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Original Article

Anaerobic power and capacity in short-, middle- and long-distance young swimmers

MIHAIL KACHAUNOV[1], RUMEN IOSSIFOV[2]
[1,2] Department of water sports, National Sports Academy "Vassil Levski", Sofia, BULGARIA

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Abstract
Problem statement: Swimming achievements depend on the efficiency of energy supply systems that sustain muscle function. For short distances, anaerobic systems take precedence, while for middle and long distances, the significance of the aerobic system in supplying energy becomes more pronounced. Additionally, sprinters and distance swimmers possess distinct physiological traits, such as differing muscle fibre characteristics, requiring customised training protocols tailored to athletes competing across various distances. Beyond genetic predispositions and training variables, anaerobic capacity also correlates with age, showing gradual improvement with growth and maturation. **Purpose:** The study's primary objective was to evaluate and compare the anaerobic power and capacity among highly trained adolescent swimmers participating in short-, middle- and long-distance events. These findings offer valuable insights for more accurately assessing the anaerobic performance of young swimmers and optimising their training loads. **Approach:** A cohort comprising 88 swimmers (32 girls and 56 boys) aged 15–17 years participated in the study. All individuals were members of the Bulgarian Youth National Swimming Team. They were categorised into groups based not only on gender but also according to their primary event distance: short (50 and 100 m), middle (200 and 400 m) and long (800 and 1500 m). Wingate anaerobic tests were administered at the end of the general preparation phases during the training seasons over three years. **Results:** In girls, peak power was 272.4–694.8 W, average power 234.4–516.5 W and minimum power 142.4–360.9 W. Power drop was 95.7–362.9 W, and fatigue rate was 24–71.8%. Male swimmers' peak power was 510.3–1047 W, average power 420.5–737.8 W and minimum power 281.7–535.9 W. The minimum power drop was 162–613.1 W, and fatigue rate was 29.5–65.6%. Conclusions: Peak power among 15–17-year-old swimmers varied based on the length of their primary event. Short-distance swimmers exhibited the highest peak power values, while long-distance swimmers showed the lowest. As fatigue set in, the power differences between different types of swimmers decreased. Sprinters experienced the greatest power drop, whereas long-distance swimmers experienced the least. Interestingly, the variation in minimum power values was greater than that of peak power values across the different types of swimmers.
Keywords: swimming, Peak Power, Anaerobic Fatigue, Wingate

Introduction

Achievements in swimming depend to a large extent on the power of the energy supply systems to ensure the work of the muscles. While at short distances anaerobic systems dominate, at middle and long distances the importance of the aerobic system for energy supply increases. In addition, sprinters and distance swimmers have different physiological characteristics, such as different muscle fibers characteristics. This determines the specificity of planning the preparation of swimmers competing at different distances.

Energy is stored in the human body in combination with the following chemical compounds: adenosine triphosphate (ATP), creatine phosphate (CP), carbohydrates, fats, and proteins. ATP is the only source of energy that our bodies can use for muscular contraction. All the other energy-containing chemicals are used to recycle ATP after its energy has been used for muscular work (Maglischo, 2003). ATP is recycled through three different biochemical systems that can be found under different names in the literature. Two of these systems do not require oxygen and are considered anaerobic: the ATP-CP system (phosphagen system or alactic anaerobic system) and the anaerobic glycolytic system (anaerobic glycolysis, lactic acid energy system, or anaerobic metabolism). The third one has been called the aerobic energy system or aerobic metabolism (Kenney et al, 2012; Kraemer et al., 2016; Maglischo, 2003; McArdle et al., 2015).

The relative contribution of the body's energy transfer systems differs markedly depending on the intensity and duration of physical activity and the participant's current fitness status. Experts try to make estimates using different methods for the percentage of ATP obtained from anaerobic and aerobic sources for physical activity of different lengths, as well as for specific activities. Swimming events are usually called aerobic or anaerobic, but all three phases of the metabolic process operate from the first moment of exercise. The difference is in the contribution of each phase to the different distances. The anaerobic glycolytic system is the major contributor to short race distances in swimming. The share of the ATP-CP system in the energy supply at

Corresponding Author: MIHAIL KACHAUNOV, E-mail: mihail.kachaunov@nsa.bg

100 m is 10-20%, and at 50 m it can exceed 35% in top-level sprinters. For 200 m the share of ATP-CP system is 5-13%, and for longer distances, it is even smaller to negligible. Aerobic metabolism delivers up to 20–25% of the energy for 50 m and up to 35–44% for 100 m. Its role becomes more important for middle-distance races – 53–58% for 200 m and 65–73% for 400 m, with a significant contribution of anaerobic glycolysis. Aerobic metabolism is the chief source of energy for long-distance races. Its share is 75–80% for 800 m and 85–86% for 1500 m (Maglischo, 2003; Ribeiro et al., 2015; Rodrigues & Mader, 2010; Wilke & Madsen, 2015).

Knowledge of the metabolic requirements of the different swimming events and strokes may help the coach develop training plans to enhance the underlying metabolic capacities. In 50-m events ATP and CP stores are rapidly depleted and glycolysis is almost immediately activated to maintain energy output. 100-m events require the complete and rapid activation of both the glycolytic and aerobic energy systems since the decreasing glycolytic energy supply is compensated in part by increasing oxidative ATP production during the last two-thirds of the race. Middle-distance events require very high maximal oxygen consumption ($\dot{V}O_{2max}$) values, as well as moderate to high glycolytic power. Long-distance events are characterized by a predominance of aerobic energy delivery processes (Rodrigues & Mader, 2010). Acidosis, which is a consequence of anaerobic metabolism, is considered the main cause of fatigue in all events longer than 20 to 30 seconds. However, an athlete would not be able to maintain competitive speed in any race if the muscles were not supplying energy anaerobically (Maglischo, 2003). According to Olbrecht (2013), to achieve the best possible performance in competition, the aerobic and anaerobic capacity must both be well-balanced.

Anaerobic power and anaerobic capacity are most often used as the main indicators of the anaerobic abilities of athletes in exercise physiology. Maximal anaerobic power is the maximal rate, at which ATP is resynthesized via anaerobic metabolism (by the whole organism) during a specific type of short-duration, maximal exercise, and anaerobic capacity is the maximal amount of ATP resynthesized via anaerobic metabolism during that exercise. Anaerobic work capacity, on the other hand, is the total amount of external (mechanical) work performed during a specific type of exhausting exercise that is of sufficient duration to incur a near-maximal anaerobic ATP yield, given that this ATP yield exceeds that from aerobic metabolism. (Green, 1994).

In practice, it is usually the mechanical work done rather than the chemical energy that is measured, although some inaccuracies can occur in the interpretation of the results (Beneke et al., 2002; Van Praagh, 2007). Anaerobic mechanical performance can be studied under field and laboratory conditions, the tests being more or less specific to swimmers (Demarie et al., 2019; Guilherme et al., 2000; Shimoyama et al., 2018; Stager & Coyle, 2005). Some experts believe that tests for swimmers should be specific so that the movements are performed by the swimming-specific muscle groups (Maglischo, 2003; Rohrs et al., 1990). On the other hand, testing swimmers in a laboratory environment is a reliable procedure and can be used to detect differences between athletes' training status and evaluate training-induced changes (Dalamitros et al., 2014). Wingate anaerobic test is the most often used test for assessing anaerobic power and anaerobic capacity (Inbar et al., 1996; Driss & Vandewalle, 2013). It is also used for the evaluation of anaerobic performance in competitive swimming (Dalamitros et al., 2014). Unlike swim tests, it eliminates the influence of swimming technique on test results.

Achieving high personal results in swimming requires a good multi-year training plan. Methods of training over the years depend on the physiological characteristics during the various stages of human growth and development, sex, and main swimming distance that swimmers compete in. Emphasis on different physical skills during sensitive periods for their development is a necessary condition for achieving maximum results. Apart from some genetic and training factors, anaerobic capacity is also age-dependent and increases with growth and maturation (Armstrong et al., 2000; Carvalho et al., 2011; Santos et al., 2002; Van Praagh, 2000). The main aim of the study was to compare the anaerobic power and capacity of highly trained adolescent swimmers competing in short, middle, and long distances. These data may be useful for better assessing the anaerobic performance of young swimmers and better planning their training loads.

Material and Methods

Participants

A total of 88 swimmers (32 girls and 56 boys) aged 15–17 years took part in the study. Their age was determined by the year of birth. All participants were part of the Bulgarian Youth National Swimming Team. The best personal times of the boys ranged between 680 and 915 FINA points, and those of the girls between 603 and 831 FINA points. The participants were divided into groups not only by gender but also according to the distance of their main event: short (50 and 100 m), middle (200 and 400 m), and long (800 and 1500 m) distances. Thus, six groups were formed as follows: girls – short-distance (GSD), n = 11; girls – middle-distance (GMD), n = 12; girls – long-distance (GLD), n = 9; boys – short-distance (BSD), n = 17; boys – middle-distance (BMD), n = 20; and boys – long-distance (BLD), n = 19.

Procedure

Wingate Anaerobic Tests (WanT) were conducted over 3 years between 2018 and 2020. Such tests are carried out in the laboratory of the Directorate "Coordination and Control of Sports Training" at the Ministry of Youth and Sports of Bulgaria by order of the Bulgarian Swimming Federation. The tests were conducted at the end of the general preparation periods of the training seasons. Only the cases with the highest Relative Average Power were included when the swimmers passed more than one test over those years. The measurements were performed by approved standard protocols and according to the ethical standards established in the Declaration of Helsinki for Human Research.

The warm-up consisted of low-intensity pedaling at 60 rpm for 3 min and resistance equal to the weight of the basket (1 kg). Sprints lasting 5 seconds were performed at the end of the 1st and 2nd minutes. The recovery from the warm-up was 3 minutes.

Every Wingate Anaerobic Test was performed on a weight ergometer – Monark 894E. The duration of the test was 30 seconds, and the resistance was equal to 7.5% of the participants' weight. The weight of the swimmers was measured with an electronic scale. The height of the competitors was measured to determine the height of the seat. The weights used for mechanical resistance were placed in the specially designed basket specific to the 894E model, with a net weight of 1 kg, located at the front of the ergometer. The time from which the test begins is when the weight basket is lowered. This happens automatically when certain revolutions are reached by the examined person. The test ends at the end of the 30-second time. Recovery after the end of the load was done by steady work without resistance lasting 2 minutes. Results were calculated by Monark Anaerobic test software.

The following variables were measured by the test: Peak Power (PP) – the highest amount of power generated during the test. It is measured in watts [W]; Relative Peak Power (RPP) – peak power divided by the athlete's body mass [W/kg]; Average Power (AP) – the average power that is maintained during the entire 30-second test [W]; Relative Average Power (RAP) – the average power divided by the athlete's body mass [W/kg]; Minimum Power (MP) – the lowest power achieved during the test [W]; Relative Minimum Power (RMP) – minimum power divided by the athlete's body mass [W/kg]; Power Drop (PD) – the difference between PP and MP [W]; Fatigue Rate (FR) or Anaerobic Fatigue – the percentage of power drop [%]. It is calculated as follows: $FR = (PD \div PP) \times 100$; Total Work (TW) or Anaerobic Capacity – the total amount of work accomplished during the test. It is calculated in joules [J].

Statistical analysis

Statistical analysis was conducted using Statistical Package for Social Sciences (SPSS) version 24, IBM, USA. The data set was summarized using descriptive statistics. Distribution normality tests were performed using the Shapiro-Wilk test. Differences between the mean values of the studied variables with normal distribution were analyzed by one-way ANOVA for independent samples with the Bonferroni post hoc test. The Kruskal-Wallis H test was used for non-normal distributions.

Results

Anthropometric characteristics and Wingate Anaerobic Test results of the three studied groups of female swimmers are presented in Table 1. Their height was between 156 and 180 cm, and their weight was between 54 and 68 kg. Values of standard deviation (SD) for these anthropometric characteristics were relatively low, and the coefficient of variation (CV) was up to 5.6%. The absolute value of Peak Power in girls ranged between 272.4 and 694.8 W, Average Power between 234.4 and 516.5 W, and Minimum Power between 142.4 and 360.9 W. Power Drop was between 95.7 and 362.9 W and Fatigue Rate from 24 to 71.8%. RPP ranged between 4.6 and 11.5 W/kg, RAP between 4 and 8.1 W/kg, and RMP between 2.4 and 6.1 W/kg. The total amount of accomplished work was within 7009.2 and 15256.7 J. CV exceeded 10% for MP and RMP in GSD (20.7 and 19.8%) and for MP in GMD (10.6%). It was above 10% for all variables in GLD – 29.5% for PD and between 15.9 and 21.9% for the rest (not applicable to FR).

Table 1. Descriptive statistics of height, weight, and WanT results of female swimmers (n=32).

Variables	GSD (n=11)				GMD (n=12)				GLD (n=9)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Height [cm]	158	178	170.8*	5.98	166	177	170.2*	3.35	156	180	169.7*	8.57
Weight [kg]	57	68	61.6*	3.18	55	66	60.43*	3.40	54	63	59.43*	3.24
PP [W]	505.3	694.8	627.6	49.62	509.9	598.3	555.1*	34.24	272.4	581.8	474.3*	95.37
RPP [W/kg]	8.70	11.50	10.21*	0.69	8.10	10.00	9.22*	0.59	4.60	9.70	7.97*	1.48
AP [W]	384.1	516.5	465.6*	37.69	392.1	478.7	433.9*	25.23	234.4	446	384.2*	67.43
RAP [W/kg]	6.60	8.10	7.57*	0.42	6.60	7.70	7.18*	0.28	4.00	7.60	6.46	1.02
MP [W]	142.4	360.9	312.8	64.62	253.6	345.2	296.1*	31.45	146.4	316.7	277.0	58.63
RMP [W/kg]	2.40	6.10	5.06	1.00	4.30	5.80	4.91*	0.48	2.50	5.50	4.66	0.94
PD [W]	266.1	362.9	314.7*	29.97	187.4	333.5	259.0*	45.69	95.7	271.7	197.3*	58.19
FR [%]	42.6	71.8	50.6	8.07	36.8	55.7	46.5*	6.43	24.0	50.8	41.4*	8.07
TW [J]	11072.0	15256.7	13710*	1205.9	11435.7	14087.8	12773*	751.7	7009.2	13159.3	11372*	1972.6

*normal distribution

The results of the groups of male swimmers are presented in Table 2. The height of the boys was between 161 and 197 cm, and their weight was between 53 and 81 kg. The coefficient of variation for these parameters was below 10%. Peak Power of male swimmers varied between 510.3 and 1047 W, Average Power between 420.5 and 737.8 W, and Minimum Power between 281.7 and 535.9 W. Minimum Power Drop was 162 W and maximum 613.1 W and Fatigue Rate was between 29.5 and 65.6%. Relative Peak Power ranged between 7.9 and 14.7 W/kg, RAP between 6.2 and 9.9 W/kg, and RMP between 4.4 and 7.2 W/kg. Total amount of work done was between 12461.4 and 21831 J. CV exceeded 10% for RPP (10.5%), MP (14.4%), RMP (10.1%) and PD (18.4%) in BSD; for MP (11.3%), RMP (10.8%) and PD (21.8%) in BMD; and PP (10.7%), AP (10.7%), MP (13.4%), RMP (12%), PD (21.9%), and TW (10.9%) in BLD.

Table 2. Descriptive statistics of height, weight, and WanT results of male swimmers (n=56).

Variables	BSD (n=17)				BMD (n=20)				BLD (n=19)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Height [cm]	171	197	180.4*	6.81	175	189	181.3	3.83	161	186	174.5*	7.25
Weight [kg]	64	81	71.74*	5.48	62	81	68.8	4.95	53	79	63.6*	6.22
PP [W]	745.9	1047.0	898.2*	86.98	682.6	898.1	778.2*	58.72	510.3	749.2	643.7*	69.16
RPP [W/kg]	9.90	14.70	12.56*	1.31	9.70	13.40	11.35*	1.03	7.90	11.40	10.14*	0.96
AP [W]	561.0	737.8	642.7*	53.94	552.5	663.7	592.8	30.60	420.5	619.0	503.4*	53.72
RAP [W/kg]	7.90	9.90	8.97*	0.59	8.00	9.30	8.62*	0.38	6.20	8.90	7.94	0.71
MP [W]	314.4	535.9	428.3*	61.65	337.9	486.8	413.8*	46.57	281.7	452.2	362.6*	48.44
RMP [W/kg]	4.90	6.80	5.97*	0.61	4.60	7.20	6.03*	0.65	4.40	6.90	5.72*	0.69
PD [W]	334.0	613.1	469.9*	86.29	214.6	519.4	364.4*	79.41	162.0	375.7	281.0*	61.47
FR [%]	39.1	65.6	52.1*	6.70	30.6	58.6	46.5*	7.65	29.5	54.3	43.4*	7.24
TW [J]	16417.7	21831.0	18930*	1643.0	16190.5	19658.9	17569*	923.3	12461.4	18409.4	14945*	1622.6

*normal distribution

The differences between the means in the three groups of female swimmers are shown in Table 3. The only variable in which there was a statistically significant difference between all three studied groups is PP. Mean PP was 627.6 W for GSD, 555.1 W for GMD, and 474.3 W for GLD. Means of RPP, AP, RAP, PD and TW in GLD (7.97 W/kg, 384.2 W, 6.46 W/kg, 197.3 W and 11372.5 J) were significantly lower than in GSD (10.21 W/kg, 465.6 W, 7.57 W/kg, 314.7 W and 13710.3 J) and also than those in GMD (9.22 W/kg, 433.9 W, 7.18 W/kg, 259 W and 12773.1 J). The mean FR of GSD (50.6%) was significantly higher than the mean FR of GLD (41.4%). No significant difference in FR was found between GMD and the other two groups. Although there were some differences in MP and RMP in favor of shorter distances, they were not statistically significant. No significant differences were also found between the three groups regarding the anthropometric data for the height and weight of the girls.

Table 3. Comparison of the mean values of height, weight, and WanT parameters in short-, middle- and long-distance female swimmers.

Variables	Mean			p-value		
	GSD	GMD	GLD	GSD-GMD	GSD-GLD	GMD-GLD
Height [cm]	170.8	170.2	169.7	1.000	1.000	1.000
Weight [kg]	61.6	60.4	59.4	1.000	0.483	1.000
PP [W]	627.6	555.1	474.3	**0.026**	**0.000**	**0.018**
RPP [W/kg]	10.21	9.22	7.97	0.054	**0.000**	**0.017**
AP [W]	465.6	433.9	384.2	0.297	**0.001**	**0.049**
RAP [W/kg]	7.57	7.18	6.46	0.422	**0.001**	**0.036**
MP [W]	312.8	296.1	277.0	1.000	0.422	1.000
RMP [W/kg]	5.06	4.91	4.66	1.000	0.865	1.000
PD [W]	314.7	259.0	197.3	0.180	**0.000**	**0.013**
FR [%]	50.6	46.5	41.4	0.594	**0.031**	0.402
TW [J]	13710.3	12773.1	11372.5	0.312	**0.002**	**0.048**

p<0.05 – significant difference

Table 4 presents the differences between the means in the three groups of male swimmers. Significant differences between the three groups were revealed in PP, RPP, AP, PD, and TW. The highest mean values were those of BSD (898.2 W, 12.56 W/kg, 642.7 W, 469.9 W, and 18929.8 J), followed by those of BMD (778.2 W, 11.35 W/kg, 592.8 W, 364.4 W, and 17569.1 J). BLD had the lowest mean values (643.7 W, 10.14 W/kg, 503.4 W, 281 W, and 14944.6 J). Significant differences were found in Height, Weight, RAP, and MP between BLD (174.5 cm, 63.6 kg, 7.94 W/kg, and 362.6 W) and BSD (180.4 cm, 71.74 kg, 8.97 W/kg, and 428.3 W) and also between BLD and BMD (181.3 cm, 68.8 kg, 8.62 W/kg, and 413.8 W). Differences in FR were significant only between BSD (52.1%) and BLD (43.4%). The mean FR of BMD (46.5%) was not statistically different from that of BSD and BLD. No significant differences were found between the three groups only in RMP.

Table 4. Comparison of the mean values of height, weight, and WanT parameters in short-, middle- and long-distance male swimmers.

Variables	Mean			p-value		
	BSD	BMD	BLD	BSD-BMD	BSD-BLD	BMD-BLD
Height [cm]	180.4	181.3	174.5	1.000	**0.017**	**0.003**
Weight [kg]	71.74	68.8	63.6	0.358	**0.000**	**0.015**
PP [W]	898.2	778.2	643.7	**0.002**	**0.000**	**0.000**
RPP [W/kg]	12.56	11.35	10.14	**0.002**	**0.000**	**0.000**
AP [W]	642.7	592.8	503.4	**0.035**	**0.000**	**0.001**
RAP [W/kg]	8.97	8.62	7.94	0.254	**0.003**	**0.006**
MP [W]	428.3	413.8	362.6	1.000	**0.001**	**0.010**
RMP [W/kg]	5.97	6.03	5.72	1.000	0.799	0.450
PD [W]	469.9	364.4	281.0	**0.000**	**0.000**	**0.004**
FR [%]	52.1	46.5	43.4	0.066	**0.002**	0.571
TW [J]	18929.8	17569.1	14944.6	**0.016**	**0.000**	**0.000**

p<0.05 – significant difference

Discussion

The results were homogeneous in relation to PP. CV was greater in MP and PD, meaning that differences in swimmers' fatigue were more pronounced. Besides physiological differences and fitness, motivation could also influence these parameters. The RPP and RAP values were similar to those of the study by Hawley et al. (1992) who reported 9.51 and 10.75 W RPP and 6.58 and 8.26 W RAP in females and males, respectively. A direct comparison cannot be made because the average age of the swimmers they studied was 13.2 and 13.6 years, respectively, and they were not divided into sprinters and distance swimmers. Additionally, they used resistance equal to 6.7 and 7% of the participants' body weight.

A significant difference in peak power was found between short-distance, middle-distance, and long-distance swimmers in both sexes. Mean values were higher for swimmers of shorter distances. It can be attributed to the different muscle fibers characteristics of different types of swimmers. Sprinters tend to be more muscular than distance swimmers and have a greater potential to improve muscle size, strength, and power because they possess more fast-twitch muscle fibers (Maglischo, 2003).

Mean values of almost all other power variables were higher for swimmers of shorter distances, but not all differences were significant. The relative Average Power of long-distance swimmers was significantly lower than the RAP of the others, in both boys and girls. Relative Peak Power, Average Power, and Total Work were significantly different in male swimmers from the three groups, while in female swimmers they were significantly different only for GLD. This is possibly due to the larger differences in muscle mass in men. The minimum Power of BLD was significantly lower than the MP of BSD and BMD, while in girls no significant differences in MP were found between the three groups, although the means of MP were higher for female swimmers of shorter distances. The extremely low MP values of one of the girls from GSD and one from GLD, due to fatigue or earlier cessation of effort, may account for the lack of significant differences between female groups in MP and some MP-related parameters, such as AP, PD, and TW. No significant differences were found between the groups in Relative Minimum Power. The mean RMP values of long-distance swimmers were the lowest. The RMP of GSD was highest for the girls, while the RMP of BMD was slightly higher than the RMP of BSD for the boys. It should be noted that the differences in MP between the groups were smaller than the differences in PP. That is, power differences between different types of swimmers decrease with the onset of fatigue.

There was a significant difference in Power Drop between the three groups of male swimmers. PD was greatest in sprinters and least in long-distance swimmers. This could be explained by the higher percentage of fast-twitch muscle fibers in sprinters, which are more powerful but fatigue more quickly. In girls, only the PD of GLD was significantly lower. One study reported that fewer women have extreme types of muscle fiber distribution, i.e., women with a very high percentage of fast-twitch muscle fibers are less common (Saltin & Gollnick, 1983). Long-distance swimmers were shorter and lighter, with differences only significant in boys. It is common for long-distance swimmers to be slightly shorter and have less muscle mass. Smaller body sizes imply less energy expenditure to overcome swimming resistance and greater endurance, and slow-twitch muscle fibers are smaller than fast-twitch. Differences in height and weight between short-distance and middle-distance swimmers were small, and the mean height of BMD was a little higher than that of BSD. There were several boys of relatively short stature among the short-distance swimmers. Height and weight are related to muscle mass. Unfortunately, relative muscle mass was not measured in this study.

Conclusions In summary, the peak power of 15-17-year-old swimmers differed according to the length of their main event. Short-distance swimmers had the highest peak power values and long-distance swimmers had the lowest. Power differences between different types of swimmers decreased with the onset of fatigue. Power drop was greatest in sprinters and least in long-distance swimmers. The variation of minimum power values was greater than that of peak power values. Long-distance swimmers were shorter and lighter, with differences only significant in boys.

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