Physical activity and training: effects on stature and the adolescent growth spurt

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ABSTRACT

MALINA, R. M. Physical activity and training: effects on stature and the adolescent growth spurt. *Med. Sci. Sports Exerc.* Vol. 26, No. 6, pp. 759–766, 1994. Statural growth (size attained), age at peak height velocity (PHV), and growth rate were compared in two samples of boys classified as habitually physically active and inactive, and in two samples of boys regularly training in sport (primarily team sports). Individual growth records were fitted mathematically in three of the samples (two as reported by the respective authors and one for the present report), while curves were fit to group means for the fourth sample. There were no differences in size, age at PHV, and PHV between active and inactive boys, but the parameters of the adolescent spurt for boys regularly involved in sport were characteristic of early maturers. Longitudinal data are less extensive for girls. Stature data for three samples of young athletes in gymnastics, swimming, and track/rowing indicated a stable pattern relative to reference data for nonathletes, i.e., swimmers, track athletes, and rowers were already taller and gymnasts already shorter than average during childhood and maintained their position relative to reference data during childhood and adolescence. Allowing for sample size and variation in descriptions of habitual physical activity and training for sport, the data suggest that regular physical activity, sport participation, and training for sport have no effect on attained stature, timing of PHV, and rate of growth in stature. Prospective data for the swimmers, track athletes, and rowers indicate no effect of training on the timing of menarche.

MATURATION, YOUTH SPORTS, PEAK HEIGHT VELOCITY, GROWTH RATE, MENARCHE

The literature dealing with the effects of regular physical activity and/or training on growth, though limited, has a relatively long history. The terms activity and training are often used interchangably, and programs are variably described and quantified. Two early experimental studies (8,47) suggest a stimulatory influence of regular training on statural growth of adolescent males. In the study of boys 13–17 yr (47), the programs involved daily after school "intensive physical exercise" for about 5 months, while in the study of naval cadets 16–22 yr (8), the program involved 45 min of daily (5 d) systematic gymnastics (light calisthenics to heavy apparatus work) for about 6 months. The observations of these two studies are limited, however, due to lack of consideration of interindividual variation in biological maturity status and subject selection. Early studies also indicate significant weight gain in association with regular activity in adolescent males (8,21). The weight gain likely reflects continued growth of fat-free mass into late adolescence and young adulthood and potential effects of activity on fat-free mass. Note that marginal nutritional status was an issue in some early studies, e.g., "substandard" recruits 16–21 yr of age (21), and regular, perhaps improved, diets accompanied training programs. Increase in fat-free mass with regular training is, however, not consistent across more recent studies of late adolescents and young adults (12).

Concern for potential negative influences of regular training, specifically competitive sport, on growth was also expressed. Rowe (46), for example, noted that participants in an interscholastic touch football program, though taller, gained less in stature over 2 yr, about 14–16 yr, than nonparticipants, with the implication that participation in sport during the period of rapid growth may have a negative influence on growth rate in stature. Some have accepted this observation at face value and concluded that training for athletic competition may slow down growth in stature (23,39,45). A critical observation in Rowe (46, p. 115) was overlooked, i.e., variation in maturity status: ". . . since the athletic group is composed of boys who have matured earlier, age considered, than the group of nonathletic boys, the athletic boy is not going to grow as much as the nonathletic boy over the period studied."

More recently, girls have replaced boys in concerns about effects of athletic training during childhood and youth. The focus is more on maturation than on growth, and specifically on later, retrospectively reported mean ages at menarche among athletes. Means ages at menarche for athletes in a variety of sports range from 13.0 to about 15.5 yr of age (5,24,31). Regular swim, track and ballet training before menarche is suggested as the causative agent in the lateness in these athletes (13,15). Men-

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arche is a late maturational event that occurs, on average, a year or so after peak height velocity, and the same hormones are involved in the regulation of the growth spurt and sexual maturation (31).

There is thus concern about the potential influence of intensive training on both growth, i.e., size attained, and maturation, i.e., timing and tempo of progress toward the mature state. This paper compares statural growth (size attained), age at peak height velocity (PHV, an indicator of somatic maturation), and growth velocity of boys classified as habitually physically active and inactive, and of boys and girls regularly training in sport. The data are drawn from the literature. Some of the published data are reanalyzed with curve fitting techniques, while other data from several sources are integrated.

MATERIALS AND METHODS

Longitudinal data are necessary to address the question under study, and the available data that span childhood and adolescence are limited to boys. Data from the Saskatchewan Growth and Development Study (36,37), the Leuven Growth Study of Belgian Boys (6,7), the Wroclaw (Poland) Growth Study (30), and the Prague (Czech Republic) Study (38–40,49,50) are used. The authors' designation of activity or training status of the boys is subsequently described.

The Canadian and Belgian studies compared boys classified as active and nonactive. The former followed 14 active and 11 inactive boys from 10–16 yr, while the latter compared 32 active and 32 nonactive boys from 12–18 yr. In the Canadian study, boys were classified as active or inactive on the basis of activity questionnaires, teacher assessment of activity level, and a sport participation inventory. The boys were classified as active or inactive in four of five evaluations between 11 and 15 yr and at follow-up 2 yr after the study was completed (36,37). In the Belgian study, active boys participated in sport activities for > 5 $h \cdot wk^{-1}$ during the first 3 yr of the longitudinal study (about 12–15 yr, which includes the interval of the adolescent spurt) in addition to compulsory physical education, while inactive boys participated $\leq$ 1.5 $h \cdot wk^{-1}$ of sport activity outside of compulsory school physical education over the same time interval. Compulsory school physical education varied between 1–3 $h \cdot wk^{-1}$ (6).

The Wroclaw and Prague studies compared boys who were actively involved in sport training. In the Wroclaw study, the growth of 13 boys who were active in sport during childhood, adolescence, and young adulthood was followed from 8–18 yr of age (30). The boys active in sport were compared with reference data from the Wroclaw Longitudinal Study. The Prague study followed three groups of boys with different sport/physical activity programs from 10–17 yr. Activity levels and numbers in the three groups are variably defined. Parizkova (39) describes the activity levels as follows: 8 active boys trained regularly 6 $h \cdot wk^{-1}$ in sport activity, 18 moderately active boys averaged 4 $h \cdot wk^{-1}$ in organized sport activity, and 13 boys had limited, unsystematic sport activity, < 2.5 $h \cdot wk^{-1}$, including physical education. Sprynarova (49) characterizes the activity levels as follows: 8 active in basketball ($N = 6$) and athletics ($N = 2$) 4 $h \cdot wk^{-1}$ from 11–15 yr and 6 $h \cdot wk^{-1}$ from 15–18 yr, 19 active in sport but not on a regular basis with average activity of 2 $h \cdot wk^{-1}$ from 11–15 yr and 3 $h \cdot wk^{-1}$ from 15–18 yr, and 12 untrained with an average of 1 $h \cdot wk^{-1}$ from 11–15 and no training thereafter. Boys markedly advanced or late in somatic development were eliminated in sample selection (39). The statures and weights of the three samples of Prague boys (38) were compared with Czech reference data for the time period (44).

The Canadian and Belgian studies thus focus on active and inactive boys, while the Wroclaw and Prague studies compare boys active in sport. The latter is important because boys who are successful in sport from relatively young ages tend to be advanced in biological maturation (25).

Each study provides data on size attained in stature and weight at each age. Curve fitting procedures were used to estimate two significant parameters of the adolescent growth spurt, age at PHV and PHV ($cm \cdot yr^{-1}$). The procedures involve the fitting of a specific mathematical model to longitudinal growth records of individual children in order to derive the parameters. The Preece-Baines model I (18,33) was used in three of the four analyses. The parameters of the adolescent spurt in the Canadian study were previously reported (36). The Preece-Baines model was also applied to the individual data of boys in the Wroclaw study, for whom graphic estimates were previously reported (30), and to the mean statures of Prague boys (38) and Czech reference data (44). The original estimates of age at PHV and PHV in the Prague study were based on graphic interpolation (50). The Preece-Baines model has been previously applied to mean values in order to compare populations (51). Nonsmoothed polynomials were used to estimate parameters of the spurt in the Belgian study (6,7).

Longitudinal data for habitually active girls and/or female athletes that span childhood and adolescence are not available. Available data for girls active in sport include retrospective longitudinal data for stature of Dutch gymnasts and swimmers (41,42), and Swedish swimmers (1), and prospective data for Polish girls enrolled in sports schools (33). The Dutch data include three groups of gymnasts, 19 recreational, 32 regionally select and 9 nationally select, and 11 club swimmers. The four groups began training, on average, between 5.3 and 6.0 yr of age. The nationally select gymnasts and swimmers trained, on average, 6.7 and 6.0 $h \cdot wk^{-1}$, respectively, while the recreational and regional gymnasts trained, on average, 4.6 and 4.1 $h \cdot wk^{-1}$, respectively (41). Stature growth histories were obtained from physician records which were combined with current measurements (taken between 10–15 yr of age) to provide a record of stature from 1–11 yr (42).

The Swedish data (1) include 30 swimmers whose stature at about 7 yr was obtained from school records and was measured between 12.3–16.4 yr of age (mean and SD, 14.3 ± 1.3 yr). The training time of the swimmers ranged from 3–7 d·wk^{-1} and 6–28 h·wk^{-1}, while volume ranged from 6,000–65,000 m·wk^{-1}. The Polish data (33) include 30 girls measured annually from 11–14 yr. They trained 8–12 h·wk^{-1} in rowing and track.

The data for the three series of young female athletes were expressed as standard deviation scores (z-scores) relative to local reference data. Stature data for three cross-sectional samples were used to complement the longitudinal series: age group swimmers (Malina, unpublished), Olympic swimmers from the Mexico City, Munich, and Montreal Games (32,34), and elite gymnasts participating at the 24th World Championship Artistic Gymnastics in 1987 (10). Mean statures for the three samples were converted to standard deviation scores relative to U.S. reference data (14).

The Dutch data for gymnasts and swimmers are limited to premenarcheal girls. Prospectively recorded ages at menarche are available for the Swedish swimmers and Polish sport school participants. All but one girl in the two samples (Swedish swimmer, 12.3 yr of age) attained menarche.

RESULTS

Active and inactive Canadian and Belgian boys do not differ in stature (Fig. 1), ages at PHV and PHV (Table 1), but inactive Canadian boys tend to be slightly heavier throughout and especially during adolescence (significance of the differences was not reported). Polish (Fig. 2) and Czech (Fig. 3) boys involved in sport are consistently taller than reference data and boys less involved in sport, and attain PHV at an earlier age (Table 1). Weights of the two less active Prague samples are more variable.

TABLE 1. Ages at peak height velocity (PHV) and peak height velocities in boys grouped by level of physical activity.

		Age at PHV (yr)		PHV (cm·yr^{-1})	
	N	Mean	SD	Mean	SD
Canadian (36,37)					
Active	14	14.26	1.17	8.7	1.1
Inactive	11	14.14	0.73	9.9	1.4
Belgian (6)					
Active	32	14.17	0.83	9.4	1.5
Inactive	32	14.05	0.81	8.9	2.1
Polish					
Active in sport (30)*	13	13.66	0.89	9.5	1.0
Reference sample (19)	191	14.07	1.07		
Czech (50)					
Active in sport	8	14.15 (13.21)†	0.91	10.1 (7.9)†	1.2
Moderately active	19	14.50 (13.89)†	0.96	9.7 (7.6)†	1.5
Limited activity	12	14.63 (13.87)†	1.20	9.8 (7.5)†	1.5
Reference data (44)		(13.82)†			

* The Preece-Baines model I (18,43) was applied to individual records of the boys described in Malina and Bielicki (30). The original estimates were based on graphic procedures.

† Estimates in parentheses are based on the Preece-Baines model I applied to mean statures reported in Parizkova (38) and Prokopec et al. (44).

Female gymnasts are shorter, while swimmers, track athletes and rowers are taller than reference data from early childhood (Fig. 4). The most select gymnasts are shortest. Stature differences between girls active in sport and the reference data are consistent from childhood through adolescence. Estimated velocities of statural growth in the active Polish girls decline from 11–14 yr (Fig. 5). This suggests somewhat earlier somatic maturation, which is consistent with their age at menarche, 12.5 ± 1.0 yr (range 9.9–14.2 yr) compared with refer-

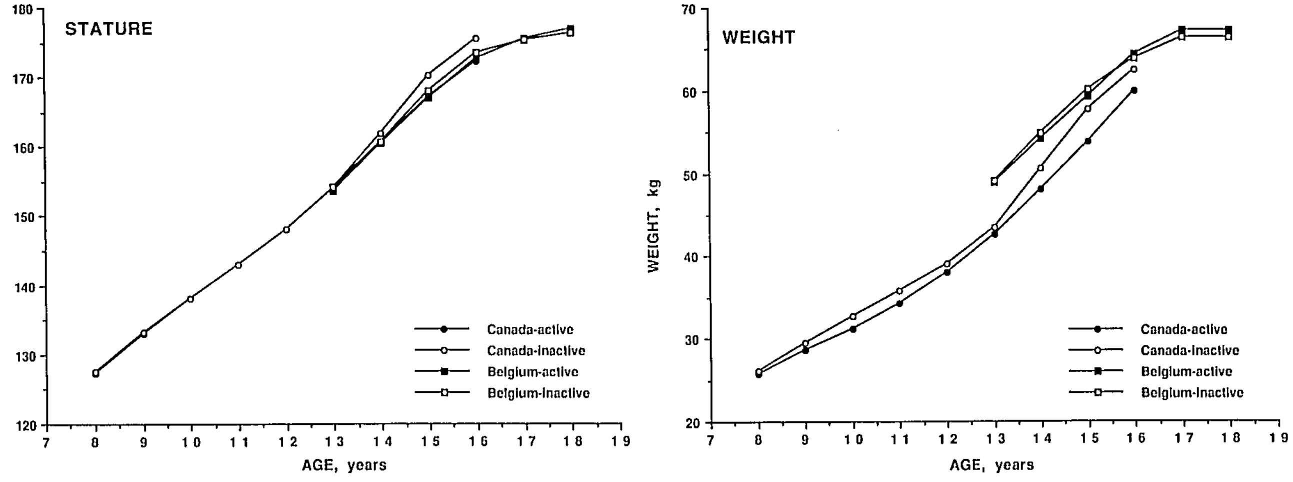

Figure 1—Statures (*left*) and weights (*right*) of active and inactive Canadian and Belgian boys. The Canadian data are from Mirwald and Bailey (36), and the Belgian data are from Beunen et al. (6).

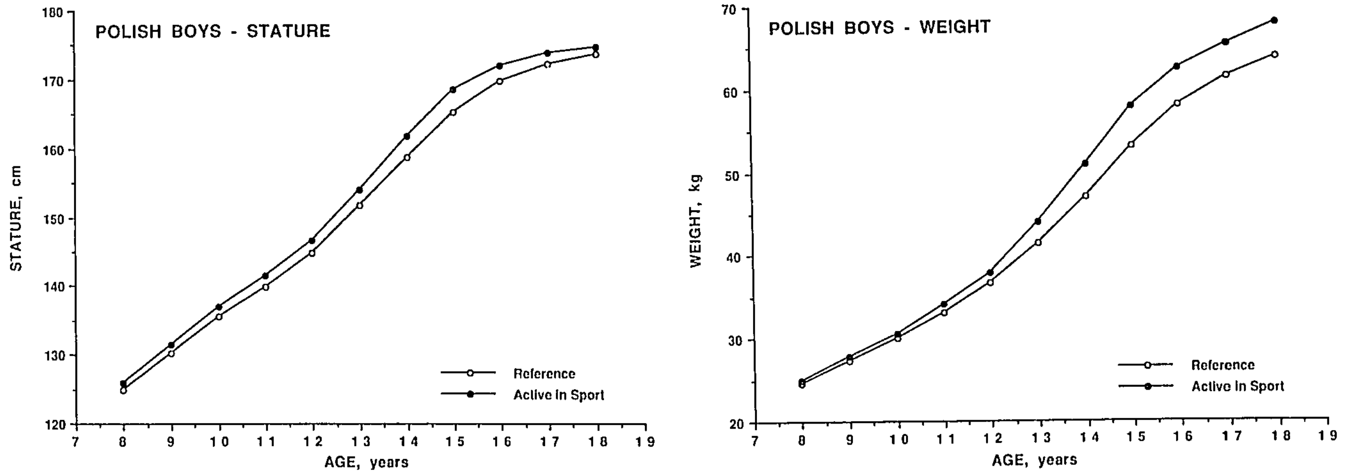

Figure 2—Statures (*left*) and weights (*right*) of Polish boys active in sport and Polish reference data. The data are from Malina and Bielicki (30).

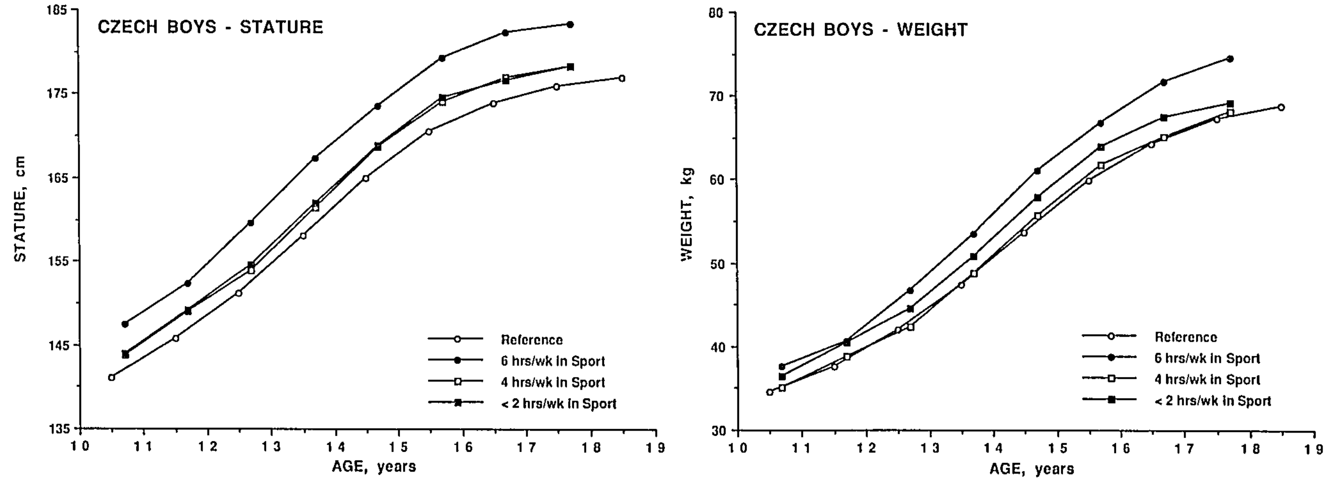

Figure 3—Statures (*left*) and weights (*right*) of Czechoslovak boys with different sport activity levels and Czechoslovak reference data. The data for boys with different activity levels are from Parizkova (38) and the reference data are from Prokopec et al. (44).

ence data for Warsaw, 12.7 ± 1.1 yr. Age at menarche in the Swedish swimmers is 12.9 ± 1.1 yr (range 11.0–14.9 yr).

DISCUSSION

The data suggest that regular physical activity, sport participation, and training for sport have no effect on attained stature, the timing of PHV, and rate of growth in stature. Active and inactive Canadian and Belgian boys do not differ in these indicators of growth and maturity status. Skeletal age data for the Belgian boys are consistent with these observations (6). The growth pattern of Polish and Czech boys regularly involved in sport is that characteristic of early maturers (31), which is also apparent in earlier ages at PHV (Table 1) and advanced skeletal ages in the most active Prague boys between 13–16 yr (39). The data for Polish and Czech boys are consistent with available information on the growth and maturity status of young male athletes in a variety of sports (25,31). The difference between the three samples of Prague boys and the reference data may also reflect the select status of urban children in the Eastern European sociopolitical system of the 1960s, i.e., better access to health care and nutrition (9).

The Polish and Czech boys were active primarily in team sports. Data for other sports are limited. Two short-term longitudinal studies (12 and 22 months) of boys 12–14 yr (11) and 9–15 yr (48) actively training in distance running indicate that size attained and rate of growth in stature are not affected by endurance training. Short-term longitudinal data (12–15 yr) for Moravian boys in Brno who were actively training in cycling, rowing, and ice hockey indicate no effect on growth in stature and skeletal maturation (22). The three groups varied in maturity status, with the cyclists and rowers having advanced skeletal ages and the ice hockey players having slightly delayed skeletal ages relative to chronological

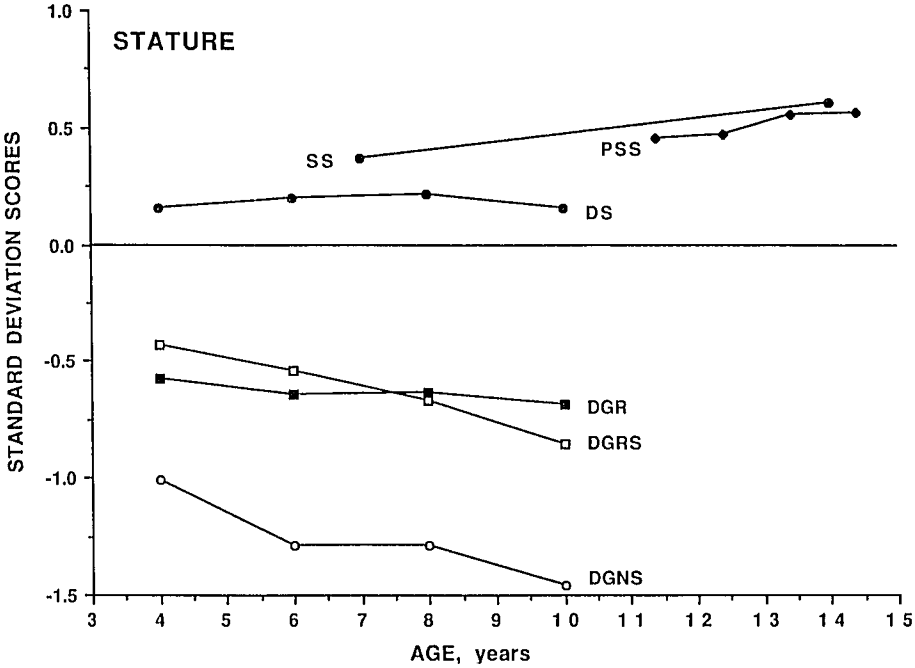

Figure 4—Standard deviation scores (z-scores) for statures of longitudinal samples of young female athletes: DS = Dutch swimmers, DGR = Dutch gymnasts recreational, DGRS = Dutch gymnasts regional selection, DGNS = Dutch gymnasts national selection (42); SS = Swedish swimmers (1); PSS = Polish sport school participants (33).

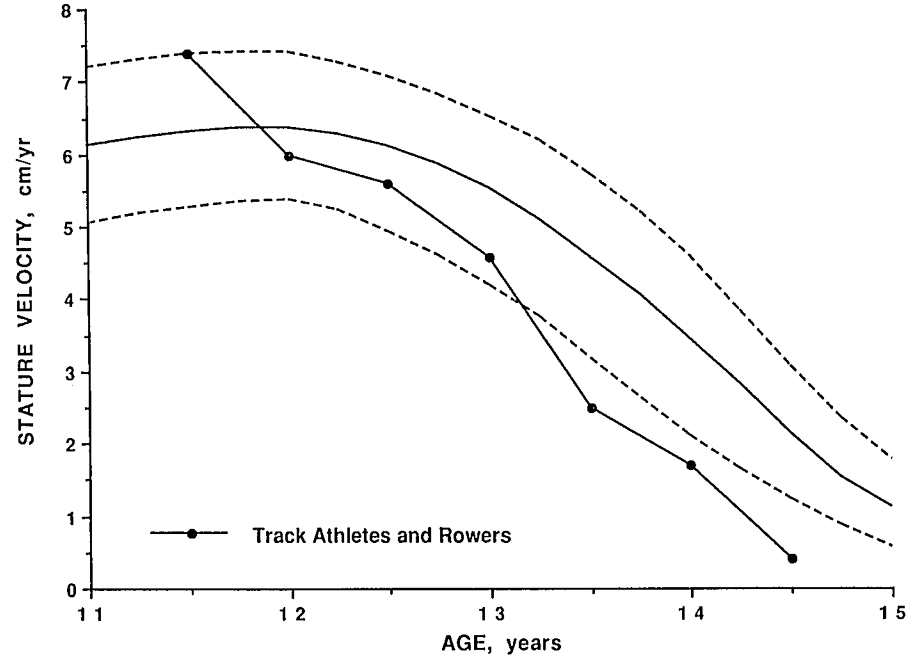

Figure 5—Velocities of statural growth in Polish female track athletes and rowers enrolled in sports schools compared with British reference data. The data are from Malina et al. (33).

age. The skeletal maturity status of each group persisted over 3 yr of training from 12–15 yr so that it may be inferred that the training for sport did not influence the progress of skeletal maturation. Similar longitudinal observations from 11–14 yr of Polish boys training 8–12 h·wk^{-1} in sport schools for track, basketball, and wrestling indicate a pattern of advanced somatic (velocity of statural growth) and sexual maturation (genital and pubic hair development) (33).

The data for boys thus suggest no effect of regular physical activity or sport training on growth and maturation. This is especially apparent when allowance is made for selection, either self or otherwise. Boys regularly active and successful in many sports tend to be advanced in biological maturation, which accounts for their larger body size and more rapid rate of growth during childhood and adolescence. In later adolescence, there is some catch-up of later maturing boys so that stature differences are reduced.

Statures of female gymnasts, swimmers, rowers, and track athletes followed longitudinally through childhood and early adolescence indicate a stable pattern relative to

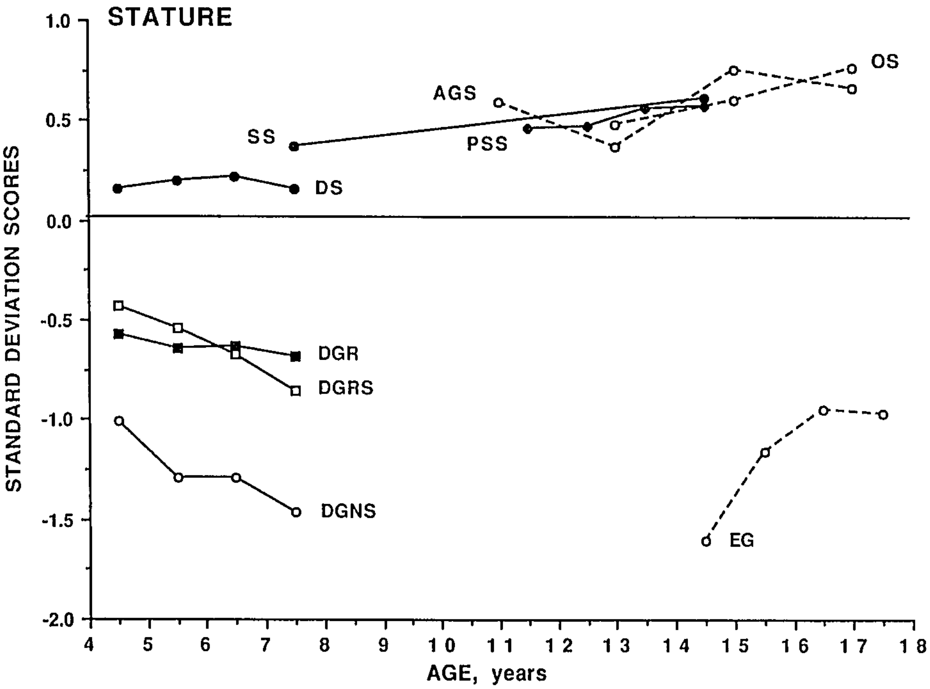

Figure 6—Standard deviation scores (z-scores) for statures of longitudinal samples of female athletes (*solid lines*, from Fig. 4) and cross-sectional (*dashed lines*) samples of female athletes: AGS = age group swimmers (Malina, unpublished); OS = Olympic swimmers (34); EG = elite gymnasts (10).

reference data for nonathlete girls (Fig. 4). The trends suggest no effect of regular training for these sports on statural growth, i.e., swimmers are already taller and gymnasts already shorter than average during childhood and maintain their position relative to reference data during childhood and adolescence.

The data for female gymnasts and swimmers are consistent with cross-sectional observations. Gymnasts tend to be later in sexual and skeletal maturation (3,10,32), while successful young swimmers tend to be average or slightly advanced in sexual and skeletal maturation (25,32). Their statural growth is consistent with the maturational differences between athletes in the two sports.

Given the relatively small samples in the longitudinal series, mean statures expressed as z-scores for cross-sectional samples of age group swimmers, Olympic swimmers and world class gymnasts are superimposed on the longitudinal data in Figure 6. The data indicate similar trends. Z-scores for late adolescent gymnasts likely reflect prolonged period of adolescent growth associated with later maturation.

Longitudinal observations on Polish track athletes and rowers are consistent with those on swimmers, although skeletal maturation of a cross-sectional sample of elite adolescent track athletes 15–18 yr of age indicate a pattern of later skeletal maturation relative to chronological age (29).

Longitudinal observations on young female athletes in other sports are extremely limited. Short-term (12 months) data for elite distance runners 9–15 yr (48) and junior Olympic divers 9–18 yr (35) indicate no effect on stature and rate of growth in stature.

The data for gymnasts must also be considered in the context of the extremely selective criteria applied to this sport, including selection for physical characteristics commonly associated with later maturation (2,17). Diet is a potentially confounding factor, as indicated in a recent study of young gymnasts from the former German Democratic Republic (East Germany). The gymnasts were on a dietary regime "... intended to maintain the optimal body weight, i.e., a slightly negative energy balance, and thus (had) a limited energy depot over a long period" (20, p. 98). Similar dietary restrictions are apparent among ballet dancers who are selected for thinness and who are characterized by later menarche (15,16,52). Ages at menarche in ballet dancers, however, are not as late as reported for gymnasts (5,10,24).

Data on age at menarche in athletes are largely derived from late adolescents and adults. The inferred relationship between training and sexual maturation is thus retrospective and associational, and other factors related to later menarche are not considered (24,26). Status quo estimates of ages at menarche based on probit analysis in active girls and elite young athletes are quite limited. Median ages at menarche based on probit analysis for age group swimmers from elite programs (27), junior Olympic divers (35), and world class gymnasts (10) are 13.1, 13.6, and 15.6 yr, respectively. The estimate for swimmers matches closely that for elite Swedish swimmers from the 1950s. Note that the sample of world class gymnasts does not include girls < 13 yr of age so that the probit estimate may be somewhat biased toward an older age. Their size (Fig. 6) and menarche are consistent with later maturation and extreme selectivity associated with gymnastics at the elite level.

Longitudinal data on the growth and maturation of children and youth regularly training for several sports or characterized by high levels of habitual physical activity are derived largely from European programs, with the exception of the sample of Canadian boys. Nevertheless, ages at PHV and PHVs in longitudinal samples of United States, Canadian, and European boys and girls are not markedly different, especially when allowance is made for the different curve fitting models used to derive parameters of the adolescent growth spurt. The uniformity of results is more striking given the period of time over which the longitudinal studies were made. The major United States studies (Berkeley, Denver, Fels, Harvard) were begun in the late 1920s. Many of the European studies were begun in the mid-1950s, while others were done in the 1960s and 1970s (4,28). Hence, generalizations should apply to samples of well-nourished children in North America and Europe.

The data are also limited, to some extent, by relatively small numbers. Relatively small samples are, with few exceptions, generally a feature of longitudinal growth studies. For example, in 54 longitudinal analyses of the adolescent spurt, only 13 have sample sizes > 100, while other samples range from 22–94 (4,28). It is no wonder, therefore, that longitudinal samples of elite young athletes and habitually active children and youth are likewise small.

Variation in description and quantification of training and/or habitual physical activity is an additional concern in generalizing results of the comparisons presented. Nevertheless, a broad spectrum of training/activity levels is represented, and differences in stature and age at PHV associated with the various modes and intensities of training are relatively small. The samples of active and nonactive Belgian boys do not differ from Belgian reference data (6), while the longitudinal data for athletes in several sports are consistent with cross-sectional analyses of size attained by athletes in the same and other sports.

Thus, allowing for population variability, sample size, and variation in descriptions of habitual physical activity and training for sport, the data suggest that regular physical activity, sport participation, and training for sport has no effect on attained stature, timing of PHV, and rate of growth in stature. Longitudinal data on the sexual maturation of boys and girls regularly active or training for sport are not extensive. There is a need for prospective longitudinal studies following youngsters training for different sports from the prepubertal years through puberty. Such studies should include a variety of somatic and maturity characteristics together with specific information on activity/training levels, nutrition, and hormonal secretions.

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