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The relationship between changing body height and growth related changes in maximal aerobic power

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Summary. In order to analyse the relationship between maximal aerobic power ($\dot{V}_{O_{2\,max}}$) and height, body mass and lean body mass a multi-longitudinal survey was conducted on three different age groups of randomly selected children from a small Czech community. Beginning at the initial ages of 8, 12 and 16 years subjects were subsequently retested three times at 2-year intervals. At overlapping ages there were no differences in the various age groups between height and $\dot{V}_{O_{2\,max}}$. By utilizing mean values for the various parameters at specific calendar ages a growth curve was constructed for each sex for the age range 8–20 years. The values were compared with longitudinal studies in various countries and no substantial differences were found. When $\dot{V}_{O_{2\,max}}$ was then compared to height, body mass and lean body mass it was apparent that the almost linear relationship with height was the most precise. In addition the children remained, generally speaking, in their same rank order for $\dot{V}_{O_{2\,max}}$ for the three different age groupings.

Key words: Maximal aerobic power – Growth – Physical activity – Tracking

Introduction

It is generally agreed that the maximal aerobic power ($\dot{V}_{O_{2\,max}}$) is the best indicator of the capacity of the oxygen transport system and utilization at the tissue level (Robinson 1939; Valentin et al. 1955/56; Astrand 1952). Because similar $\dot{V}_{O_{2\,max}}$ values for individuals with differing body mass indicate different levels of aerobic power, the ratio $\dot{V}_{O_{2\,max}}$:body mass has been frequently used to compare both adult subjects and children. This procedure has been questioned by Asmussen (1974) for children and adolescents. Using the cross-sectional data of Astrand he concluded that $\dot{V}_{O_{2\,max}}$ was best related to body height raised to a power of 2.8 during childhood and adolescent years. v. Döbeln and Eriksson (1972) also agreed with this conclusion as a result of a 4-month study of 12 boys aged 11–13 years.

The Saskatchewan Growth and Development Study (Bailey et al. 1978) provided control for the dimensional theory of Asmussen using longitudinal data of 51 boys aged 8 to 15 years and came to the conclusion that $\dot{V}_{O_{2\,max}}$ was best related to body height raised to a power of 2.25.

Because the data base of the above-mentioned publications is small and the experimental designs and methods for the determination of $\dot{V}_{O_{2\,max}}$ are different, it seems appropriate to reinvestigate the problem using longitudinal data from various European countries which have been previously published in part by Kemper et al. (1983), Rutenfranz et al. (1981) and Rutenfranz et al. (1989).

Methods

This particular growth and development study began with a cross-sectional approach which investigated three different age groups of randomly selected boys and girls with initial ages of 8, 12 and 16 years. In total 129 children participated initially in the study although 12 subjects dropped out during the course of the investigation. After the initial measurements were taken two subsequent measurements were taken on the same subjects at 2-year intervals. The youngest age group was 12 years of age by the time of the final measurement period and this represented an overlapping age with the initial middle age group. Similarly, the overlapping age for the oldest group of subjects was 16 years. Thus this combined cross-sectional/longitudinal, or multiple longitudinal survey, covered a total age range from 8 to 20 years. The initial intention of this particular experimental design was to study both the structural and functional aspects of growth and their various interrelationships during the pre-pubertal, pubertal and post-pubertal phases of growth. It was imperative that such a design should have no age effects on the essential parameters which, as it turned out, was the eventual result. The procedures of subject selection and details of their numbers, physical characteristics, social background and places of residence have been described previously (Máček et al. 1985).

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Table 1. Physical characteristics of subjects

Cohort no.	Sex	n	Chronological age (years)	Height (cm)		Mass (kg)		Lean body mass (kg)		Fatness (%)	
				mean	SD	mean	SD	mean	SD	mean	SD
I	♂	21	8.2	132.5	6.7	30.1	6.4	24.2	3.8	18.7	4.3
		19	10.2	142.1	7.1	36.9	9.0	28.8	5.1	21.0	5.8
		19	12.1	153.6	8.2	46.3	12.3	35.9	6.5	21.2	6.2
	♀	22	8.1	132.3	4.4	28.3	4.4	22.1	2.8	21.5	2.9
		21	10.1	144.3	6.3	36.3	6.4	27.6	4.2	23.7	3.4
		21	12.0	156.4	6.5	45.3	8.3	34.4	5.3	23.6	3.1
II	♂	22	12.0	150.3	6.5	41.0	8.4	32.5	5.6	20.4	3.5
		22	14.0	164.7	7.0	52.8	10.8	43.7	8.0	16.7	3.9
		22	16.0	175.1	5.5	63.6	9.9	51.3	6.4	19.0	5.2
	♀	20	11.9	154.3	6.5	41.3	5.7	31.8	4.0	22.9	1.7
		18	13.9	164.5	6.8	51.7	6.3	39.9	4.3	22.7	2.4
		17	15.9	167.8	7.1	58.9	8.4	42.7	5.2	27.2	3.1
III	♂	23	16.0	177.4	6.8	66.9	10.3	53.6	7.1	19.5	4.8
		21	18.0	179.8	6.6	72.9	10.6	62.1	7.9	14.4	3.8
		21	20.0	181.6	6.9	76.2	10.1	63.0	7.5	16.8	4.9
	♀	21	16.1	167.2	8.6	59.5	8.7	44.8	5.9	24.7	2.5
		18	18.1	168.1	9.0	63.0	10.1	48.6	6.3	22.4	4.1
		17	20.1	169.3	9.5	65.2	10.0	48.6	6.8	25.3	3.4

Anthropometric measurements. Height and body mass were recorded from nude subjects to an accuracy of 0.5 cm or 0.5 kg, respectively. Skinfold measurements were taken at the lower edge of the scapula and the posterior portion of the middle upper arm with a Holtain skinfold caliper. Procedures and methods for calculating lean body mass and percentage body fat have been previously described by Rehs et al. (1975), Rehs et al. (1978) and Pařízková (1977).

Maximal aerobic power. The $\dot{V}_{O_{2max}}$ was determined on a cycle ergometer (Monark) utilizing two submaximal, followed by two maximal, exercise intensities which did not produce an elevated level of oxygen uptake which is an accepted criterion for the attainment of $\dot{V}_{O_{2max}}$. The sampling techniques and subsequent gas analysis and calculations followed the methods originally outlined by Lange Andersen et al. (1971).

Statistical analysis. For the purposes of data analysis subjects were arranged in groups according to sex and calendar age. Means, standard deviations and standard errors of the means were calculated in the usual way while statistical differences between the means were determined by a *t*-test and analysis of variance. Spearman's rank correlation coefficient was employed to determine the significance of the tracking phenomenon. Finally, skewness indices were calculated to test the distribution of normality within each age group. Simple correlation coefficients for cohorts I, II and III were calculated.

Results

Height and body mass

Table 1 shows the different physical characteristics for both boys and girls. For the three different age groups (cohorts) no statistically significant effect of age and sex could be detected as the data of overlapping ages were quite similar. Accordingly, a growth curve from the ages of 8 to 20 was constructed and, when compared to similar surveys carried out in the Netherlands, Norway and Germany, similar results were obtained (Kemper et al. 1983; Rutenfranz et al. 1981).

Changes in body mass did, however, show an age effect for those boys who weighed less during puberty (cohort II) than would have been expected based on both pre- and post-pubertal values. Comparisons with longitudinal data from Germany, Norway and the Netherlands showed that the Czechoslovakian boys were heavier at all ages, while the girls had similar body mass at all ages as girls from the other countries.

Maximal aerobic power

Data for $\dot{V}_{O_{2max}}$ at the various chronological ages are presented in Fig. 1 and Table 2. Skewness indices (data not presented) indicated normal distributions for most of the groups. As expected, absolute values for $\dot{V}_{O_{2max}}$ ($l \cdot min^{-1}$) increased with age for both sexes with peak values being reached at a mean age of 16 years, rather later for the boys and somewhat earlier for the girls. Average values for the boys were higher than for the girls at each calendar age and there were only small, insignificant differences in the values at overlapping ages. Again, this allowed the construction of a growth curve for maximal aerobic power for both sexes from the ages of 8 to 20 years.

Sex differences became apparent when $\dot{V}_{O_{2max}}$ was expressed relative to body mass (Fig. 2) although both sexes reached peak values at the approximate ages of

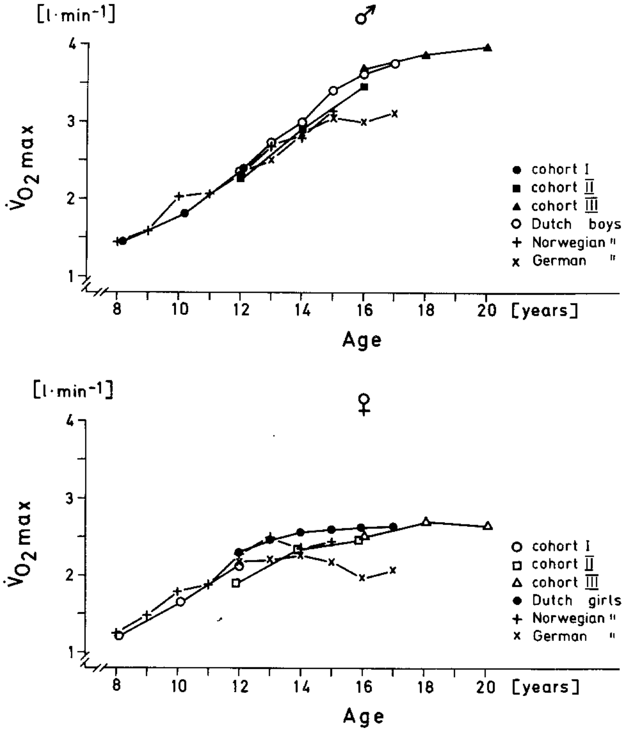

Fig. 1. Mean maximal aerobic power ($\dot{V}_{O_{2\,max}}$) in relation to calendar age in boys and girls

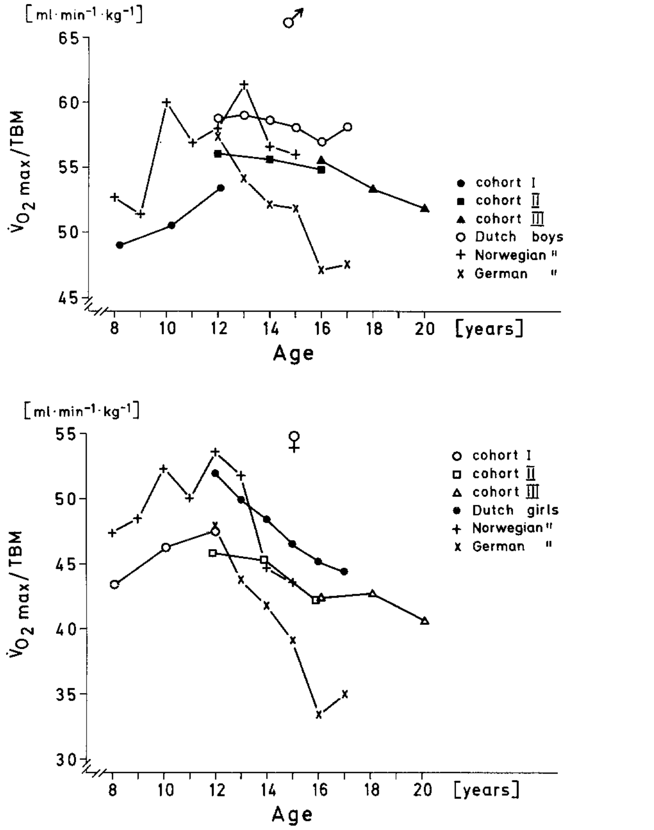

Fig. 2. Mean maximal aerobic power ($\dot{V}_{O_{2\,max}}$) expressed as a function of total body mass (TBM) in relation to calendar age in boys and girls

12–13 years. Cohort differences existed at the overlapping ages and, generally speaking, fitness, as defined by $\dot{V}_{O_{2\,max}}$, increased in both sexes from the ages of 8 to 12

Table 2. Maximal aerobic power

Cohort no.	Sex	n	Chronological age (years)	$\dot{V}_{O_{2\,max}}$ ($l \cdot min^{-1}$)		$\dot{V}_{O_{2\,max}}$/TBM ($ml \cdot min^{-1} \cdot kg^{-1}$)		$\dot{V}_{O_{2\,max}}$/LBM ($ml \cdot min^{-1} \cdot kg^{-1}$)	
				mean	SD	mean	SD	mean	SD
I	♂	21	8.2	1.45	0.27	49.0	9.2	60.1	10.3
		19	10.2	1.81	0.29	50.5	10.4	63.6	10.5
		19	12.1	2.40	0.36	53.4	7.8	67.6	5.8
	♀	22	8.1	1.21	0.14	43.4	4.9	55.2	5.3
		21	10.1	1.65	0.26	46.2	7.6	60.4	8.1
		21	12.0	2.13	0.35	47.5	5.1	62.1	5.8
II	♂	22	12.0	2.26	0.36	56.0	9.0	70.1	9.4
		22	14.0	2.90	0.56	55.6	7.1	66.6	7.4
		22	16.0	3.47	0.59	54.8	6.7	67.6	6.0
	♀	20	11.9	1.89	0.36	45.8	6.2	59.4	7.8
		18	13.9	2.33	0.40	45.3	6.8	58.6	8.5
		17	15.9	2.46	0.41	42.1	6.6	57.7	7.2
III	♂	23	16.0	3.68	0.58	55.5	7.4	68.9	8.1
		21	18.0	3.87	0.63	53.3	7.2	62.3	7.8
		20	20.0	3.98	0.76	51.8	6.9	63.9	8.6
	♀	21	16.1	2.51	0.44	42.3	5.0	56.0	5.8
		18	18.1	2.69	0.54	42.7	5.0	55.1	6.5
		17	20.1	2.64	0.46	40.6	4.8	54.5	6.5

TBM = total body mass; LBM = lean body mass; $\dot{V}_{O_{2\,max}}$ = maximal aerobic power

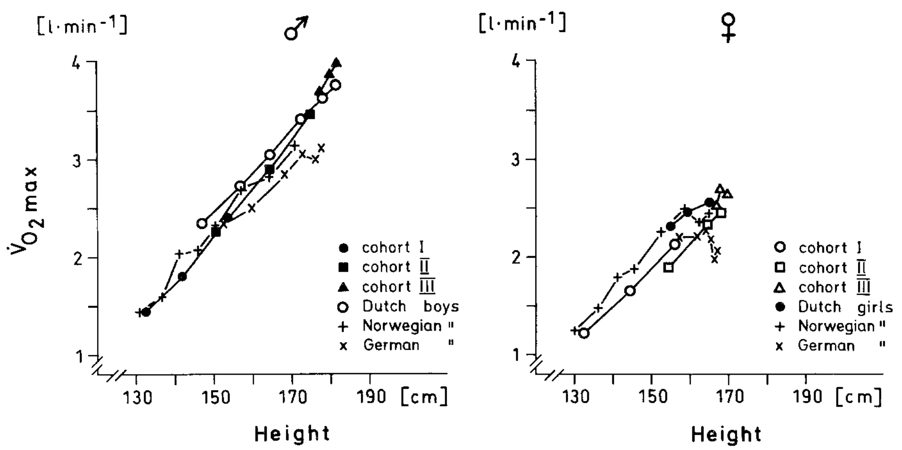

Fig. 3. Mean maximal aerobic power ($\dot{V}_{O_{2max}}$) related to body height; $r=0.878$ for boys and 0.877 for girls in cohorts I, II, III

years. Fitness levels declined for girls from the ages of 14 to 20 years while levels for boys during the pubertal stage of growth (cohort II) were higher than either pre- or post-pubertal stages. This was probably related to the lower body mass during puberty. Fitness levels also declined somewhat for boys during the post-pubertal years.

Discussion

Growth

The change in height from the ages of 8 to 20 years closely followed the pattern previously established for children of various Western European countries (Tanner et al. 1966). Because of this consistency height may well be a useful reference index when comparing and interpreting variations in structural and functional growth for various populations of children.

Some age effects were evident in those boys having a lighter body mass during puberty as compared to the pre- and post-pubertal stages of growth. The Czechoslovakian boys showed higher body mass values than either the Dutch boys involved in a recent multi-longitudinal study (Kemper et al. 1983) or the German and Norwegian boys (Rutenfranz et al. 1981). When body mass was related to height, differences in body composition were also evident; so, apparently, Czechoslovakian boys have higher percentage body fat values than the other populations with whom they were compared. Czechoslovakian girls, however, did not show these age related differences in body mass, as absolute values were quite similar to those reported for the Dutch girls.

Absolute and relative $\dot{V}_{O_{2max}}$

During the pre-pubertal stage of growth (cohort I) increases in absolute $\dot{V}_{O_{2max}}$ values were seen in both sexes with values for boys higher than for girls. When $\dot{V}_{O_{2max}}$ was expressed in terms of body mass, an age related increase was shown for both sexes which is contrary to the previous reports of either unchanged or decreased levels of physical fitness during the pre-pubertal years (Table 2). When mean $\dot{V}_{O_{2max}}$ values were related to mean height and square of height values, a close linear relationship was apparent which was interpreted as evidence of a parallel development of both functional and structural growth related to age (cohort) (Figs. 3, 4). The $\dot{V}_{O_{2max}}$ expressed in terms of body mass may reflect the variations in body composition due to nutritional habits and life style during the pre-pubertal stage of growth.

The $\dot{V}_{O_{2max}}$ continued to increase for both sexes

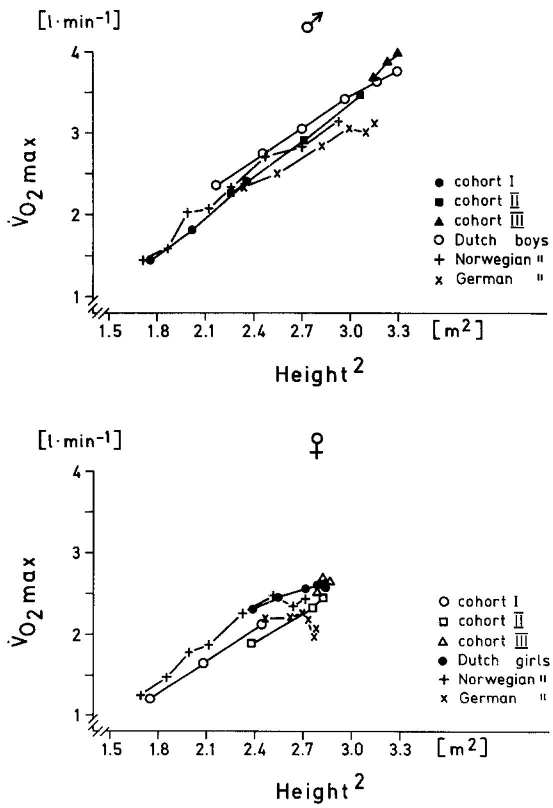

Fig. 4. Mean maximal aerobic power ($\dot{V}_{O_{2max}}$) related to the square of body height ($Height^2$); $r=0.879$ for boys and 0.840 for girls in cohorts I, II, III

Table 3. Comparison of maximal aerobic power of children in different countries during growth from longitudinal or multilongitudinal surveys. Number of subjects in bracket

Sex	Chronological age (years)	Norway 1968–1974 $\dot{V}_{O_{2max}}$ (l·min^{-1}) mean	SD	$\dot{V}_{O_{2max}}$/TBM (ml·min^{-1}·kg^{-1}) mean	SD	West Germany 1974–1978 $\dot{V}_{O_{2max}}$ (l·min^{-1}) mean	SD	$\dot{V}_{O_{2max}}$/TBM (ml·min^{-1}·kg^{-1}) mean	SD	Holland 1976–1980 $\dot{V}_{O_{2max}}$ (l·min^{-1}) mean	SD	$\dot{V}_{O_{2max}}$/TBM (ml·min^{-1}·kg^{-1}) mean	SD	Czechoslovakia 1983–1987 $\dot{V}_{O_{2max}}$ (l·min^{-1}) mean	SD	$\dot{V}_{O_{2max}}$/TBM (ml·min^{-1}·kg^{-1}) mean	SD
♂	8	1.44 (29)	0.19	53	3.9	—		—		—		—		1.45 (21)	0.3	49	9.2
	12	1.89 (12)	0.17	50	7.5	2.33 (28)	0.32	57	7.1	2.35 (26)	0.37	59	5.0	2.26 (22)	0.4	56	9.0
	16	3.12 (13)	0.62	49	7.8	3.00 (23)	0.34	47	3.6	3.62 (76)	0.47	57	5.2	3.68 (23)	0.6	56	7.4
	20	—		—		—		—		—		—		3.98 (20)	0.8	52	6.9
♀	8	1.25 (33)	0.20	47	7.0	—		—		—		—		1.21 (22)	0.14	43	4.9
	12	1.66 (15)	0.24	42	5.8	2.19 (24)	0.30	48	7.4	2.31 (31)	0.36	52	5.6	1.89 (20)	0.36	46	6.2
	16	2.07 (9)	0.15	38	4.2	1.97 (17)	0.31	33	4.9	2.62 (96)	0.37	45	4.4	2.51 (21)	0.44	42	5.0
	20	—		—		—		—		—		—		2.64 (17)	0.46	41	4.8

TBM = total body mass; $\dot{V}_{O_{2max}}$ = maximal aerobic power

during puberty (cohort II) with boys having higher values than girls. When expressed in terms of body mass the rate of increase in $\dot{V}_{O_{2max}}$ decreased in girls after the age of 14, so that relative fitness levels at the age of 16 were, in fact, less than those at the age of 15. Fitness levels for boys did not change and the close linear relationship of $\dot{V}_{O_{2max}}$ to mean body height and square of height remained intact for both sexes throughout puberty.

During the post-pubertal period (cohort III) body mass increased more than height and, again, fitness levels decreased when $\dot{V}_{O_{2max}}$ was expressed in terms of body mass. Even so, the linear relationship between $\dot{V}_{O_{2max}}$ and body height and square of height was still evident (Figs. 3, 4).

When the present multi-longitudinal data on $\dot{V}_{O_{2max}}$ were compared to values (Fig. 1, Table 3) on Dutch children aged 12 to 17 years (Kemper et al. 1983) it was noted that the Dutch values were 5%–10% higher. It should be noted that the Czechoslovakian, German and Norwegian data were gathered from cycle ergometer assessments while the Dutch children were tested on a treadmill which usually yields $\dot{V}_{O_{2max}}$ values approximately 10% higher (Astrand and Rodahl 1986).

The $\dot{V}_{O_{2max}}$·kg body mass^{-1} is the most commonly used index of maximal aerobic power in children as it enables the maximal aerobic power to be compared in individuals of different body mass. However, those changes in $\dot{V}_{O_{2max}}$ caused by growth related changes in both dimensional and functional capacities are not accounted for and, as a result, some new theories have been proposed in recent years. For example, the dimensional theory of Asmussen and Heebøll-Nielsen (1955) and Asmussen (1974) assumed that specific body properties remained constant during physical development. Therefore the parameter of comparative importance, from which other values could then be derived, should be body height. According to Asmussen (1974) and v. Döbeln and Eriksson (1972) the same rationale could be applied to various other physiological functions. For example, various functions of the oxygen transport system have been related to the cube of height (Ht^3) and, therefore, power, which is work/time, should thus be related to the square of height (Bar-Or 1983). Previous longitudinal studies have shown that $\dot{V}_{O_{2max}}$ may be related to a variety of height exponents ranging from 1.5 to 3.2 (Asmussen 1974; v. Döbeln and Eriksson 1972; Bailey et al. 1978). This relatively large variation could well be influenced by the individual variations due to the small sample sizes studied in these previous investigations. In contrast, the present study compared 456 children from four longitudinal studies; three performed by the authors showed that similar results were obtained whether using height, the square of height or height raised to the power of 2.8 to predict $\dot{V}_{O_{2max}}$. Because of the relationship between body height and $\dot{V}_{O_{2max}}$, height can be used as a simple, practical measure to provide reference data on the $\dot{V}_{O_{2max}}$ of a child of smaller size or to provide information on the development of $\dot{V}_{O_{2max}}$ over a longer period. Unfortunately, it is probable that this relationship is of little value after the individual achieves the height of maturity. The correlation coefficients between $\dot{V}_{O_{2max}}$ and both height and the square of height, have nearly the same value.

In an earlier publication Rutenfranz et al. (1982) suggested that the development of maximal aerobic power during the formative years of life was influenced by the growth process for ordinary children living under conditions that are characteristic of modern, relatively affluent Western societies. Under such conditions additional life-style factors seemed to have little or no

Table 4. The rank order correlation coefficients comparing the initial value with the retested values and their ranks in the cohorts. Calculations have been made using the total population of children

Characteristic	1983–85	1983–87	1985–87
$\dot{V}_{O_{2max}}$ ($l \cdot min^{-1}$)	0.890	0.746	0.788

effect and the results of the present study appear to strengthen that original hypothesis.

Rank order correlation

Inter-individual variations ranging from 10% to 20% existed for all age groups (cohorts) at each calendar age. These variations are mainly a result of the natural characteristics of each individual as well as the influence of specific life-style characteristics such as participation in various sports activities and the degree of regular physical activity. The degree to which each subject maintained his or her initial rank order of maximal aerobic power was measured by means of a Spearman rank order correlation coefficient (Table 4). This correlation was approximately 0.8 which proved to be highly significant and, therefore, it can be concluded that the children in this study generally retained their rank order for $\dot{V}_{O_{2max}}$ in a specific age group (cohort) during growth.

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