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PATTERNS OF GROWTH FOR SOME CHARACTERISTICS OF PHYSICAL DEVELOPMENT, FUNCTIONAL AND MOTOR ABILITIES IN BOY-SWIMMERS 11-18 YEARS.

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ABSTRACT.

The objectives of the study were: 1) to obtain information about growth velocity and patterns of morphological, functional characteristics and motor abilities in boy-swimmers; 2) to assess the level of motor maturity of boy-swimmers at each age; 3) to specify age margins for consecutive stages of multi-year training programme. The measurements included: height, weight, vital capacity, biological age, ratios weight/height, VC/weight; double arm pulling force in bench test, endurance in 30-s and 3-min pulling tests, pulling force during tethered swimming in still water and in water flume at water velocities of 0.6 - 1.4 m/s; Vo_2, V_E, $ExcCO_2$ during stage-test in water flume; blood lactate after swimming test 4 x 50 m. The subjects were about 400 boy-swimmers 11-18 years of age from special swimming schools undergoing annual observations. The results trace year-by-year formation of functional and motor potential in boy-swimmers. Periods of most rapid growth (PMRG) and maximal annual gain (MAG) were established for all characteristics. The models of motor maturity were used to demonstrate readiness of boy-swimmers to adapt to different training methods at every age.
Key words: growth and development, young swimmers, motor readiness.

INTRODUCTION

The purpose of this project was to obtain comprehensive information about physical growth and motor development in boy-swimmers between 11 and 18 years of age. The objectives of studies were: 1) to get information about growth velocity and patterns of morphological, functional characteristics and motor abilities in boy-swimmers; 2) to assess the level of motor maturity of boy-swimmers at every age; 3) to specify age margins for consecutive stages of multi-year training.

METHODS

The studies included measurements of such a traditional characteristics of physical development as height, weight and vital capacity (VC) which are widely recognised as important criteria of growth intensity. The rate of changes of these characteristics were used as a scale to evaluate a relative intensity of growth and development of motor and functional abilities, general and specific working capability, etc. We included into consideration the ratios: weight/height and VC/weight because their growth patterns differ significantly from age dynamics of the absolute values of height, weight and VC and these ratios reflect the process of maturation (Bulgakova, 1986; Timakova, 1985).

The complex of general and specific strength characteristics in young swimmers included: maximal double arm pulling force on land in bench test – PF_L; relative pulling force on land - PF_L (kg)/weight (kg) x 100%; endurance index (EI) in 30-s double arm pulling bench-test using Huttel-Mertens device with resistance of 80% from individual maximal PF_L as established in bench-test; endurance index (EI) in 3-min pulling bench-test with resistance of 60% from individual maximum PF_L as established in bench-test; pulling force during tethered swimming in still water (V=0) using full co-ordination and kicking only – PF (V=0); pulling force during tethered swimming in water flume at water velocities of 0.6; 1.0; 1.2 and 1.4 m/s (PF V=0.6; V=1.0; V=1.2; V=1.4) (Dyrco, 1986;Vorontsov et al., 1982).

Subjects performed PF_L measurements and both pulling bench-test in prone position. For PF_L measurements paddles were connected by ropes to the dynamometer. Swimmers exerted maximal effort for 4-6 s with arm in catch position. The best of 3 trials was taken into consideration as maximal pulling force.

In 30-seconds and 3-min endurance tests using Huttel-Mertens device subjects were instructed to perform as many pulling movements during the test time as they could. Only complete actions were counted. Assessment of PF_L in bench test and both endurance tests were performed in the same day with 30 min of rest inbetween (3-min test was executed first after PF_L measurement). EI (30 s) and EI (3-min) were calculated as follows:

EI (30-s)= R x n = 0.8 x PF_L x *n* - where *n* = number of pulling movements in 30 seconds;
EI (3-min) = R x n = 0.6 x PF_L x *n* - where *n* = number of "pulls" per 3 min.

Mesurements of pulling force during tethered swimming in still water (V=0) and in water flume at water velocities 0.6; 1.0; 1.2; 1.4 m/s were performed in water flume of the Moscow Olympic Centre of Aquatic Sports. The subject performing both still water and flume tests was connected to the measuring device by rope with rubber insert 3 m long and 1 cm in diameter (k=1.5). This was made to eliminate the dynamic impact caused by cord stretching upon magnitude of pulling force. The subjects were instructed to exert maximal effort for 5-7 seconds. Result of the best of three trials was taken as the maximal pulling force at a given water velocity. The same procedure was followed for each velocity of the water flow with rest intervals 1.5 min in-between. To measure PF_L and PF during tethered swimming a mechanical dynamometer with clock-like face and accuracy of measurement $\pm$ 1.5 N was used.

The stage-test in water flume was used to evaluate aerobic power (VO_2 max, V_E, VO_2 max ml/kg x min^{-1}, anaerobic response to workload ($ExcCO_2$) and swimming speed at anaerobic threshold (V_{AT}) as mechanical equivalents of aerobic efficiency. Before stage-test subjects performed standard warm up of 2 min swim at water velocity 0.8-1 m/s followed by 2 min rest. Execution of the test began at water velocity 0.8 m/s for 11-12 years old boys, 0.9 m/s for 13 years olds and 1.0 m/s for 14-18 years old swimmers. During the test water velocity was increased: for young swimmers 11-13 years of age by 0.1 m/s every 2 min of work until they were not able to cope with water stream any longer; for swimmers 14-18 years of age by 0.2 m/s every 2 min of work until velocity 1.6 m/s and thereafter by 0.1 m/s every 2 min of work successively. All subjects swam front crawl.

Air samples were collected into Douglas bags during the last 30 s of work at each stage. Last sample was taken immediately after the swimmer refused to continue swimming due to exhaustion. Measurements of gas volumes in bags were performed with special gas meter. All gas volumes were corrected to BTPS conditions. Oxygen intake was calculated from expired air samples collected in Douglas Bags and analysed for O_2 and CO_2 content by Haldane technique. When air samples were used for evaluation of metabolic rate they were corrected to STPD. As a criteria for the VO_2max by individuals we used the plateau in individual VO_2 consumption or the respiratory quotient R = 1.1-1.15.

Anaerobic threshold in stage-test was estimated as the swimming speed (V_{AT}) in the moment when non-linear increase of expired CO_2 began (Margaria, Cerretelli, Mangili, 1964; Wasserman et al., 1973). We took for this moment as the breaking point of the semi-logarithmic graph $\Delta ExcCO_2 / V_{FLUME}$, where $\Delta ExcCO_2 = ExcCO_2 - ExcCO_2max$; and V_{FLUME}

= water stream velocity. $W_{AT} = V_{AT}{}^3$ was used as approximate equivalent of mechanical power of anaerobic threshold.

Anaerobic power exerted by swimmers in stage-test was assessed by $ExcCO_2$. Lactic acid forming during intensive muscular exercise is buffered by blood bicarbonates. It leads to excretion of additional quantity of CO_2 above the level of metabolism. $ExcCO_2$ was determined as: $ExcCO_2 = \Delta R \times VO_2$, where $\Delta R = R_{work} - R_{rest}$ and $R_{rest} = 0.75$

Anaerobic abilities were also assessed by blood lactate (Bl. Lact.) level after performing maximal swimming test of 4 x 50 m freestyle with 15-s rest intervals. Subjects performed the test after a standard warm-up of 800 m. Blood samples were taken from index finger in the begining of 4^{th} minute of recovery. Blood lactate concentration was determined using method of Barker-Summerson as modified by Sröm (Sröm, 1949). Total swimming time in this test, V_{4x50} (swimming speed) and W_{4x50} was used as criteria of anaerobic working capability.

Biological age (maturity) of subjects was determined at points using the method of somatoscopy (Vlastovsky, 1976; Timakova, 1985). This method is based upon evaluation of the expression of four secondary sex characteristics in individuals: pubic and axillary hair development, breast nipple development, voice transformation (each parameter could earn from 0 to 12 points) with following calculation of the average maturity score.

To obtain information on growth for all characteristics the records of a number of cross-sectional, longitudinal and multi-longitudinal studies performed by the Swimming Department of the Academy of Physical Culture during 1982-1990 was used. The number of subjects accumulated in every age group and was varying due to different characteristics from 108 to 19 with total number being about 400. The subjects were boy-swimmers of Moscow's Special Swimming Schools and candidates of the National Junior Team who underwent compulsory annual observations. Measurements occured during the 3^{rd} - 5^{th} weeks of a new sport season. Thus boys were fit to perform all power and functional tests but did not undergo hard specialised training yet.

RESULTS AND DISCUSSION

Growth patterns of anthropometric characteristics, general and specific strength:

During the age span of 11-18 years the values increased for: height 21%, weight 89%, VC 120%. The PMRG for height was observed between 12 and 15 years with the MAG at 13-14 years. The MAG for body weight was at 14 to 15 years, one year after height's leap. An increase of weight/height ratio up to 18 years is mainly due to the plateauing of height increase as accompanied to weight increase. The VC from 11 to 18 years increased as much as 120% of its initial value with PMRG between 12-16 years. At the same time the VC/Weight ratio attained only 15% of it's value in the age of 11 years.

Maximal double arm pulling force in bench test increased from 11 to 18 years as much as 3 fold with PMRG at 13-16 years and MAG at 14-15 years. The PF_L /Weight ratio changed slowly from 11 to 13 years, with its PMRG at 13-16 years and its maximal value at age of 17.

The Endurance Index in 30-s pulling test grew as much as 4 fold from the ages 11 to 18 while the endurance in 3-min pulling test increased as much as 3.1 fold. The PMRG of EI (30-s) was between 13 and 16 with its MAG at 14-15 years. The EI (3-min) grew up quickly from 12 to 15 years of age with its MAG also at 14-15 years.

The PF (V=0) using full stroke co-ordination increased as much as 2.2 fold while the PF (V=0) using kick only by 1.6 fold with the MAG for both at 14-15 years. The growth patterns of PF (V=0.6) and PF (V=1.0) didn't differ from that for PF (V=0). For magnitudes of PF at higher water velocities (V=1.2 and V=1.4 m/s) rapid growth was observed already at 11-12 years of age with the second peak at 14-15 years. The first increase may be attributed mainly to improvement of core swimming skills on early stages of multi-year training (this time no

Table 1. Age dynamics of anthropometrical characteristics, functional and motor abilitie in boy-swimmers 11-18 years of age.

Characteristics		AGE in YEARS 11	12	13	14	15	16	17	18
Maturity (Biological Age),	X	0.4	0.9	3.5	5.7	9.4	10.6	11.6	12
in points	± SD	0.2	0.8	2.6	2.1	1.8	1.3	0.5	-
Height, cm	X	149.6	153.8	159.3	169.3	173.4	176.4	178.1	180.9
	± SD	5.9	6.4	7.0	5.4	4.4	4.8	4.3	4.3
Weight (body mass), kg	X	38.7	42.0	48.5	55.6	62.9	65.1	69.2	73.0
	± SD	3.4	4.2	5.8	5.4	6.6	5.4	5.5	5.1
Vital Capacity (VC), ml	X	2613	2947	3461	4088	4563	5070	5350	5758
	± SD	326	411	322	398	317	569	571	512
Weight / Height, g/cm	X	259	273	301	328	363	369	388	403
	± SD	11	15	22	21	28	20	24	18
PF_L, N	X	159.7	187.2	228.3	293.0	372.4	432.2	463.5	486.1
	± SD	18.6	25.5	33.3	50.0	61.7	55.9	54.9	50.0
(PF_L / Weight) x 100 %	X	42.1	45.5	48.0	53.8	60.4	67.7	68.3	67.9
	± SD	1.2	1.5	1.3	4.0	3.7	3.2	2.7	2.2
EI 30-s pulling test, c.u.	X	2508	3185	4184	6488	8095	9486	10662	10153
	± SD	490	852	804	1539	1470	1107	1186	1294
EI 3-min pulling test, c.u.	X	9839	12270	17699	22059	28616	29037	30341	30939
	± SD	1773	2322	3459	5312	7771	4733	5008	4724
PF V=0, N	X	107.8	118.6	141.1	159.7	200.9	221.5	235.2	237.2
full stroke	± SD	12.7	9.8	13.7	28.4	22.5	22.5	21.6	21.6
PF V=0, N	X	72.5	79.4	88.2	95.1	108.8	110.7	115.6	118.6
kick only	± SD	7.8	7.8	8.8	8.8	8.8	11.8	10.78	10.8
PF V=0.6 m/s, N	X	69.6	79.4	95.0	109.8	138.2	155.8	160.7	164.6
	± SD	8.8	11.8	11.8	16.7	15.7	15.7	14.7	14.7
PF V=1.0 m/s, N	X	43.1	53.9	69.6	85.3	106.8	127.4	138.2	147.0
	± SD	10.8	8.8	11.8	15.7	16.7	16.7	16.6	15.7
PF V=1.2 m/s, N	X	25.5	38.2	54.9	76.5	94.1	113.7	117.6	125.4
	± SD	10.8	8.8	11.8	11.8	11.6	13.7	14.7	11.8

Table 1. (continuation).

Characteristics		AGE in YEARS 11	12	13	14	15	16	17	18
PF V=1.4 m/s, N	X	8.8	20.6	37.2	53.9	77.4	94.1	99.0	103.9
	± SD	6.9	8.8	12.7	16.7	11.6	10.8	11.8	11.8
VO_2 max, l/min	X	1.70	1.84	2.30	2.85	3.53	3.99	4.23	4.48
	± SD	0.31	0.29	0.43	0.43	0.53	0.53	0.54	0.51
VO_2 max/ Weight, ml/kg x s^{-1}	X	47.2	45.6	49.3	52.4	56.7	59.1	61.1	61.4
	± SD	6.5	5.2	5.9	5.7	5.7	6.0	5.8	3.6
V_E, l/min	X	45.7	49.4	59.4	64.2	83.0	90.9	101.5	111.0
	± SD	9.4	9.4	12.0	9.2	11.7	14.7	16.3	16.7
ExcCO_2, l/min	X	0.28	0.33	0.43	0.55	0.67	0.72	0.97	1.23
	± SD	0.13	0.12	0.22	0.18	0.23	0.19	0.17	0.18
V_{AT}, m/s	X	1.10	1.19	1.28	1.36	1.46	1.49	1.51	1.52
	± SD	0.04	0.04	0.05	0.06	0.06	0.06	0.06	0.05
W_{AT}, c.u.	X	1.33	1.68	2.10	2.52	3.11	3.31	3.43	3.51
	± SD	0.15	0.16	0.27	0.33	0.39	0.40	0.42	0.35
Blood Lactate, mmol/l	X	7.1	8.3	9.1	9.2	12.0	12.2	14.6	14.3
	± SD	2.0	2.7	2.4	2.7	3.4	2.9	2.9	2.7
Total time 4 x 50 m free, s	X	156.4	150.1	139.1	131.1	126.2	123.9	118.1	114.4
	± SD	8.9	8.1	8.0	5.9	5.1	4.6	4.4	3.9
Bl.Lactate/ Total time 4x50 m, Mmol/l x s^{-1}	X	0.045	0.055	0.065	0.070	0.095	0.098	0.124	0.125
	± SD	0.014	0.020	0.019	0.020	0.022	0.024	0.026	0.027
$V_{4 x 50}$, m/s	X	1.28	1.33	1.44	1.52	1.58	1.61	1.69	1.75
	± SD	0.07	0.08	0.08	0.07	0.06	0.06	0.07	0.06
$W_{4 x 50}$, c.u.	X	2.09	2.37	2.97	3.55	3.97	4.20	4.85	5.34
	± SD	0.32	0.39	0.45	0.48	0.39	0.46	0.59	0.58

significant increases in muscle power was observed) and the second peak should be considered as a result of the growth of muscle power.

For the entire age period of 11-18 years PF (V=0.6) increased only 2.4 fold, PF (V=1.0) 3.4 fold while PF (V=1.4) increased as much as 11.8 fold. Since PF_L increased only as much as 3.0 times, such high growth rates of pulling force during swimming at submaximal speed may be explained as a result of swimming technique improvement rather than growth in muscle power. It is likely that this is a combined effect of both factors.

Growth patterns of aerobic and anaerobic capabilities:

The absolute values of maximal O_2-intake demonstrated the PMRG at 12-16 years with the MAG at 14-15 years. It should be noted that the assessment of aerobic abilities of young swimmers took place during the swimming stage test in water flume (specific exercise). The young swimmers from 11-13 years of age had relatively low values of VO_2 max ml/kg x min^{-1} as compared to the values obtained during running or cycling (Solomatin, Vorontsov, 1990). The reason for this may be seen in low efficiency of swimming technique found in these young swimmers. Poor swimming skills and inability to stand against gradually accelarated water stream do not allow young swimmers to achieve the same values of VO_2 max which they did for running or cycling. But starting with the age of 14 they demonstrated higher values of VO_2 max during the performance in the stage-test in water flume than during cycling (Vorontsov, Solomatin, 1990). This is a result of multi-years purposeful training in swimming. The PMRG for VO_2max and VO_2max ml/kg x min^{-1} was observed for 12 to 15 year-olds. After the age of 15 years the growth of both characteristics began to slow down.

The ergometric criteria of aerobic abilities - V_{AT} and W_{AT} had PMRG in 11-15 years of age are supporting the opinion to prefer predominantly aerobic character of training of young swimmers on the early stages of multi-year training programme. While V_{AT} demonstrated almost steady annual growth rate, W_{AT} had MAG in 14-15 years followed by a plateau in growth at 15-18 years of age.

Anaerobic response during performance in stage-test in water flume ($ExcCO_2$) grew up as much as 4.1 times from 11 to 18 years. The rapid increase of this characteristic was seen between 12-14 and 16-18 years.

Characteristics of anaerobic lactic capacity (Bl.Lact.) and power (Bl.Lact. /TT4x50) in maximal swimming test 4x50 m demonstrated slow growth from 11 to 14 years with two consecutive peaks of growth in 14-15 and 16-17 years. The mechanical power during the performance of this test (W_{4x50}) showed a fast increase at 12-14 and 16-18 years of age. The first peak could be related to the improvement of basic swimming technique, the second to the maturity of anaerobic mechanisms of energy supply and growth of muscle power.

The experimental evidence may be used to presume that a rapid development of aerobic abilities occurs in boys from 11 to 15-16 years whilst intensive development of anaerobic metabolism takes place later - in the age 14-17 years. It is significant that for all ages the variability of ergometric criteria -V_{AT}, W_{AT}, V_{4x50} and W_{4x50} - was smaller than those of functional characteristics were. This shows that equal swimming results may be achieved at the expense of different individual relationship of aerobic and anaerobic abilities, mechanical efficiency and muscular power.

Individuals either with very high or very low values of characteristics were found in all age groups. The difference between maximal and minimal individual values of VO_2 max l/kg x min^{-1} achieved 40-50% of maximum and individual values of Bl.Lact. in some age groups differed by more than 3 fold from minimum. These differences may have a fundamental inborn character that makes possible the use of functional characteristics as the criteria of sport abilities in swimming.

Physical Development, Functional and Motor Abilities in Boy-Swimmers at Different Ages:

Table 2 shows the maturity levels of different characteristics in boy-swimmers, ages 11-17 years, measured as a percent value of their respective definite value (definite = ultimate conditionally accepted values of parameters in 18 year-old boys). It is evident that height is the most mature. Weight and VC fall behind height significantly until the age of 14-15 years. Importantly, in all ages the ratios for weight/height and VC/weight are more mature than the VC and weight. It follows that in younger ages there already exist morphological premises for development of aerobic endurance.

Table 2. Maturity characteristics of boy-swimmers (% to definitive level*).

	AGE in YEARS						
Characteristics	11	12	13	14	15	16	17
Height	82.7	85.0	88.0	93.6	95.8	97.5	98.4
Weight	53.0	57.5	66.4	76.1	86.2	89.2	94.8
Vital Capacity	45.4	51.2	60.1	71.0	79.2	88.0	92.9
Weight / Height	64.3	67.7	74.7	81.4	90.1	91.6	96.3
VC / Weight	85.5	89.0	90.5	93.2	91.0	98.7	98.0
PF_L	32.9	38.5	47.0	60.3	76.6	88.9	95.4
PF_L / Weight	62.0	67.0	70.7	79.2	88.9	99.7	100.7
EI 30-s	24.7	31.5	41.2	63.9	79.7	93.4	97.3
EI 3-min	31.8	39.7	57.2	71.3	92.4	93.8	98.1
PF V=0 full stroke	45.5	50.0	59.5	67.4	84.7	93.4	98.1
PF V=0 kick only	61.2	66.9	74.3	80.2	91.7	93.3	97.5
PF V=0.6 m/s	42.3	48.2	57.1	66.7	83.9	94.6	97.6
PF V=1.0 m/s	29.3	36.7	47.3	58.0	72.7	86.7	94.0
PF V=1.2 m/s	20.3	30.5	43.8	57.8	75.0	90.6	93.8
PF V=1.4 m/s	8.5	19.8	35.8	51.9	74.5	90.5	95.3
VO_2 max , l/min	37.9	41.1	51.3	63.6	78.1	89.1	94.4
VO_2max ml/ kg x min^{-1}	76.9	74.3	80.3	85.3	92.3	96.2	99.5
$ExcCO_2$	22.7	26.8	34.9	44.7	54.5	58.5	78.9
V_E	41.2	44.5	53.5	57.8	74.8	81.9	91.4
V_{AT}	72.3	78.3	84.2	89.5	96.0	98.0	99.3
W_{AT}	37.9	47.9	59.8	71.8	88.6	94.3	97.7
Bl. Lactate4 x 50 m	49.6	58.0	63.6	64.3	83.9	85.3	102.3
Bl.Lact. / TT 4 x 50 m	36.0	44.0	52.00	56.0	76.0	78.4	99.2
$V_{4 x 50 m}$	73.1	76.0	82.3	86.8	90.2	92.0	96.6
$W_{4 x 50}$	39.1	44.4	55.6	66.5	74.3	81.9	90.8

The most immature among strength characteristics in all age groups are EI (30-s) and EI (3-min). At the age of 13-15 years they attain only 50% of their definite values. It seems that better conditions for development of local muscle endurance to workloads of submaximal and high intensity appears in boys after 14 years. But young swimmers at the age of 11-14 years are capable to improve significantly their local muscle endurance in exercises with moderate and low resistance. In those age groups EI (30-s) and EI (3-min) increase year-by-year at the expense of pulling frequency, in older ages predominantly at the expense of maximal muscle power growth.

PF (V=0) using kick only is the most mature among all characteristics of specific strength exerted by young swimmers in the water. The natural growth almost ends at the age of 15-16 years. The crawl kick is the basic swimming skill with a very simple structure and low efficiency. Younger swimmers, having better buoyancy and less resistance, can exert enough power during kicking to swim almost as fast as their older counterparts.

Less mature than other characteristics of specific strength are the values of PF in water flume. It may be seen from table 2 that the higher the velocity was in flume the lower the maturity levels were in PF at each age group. Even among the 15-year old boys the maturity of PF V=0.6-1.4 m/s was significantly less than the maturity of PF (V=0) as well as of strength in land tests. The value of PF during tethered swimming in water flume at higher water velocities are connected most closely to sport specific results in swimming in young and adult swimmers (Dyrco, 1986; Vorontsov, 1982). There is evidence enough to show that special training which helps to increase PF during tethered swimming at high water velocities in water flume will result in higher increase in sport results (Vorontsov, Fomichenko, 1987).

The characteristics of functional abilities in the ages of 11-13 years are lagging far behind height, weight and VC in maturity levels. One exception was VO_2max ml/kg x min^{-1} which yielded only a little bit to height and VC/weight. This is in accordance with the data of other authors (Kozlov, Farber, 1980, Sonkin, 1979) that in every age maximal aerobic power per unit of body weight is more mature than its absolute value. Perhaps because of the more mature level of VO_2 max ml/kg x min^{-1} and VC/weight of young swimmers they are able to perform large training volumes of extensive swimming and show fast improvement of swimming results in distance swimming at the age 11-12 years (Bulgakova, 1986, Timakova, 1985).

In young swimmers of all ages the maturity of V_{AT} and W_{AT} were higher than the maturity of maximal O_2-intake ml/kg x min^{-1}. It may reflect one more time the predisposition of young swimmers to extensive aerobic training.

Bl.Lact. and Bl.Lact/TT4x50 in all age groups were closer to their definitive levels than aerobic abilities, but the rate of maturation in anaerobic abilities was much slower than for aerobic ones. The mechanical equivalent of aerobic power - W_{AT} also gained maturity more rapidly than W_{4x50}. Consequently, the present data suggests that the optimal time period to develop anaerobic abilities in boy-swimmers is after they are already 14-15 year-old.

CONCLUSIONS

The results of the present investigation were used to develop scales for assessment and monitoring of growth and development in boy-swimmers at 11-18 years of age. The scales allow subdivision of young athletes into high, medium or low morphological, strength and functional classes in each age group (Vorontsov, Solomatin, 1990).

The data on PMRG and MAG, sexual and physiological maturity of morphological, functional and motor criteria may be interpreted from the point of view of *the Theory of Sensitive Periods* (Arshavsky, 1981; Bulgakova, 1986; Timakova, 1985). According to that theory maximal positive training or learning effects upon development may be achieved during periods of rapid growth. The obtained data permit us to presume that the optimal age to develop aerobic capacity and efficiency (period of fast growth for VO_2max ml/kg x min^{-1}, V_{AT}, W_{AT}) is from 11 to 14, for aerobic power (VO_2max) 12-16, for anaerobic capabilities 14-17, and for strength training 15-18 years.

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