Differences in Aerobic and Anthropometric Characteristics Between Peripubertal Swimmers and Non-Swimmers

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Abstract

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In order to judge the effect of moderate sports training on the anthropometric characteristics and aerobic capacity of boys before and during puberty, a comparative study was conducted of 140 children, 94 of whom were not undergoing any specific training and 45 of whom were spending more than 3 hours a week practising swimming. The boys were divided into three maturity groups according to pubic hair status: prepubertal, pubertal, and end of puberty. The study shows greater maximal oxygen uptake in absolute terms, body weight, lean body mass, chest circumference, arm circumference, and arm muscle area for the swimmers. The morphological differences between the swimmers and non-swimmers concern physical characteristics generally involved in swimming. The difference in aerobic capacity, however, may be in part due to the morphological changes engendered by training; a longitudal study would confirm this. It is suggested that anthropometric indicators of arm muscles may be used in the biological supervision of swimming training.

Key words

Anthropometry, maximal aerobic uptake, swimming, training

Introduction

The effects of intensive regular training on the anthropometric and aerobic characteristics of children are a matter of debate. In a recent article Bar-Or has shown the observed effects of training on maximal oxygen uptake ($\dot{V}O_2max$) to be less than expected (3). Similarly, the real effects of regular training on morphological status are difficult to evaluate (2, 4, 20). This may be due to the fact that changes linked to growth (1) and spontaneous physical activity (21), which are complex and interwoven factors, are difficult to differenciate.

The effects of moderate regular training have not been studied up to now. Nevertheless, with more and more children taking up a regular sport, it has become important to know the effects of moderate regular sport training on anthropometric and aerobic development.

The aims of this study were twofold: 1) to describe the differences in aerobic capacity and anthropometric characteristics associated with moderate regular swimming in children prior to and in the early stages of puberty as compared to non-swimmers, and 2) to define any relationship which might exist between these aerobic and anthropometric features.

Subjects and Methods

Subjects

The study included 140 boys aged from 10 to 15 years who were divided into 2 groups according to their athletic habits, not including regular physical education (3 hours a week). Group 1 consisted of 95 schoolboys who practiced no regular sport. All children practising or having practised a sport for more than 4 hours weekly were eliminated from this group. Group 2 consisted of 45 children who were members of 3 municipal swimming clubs and had been competing at a regional level for at least 2 years. They trained regularly at an aerobic level 3 to 5 times a week for 2 hours each session. Interviews allowed us to quantify the extra-curricular athletic activity of the controls and the training of the swimmers. Socioeconomic factors were evaluated by directly interviewing the children or by information collected from the schools and club trainers. All these children were from a similar social background and of a similar academic level. Examination of official health records allowed us to determine retrospectively the peak height growth. After careful clinical and electrocardiological examination, only children in excellent health were included in the survey. Their parents' written permission was obtained as well as the approval of the National Ethical Committee.

Stage of Development

The level of pubertal maturation was assessed by inspecting pubic hair according to Tanner's five stages (22). Each group was subdivided into 3 maturational groups. These were: prepubertal (Stage I), pubertal (Stages II and III), and end of puberty (Stages IV, V) (Table 1).

Anthropometric Characteristics

The following measurements were taken: weight, height, upper arm circumference, upper thigh circumference, maximal calf circumference, chest circumference (in expiration), and bicipital, tricipital, subscapular, and suprailiac skinfold thickness. All these measurements were taken by the same observer in the positions and following the techniques established by the International Biological Programme (25).

Brook's equations (5) were used to estimate body density on the basis of 4 skinfold thickness measurements, and Siri's formula (8) was used to determine the fat body mass proportion. Lean body mass was calculated by subtracting fat body mass from the total body mass. Gurney and Jelliffe's formulas (11) were used to determine arm muscle structure:

Muscular Circumference = Circumference of the arm $- \pi \times$ Tricipital Skinfold.

Muscular Area = (Muscular Circumference) 2/4 π

Maximal Effort Test

An ergometric bicycle with an electromagnetic brake was used to test maximal effort (EPC 7701, Gauthier). The children breathed through a low-resistance valve (Hans Rudolph). Inspiratory airflow was measured during exercise with a pneumotachograph (Fleisch n °3) and a Validyne MP 45 pressure transducer with a measuring range of ± 27 cm H_2O. The pneumotachograph was placed on the inspiratory tubing in order to avoid problems due to water vapor. Calibration of the flow module was accomplished by introducing a calibrated volume of air at several flow speeds. Expired gases were sampled in a mixing box (5 liters) and analyzed for O_2 with a polarographic analyzer (Beckman OM 11) and for CO_2 with an infrared analyzer (Cosma Diamant 6000). Each gas analyzer was calibrated before and after each test according to standard gases. Inspiratory airflow and the fractions of expired O_2 and expired CO_2 ($FECO_2$) were processed by a computer which calculated: minute ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$), respiratory ratio (R), and ventilatory equivalent for O_2 ($\dot{V}E/\dot{V}O_2$) and CO_2 ($\dot{V}E/\dot{V}CO_2$) from ten ventilatory cycles. During the exercise, the heart rate was continously recorded with a cardiograph (Simonsen and Weel).

A continuous progressive protocol was used; after 3 minutes of warming up at a load of 30 watts, the work load was increased until exhaustion. For the younger children the work load was increased by 20 watts each minute and for the older children by 30 watts each minute. The children were to maintain a constant pedalling rate of 50 rpm to the best of their ability and were actively encouraged periodically throughout the test. We considered that the value of maximal oxygen uptake was obtained when 3 of the following criteria were observed: 1) the stabilization of oxygen uptake in spite of the increase of work load, 2) a heart rate close to its maximal value, 3) a respiratory exchange ratio > 1.1, and 4) the inability of the subject to maintain a pedalling rate of 40 rpm.

Statistical Analysis

Training and maturational stages were accounted for when the anthropometrical and physiological changes were analyzed. Thus, for each measurement a two-way analysis of variance (ANOVA) was performed by means of the 2V program from the BMDP computer package (BMDP Statistical Software, Inc.).

Results

Table 1 shows that for a given maturational stage there are no significant differences in age among the children: the swimmers were not found to be precocious or late in reaching puberty in comparison with the non-swimmers. There was also no interaction between maturity and the number of weekly hours of training.

Table 2 shows measurements taken for each group. The values increased with maturational stages, except for fat body mass, which decreased slightly. In general, values for subjects undergoing training tended to be higher than for the others. A significant difference was observed for body weight, arm and chest circumference, and muscle mass indicators, that is, lean body mass and arm muscle area.

Table 3 shows changes in the children's aerobic capacity in absolute terms, which increased with maturational stages and which differed with the intensity of the physical activity undertaken. When $\dot{V}O_2max$ was expressed as a function of weight or of lean body mass, the differences linked to maturational stages disappeared, but those connected with the activity remained. When $\dot{V}O_2max$ was expressed in arm muscle area units, however, no differences remained, with respect to maturational stages or with respect to activity.

Discussion

In the sample studied, there was no interaction between the maturational status and either the practice of swimming or the amount of training. However, for all three maturational groups, these results showed the young swimmers to have greater aerobic capacity, greater arm and chest circumference, and greater body weight, and muscular mass than the children not undergoing training.

The increase in $\dot{V}O_2max$ remained limited to 10% for the prepubertal swimmers, and 15% for those at the end of puberty. These figures are slightly lower than those of 15%–20% obtained from longitudinal surveys (9, 14, 19). However, these studies highlighted the effects of training on children just prior to, or during, puberty with maximal impact during peak height growth velocity, whereas for this study only 15 children were in their period of peak height growth. The amount of physical training may also play an important role: a 16% to 17% difference was noted for children undergoing 14 hours of training each week (18). In our case, even small increases in aerobic capacity are worth stressing as the children

Table 1 Age status and training quantities of boys by pubertal stages and physical activity groups

Pubertal groups (1)		PH2		PH2−PH3		PH4−PH5		Two-way analysis of variance	
Training groups (2)		I = 44 II = 22		I = 26 II = 13		I = 25 II = 10		between pubertal groups	between training groups
		mean	SD	mean	SD	mean	SD	F P	F P
Age	I	12.1	1.2	13.4	1.2	14.3	1.0	55.7	0.1
(years)	II	11.7	1.0	13.6	1.3	14.7	0.7	***(3)	NS
Training quantity	I	1.7	1.1	1.4	1.1	1.7	1.2	2.04	149.29
(hours/week)	II	5.0	1.1	5.2	1.4	6.3	4.2	NS	***

(1) Pubic Hair stages (PH) according to Tanner's classification (24)
(2) Group 1: 3 hours/week physical education; group II: 6 to 10 hours/week swimming training
(3) *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; NS: non-significant.

Table 2 Anthropometric measures of boys by pubertal stages and physical activity groups

Pubertal groups (1)		PH1		PH2−PH3 PH4−PH5				Two-way analysis of variance	
Training groups (2)		I = 44 II = 22		I = 26 II = 13		I = 25 II = 10		between pubertal groups	between training groups
		mean	SD	mean	SD	mean	SD	F P	F P
Body weight (kg)	I	39.1	8.7	48.9	7.9	55.5	9.6	52.5	3.6
	II	40.5	6.5	49.1	7.9	63.0	9.2	*** (3)	*
Height (cm)	I	147.0	9.7	157.8	8.6	166.7	9.7	51.0	1.9
	II	149.1	8.3	159.8	8.1	169.7	6.7	***	NS
Upper arm	I	20.9	2.4	23.3	1.9	23.6	1.8	30.3	5.21
circumference (cm)	II	21.6	1.4	22.6	1.9	26.4	3.1	***	•
Upper thigh	I	43.7	4.8	48.2	3.9	49.0	3.8	21.1	3.43
circumference (cm)	II	45.3	4.7	47.7	4.0	52.2	4.3	***	NS
Maximal calf	I	29.7	3.0	32.6	1.9	33.7	2.7	29.9	0.5
circumference (cm)	II	30.0	1.8	32.3	2.5	34.7	2.6	***	NS
Chest	I	66.0	5.2	71.5	4.2	75.1	5.0	38.3	8.3
circumference (cm)	II	68.7	6.2	72.4	4.2	80.1	5.8	***	***
Arm muscle	I	25.5	5.4	32.4	5.8	36.4	6.3	62.8	11.4
area (cm^2)	II	27.4	3.8	31.9	5.2	46.1	9.8	***	***
Fat body mass (%)	I	0.190	0.051	0.190	0.054	0.160	0.057	4.3	0.1
	II	0.200	0.047	0.170	0.057	0.170	0.040	**	NS
Lean body mass (kg)	I	31.1	6.4	39.1	6.2	46.4	7.9	73.7	4.71
	II	32.2	4.8	40.5	5.7	51.7	5.8	***	*

(1) Pubic Hair stages (PH) according to Tanner's classification (24)
(2) Group I: 3 hours/week physical education; group II: 6 to 10 hours/week swimming training
(3) *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; NS: non-significant.

concerned were younger and trained at a lower level than that of the studies quoted.

In our study, there is no significant difference of height between the swimmers and non-swimmers. This finding agrees with the literature (4, 23). For fat body mass, the use of skinfold thickness measurements is advised for children (5, 8, 10). As in the study of Cronk et al. (7), we observed a decrease of fat body mass at the end of puberty. It may be said, therefore, that physical activity has no real effect on morphological growth (2). Similarly, the swimmers did not mature earlier than the non-swimmers. However, the children who swam were shown to possess specific morphological traits: greater chest circumference, lean body mass and arm muscle area. The

Table 3 Absolute and relative values of V̇O2max of boys by pubertal stages and physical activity groups

Pubertal groups (1)		PH1		PH2–PH3		PH4–PH5		Two-way analysis of variance	
Training groups (2)		I=44 II=22		I=26 II=13		I=25 II=10		between pubertal groups	between training groups
		mean	SD	mean	SD	mean	SD	F P	F P
V̇O2max	I	1.8	0.4	2.2	0.5	2.6	0.5	49.0	17.8
($l \cdot min^{-1}$)	II	2.0	0.4	2.5	0.3	3.1	0.4	*** (3)	***
V̇O2max/kg weight	I	46.7	8.2	45.6	6.3	46.7	4.9	0.3	9.6
($ml \cdot kg^{-1} \cdot min^{-1}$)	II	49.1	6.4	52.2	5.8	49.6	6.1	NS	***
V̇O2max/kg LBM	I	58.2	8.8	57.0	7.3	55.9	6.5	0.7	9.92
($ml \cdot kg^{-1} \cdot min^{-1}$)	II	61.6	7.2	63.1	7.7	60.1	7.0	NS	***
V̇O2max/AMA	I	71.2	11.2	69.4	11.4	71.5	10.6	1.1	2.45
($ml \cdot cm^{2-1} \cdot min^{-1}$)	II	73.6	18.4	80.5	9.7	69.1	13.2	NS	NS

(1) Pubic Hair stages (PH) according to Tanner's classification (24)
(2) Group I: 3 hours/week physical education; group II: 6 to 10 hours/week swimming training
(3) *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.01$; NS: non-significant.

aim of physical training is to provoke the biological adaptations that contribute the most to fulfilling the required task (17). For swimming, this means floating in a horizontally balanced position while propelling oneself and combatting resistance. The increase in lean body mass corresponds to the need for muscular strength. The increase in chest circumference may be seen as a response to the breathing restrictions and hypoventilation imposed by swimming (10); in addition, it increases the buoyancy of the human body. Finally, propulsion in free-style swimming is mainly the work of the upper members, which operate as an airscrew (15), while the lower members are mainly concerned with maintaining horizontal equilibrium. Hence, the observed anthropometric developments in the young swimmers may be seen as specific, adaptational responses to the constraints imposed by their activity. Such developments have been documented for adolescents beyond puberty and for young adults (6, 23, 26), but little has been known about younger children, or of those less involved in competition, as those covered in this study.

Body weight and/or lean body mass, representing the active muscular mass (1), is often used to express V̇O2max in a relative way in order to compare different age groups. This was the case here, where differences connected with age disappeared, while those linked to physical training remained. Swimmers, however, do not have to support their weight, so their V̇O2max ought to be expressed as a function of their total weight or lean body mass in water (10). More precise expressions of V̇O2max should be found. Anthropometric indicators for the arm, such as muscle mass area, are considered to be good approximations of total muscle mass (12). They have been validated by tomodensitometry (13), and in children are highly correlated to urinary excretion of creatinine (24). Our results showed that, when V̇O2max was expressed per unit of muscular area, the difference between swimmers and non-swimmers ceased to exist. The difference in aerobic capacity between the two groups appears to be linked to the difference in muscle mass, which in this study is much more evident for the upper members (arm circumference, arm muscle area) than the lower members (thigh and calf circumference).

It is obvious that exercise on a ergometric bicycle uses predominantly the lower member muscle groups, therefore a test should be performed involving the upper members in order to confirm the dominant role of the arms in expressing the swimmers' aerobic strength. For practical reasons, however, use of the bicycle is both standard and satisfactory. Given the fact that at high-load-level not only the legs but also the arms are involved, it is possible to standardize V̇O2max by arm surface area. The reason for using muscular area rather than muscular circumference to gauge the muscular structure of the arm was twofold: 1) muscular area amplifies variations more than circumference does (11), and 2) it represents the force developed better, which, according to the dimensions theory, is proportional to the area of the muscle section (1).

The aerobic and anthropometric differences reported in this paper may be a consequence of training. Several longitudinal studies of more intensively trained subjects support this interpretation. However, this is a transversal study, and there is the possibility that these differences existed before training began. Although this possibility is unlikely, it would be best eliminated by a longitudinal study.

In conclusion, this study shows that children having undergone regular swimming training have aerobic and anthropometric characteristics significantly different from the non-swimmers. Such differences are slight and do not seem to influence the children's normal growth and maturation. These differences can be considered beneficial and may favour the early practice of regular sport. These results also have a practical aspect: they draw attention to the specific differences brought about by a given sport on the desired muscular groups. Hence, simple anthropometric indicators may be elaborated for biological supervision of on-the-field training, such as arm muscle area in the case of swimming.

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