS, University of Savoie, France

YULI TOSHEV

Laboratory for Analysis of Mechanical Constraints (LACM), UFRSTAPS,
University of REIMS, France
Institute of Mechanics and Biomechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria

The main aim of this study was to propose and to test a reliable method allowing us to obtain data both from static numeric images and numeric video images taken in real swimming conditions and using appropriate computer procedure. Based on these images it is possible to estimate the swimmer's anthropometric parameters and the projected frontal surface (*PFS*) during swimming. Measurements of sportsmen anthropometric parameters, including swimmers, are usually carried out in a static anatomic position using standard anthropometric method. In the present study, this common method is compared with a new approach which enables us to carry out the anthropometric measurements using numeric images collected both in static and in real swimming conditions. This method offers two advantages: the results are obtained in real dynamic conditions and the measurements are characterized by a high precision and repeatability. The proposed measurement approach is suitable also for other applications in the field of biomechanics.

Key words: sports biomechanics, swimming, anthropometric parameters, numeric images

---

* Corresponding author:UFRSTAPS, Chemin des Rouliers, Bâtiment 5 ter, BP 1036, 51687 Reims cedex 2, tel.: (33) 06-77-94-46-28, fax: (33) 03-26-91-38-06, e-mail: redha.taiar@univ-reims.fr.

1. Introduction

Morphometric data are often used to characterise a sportsman population. In swimming, for example, such data enable us to follow up the individual growth, to estimate the physical distinctions between swimmers in different styles, etc. Anthropometric data are often used to create different models of swimming movements. In many studies related to swimmers, direct measurements have been used, i.e. standard anthropometric method (SPRAGUE [14], CATTEAU and RENOUX [7], SMITH [13], CLARYS [8], GRIMSTON and HAY [9]), and usually absolute error reported approaches 0.1 cm (VANDERVAEL [16]). A correlation between the swimmer's height and the maximum swimming speed was reported (BLOOMFIELD and SIPERSETH [3]). Other authors stated an important increase in the height of the swimmers taking part in the finals of Olympic Games between 1968 and 1988. Their morphotype was reported to become more and more threadlike (CATTEAU and RENOUX [7], BEDARD et al. [1]). The individual swimmer's morphotype has been defined using body contours method (Boulgakova and Voroncov 1978).

It is important to note that somatic measurements have been also used to appreciate the drag of fishes and swimmers (e.g. to calculate their Reynolds number). As is well known, the drag experienced by an object (body) moving through a fluid is given by the drag equation:

$$D = C_d \rho \frac{V^2}{2} A, \tag{1}$$

where: D is the force of drag, C_d is the drag coefficient (dimensionless), ρ is the density of the fluid, V is the velocity of the object relative to the fluid, A is the reference area. Equation (1) shows a particular importance of V^2, since the drag increases with the squared velocity of a body. It is important to note that the reference area A is not exactly equal to the area of the projection of the object on a plane perpendicular to the direction of motion (i.e. the frontal surface area), but for practical use this difference could be neglected (e.g. VOGEL [17]). So, we can rewrite equation (1) as follows:

$$D = C_d \rho \frac{V^2}{2} S, \tag{2}$$

where S (or PFS) is the body *Projected Frontal Surface.* In the case of living bodies, S is closely related to the morphometric parameters. Fish drag was estimated by determining the frontal surface area from a ratio of the maximal width (on a frontal view) to the maximal length (HOUSSAY [10]). This ratio, named later the "fineness ratio" (WEBB [18], BLAKE [2], STATZNER and HOLM [15]), makes the evaluation of the influence of body shape on drag possible. In fishes, the minimal drag is obtained for a fineness ratio of about 0.22, and the drag increases by about 10% when the fineness ratio changes from 0.14 to 0.33 (WEBB [18], BLAKE [2]). As a general rule, the bodies whose fineness ratio is low, experience a weak drag of moving fluids (CARSTENS [6]).

In swimmers, the frontal surface area *S* and the drag *D* (equation (2)) depend on the respective positions of the body segments. Few researchers have been calculated the frontal surface area of swimmers. An estimation of *S* based on the swimmer's cross-sectional area has been reported (CLARYS [8]), but the equation proposed is rather approximate. The swimmer's frontal surface area *S* has been determined from a complete swimming pattern using the digitalized images of 10 swimmers (CAPPEART et al. [5]) and compared to the results of both CLARYS [8] and KOLMOGOROV and DUPLISHEVA [11] and it was noted that all methods produce significantly different results. It was also recommended to obtain the anthropometric variables as functions of the time.

The main aim of this study was to present a reliable methodology of obtaining data both from static numeric images and numeric video images taken in real swimming conditions and using appropriate computer procedure to estimate the swimmer's anthropometric parameters and the projected frontal surface (*PFS*) during swimming. The reliability of the method proposed consists in the possibility of obtaining results both in static and in real swimming conditions and comparing them with the results obtained using the well-known somatic (anthropometric) method.

2. Methods

2.1. Subjects

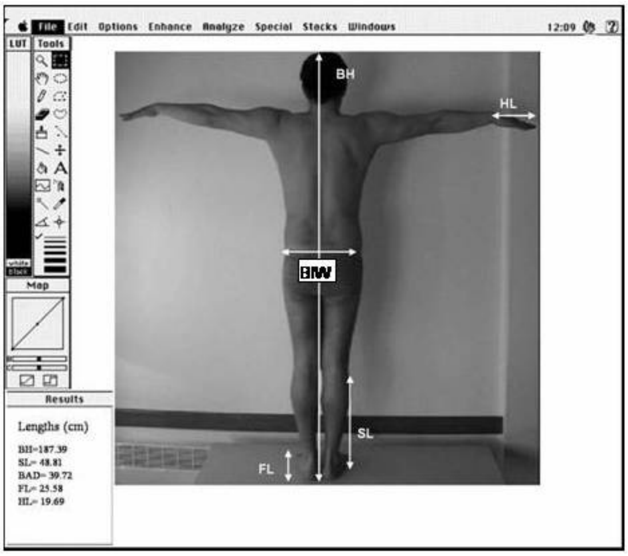
Thirty male butterfly swimmers, with mean age of 22 (StDev = ± 2.66) were recruited for the study. Eighteen subjects were involved in the France Championship and twelve were involved in regional competitions. The swimmers completed 100 m butterfly with mean velocity of 1.6 m/s (StDev = 0.12). The data were obtained and analysed for one standard anthropometric study (*Direct*), 30 independent measurements using static numeric images (*Static*) and 30 independent swimmer's attempts filmed by numeric video cameras (*Dynamic*). The study was carried out in compliance with the law. As mentioned above the main aim of this study was to propose and to test a reliable methodology of obtaining data both from static numeric images and numeric video images and comparing them with the standard anthropometric data collection. For these purposes standard anthropometric data (*Direct*) were obtained for one swimmer (involved in the France Championship) and compared with his *Static* and his *Dynamic* data. The same set of data was used to estimate the *Projected Frontal Surface* (*PFS*). In our future study, all the data collected for 30 swimmers will be analysed and compared from the viewpoint of the swimmer's level and the swimmer's style. The *Projected Frontal Surface* will be obtained for different key positions during butterfly swimming.

2.2. Standard anthropometric data collection

Direct measurements were carried out on one swimmer in anatomical position. A morphometric equipment (the Martin system) was used: (a) anthropometer to measure lengths; (b) compass to measure widths; (c) weighting scales to measure weights and (d) ribbon to measure perimeters. The following measurements are performed: (a) *Body Height* (*BH*) in anatomical position (between the floor and "vertex"); (b) *Shank Length* (*SL*) (between "tibiale" and "sphyrion"); (c) *Bi-Illiocristal Width* (*BIW*); (d) *Foot Length* (*FL*) (between "pternion" and "acromion") and (e) *Hand Length* (*HL*) (between "stylion" and "dactylion").

2.3. Numeric data collection in static conditions

Thirty male butterfly swimmers were recruited for the study. In static conditions the frontal, the dorsal and the lateral views of a standing swimmer were taken (figure 1) using a digital video camera AG-EZ1E (30 Hz). The camera was mounted 1 m away from the ground and 5 m away from the swimmer. Values for all anthropometric variables mentioned above have been obtained: *Body Height*, *Shank Length*, *Bi-Illiocristal Width* and *Hand Length*.



```
Lengths (cm)

BH=187.39
SL= 48.81
BAD= 39.72
FL= 25.58
HL= 19.69
```

Fig. 1. Computer screen during numeric data collection in static conditions. Frontal, dorsal and lateral views of a standing swimmer were obtained using a digital video camera AG-EZ1E (30 Hz). The camera was mounted 1 m away from the ground and 5m away from the swimmer. The numeric images obtained have been treated using Image NIH™. Results of the following anthropometric variables have been obtained: (a) *Body Height* (*BH*) (between the floor and "vertex"); (b) *Shank Length* (*SL*) (between "tibiale" and "sphyrion"); (c) *Bi-Illiocristal Width* (*BIW*); (d) *Foot Length* (*FL*) (between "pternion" and "acromion") and (e) *Hand Length* (*HL*) (between "stylion" and "dactylion")

2.4. Numeric data collection in dynamic conditions

Thirty male butterfly swimmers were recruited for the study. In dynamic conditions (i.e. during swimming), two numeric video cameras AG-EZ1E were placed, frontally and laterally according to the swimming direction with an angle between the optic axis equal to 90° (figure 2). Settings were similar for both cameras (focal length = 60 mm and speed = 1/250 s). Each camera was placed in a plexiglass watertight box fixed against the pool wall at 0.6 m under the water surface. The filmed part of the pool was 12 m long and a black and white graduated reference scale has been filmed in the water before the measurements. The swimming corridors' floats have been also used for primary orientation.

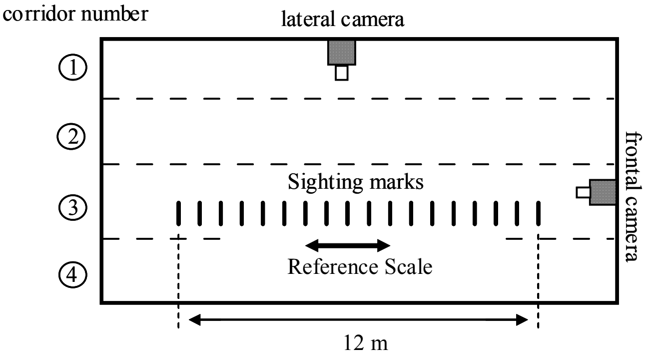


Fig. 2. Numeric data collection in dynamic conditions. Two numeric video cameras AG-EZ1E are placed frontally and laterally according to the swimming direction. Each camera is placed in a plexiglass watertight box at 0.6 m under the water surface and the filmed part of the pool is of 12 m length. A black and white graduated reference scale was filmed previously in the water in order to assure the precision of the numeric measurements. The swimming corridors' floats can be used for primary orientation

2.5. Numeric video data treatment

The video sequences were split into successive images by Videoshop™ using a PCI video card. The mentioned software allows an optimal images setting. The numeric images obtained have been treated using Image NIH™, allowing treatment of videotapes, numeric photoimages and video camera films (SAGNES [12]). After calibration, using the reference scale filmed previously, the necessary lengths and areas have been obtained (figure 3). For better analysis the numeric images have been enhanced 2.4 times. Such enhancement allowed a data treatment with a precision of one pixel. Thus, the precision of determining the position of a given body point is about one pixel and therefore the precision of measuring a length between two neighbouring body points approaches two pixels. This means means that an absolute error of the measurement of the length between two selected body (anthropometric) points at a distance of n pixels is equal to $2/n$. For example, in the case, a swimmer with *Body Height* of 1.84 m fills a computer screen length of 736 pixels, each pixel represents 184 cm/736 = 0.25 cm and the absolute error of the length measurement will be about 2 × 0.25 cm = 0.5 cm.

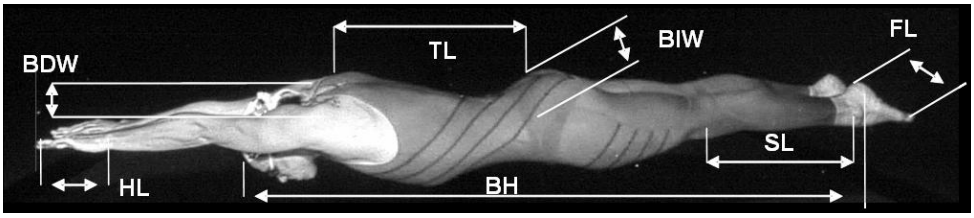


Fig. 3. Anthropometric variables in dynamic conditions (lateral view): *Body Height* (*BH*), *Shank Length* (*SL*), *Bi-Illiocristal Width* (*BIW*), *Foot Length* (*FL*) and *Hand Length* (*HL*). Two additional anthropometric parameters are intrduced: *Bi-Deltoid Width* (BDW) *and* the *Trunk Length* (*TL*). In this figure, only the parameters visible in the frontal view could be used directly to calculate *PFS*: *BDW* and *BIW*. In frontal view, the other parameters (including *FL*) are functions of time

2.6. Statistical analysis

The somatic measurements and the measurements obtained from the digitalized images were repeated 30 times to estimate their precision and repeatability. The data obtained have been stored in Excel format. The results have been analysed using ANOVA™. Both for static (somatic) and dynamic (numeric images) measurements, the mean and the standard deviations of each studied variable have been obtained (table). The *Per Cent Difference* (%) was used to compare experimental values obtained using different methods:

$$PD[\%] = \frac{E_1 - E_2}{(E_1 + E_2)/2} 100, \tag{3}$$

where E_1 and E_2 are two experimental values. We can rewrite equation (3) in order to use the mean values from the table:

$$\overline{PD}[\%] = \frac{\overline{E_1} - \overline{E_2}}{(\overline{E_1} + \overline{E_2})/2} 100, \tag{4}$$

where: $\overline{E_1}$ represents the mean values obtained from static numeric measurements and $\overline{E_2}$ represents the mean values obtained from dynamic measurements (the table). The

Per Cent Discrepancy (%) was used to compare the standard anthropometric data obtained with the results obtained by means of the numeric methods:

$$PDS(\%) = \frac{T - E}{E} 100 \, , \tag{5}$$

where: *PDS* is the *Per Cent Discrepancy*; *T* represents the mean values obtained by standard anthropometric measurements (accepted for theoretical values) and *E* stands for the mean values obtained using numeric methods.

Table 1. Anthropometric variables obtained for one swimmer by three different methods: standard anthropometric measurements (noted *Direct*); computer analysis of numeric images taken in static conditions (noted *Static*) and computer analysis of video numeric images taken during swimming (noted *Dynamic*). The data are obtained from one standard anthropometric study (*Direct*), 30 independent measurements (*Static*) and 30 independent swimmer's attempts filmed by numeric video cameras (*Dynamic*). The data analysis is performed using ANOVA™

Variables	Direct Data (cm)	Static Mean (cm)	Static StDev (cm)	Dynamic Mean (cm)
Body Height (*BH*)	187.31	187.39	1.35	188.06
Shank Length (*SL*)	48.86	48.81	0.94	48.45
Bi-Illiocristal Width (*BIW*)	39.77	39.72	0.74	39.34
Foot Length (*FL*)	28.51	28.58	0.79	28.69
Hand Length (*HL*)	19.78	19.69	0.76	19.12

Variables	Dynamic StDev (cm)	Per Cent Difference[1] Static/Dynamic (%)	Per Cent Discrepancy[2] Direct/Static (%)	Per Cent Discrepancy[2] Direct/Dynamic (%)
Body Height (*BH*)	1.00	–0.36*	–0.04*	–0.36*
Shank Length (*SL*)	0.69	+0.74	+0.10	+0.74
Bi-Illiocristal Width (*BIW*)	0.56	+0.96	+0.12	+0.96
Foot Length (*FL*)	0.71	–0.38*	–0.24*	–0.38*
Hand Length (*HL*)	0.72	+2.94	+0.45	+2.89

[1] The *Per Cent Difference* is used to compare the *Static* and the *Dynamic* experimental values (equation (4)).

[2] The *Per Cent Discrepancy* is used to compare the direct data and the experimental numeric data (equation (5)).

* Negative signs appear when two values are compared and the first one is greater than the second one.

3. Results

3.1. Comparison of the different methods

The comparison of the results obtained by standard anthropometric measurements (noted *Direct* in the table) and by computer analysis of numeric images taken in static conditions (noted *Static* in the table) is expressed by *Per Cent Discrepancy Static*/*Dynamic* (equation (5)) and it is seen that all differences obtained in the table are less than 0.5%. This result proves that in anthropometric studies it is advisable to use numeric images instead of a commonly adopted approach.

The comparison between *Static* and *Dynamic* numeric measurements shows that the average uncertainty of the measurements (expressed by the standard deviations (StDev)) is less for the *Dynamic* measurements (StDev ranges from 0.56 to 1.00). The standard deviations for the *Static* method are visibly higher (0.74–1.35), which means that the repeatability of the results is better in dynamic conditions.

Static and *Dynamic* methods are also compared using the *Per Cent Difference Static*/*Dynamic* (equation (5)). It is to note that negative signs mean that the *Static* mean value is higher than the *Dynamic* mean value (and vice versa). All the values obtained are less than 1%, except for the *Hand Length* (+2.94%). A relatively significant difference is obtained also for the Bi-acromial diameter *BD* (+0.96%). The *Hand Length* equal to 19.69 cm is a shorter segment under investigation and the greatest difference obtained for this variable is not a surprise. This anthropometric length has been reported with significant differences in many previous studies. The smallest difference between the two methods is equal to –0.36% and was obtained for the longest anthropometric distance, i.e. *Body Height*.

The *Static* and the *Dynamic* numeric methods are compared separately to the standard anthropometric method (*Direct*). The comparison of *Direct*/*Static* is expressed by *Per Cent Discrepancy Direct*/*Static* and the results demonstrate a high closeness – all differences are less than 0.5%. The comparison of *Direct*/*Dynamic* is expressed by *Per Cent Discrepancy Direct*/*Dynamic* and the differences obtained are also sufficiently small – all differences are less than 1.00% except the difference for *Hand Length*.

The results show that the numeric methods proposed are valuable and of high precision. It is very important that the *Dynamic* method is proved to be valuable because it could be used successfully to measure some parameters which are not accessible for the standard anthropometric approach, e.g. the *Projected Frontal Surface* in real swimming conditions.

3.2. Estimation of the projected frontal surface

Using the *Dynamic* method proposed (numeric video images taken in real swimming conditions and computer data processing) *PFS* could be for different body positions during swimming, using different approximations. For example, at the beginning of the butterfly cycle, *PFS* is determined mainly by the frontal trunk surface, which could be simply approximated by a trapezium *ABCD* with two parallel sides *AB* and *CD*: *AB* is equal to the *Bi-Illiocristal Width* (*BIW*) and *CD* is equal to the *Bi-Deltoid Width* (*BDW*) (figure 3). The trapezium height is equal to the *Trunk Length* (*TL*). Finally, the *Projected Frontal Surface* (*PFS*) for the selected characteristic position was obtained to be about 0.31 m^2. The maximal *PFS* values during one complete butterfly cycle have been calculated to be in the range between 0.7 m^2 and 0.8 m^2. This butterfly position is given as example because it allows calculating *PFS* more simply using geometrical approximation. Other positions require appropriate software – Image NIH™, which allows us to select the visible frontal surface for every position and to calculate the respective *PFS*.

4. Discussion

It was proved that the differences between the standard anthropometric measurements (*Direct*) and the computer analysis of numeric images taken in static conditions (*Static*), expressed by *Per Cent Discrepancy Static*/*Dynamic* (table) are less than 0.5%. We have to note that the anthropometric lengths obtained by the *Static* method are more repeatable than those obtained by the *Direct* method. This fact could be explained by the completely different approaches to identification of the anthropometric points. During a standard anthropometric measurement the localisation of the joints' rotation centres is rather approximate, e.g. the length of the knee joint approaches
4 cm and the anatomical point to be considered should be in the rotation centre of this articulation (VANDERVAEL [16]). It is not so easy to determine accurately such a point during standard measurements and the repeatability is not very high. Using computer measurements on a numeric image, the knee area corresponds to a group of pixels and an appropriate image enhancement allows locating accurately the middle pixel of the area, corresponding to the joint rotation centre.

It was shown that the average uncertainty of the measurements (expressed by the standard deviations) is less for the *Dynamic* measurements in comparison with the uncertainty obtained for the *Static* method. This means that the repeatability of the results is better in dynamic condition. This result is important for further application of numeric films to measurements in swimming.

As mentioned above, the precision of determining the position of a given body point is about one pixel and therefore the precision of measuring a length between two neighbouring body points is about two pixels. In our case, the swimmer's *Body Height* is equal to 187.31 cm and this length fills a computer screen of the length of 736 pixels and therefore each pixel represents 187.31 cm/736 = 0.254 cm. So, the absolute error of this length measurement is 2 × 0.254 cm ≈ 0.51 cm and the relative error respectively is equal to 0.27%. The relative error for the variable *Hand Length* of 19.78 cm (the shortest anthropometric length in our case) was calculated to be 2.5%. It is to note that in principle the relative errors increase in computer measurements of short lengths. In such cases, relative errors of 5% have been usually accepted (VANDERVAEL [16]). One more advantage of computer measurements is the possibility of image enhancement in order to decrease the relative errors.

The *Projected Frontal Surface* could be calculated for different characteristic body positions during swimming. As example, a characteristic position for butterfly has been selected – the beginning of the butterfly cycle. In this body position, *PFS* is determined mainly by the frontal trunk surface, which could be approximated by a trapezium and the calculated value was *PFS* ≈ 0.31 m^2. The maximal *PFS* values during one complete butterfly cycle have been calculated to be in the interval of 0.7–0.8 m^2. The results obtained by CLARYS [8] are different (up to 15%), but in our opinion our results are more valuable due to the higher measurement precision. It is to underline that the *Dynamic* method proposed allows us to obtain accurately the *Projected Frontal Surface* as a function of the time – 30 times per second. This advantage is very important both for theoretical and practical purposes.

5. Conclusion

We have proved that it is valuable to use numeric images for anthropometric measurements instead of the commonly used approach. It is shown that the *Per Cent Discrepancy* of the static numeric measurements compared to the standard anthropometric measurements is for all variables less than 0.5% and respectively for the dynamic numeric measurements – less than 1.0% (except for the variable *Hand Length*). We have to note that the results of the anthropometric lengths obtained using both static and dynamic approaches have a less uncertainty, i.e. are more repeatable, than those obtained by means of the standard anthropometric measurements. It is also demonstrated that the repeatability of the results is better using images taken in dynamic condition. Based on the proved high precision of the *Dynamic* method (numeric video images taken in real swimming conditions and computer data processing), the *Projected Frontal Surface* of the swimmer studied was calculated to be about 1.14 m^2. In our opinion, the contradiction between our results and those of CLARYS [8] is due to inaccuracy of the Clarys approach. It is to underline that the *Dynamic* method proposed allows measuring accurately the *Projected Frontal Surface* (and other important variables) as function of the time (in our case – 30 times per second). This advantage is very important both for theoretical and practical purposes.

The measurement approach proposed is suitable also for other applications in the field of biomechanics.

References

[1] BEDARD R., PAQUET R., GAGNON M., *La Natation*, Québec, Canada,1979.

[2] BLAKE R.W., *Fish locomotion*, University Press, Cambridge, 1983.

[3] BLOOMFIELD J., SIGERSETH P., *Anatomical and physiological diffences between sprint and middle distance swimmers at the university level*, Journal of Sports Medicine and Physical Fitness, 1965, **5**, 76–81.

[4] BOULGAKOVA N., *Sélection et préparation des jeunes nageurs*, Vigot, Paris, 1990.

[5] CAPPEART J., GORDON B.J., FRISBIE K., *Frontal surface area measurements in national caliber swimmers*, Medecine and Science in Sports and Exercise, 1997, **5**, Supplement, abstract 712.

[6] CARSTENS T., *Wave forces on boundaries and submerged bodies*, Sarsia, 1968, **34**, 47–60.

[7] CATTEAU A., RENOUX Y., *Les coup de bras en natation*, Sport et Plein Air, 1977, **208**, 25–28.

[8] CLARYS J.P., *Human morphology and hydrodynamics*, [in:] J. Terauds, E. Wendy Bedinfield (eds.), *International Series on Sport Sciences, Swimming III*, 1979, Baltimore, University Park Press.

[9] GRIMSTON S.K., HAY J.G., *The relationship among antropometric and stroking charateristics of college swimmers*, Medicine and Science in Sport and Exercise, 1986, **18**, 60–68.

[10] HOUSSAY T., *Nouvelle experience sur la forme et la stabilité des poissons*, Revue Générale des Sciences Pures et Appliquées, 1909.

[11] KOLMOGOROV S.V., DUPLISHEVA O.A., *Active drag useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity*, J. Biomechanics, 1992, **3**, 311–318, MONTPETIT R., *La morphologie du nageur, un facteur important*, Natation Québec, 1983, 1, **3**, 18–19.

[12] SAGNES P., *Un outil de prise de données sur une image numérisée et son utilité dans les études relatives aux poisson: exemple d'une application concrète en morphométrie*, Bulletin Français de la Pêche et de la Pisciculture, 1995, **337/338/339**, 131–137.

[13] SMITH L., *Anthropometric measurements, and arm and leg speed performance of male and female swimmers as predictors of swim speed*, International Journal of Sports Medicine, 1978, **18**, 153–168.

[14] SPRAGUE H.A., *Relationship of certain physical measurements to swimming speed*, Research Quarterly, 1976, **47**, 810–814.

[15] STATZNER B., HOLM T.F., *Morphological adaptation of shape to flow: microcurrents around lotic macroinvertebrates with known Reynolds numbers at quasi-natural flow conditions*, Oecologia, 1989, **78**, 145–157.

[16] VANDERVAEL F., *Biométrie Humaine*, Paris, 1980, Masson, 155 p.

[17] VOGEL S., *Life in Moving Fluids*, 2nd ed., 1994, Princeton, Princeton University.

[18] WEBB P.W., *Hydrodynamics and energetics of fish propulsion*, Bulletin of the Fisheries Research Board of Canada, 1975, **190**, 1–160.