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Biological and performance variables in relation to age in male and female adolescent athletes

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To observe the cross-sectional nature of the effect of age, height, and body mass on motor performance during adolescence (13-18 years), 103 boy and 65 girl athletes were measured for motor performance and anthropometric variables. Motor performances included tests of strength, muscular endurance, flexibility, aerobic capacity, anaerobic power, speed, and agility. Anthropometric determinations included height, body mass, lean body mass, %fat, and somatotype. Boys were significantly different from girls in all measurements except endomorphy, while girls were significantly superior to boys only in flexibility. Physical maturation, as reflected by height and body mass, was a major contributor to increases in motor performance. Somatotype did not differ greatly across the age groups. Boys were significantly more mesomorphic than girls, while girls were significantly more ectomorphic than boys. Higher %fat and more endomorphy were significantly related to poorer performance for relative aerobic capacity, 40-yd dash, and agility in boys but only for upper body muscular endurance in girls. Mesomorphy had higher relationships with performance variables among boys than among girls. Growth would appear to contribute significantly to enhanced motor performance with age, and its effect may be different in boys than in girls.

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Adolescence is a time of great growth and physical maturation. This increased size should have great impact on fundamental motor performance and athletic skill. It is possible that much of the demand of sports for physical prowess has its foundation in the growth of young athletes.

With the increasing interest in pediatric sport sciences, more research is needed on the changes in physique, somatotype, and body composition in relation to various performance measures during the years of rapid growth. The present study, therefore, was a cross-sectional examination of the changes in height, body mass, somatotype, and percent fat in relation to strength, muscular endurance, flexibility, aerobic capacity, anaerobic power, speed, and agility in young male and female athletes between the ages of 13 and 18 years. The purpose of this study was to examine the changes in these variables during growth and development at adolescence.

Methods

The subjects for this study were healthy boys (n=103) and girls (n=65), ages 13-18 years, who were members of interscholastic athletic teams. Coaches and physicians explained the testing procedures to the athletes and their parents before informed consent to participate was obtained. A medical history was recorded by student physicians on each athlete prior to testing.

Anthropometric dimensions. Upon entering the testing facility, each athlete was measured for 11 anthropometric dimensions. Skinfolds were taken at the triceps, subscapular, midaxillary, suprailiac, abdominal, thigh, and calf sites using a Harpenden caliper. Muscle circumferences were measured with a steel tape around the right flexed upper arm and calf. Bone diameters were recorded across the right distal humerus and femur. All measurements were taken by an experienced anthropometrist whose test-retest reliability had previously been established at $r > 0.90$. Three measurements were taken at each site, and the average used in all calculations. Somatotype was calculated using the Heath-Carter procedure.[1] Body composition was estimated from equations developed on adolescent athletes.[2]

Performance measurements. Performance variables included measurements of strength, muscular endurance, flexibility, maximal oxygen uptake (VO_2max), anaerobic power, speed, and agility. Isometric grip strength was measured using a Stoelting grip dynamometer. After the grip was adjusted to the proper size, each subject was given two attempts with each hand in an alternate fashion. The higher value for each hand was recorded.

Two measurements of muscular endurance were performed. One was the maximum number of repetitions in a free-weight bench press using 50% (female) or 70% (male) of body mass. The subject was instructed to keep a slow, steady rhythm and to avoid bouncing the bar off the chest. The maximum number of complete repetitions to muscular failure was recorded. The other test was the maximum number of bent-knee situps performed in one minute. The subjects placed their arms across their chest with the hands on the opposite shoulders. During each repetition, the subjects were required to touch their thighs with their elbows and to return to touch their upper shoulders on the floor. A partner held their feet securely during the test.

Flexibility was measured using the sit-and-reach test. A specially designed box equipped with a sliding block was used. Each subject was given three trials separated by approximately 30 seconds, and the highest values used. The baseline on the measurement scale which corresponded to the soles of the feet was 22.5 cm.

VO_2max was estimated from the submaximal bicycle ergometer test of Astrand and Ryhming.[3] The ergometer seat was adjusted so that the leg was slightly flexed at the bottom of a pedal revolution. The pedal cadence was set at 50 rpm and maintained by a metronome. Once the subject had acquired the cadence, a workload of 50 W was applied for the first minute. Heart rate recorded at the end of the first minute determined the appropriate workload for the remainder of the six-minute ride. Final heart rates were recorded during the last 15 seconds of the fifth and sixth minutes, and the average used to estimate VO_2max using the Shephard formula.[4] This procedure has been shown to underestimate predicted VO_2max in males by an average of 3.5% and in female VO_2max by 7.5% (unpublished data). A regression procedure was used to correct this discrepancy.

Anaerobic power was determined from the Margaria-Kalamen stair run test.[5] Electronic switchmats were placed on the third and ninth steps of an ordinary staircase (vertical distance = 1.02 m; angle = 30.5 deg). Each subject was given a six-meter approach and ascended the steps three at a time. Five trials were given with approximately one minute rest between each. The average of the three fastest tri-

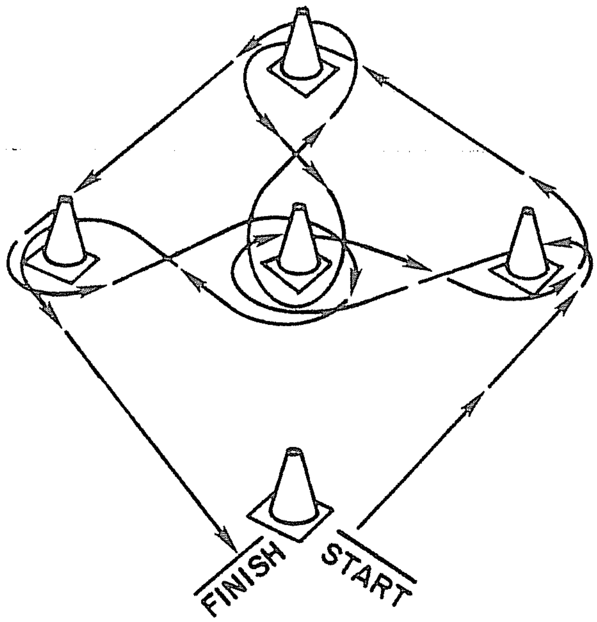

Fig. 1.—Figure-8 agility run pattern.

als was used to estimate anaerobic power using the formula: power (W)=body mass (kg)×1.02 (m)/time (s)×9.8 ms^{-2}.

Speed for a 36.5-m (40-yd) dash was measured using infrared sensors and a digital timer. The subject began in an upright stance and started the timing mechanism with the initial movement forward. The timer was stopped by an infrared sensor. Each subject was given two trials separated by a five-minute rest. The better time was recorded.

Agility was measured using a figure-8, clover-leaf pattern (Fig. 1). The subject began in an upright stance and sprinted to the right circling the first cone (Cone 1). The subject then moved to the center cone (Cone C) and circled it before returning to the first cone. Continuing to cone 2, the subject circled it and proceeded to do a figure-8 loop around the center cone. This procedure was followed until the subject had circled all peripheral cones and made three figure-8 loops around the center cone. The total distance covered was 45.7 meters (50 yds). Prior to testing, each subject walked through the course five times to become familiar with the pattern. Two trials separated by five minutes rest were given to each subject, and the better time used for analysis.

TABLE I.—*Means (±SD) of physique, somatotype, and performance variables in adolescent athletes.*

Variables	Boys (n=103)		Girls (n=65)		%Diff.*	t**
	Mean	SD	Mean	SD		
Age (yrs)	15.6	1.3	14.8	1.5	5.1	3.66
Height (cm)	173.0	9.1	161.8	8.5	6.5	7.97
Weight (kg)	65.7	12.1	51.2	9.4	22.1	8.22
%Fat	12.8	4.5	18.9	3.9	−47.7	9.00
Endomorphy	3.3	1.1	3.6	0.9	−9.0	1.84
Mesomorphy	4.7	1.1	3.0	1.0	36.2	10.10
Ectomorphy	3.0	1.3	3.6	1.1	20.0	3.09
Flexibility (cm)***	34.6	5.2	39.2	5.5	−13.3	5.46
Anaerobic power (W)	1,231.9	262.6	780.1	208.7	36.7	11.72
Right grip (kg)	29.7	7.5	20.2	5.1	32.0	8.98
Left grip (kg)	28.7	8.2	17.2	4.7	40.1	10.28
VO_2max ($l \cdot min^{-1}$)	2.5	0.6	1.8	0.5	30.8	8.96
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	39.9	8.0	35.0	8.0	12.2	3.87
Bench press reps	13.6	8.7	7.3	7.2	46.3	4.88
Sit ups	50.4	7.8	43.6	8.0	13.5	5.45
Agility (s)	18.5	1.0	20.1	1.3	−8.6	8.98
40-yd dash (s)	5.5	0.4	6.2	0.4	−12.7	11.05

*%Diff = (Boys-Girls)/Boys × 100; **t ≥ 2.58 significant at $p<0.01$; ***Baseline (sole of the feet) = 22.5 cm.

TABLE II.—*Correlations between physique, somatotype and performance variables in adolescent athletes.*

Variables	Height		Weight		%Fat		Endomorphy		Mesomorphy		Ectomorphy	
	B*	G**	B	G	B	G	B	G	B	G	B	G
Right grip (kg)	0.73	0.68	0.86	0.83	0.18	0.26	0.28	0.31	0.33	−0.03	−0.35	0.40
Left grip (kg)	0.53	0.49	0.63	0.54	0.08	0.18	0.16	0.25	0.37	0.03	0.25	0.16
Bench reps	0.17	−0.25	0.19	−0.39	−0.03	−0.33	−0.23	−0.27	0.33	0.25	−0.09	0.26
Situps	0.08	0.22	0.15	0.17	−0.21	−0.21	−0.25	−0.16	0.26	−0.02	−0.14	−0.03
Flexibility (cm)	0.17	0.04	0.03	0.09	−0.25	−0.02	−0.21	−0.02	−0.12	0.13	0.13	0.06
$\dot{V}O_2max$ (l/min)	0.57	0.54	0.46	0.56	−0.05	0.25	−0.05	0.26	−0.06	−0.05	0.02	0.24
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	0.05	0.06	−0.29	−0.10	−0.41	−0.07	−0.4	−0.09	−0.43	−0.07	0.44	0.08
Anaerobic power (W)	0.05	0.22	0.11	0.27	−0.04	0.14	−0.03	0.13	0.16	0.09	−0.09	0.16
40-yd dash (s)	−0.47	−0.30	−0.29	−0.25	0.41	0.30	0.30	0.23	0.00	0.03	−0.12	0.02
Agility (s)	−0.32	0.38	−0.08	−0.32	0.37	0.13	0.38	0.05	0.20	0.09	−0.24	0.00

*B = Boys, $r = 0.25$ significant at $p<0.01$; **G = Girls, $r=0.32$ significant at $p<0.01$.

Results

Mean scores (±SD) for the physique and performance variables for both sexes are presented in Table I. Boys were significantly taller, heavier, leaner, and more mesomorphic than girls. In addition, boys had greater anaerobic power, aerobic capacity, strength, muscular endurance, speed, and agility than girls. Girls were significantly superior to boys only in flexibility.

Sex by age analysis of variance revealed that height and body mass increased significantly with age in both sexes. Percent fat decreased with age in boys but generally increased in girls. This increase in relative body fat in girls was associated with poorer performances on the agility and speed items whereas the decreasing percent fat of the boys was associated with a general improvement in performance. Although there was a slight reduction in the endomorphy ratings with age in the boys and a slight increase in the girls, there were no significant differences among the somatotype ratings across age groups in either sex. It should be noted that the sample size in each age group was small and might have had a bearing on these outcomes.

Absolute anaerobic power, as measured by the Margaria-Kalamen test, increased progressively with age in both boys and girls. The increases averaged 34.9% for boys and 32.9% for girls from the 13-year-old to 18-year-old groups. When considered relative to body mass (W/kg), these increases averaged 17.7% for boys and 32.7% for girls. Since both sexes made a comparable 21% increase in body mass across this age span, these results could indicate greater relative anaerobic power development with age in girls than in boys.

Other performance items such as grip strength, bench press repetitions, sit ups, agility, and speed generally increased with age in boys but were more variable across

TABLE III.– *Effect of physical maturation on the relationships between age and physical performance.*

Variables	Correlation between age and performance: Zero-order correlation		Second-order partial correlation holding height and weight constant	
	Boys*	Girls**	Boys	Girls
Right grip strength (kg)	0.63	0.58	0.26	−0.14
Left grip strength (kg)	0.44	0.09	0.22	0.18
Bench press reps	0.46	−0.03	0.44	0.26
Situps	0.21	0.20	0.18	0.10
Flexibility (cm)	0.27	0.00	0.23	−0.04
VO_2max (l/min)	0.37	0.46	0.09	0.10
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	0.05	0.11	0.08	0.11
Anaerobic power (W)	0.00	0.09	0.52	0.12
40-yd dash (sec)	−0.63	−0.35	−0.53	−0.18
Agility (sec)	−0.42	−0.31	−0.34	−0.04

*$r=0.25$ significant at $p<0.01$; **$r=0.32$ significant at $p<0.01$.

the age groups in girls. When expressed in absolute limits, aerobic capacity (l/min) showed an increase with age in both sexes. However, when expressed relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$), these differences disappeared, supporting the view that aerobic capacity in children is more related to size than to age.[6-9]

To examine the relationships of physique, body composition, and somatotype variables with performance, zero-order correlations were computed for both sex groups (Table II). In general, only low or moderate relationships were found between the biological factors and physical performance tests. Height and body mass were moderately related to age in the boys ($r=0.62$ and 0.58, respectively) and in the girls ($r=0.50$ and 0.43, respectively). Further, height and body mass were significantly related to many of the other variables, particularly grip strength, anaerobic power, and aerobic capacity, reflecting the relative importance of physical maturity to performance on these tests (Table II).

Higher percent fat and more endomorphy were associated with poorer performances for VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$), 40-yd dash, and agility among the boys (Table II). Among the girls, however, the magnitudes of the relationships were lower (Table II). Most of the performance variables showed surprisingly low relationships with mesomorphy. Among the boys, mesomorphy was significantly related to strength and muscular endurance but negatively related to VO_2max. Among the girls, none of the correlation coefficients was significant. Ectomorphy was notably related to VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) in the boys and to right grip strength in the girls.

When the variables were examined in relation to age, some parameters appeared to be age related (Table III). When maturation was statistically controlled by partialing out the effect of height and body mass from the various age versus performance relationships, a slightly different conclusion could be reached (Table III). Age was then significantly related to five of the 10 performance measures in the boys but to none in the girls (Table III). The biggest differences in performance were noticed in the 13-year-olds, especially the boys, who had significantly lower anaerobic power, aerobic capacities, grip strengths, muscular endurance, agility, and speed than the other age groups. This suggested that many of the boys in this group may not have started the adolescent spurt in their growth and development.

Discussion

Malina [10] has suggested that growth and maturation are maintained by the interaction of genes, hormones, nutrients, and environment. Certainly at adolescence a major cause of the differences in physique and performance across age can be explained by the influence of changes in the levels of hormones, particularly an increase in the steroid hormones testosterone and estrogen. However, some of these differences such as height, though sex dependent, are relatively independent of sex hormones. Indeed the steroids together with growth hormone and somatomedins may have a strong modulating influence on growth velocity.[11]

A review of the literature on growth and development at adolescence generally indicates that boys develop a larger muscle mass, larger hearts, and consequently a greater stroke volume. They experience an increase in red blood cells and hemoglobin and greater development of lung capacity, pulmonary ventilation, and oxygen uptake with age than girls.[11-14] These structural and physiological changes result in greater increases in speed, strength, power, and physical work capacity with age in boys. However, the increase in muscle bulk of boys, though it improves strength and speed, may also explain, in part, why they are less flexible than girls at all ages between 13 and 18 years.

Inbar and Bar-Or [15] suggest that age differences in anaerobic performance cannot be explained by differences in body size or lean body mass alone. Biochemical data indicate that the differences between children and adults lie in the glycolytic pathway.[15] The concentration and anaerobic utilization of muscle glycogen are much lower in children than adults.[16] Further research on muscle metabolism in young athletes might clarify these questions.

The aerobic capacity in relation to body mass of the boys in the present study was relatively constant (38-41 $ml \cdot kg^{-1} \cdot min^{-1}$) between the ages of 13 to 18 years, whereas in the girls it was more variable (33-38 $ml \cdot kg^{-1} \cdot min^{-1}$). VO_2max in relation to age and body mass in girls may even decline due to the increase in body fat and lesser development of their leg muscles at puberty. Sociocultural factors cannot be discounted in the lack of aerobic development in girls;[17-19] however, that would not be expected to be a factor in athletes. The influence of heredity may also be important in the development of maximal aerobic power. In his review of twin studies, Bouchard [20] suggested that genetic factors accounted for 90% of the variability in VO_2max. More recent studies, however, have suggested that this estimate should be set much lower.[21] Cunningham *et al.*[21] intimated that the development of such factors in relation to growth and physical activity might be fortuitous in which both body size and function may be independent factors related to a common control-genetic endowment. Though both size and function appear largely independent during growth, size ultimately predicts the absolute capacity of the cardiorespiratory system.[22]

In addition to those factors suggested by Malina,[10] increased physical activity is another factor that affects growth and maturation, and significant changes occur both in anaerobic power and aerobic capacity during growth under the influence of training.[23] Thus there is a need for a more detailed examination of hormone responses to regular exercise especially in relation to those hormones which influence growth at adolescence. A longitudinal investigation of the interaction between growth and hormone responses to exercise would do much to add to our knowledge of the effect of physical activity.

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