Hydrodynamic characteristics of elite swimmers of different genders at final period of training for major competitions

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Abstract

Hydrodynamic characteristics of elite female and male swimmers were determined by the four variants of the perturbation method at the phase of decrease in training load before the 2016 Olympic Games in Rio de Janeiro and the 2017 World Championship in Budapest. Further, the ten best swimmers of both genders were selected by their maximal swimming velocity (v_{0max}) in all athletic strokes (80 subjects altogether). As a result of the proper processing of the data, statistical models of quantitative values of active drag force ($F_{r(ad)}$), the dimensionless hydrodynamic coefficient ($C_{x(ad)}$) and total external mechanical power (P_{to}) were determined. In all four strokes, due to their essential superiority in P_{to}, men have higher levels of v0max than women. Naturally enough that at higher v_{0max} elite male athletes have greater $F_{r(ad)}$, too. Again, in terms of $C_{x(ad)}$, there was no statistical difference between women and men within each of the strokes. Consequently, regardless of their gender, elite swimmers may be stated to be equally successful in mastering proficient swimming techniques of all athletic strokes. Besides having an independent scientific significance, the statistical models of $F_{r(ad)}$, $C_{x(ad)}$ and P_{to} allow to increase considerably the quality of the individual analysis of these indicators on athletes of different performance levels. The key criterion for such analysis at the phase of decrease in training load is $C_{x(ad)}$, which determines the hydrodynamic efficiency of the individual swimming technique in any of athletic strokes in terms of quantity.

Keywords: *swimming velocity, active hydrodynamic resistance (active drag), mechanical power.*

Introduction. Specialists in the sphere of biomechanics of human and animal water locomotions widely use the small perturbation method for measuring the basic hydrodynamic characteristics of swimmers at their maximal swimming velocity [1, 2], both in its basic variant [3-5], and in its modifications [6-9]. In all those cases, the mathematical model of the method is constant, and the technological changes only refer to the construction of technical devices, creating the perturbation factor.

In its basic variant, the perturbation is induced by an additional hydrodynamic body of a certain resistance magnitude. For this purpose, French specialists developed an electromechanical device attached to the edge of the pool [6, 7]. While swimming a subject pulls the inflexible (non-elastic) cord out of the device, which creates constant and measurable additional resistance of certain magnitude within the range from 0 to 100 N. In the variant, elaborated by the Chinese specialists, the perturbation factor is induced by the mechanical block, sliding smoothly along the cord over the pool track, which can be regulated and which allows to register the magnitude of the created force [8]. For this purpose, the Australian specialists use the system of contact hydrodynamic leadership [9]. This system allows to produce the towing force, which can be regulated and measured in the real mode of time. Obviously, the authors of this technology use the negative value of the perturbation factor in the mathematical model of the method. The above-mentioned works represent the variants of the method in more detail.

The analysis of these researches' results has shown that individual quantitative values of the basic hydrodynamic parameters vary in all athletic strokes. They have multidirectional and regular oscillations depending on the content, amount and intensity of training exercises at different phases of the greater training cycle. Again, at the phase of decrease in training load, these magnitudes tend to be optimal for each swimmer, and this is one of the main factors for successful performance at the competitions.

Objective. The research was aimed to elaborate the statistical models of the basic hydrodynamic characteristics of elite female and male swimmers at the phase of decrease in training load.

Methods. Individual values of active drag force $F_{r(ad)}$, the dimensionless hydrodynamic coefficient ($C_{x(ad)}$) and total external mechanical power (P_{to}) were determined by different variants of the small perturbation method. Regardless the variant used, these magnitudes were measured at the maximal swimming velocity (v_{0max}) at the distance of 30 m. The electronic system, used in the research, allowed to measure time within one-hundredths of a second.

The method name itself evidently implies that the accuracy of measurements depends essentially on the adequate magnitude (force) of the perturbation factor, which is determined individually in each testing. The objective quantitative criterion for the adequacy of this magnitude is the percent of the velocity change ($\%\Delta\upsilon_0$) while swimming under impact of the perturbation force in relation to the velocity of free swimming (decrease or increase of the velocity depending on the variant of the method). Due to the metrological modeling based on the mathematical model of the method, the optimal range of the magnitude was determined as $\%\Delta\upsilon_0$ = 4–6% (in this case the maximum experimental error doesn't exceed ±3%) [1, 2, 9].

Out of the great amount of experimental data at our disposal, at first we selected the results of individual hydrodynamic tests conducted on elite swimmers from different national teams, which were taken at the phase of decrease in training load before the 2016 Olympic Games in Rio de Janeiro and the 2017 World Championship in Budapest (all in all, 246 tests). These results only included the tests with the magnitude $\%\Delta\upsilon_0$ within the range 4–6%. To obtain maximally objective and accurate statistic models, at the second stage, out of 246 subjects 10 best female and male swimmers in each stroke were selected additionally (80 subjects altogether; each athlete is represented by the results of the only test). The only criterion for such selection of the best swimmers was the maximal swimming velocity value (v_{0max}) developed during testing. All the selected subjects belonged to the 25 best athletes of the current world ranking at the distances of 100 or 200 meters in the corresponding stroke.

Discussion. Table 1 represents statistical models (M±m) of the basic hydrodynamic characteristics of elite swimmers in different strokes obtained at the final period of training to the Olympic Games and the World Championship.

The analysis of the results has shown that, regardless of the subjects' gender, the athletic strokes can be ranked by the maximal swimming velocity in a determined order: freestyle, dolphin, backstroke and breaststroke (P<0,01-0,001) (Statistical difference in v_{0max} has not been revealed only between females' dolphin and backstroke). This order entirely correlates with the current World Record in swimming 50 meters by females and males. In all strokes, men have higher magnitudes of v_{0max} than women, which is the result of males' substantial superiority in developing total external mechanical power (P_{to}). Therefore, it is natural that at higher v_{0ma}x elite male swimmers have also greater active drag force $F_{r(ad)}$ in athletic strokes.

Table 1. *Statistical models (M±m) of the maximal swimming velocity ($v0_{max}$, m•s^{-1}), active drag force ($Fr_{(ad)}$, N), the dimensionless hydrodynamic coefficient ($C_{x(ad)}$) and total external mechanical power (P_{to}, W) of elite female and male swimmers in athletic strokes*

Stroke	Magnitudes	Females	t; p	Males
front crawl	v_{0max}	1,800 ± 0,012	6,70; <0,001	2,037 ± 0,033
	$F_{r(ad)}$	66,40 ± 7,01	2,87; <0,05	104,37 ± 11,22
	$C_{x(ad)}$	0,262 ± 0,028		0,263 ± 0,034
	P_{to}	119,53 ± 12,76	3,46; <0,01	212,53 ± 23,68
dolphin	v_{0max}	1,657 ± 0,036	4,98; <0,001	1,857 ± 0,019
	$F_{r(ad)}$	76,25 ± 8,08	3,40; <0,01	113,63 ± 7,46
	$C_{x(ad)}$	0,355 ± 0,028		0,359 ± 0,029
	P_{to}	126,50 ± 14,99	3,99<0,001	211,07 ± 14,99
backstroke	v_{0max}	1,618 ± 0,025	4,20; <0,001	1,756 ± 0,021
	$F_{r(ad)}$	72,03 ± 5,43	3,48; <0,01	102,38 ± 6,83
	$C_{x(ad)}$	0,347 ± 0,024		0,361 ± 0,027
	P_{to}	116,55 ± 9,45	3,35; <0,01	177,25 ± 15,48
breaststroke	v_{0max}	1,401 ± 0,020	5,76; <0,001	1,571 ± 0,022
	$F_{r(ad)}$	73,05 ± 5,12	3,30; <0,01	108,57 ± 9,48
	$C_{x(ad)}$	0,472 ± 0,012		0,477 ± 0,045
	P_{to}	102,41 ± 8,34	3,81; <0,01	170,59 ± 15,83

Again, in each of the strokes, there is no statistical difference in the dimensionless hydrodynamic coefficient between female and male swimmers. According to the aforementioned researches [2, 10], it is the magnitude of $C_{x(ad)}$ that allows to conduct the *accurate hydrodynamic comparison* of different subjects between different strokes, excluding the influence of individual values of total body size and mass of athletes as well as their swimming velocity. That is why, specialists and coaches treat $C_{x(ad)}$, determined under natural swimming conditions, as an integral quantitative indicator of the swimmer's technical ability and level. Consequently, it is definite enough that, regardless of their gender, elite swimmers are equally successful in mastering the most recent and efficient swimming techniques in all athletic strokes.

Despite the substantial difference in the values of v_{0max} between various women's strokes, the quantitative values of $F_{r(ad)}$ and *Pto* are virtually the same, since there is no statistical difference between these magnitudes. In the male subjects, the observation is analogous. The biomechanical mechanism of this phenomenon can be clarified by the analysis of $C_{x(ad)}$, the values of which depend on the swimming stroke and are observed within the determined quantitative range (Both in the female and male subjects, statistical differences between the magnitudes of $C_{x(ad)}$ have not been revealed only between dolphin and backstroke, that was repeatedly observed previously [1, 2, 10]). Consequently, $C_{x(ad)}$ apparently depends on the individual features of the athlete's body (i.e., physical build), but to much greater extent, it depends on the inherent to every athletic stroke specific biomechanical system of motions, cinematic characteristics of which are strictly regulated by the competition rules.

Summary. The statistical models of the basic hydrodynamic characteristics of elite female and male swimmers are of principal importance for specialists and coaches, as they allow to increase essentially the quality of the individual quantitative analysis of these characteristics of swimmers of different performance levels. At the phase of decrease in training load (tapering phase), the key criterion for such analysis is the dimensionless hydrodynamic coefficient, which quantitatively determines hydrodynamic efficiency of the individual swimming techniques in any of athletic strokes.

References

1. Kolmogorov S., Duplisheva O. Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. Journal of Biomechanics. 1992. Vol. 23. pp. 311-318.
2. Kolmogorov S., Rumyantseva O., Gordon B., Cappaert J. Hydrodynamic characteristics of competitive swimmers of different genders and performance levels. Journal of Applied Biomechanics. 1997. Vol. 13. pp. 88-97.
3. Kjendlie P.-L., Stallman R. Drag characteristics of competitive swimming children and adults. Journal of Applied Biomechanics. 2008. Vol. 24. pp. 35-42.
4. Marinho D. A., Barbosa T. M., Costa M. J., Figueiredo C., Reis V. M., Silva A. J., Marques M. C. Can 8-weeks of training affect active drag in young swimmers? Journal of Sports Science and Medicine. 2010. Vol.9. pp. 71-78.
5. Barbosa T.M., Costa M.J., Marques M.C., Silva A.J., Marinho D.A. A model for active drag force exogenous variables in young swimmers. Journal of Human Sport & Exercise.2010. Vol. 5(3). pp. 379–388.
6. Bideau B., Colobert B., Nicolas G., Le Guerroué G., Multon F., Delamarche P. Development of an Active Drag Evaluation System (A.D.E.S.). Proceedings IX International Symposium on Biomechanics and Medicine in Swimming. St Etienne. 2003. pp. 51-56.
7. Nicolas G., Bideau B., Colobert B., Berton E. How are Strouhal number, drag, and efficiency adjusted in high level underwater monofin-swimming? Human Movement Science. 2007. Vol. 26. pp. 426–442.
8. Xin-Feng W., Lian-ze W., We-Xing Y., De-Jian J., Xiong S. A new device for estimating active drag in swimming at maximal velocity. Journal of Sports Sciences. 2007. Vol. 25(4). pp. 375-379.
9. Sacilotto G., Ball N., and Mason B.R. A Biomechanical review of the techniques used to estimate or measure resistive forces in swimming. Journal of Applied Biomechanics. 2014. Vol. 30. pp. 119-127.
10. Kolmogorov S.V., Vorontsov A.R. The methodology of control over preparedness of elite swimmers based on relationship between the power of active metabolism, mechanical power and efficiency and swimming velocity. Proceedings XIII International Symposium on Biomechanics and Medicine in Swimming. Tsukuba. 2018. pp. 400–407.