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Physical Growth and Biological Maturation of Young Athletes

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The number of youth competing in a variety of sports at national and international levels is increasing, e.g., diving, gymnastics, swimming, and figure skating. Females appear among the elite at young ages more often than males. Significant numbers of children and youth of both sexes also begin to specialize in a sport at relatively young ages, and the process of identifying and selecting talented individuals for a given sport often begins in childhood.

The success of youth in some sports and the selection of talented individuals at young ages are not without problems. There is concern about potential negative influences of intensive training and the demands of high-performance sports on the growth and maturation of young athletes. Indeed, the treatment and some of the techniques of training young athletes for high-performance sports may fall within the bounds of child abuse. Microscopic analysis and evaluation of sport in the media contributes additional stresses. In a related matter, changes in the political systems of Eastern Europe and reevaluation of the role of sports in national agenda have placed these elaborate sport systems in jeopardy. Many of these systems had talent identification programs for young athletes, and the practices developed in some Eastern European countries, especially the former German Democratic Republic and Soviet Union, have influenced those currently used in many parts of the world. Indeed, a significant amount of data on the growth and maturation of young athletes comes from Eastern Europe.

The purpose of this review is to evaluate the growth and maturation status of young athletes. Available data are collated by sport in an attempt to describe the growth and maturity status of youngsters actively engaged in specific sports. Studies that combine athletes participating in different sports are not included. The closing section briefly addresses the effects of intensive training for sport on growth and maturation in the context of the data presented. Previous reviews have focused more on maturation [16, 111, 112] and to a lesser extent on growth [124], although both are related.

METHODOLOGICAL NOTES AND LIMITATIONS

ATHLETES. The definition of a sample as athletes was accepted as reported. Most studies include youngsters who can be classified as select, elite, junior national, or national caliber.

GROWTH. Growth refers to increase in the size of the body or its parts. It includes changes in size, body composition, physique, and specific body systems. This review is limited to two indicators of size, stature and body weight. When sufficient data are available, the size attained (growth status) by athletes from Europe and the Americas is plotted by sport relative to reference data for a nationally representative sample of U.S. youth [75]. Smoothed 10th (*P 10*), 25th (*P 25*), 50th (*P 50*, median), 75th (*P 75*), and 90th (*P 90*) percentiles are used for comparison, although only P 10, P 50, and P 90 are shown in the figures. When data are not extensive across the age span, the size of the athletes is simply described relative to the reference data. Limited data for young athletes from Japan and China are described relative to Japanese reference means [138].

The physique and body composition of young athletes is not considered. Physique is a selective factor in some sports, and young athletes in a given sport tend to have physiques similar to those of adult athletes in the sport [32, 34, 153]. Body composition is most often viewed in the context of the two-compartment model, fat-free mass and fat mass, and relative fatness is often the focus in many studies of athletes. Males, athletes and nonathletes, show a decline in relative fatness during adolescence, but athletes have less fatness. Relative fatness does not increase as much with age during adolescence in female athletes as it does in nonathletes. Thus, difference between female athletes and nonathletes is greater than the corresponding trend in males [119].

MATURATION. Biological maturation refers to the tempo and timing of progress toward the mature state. Skeletal (skeletal age), sexual (secondary sex characteristics), and somatic (age at peak height velocity) maturation are often used.

The hand-wrist is used to assess skeletal maturation, and the two more commonly used procedures are the Greulich-Pyle (GP, [73]) and Tanner-Whitehouse (TW, [185]) methods. The methods differ in criteria and scoring and in the reference samples upon which they are based [117, 119]. The upper limit (i.e., skeletal maturity) of the GP method is 18 years in both sexes; limits of the TW method are 16 years for girls and 18 years for boys. A youngster who reaches the upper limit is simply labeled as mature or adult, and should not be included in the calculation of mean skeletal age (SA) for a group. Both methods yield an SA that corresponds to the level of skeletal maturity attained by a child relative to the reference sample; SAs derived from each method are not equivalent.

SA is expressed relative to the child's chronological age (CA), and children are often classified as having an SA that is *advanced, average,* or *delayed.* The criteria that define the categories in this review are (*a*) *advanced*—SA is one year or more ahead of CA (early maturer); (*b*) *average*—SA is within plus or minus one year of CA (average maturer); (*c*) *delayed*—SA is one year or more behind CA (late maturer). The terms are descriptive labels and indicate nothing about factors underlying earliness or lateness.

Secondary sex characteristics include the breasts, pubic hair, and menarche in girls and the genitals and pubic hair in boys. Breast, genital, and pubic hair development are most often assessed relative to five stages or grades for each character [119]. The ratings are often used to characterize the maturity status of a sample and to group athletes by maturity status independent of CA. This presents problems because chronologically older children tend to be taller and heavier than younger children of the same stage of pubertal development [117].

Age at menarche, the first menstrual period, occurs, on average, about 13.0 years of age in samples of American and European girls [119]. Most data for athletes are based on the retrospective method, which requires that the individual recalls the age at which she experienced her first menstrual period. The retrospective method is severely limited when used with young athletes. Estimated mean ages are biased, since all subjects have not attained menarche. Allowing for error of recall, the retrospective method is useful with athletes after 17 years of age, when almost all girls have attained menarche.

In studies of young athletes, the prospective method is ideal; it requires longitudinal study in which athletes are examined at close intervals during puberty. The status quo method is a useful cross-sectional alternative with young athletes. It yields an estimate of the median age at menarche for the sample and can also be used with other secondary sex characteristics [117, 119]. Prospective and status quo data for menarche in young athletes are very limited, and only these are included in the main section of the review. A brief discussion of retrospective estimates is offered later in the review.

Peak height velocity (PHV) refers to the maximum rate of growth in stature during the adolescent spurt, and the age when PHV occurs is an indicator of somatic maturity. Longitudinal data are necessary to estimate PHV, but methods of estimation vary. PHV occurs, on average, at about 12 years in girls and 14 years in boys [17, 116, 119].

CHRONOLOGICAL AGE. Growth and maturation data are expressed relative to CA, the child's age as determined by the calendar. CA is usually reported to the nearest 0.1 year. Some reports simply refer to a whole year (e.g., 11 years of age). It is assumed that the authors refer to age at last birthday (i.e., the child is not yet 12 years). In plotting such data, 0.5 year was added to the reported age (i.e., 11.5 years). Some studies group children across several years (e.g., 11–13 years) and do not indicate the mean CA of the group. It is assumed that these ages refer to age at last birthday, and the midpoint of the range was used in plotting data. The upper age limit in this review is 18 years; the lower limit varies with available data for each sport.

COUNTRY NAMES. Given political change, several new nations have emerged. For convenience, the original names of several Eastern European countries are used: the Soviet Union, East Germany or German Democratic Republic (now a part of Germany), Czechoslovakia (now the Czech

Republic and Slovakia), and Yugoslavia. Considerable data on the growth and maturation of young athletes are from these countries.

TEAM SPORTS

Baseball

There is relatively little information on the growth and maturation of young players. Most participants in the 1955 Little League World Series were pubescent (17.0%) or postpubescent (45.5%) in pubic hair status [74], while among players in the 1957 World Series, equal numbers of boys had SAs that were classified as average (45.5%) or advanced (45.5%) relative to their CAs [102]. Maturity was also related to position and batting order; all except one starting pitcher and all boys who batted in the fourth position were postpubescent [74]. In contrast, successful interscholastic baseball players at the fifth and sixth grades (about 10–12 years) did not differ from nonparticipants in maturation [45]. Among older boys in the Medford Boys' Growth Study [45], there were no maturity differences between senior high school baseball players and nonplayers (about 15–18 years of age). The catch-up of later-maturing boys during the high school years reduces the size, strength, and skill differences so apparent in early adolescence. Also, at more competitive levels, skill is of more importance than the advantage afforded by greater size and strength at younger ages.

American Football

American football is a sport in which a large body size is an advantage and in which many boys are selected for a position by their body size. Data for 58 participants, 10.2–14.2 years of age, in a local league from two small communities indicate statures that approximate the reference median, but body weights just below P 75 [119, 124]. Pubic hair stages 1–4 were represented in the sample, and the distribution was similar to that seen in the general population. In contrast, interscholastic football players in the Medford Boys' Growth Study were advanced in SA at all ages between 10 and 15 years compared with nonparticipants, and the outstanding players were more advanced than other players [45]. At the senior high school level, SA did not differ consistently between players and nonplayers, probably reflecting the catch-up of late maturers and attainment of skeletal maturity by many boys. However, high school football "all stars" approximated the 90th percentile of the reference data for stature and weight [96].

Basketball

MALES. Mean statures and weights of basketball players often approximate or exceed P 90 from early through late adolescence (Fig. 13.1, *left*). Data from samples in Czechoslovakia indicate secular increases in stature and weight of players from the 1960s [107, 155] to the mid-1980s [97].

FIGURE 13.1

Statures and weights of male basketball and volleyball players (left) *and female basketball, volleyball and handball players* (right). *In all figures, points connected by a* solid line *are mixed-longitudinal or longitudinal, and those by a* dashed line *are cross-sectional. Individual points: basketball (males [42, 154, 187]; females [175, 187]); volleyball (males, [97, 141, 156]; females, [93, 126, 141, 202]).*

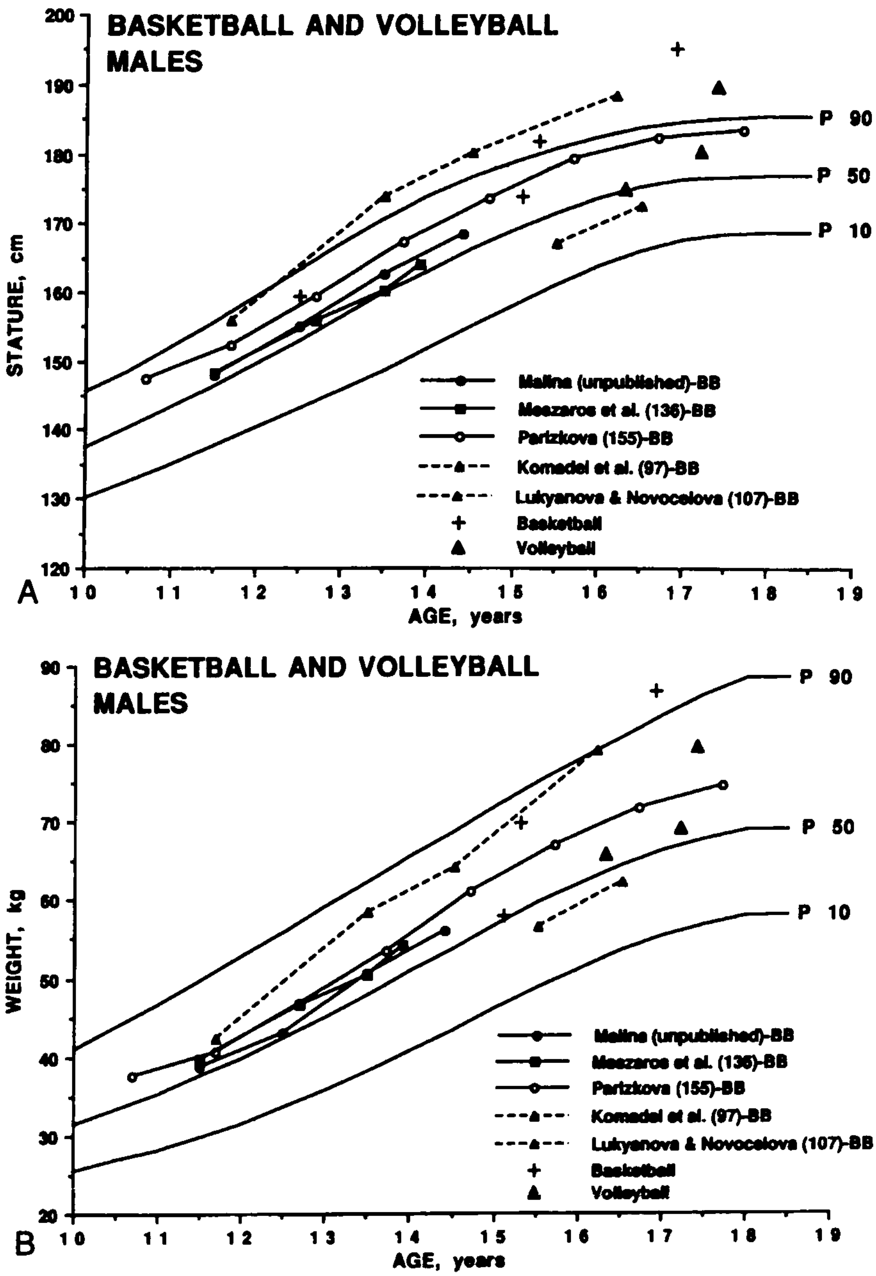
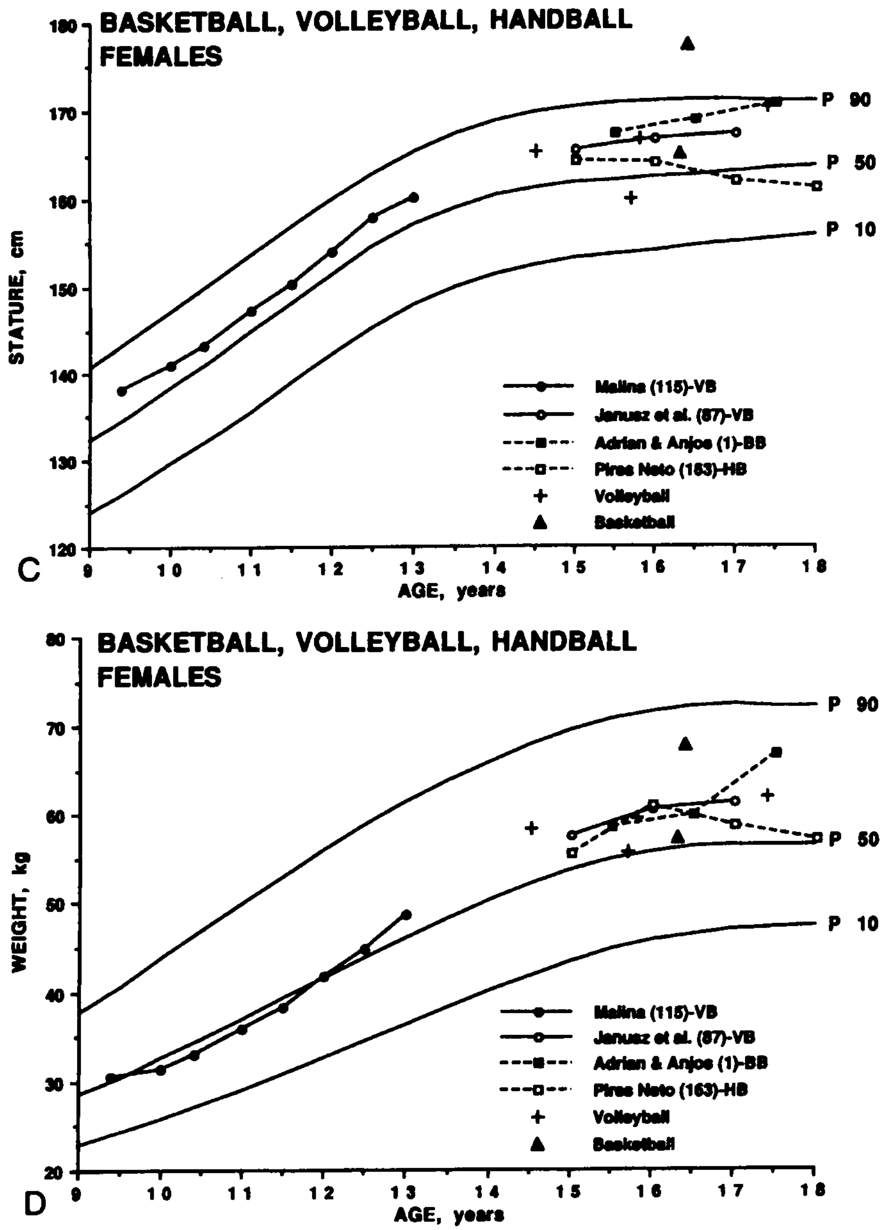


FIGURE 13.1 *(continued)*



Belgian data indicate a size difference between national and regional selections of 14- to 15-year-old players [42].

Interscholastic basketball players and nonplayers 9–12 years of age did not differ in skeletal maturity [45], while select Finnish basketball players had SAs and CAs that did not differ, 12.5 ± 1.2 and 12.5 ± 0.5 years, respectively [154]. However, between 13 and 15 years of age, successful basketball players were advanced in SA [42, 45]. Among 16 Belgian nationally select players, 10 and 6, respectively, had SAs classified as advanced and average, and there were no late maturers, while among 14 regionally select players, 11 had SAs classified as average [42]. Data for older ages in the Medford Boys' Growth Study showed no differences in SA between high school basketball players and nonplayers [45].

FEMALES. Data for female basketball players are limited to late adolescence (Fig. 13.1, *right*). Mean statures for two U.S. samples [1, 175] are between P 50 and P 75, while that for an Australian selection [187] exceeds P 90. Body weights vary between P 50 and P 90. Skeletal maturation and secondary sex characteristic development of 10 Czechoslovak basketball players (mean age, 16 years) were classified as average, and none of the athletes was advanced [151].

Volleyball

MALES. Data for male volleyball players are also limited to late adolescence (Fig. 13.1, *left*). Regionally select Chilean junior players [141] have a mean stature and weight that are at the reference medians, while two select Czechoslovak samples [97, 156] show a secular increase from the late 1960s [156] to the mid-1980s [97]. The recent sample [97] has a mean stature that exceeds P 90 and a mean weight between P 75 and P 90.

FEMALES. Two samples of volleyball players, a mixed-longitudinal sample of U.S. girls 9–13 years from a well-developed parochial school program [115] and a longitudinal sample of select players 15–17 years from Poland [87], have statures close to P 75 (Fig. 13.1, *right*). Mean weights of the younger girls are at the median, while those of the adolescent players are just below P 75. Mean statures and weights for three of four samples of adolescent players from Brazil [93], the U.S. [126], and Czechoslovakia [202] are well above the median; the mean stature of the Czechoslovak tournament participants is at P 90. Stature of the Chilean juniors [141] is just below the median, and weight is at the median.

Estimated six-monthly growth rates for stature and weight in the mixed-longitudinal sample of volleyball players 10–13 years of age were similar to medians for nonathletes [115]. Hence, their larger body size is not a function of accelerated growth rates. SAs and CAs of Czechoslovak volleyball players (n=12) were virtually identical at about 14 and 17 years [150], while secondary sex characteristic development (n=10) was classified as average [151].

European Handball
Statures of a sample of junior female handball players from Brazil [163] fluctuate about P 50, while weights tend to be slightly above P 50 (Fig. 13.1, *right*).

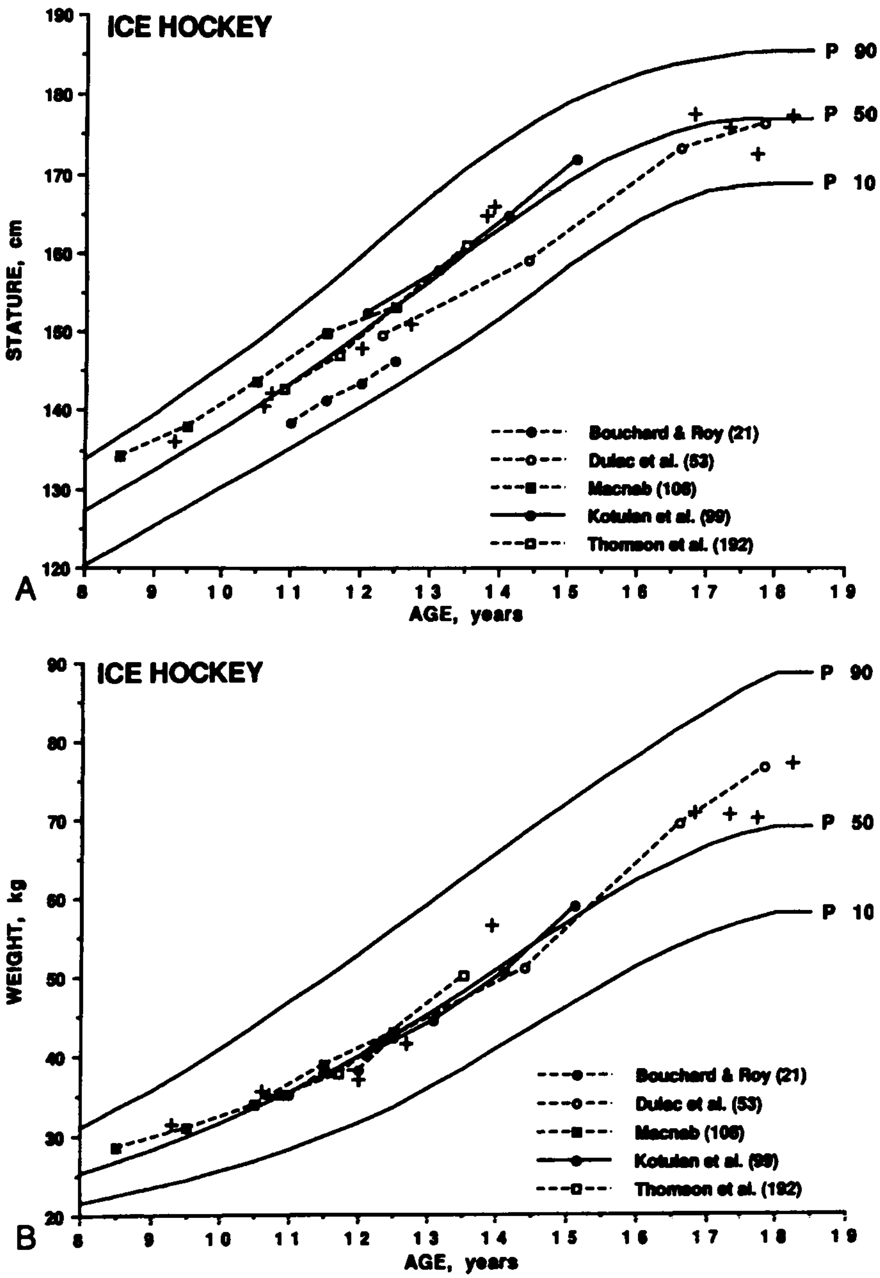
Soccer (European Football)
Given the popularity of soccer throughout the world, there is surprisingly little information on the growth and maturation of young male soccer players. Data from Europe [10, 50, 62, 98, 107, 128, 219], the Americas [53, 92], Japan [7, 172] and China [37] indicate statures that approximate the median/mean of the respective reference data from childhood through about 15 years of age. Subsequently, statures tend to be at or below the median in late adolescent players from Europe and the Americas, with the exception of the sample from the early 1960s [107] and Chilean junior players [52]. In contrast, Chinese players tend to be slightly above the Japanese reference mean (this is also true in the Chinese population in general). Mean weights of players from Europe and the Americas tend fluctuate about median from childhood through adolescence, while those for Japanese and Chinese players are, with one exception, consistently below the reference mean for Japan.

Several studies of the skeletal maturation of young soccer players in Europe [29, 128, 211] and Japan [7, 172] indicate SAs that approximated, on average, CAs, while estimated ages at PHV in 18 Welsh (n=32) and Danish (n=8) adolescent soccer players were 14.2 ± 0.9 and 14.2 years, respectively [11, 67]. This would suggest "average" maturity status from childhood through the adolescent spurt. Data for pubertal Italian soccer players suggest a tendency for adolescent players 14–16 years of age to be advanced in SA, pubic hair development, and testicular volume, and taller and heavier than nonplayers; in contrast, pubertal players and nonplayers 10–11 and 12–13 years of age did not differ in SA, sexual maturation, and body size [29, 128]. These results may suggest a trend for boys advanced in maturity status to be more successful in soccer in later adolescence. Although numbers are small (n=18), data for 12-year-old soccer players suggest maturity-associated variation by position [10]. Strikers (n=5) and midfielders (n=4) tended to attain PHV earlier than defenders (n=7).

Ice Hockey
Data on the growth and maturation of boys participating in ice hockey, with one exception, are derived from Canada, Finland, and Czechoslovakia (Fig. 13.2). Statures tend to be variable during childhood and early adolescence, especially those from Canada. This may reflect ethnic variation; players of primarily French Canadian ancestry [21, 53] tend to be shorter. From about 15 years and older, all mean statures are at or below the median. In contrast, mean body weights from diverse samples of hockey players 8–15 years of age approximate P 50, while those of older players

FIGURE 13.2

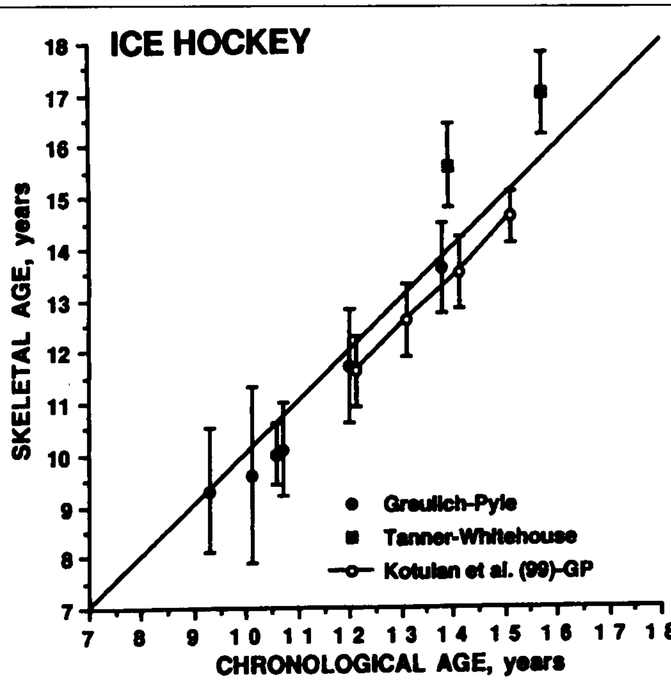
Statures and weights of male ice hockey players. Individual points: [20, 49, 77, 104, 148, 154, 156, 158, 165].



tend to be above P 50. The trend for late adolescent hockey players suggests a population that has greater weight for stature.

The maturity status of ice hockey players is consistent with the data for body size (Fig. 13.3). Cross-sectional data at 9 and 13 years of age from Finland indicate SAs and CAs that were, on average, the same [154, 165]. Longitudinal data for 16 select hockey players from Czechoslovakia indicate SAs that were behind corresponding CAs by about 0.5 years from 12 to 15 years of age [99]. This sample had an estimated age of PHV ("the point of inflection of the height growth curve") of 14.5 ± 1.0 years, which was consistent with the lag in skeletal maturation. Cross-sectional samples from Canada span 10–16 years of age. Younger groups, 10–12 years, had SAs that were behind corresponding CAs by 0.3–0.6 years [21, 49, 158]. However, among elite hockey players 13–16 years of age, SA was significantly advanced relative to CA by an average of 1.7 and 1.3 years [103]. The trend for boys advanced in maturity status to predominate among elite hockey players is illustrated in the distribution of players classified as advanced, average, or delayed in SA relative to CA. Among 12-year-old international tournament participants [124], boys classified as

FIGURE 13.3
Skeletal age versus chronological age in ice hockey players. Individual points: [21, 49, 103, 154, 158, 165].



average (43%) and delayed (37%) were about equally represented, while those classified as advanced represented a small percentage (14%). However, among 13–14- and 15–16-year-old elite players [103], no boys were delayed in SA; most were advanced, 82% and 62%, respectively.

Ice hockey also shows variation in skeletal maturity (and correspondingly body size) by position among 12-year-old boys. Among tournament participants (n=205), most defensemen were average and advanced in SA, while most forwards and goalkeepers were average and delayed in SA [119]. Only 11% of the forwards and 8% of the goalkeepers were advanced, while only 15% of the defensemen were delayed in SA relative to CA. The evidence from baseball, ice hockey, and soccer among boys 12 years of age thus suggests that in addition to maturity-associated variation in body size, there is variation in maturity status by position within a given sport.

INDIVIDUAL SPORTS

Track and Field

For convenience, events comprising track and field were grouped into distance runs (one mile or further, cross-country), sprints, jumps (long, high), and throws (shot, discus). Some studies simply describe samples as track athletes or training in light athletics, or group athletes across events. These data were not considered in the comparisons.

MALES. Young distance runners 10–18 years tend to have statures that fluctuate about P 50 and body weights that tend to be below P 50 [19, 51, 55, 109, 135, 188, 193, 195, 196, 205]. Mean statures and weights of sprinters tend to be at or above P 50 [2, 19, 130, 135, 188, 195, 196]. Results are similar for Chinese and Japanese distance runners and sprinters 13–17 years [152]. U.S. Junior Olympians [196] and Belgian national selections [19] in jumping and throwing events have similar statures. Throwers are slightly taller within each sample, approximating P 90. Weights of throwers are at P 90, while those of jumpers are at P 50. Chinese and Japanese jumpers 15–17 years show similar trends [152].

Elite male (n=18) distance runners 9–15 years of age from the state of Michigan were slightly shorter and lighter than active youth not involved in distance running, but longitudinal observations over one year indicated growth rates (cm/yr) that did not differ from those of nonrunners. The smaller size may reflect the slightly delayed SA of the runners [173]. In contrast, longitudinal observations on six junior champion distance runners in Japan indicated greater statures and weights than active and control boys, and an earlier age at PHV, 12.6 years [95].

Track athletes did not differ in skeletal maturity from nonathletes in elementary school [45]. Similar observations were reported for small samples of distance runners and sprinters 10–12 years of age [135]. At older ages, track athletes in the Medford study were advanced in SA in junior high school (12–15 years), but did not differ in SA from nonathletes in senior high school (15–18 years) [45]. At more advanced competitive levels, mean SAs of male participants 12–18 years of age (n=103) in an instructional camp for track and field athletes (events not specified) were in advance of mean CA (14.9 ± 1.3 years), slightly by the GP (15.2 ± 1.7 years) and significantly by the TW (16.8 ± 1.3 years) methods [47]. Examination of the scatter plot of SA versus CA indicated that only two boys had TW SAs less than their CAs, and the greatest advancement of SA over CA was apparent between 13 and 15 years of age. Similar trends were apparent in nationally select Belgian [118] athletes 15–18 years, and Chinese and Japanese [152] junior athletes 13–17 years. The data show a pattern of advanced SA initially. At older ages, many athletes have attained skeletal maturity, but a number of later-maturing boys are also successful performers. This indicates the reduced significance of maturity-associated variation in body size on track and field performance in late adolescence.

FEMALES. Mean statures of distance runners [1, 19, 27, 84, 137, 166, 188, 193, 194, 196, 204, 216, 217] and sprinters [19, 84, 123, 166, 188, 194, 196, 217] 10–18 years tend to be at or above P 50. However, mean weights of distance runners are consistently below P 50, while those of sprinters are, with one exception, quite close to P 50. Identical trends are apparent in Chinese and Japanese junior distance runners and sprinters 13–17 years [152]. Adolescent distance runners of both sexes tend to have less weight for stature, but the tendency is more apparent in females than in males. Data for U.S. Junior Olympians [196], Olympic Development Camp participants [84], and Olympians <18 years from the Mexico City, Munich, and Montreal Olympic Games [123] indicate greater statures in jumpers than throwers, and greater weights in throwers than jumpers. The statures of jumpers and throwers generally exceed P 90; in contrast, mean weights of the throwers are close to or above P 90, while those of the jumpers are at or above P 50. Chinese and Japanese jumpers and throwers 15–17 years do not differ in stature, but the latter are heavier, and both groups of athletes are considerably larger than the reference mean [152].

Elite female (n=14) distance runners 9–15 years of age from the state of Michigan were slightly shorter and lighter than active girls not involved in distance running. Longitudinal observations over one year indicated stature growth rates (cm/yr) that were slightly greater in the runners, most likely reflecting their slightly delayed SAs [173].

Mean SA of 168 female participants 12–18 years at an instructional track and field camp was the same as mean CA (15.0 ± 1.2 years) by the TW (14.9 ± 1.3 years) method, but slightly in delay by the GP method (14.6 ± 1.3 years) [47]. The scatter plot of TW SAs versus CAs indicated reasonably equal numbers above and below the line of unity across CA, with the exception of the older ages, suggesting generally average skeletal maturity status. Similar results were reported for 10 Czechoslovak runners, 15.5 years of age [151]. Among 29 nationally select Belgian track and field athletes

15–18 years, about one-half attained skeletal maturity (n=15), which is 16.0 years in the TW method [118]. The skeletally mature and immature were equally distributed among events. Among Chinese and Japanese athletes 13–17 years, sprinters tended to be slightly advanced in SA, while distance runners were generally average in SA. The vast majority of jumpers and throwers 15–17 years had already attained skeletal maturity [152].

Information on the sexual maturation of young female track and field athletes is not extensive. The estimated median age at menarche (probit) for a status quo sample of Hungarian track athletes 10–17 years of age was 12.6 years, a value similar to nonathlete populations in Hungary [61].

Swimming

Studies of young swimmers generally treat the athletes as a group, without attention to stroke and distance. Given the wealth of information on young swimmers, the available data were grouped geographically for convenience: the Americas (largely the U.S.), Western Europe, Eastern Europe, and Japan.

MALES. With few exceptions, statures of age-group swimmers in the Americas are above the reference median. Those from the U.S. Swimming select camp program, 14–17 years [200, 201], have statures that approximate P 90 (Fig. 13.4, *left*). Mean weights of swimmers from the Americas are at, but generally above, P 50. The U.S. select swimmers are also the heaviest.

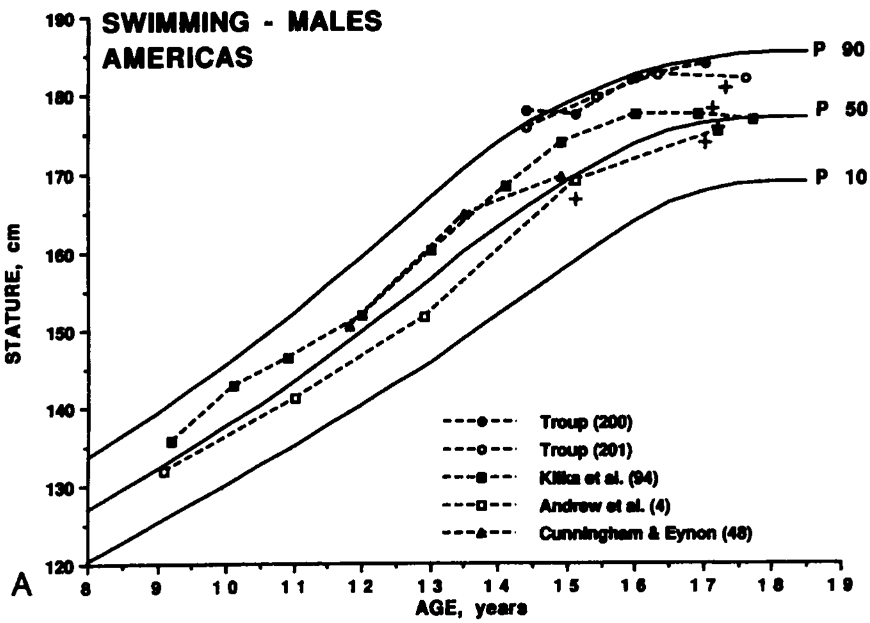
Young Western European swimmers, mostly from France [14, 36, 63, 132], have statures and weights that approximate the respective reference medians, while Belgian [207], Swedish [56, 57], and Norwegian [110] swimmers are generally taller and heavier than the medians (Fig. 13.4, *center*). Data for Eastern European swimmers are more variable (Fig. 13.4, *right*). Mean statures and weights are above and below the reference medians, and swimmers from the Soviet Union [26] are generally taller and heavier than those from the German Democratic Republic [198]. There appears to be a secular increase in size; the most recent samples from Hungary [59] and Czechoslovakia [97, 146] are taller and heavier than earlier samples. The best freestyle swimmers from East Germany in the 1960s had statures at P 50 and weights above P 50 [198].

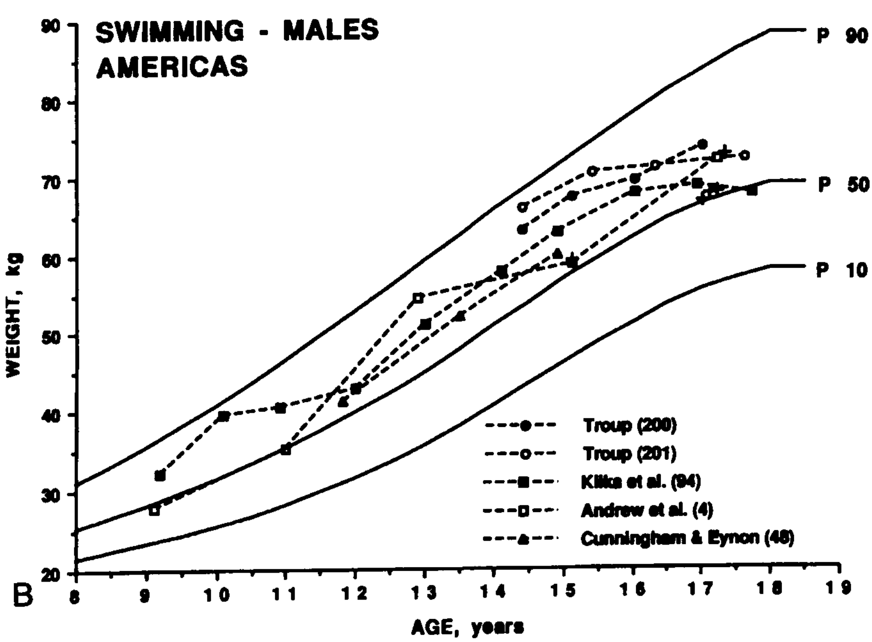
Data for young Japanese swimmers indicate statures at the Japanese reference mean and weights above the mean [127, 145].

Male age group swimmers tend to have SAs concentrated in the average and advanced categories, with relatively few late-maturing youngsters [25, 143, 162, 183]. This trend is especially apparent in late childhood and early adolescence. At these ages, better performers also tend to be advanced in skeletal maturation [191] and secondary sex characteristic development [89, 129]. The preceding thus suggests that successful young male swimmers are advanced in maturation compared with swimming peers. This trend seems to continue at more elite levels. After about 14–15 years of age, swimmers in the U.S. Swimming select camp program [200, 201],

FIGURE 13.4

*Statures and weights of male swimmers from the Americas (*left*), Western Europe (*center*), and Eastern Europe (*right*). Individual points: Americas [52, 131, 147, 197, 203]; Western Europe [36, 56, 110, 123]; Eastern Europe [146, 174].*





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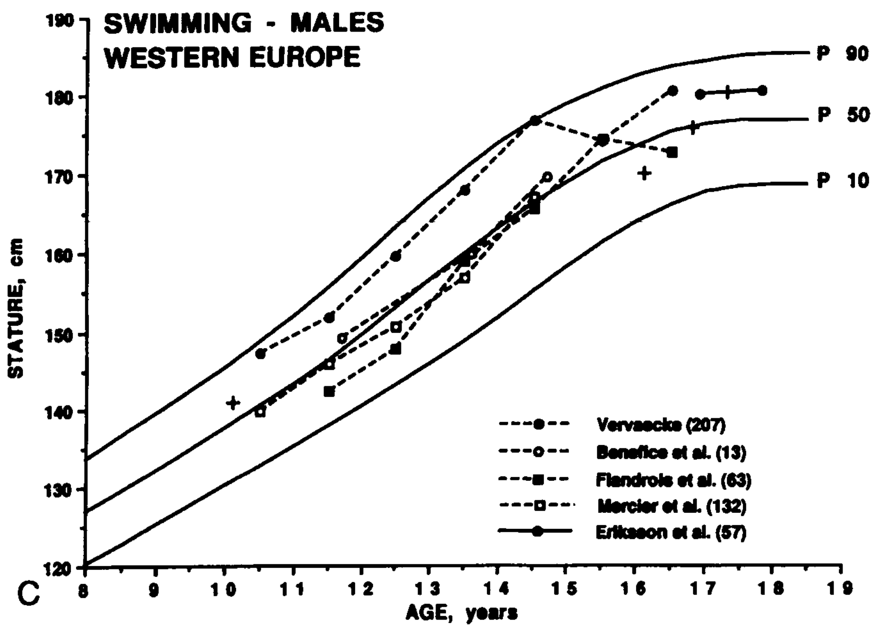

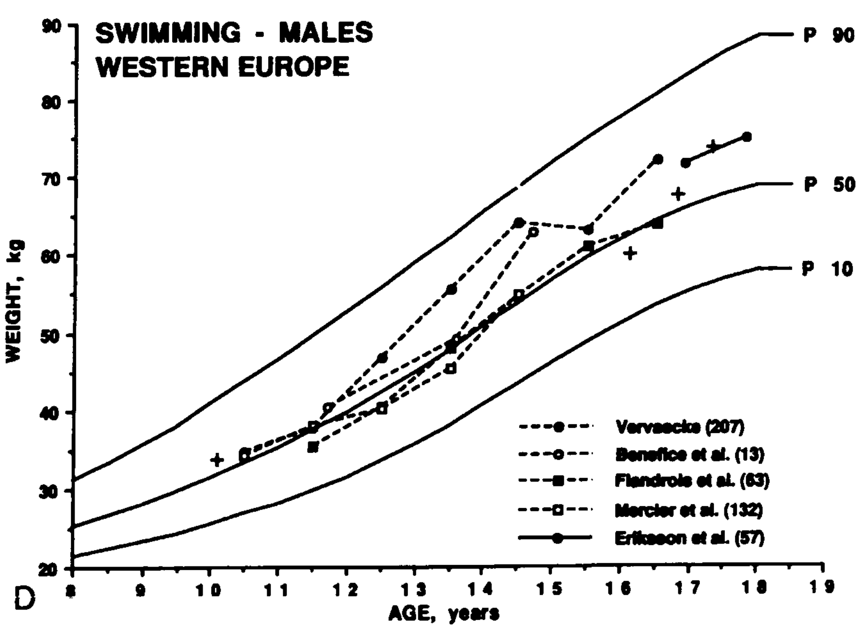

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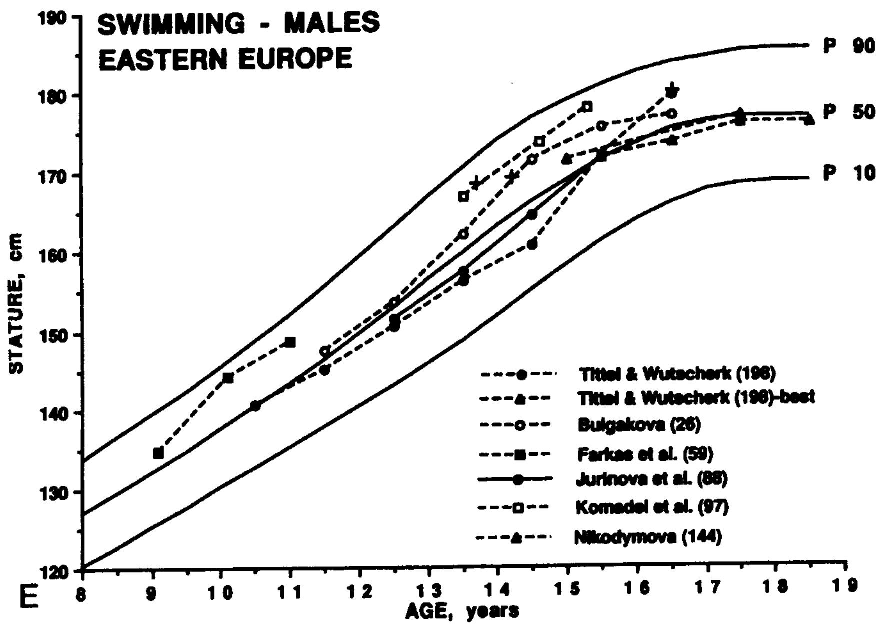
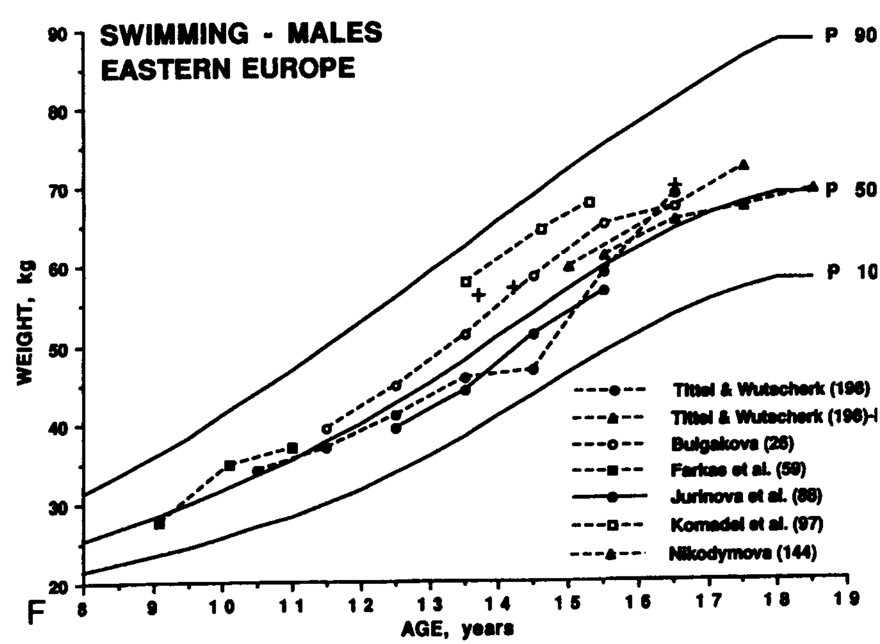




elite Belgian swimmers [207], and a small sample of Olympic swimmers under 18 years of age [120] were advanced in skeletal maturation.

FEMALES. Mean statures of female swimmers from the Americas are at and generally above P 50, while nationally select U.S. swimmers [200, 201] have statures at or just below P 90 (Fig. 13.5, *left*). In contrast, body weights are somewhat less variable and cluster at and above P 50. The nationally select U.S. swimmers do not have weights that clearly distinguish them from other samples.

Statures and weights of Western European age-group swimmers show a pattern similar to that observed in the Americas (Fig. 13.5, *center*). Data for Olympic swimmers from the Mexico City, Munich, and Montreal Olympic Games are included because most subjects were from Western European countries. From 14 to 18 years, Olympic [123] and elite Swedish [57, 208] swimmers tend to be taller and heavier than the other samples.

Statures of Eastern European swimmers are above and below P 50 during childhood and early adolescence and at or above P 50 after 14 years of age (Fig. 13.5, *right*). More recent samples of swimmers from Hungary [59] and Czechoslovakia [97, 146] are taller and heavier than earlier samples from these countries [60, 157] during childhood and early adolescence. A Czechoslovak sample 15–18 years of age from the early 1950s [144] had statures at P 50 and weights above P 50. This early sample is shorter than more recent ones, but has a similar body weight. Age-group swimmers from the Soviet Union [26] are taller and heavier than those from East Germany [198].

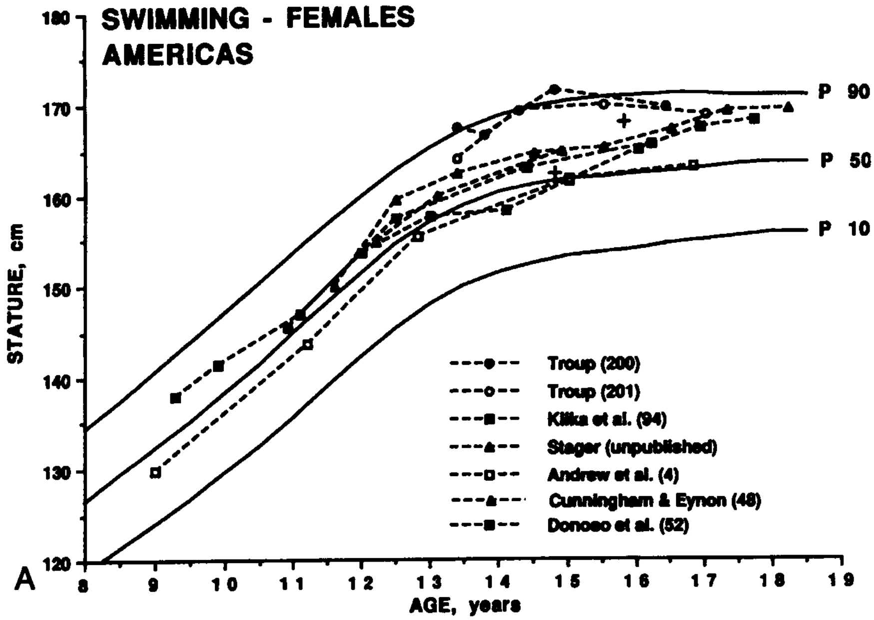
Several samples of Japanese female swimmers [127, 139, 145] present statures that are at or above the Japanese reference mean and weights that are generally above the mean.

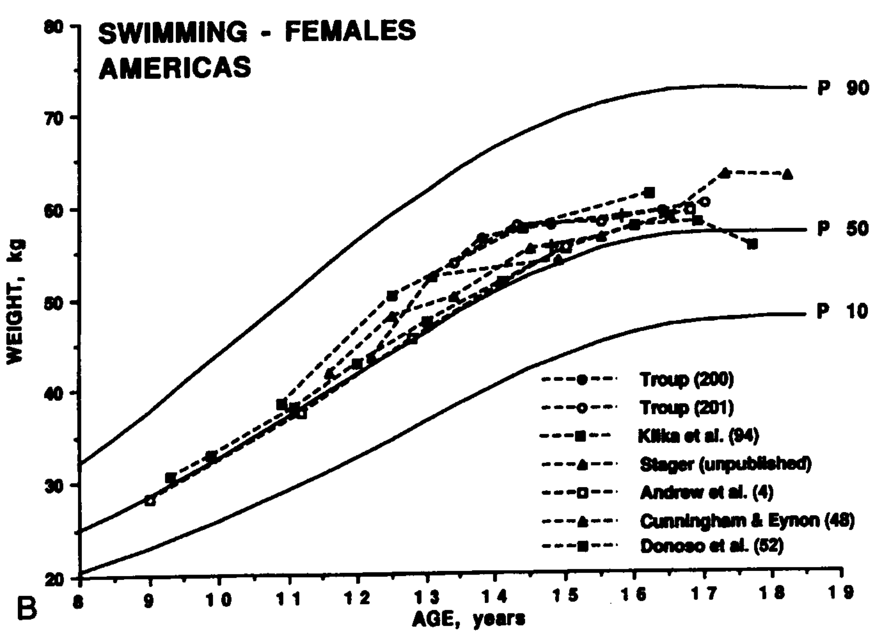
In early adolescence, about 10–13 years, female swimmers tend to have SAs appropriate for their CAs, and most are classified in the average category [142, 143, 189, 190]. Studies that treat swimmers of a wider age range as a single group show similar results [25, 151, 183]. Elite Belgian swimmers with mean CAs between 13.9 and 15.3 years had SAs that were delayed by about 0.5 year, though within the average range [207]. On the other hand, 12 swimmers under 16 years of age at the Montreal Olympic Games (1976) were advanced in SA by about 0.5–0.7 years [120]. Participants in the U.S. select camp program, 13–17 years, showed variable results. Swimmers surveyed in 1989 had SAs that were, on average, in advance of CAs by about 0.7 years [200], while those surveyed in 1990 had SAs that were, on average, about equivalent to CAs, except for the 13-year-old group, in whom SA was advanced [201]. In contrast, maturity assessments for female participants in the XII Central American Swimming Championships (1981) indicated advanced SA from about 9–14 years and then delayed SA from about 14–17 years [162].

The skeletal maturity data, though somewhat variable, suggest that most female age-group swimmers are average or advanced in SA relative to CA.

FIGURE 13.5

Statures and weights of female swimmers from the Americas (left), *Western Europe* (center), *and Eastern Europe* (right). *Individual points: Americas [131, 197]; Western Europe [15, 36, 149, 160, 208]; Eastern Europe [97, 146].*





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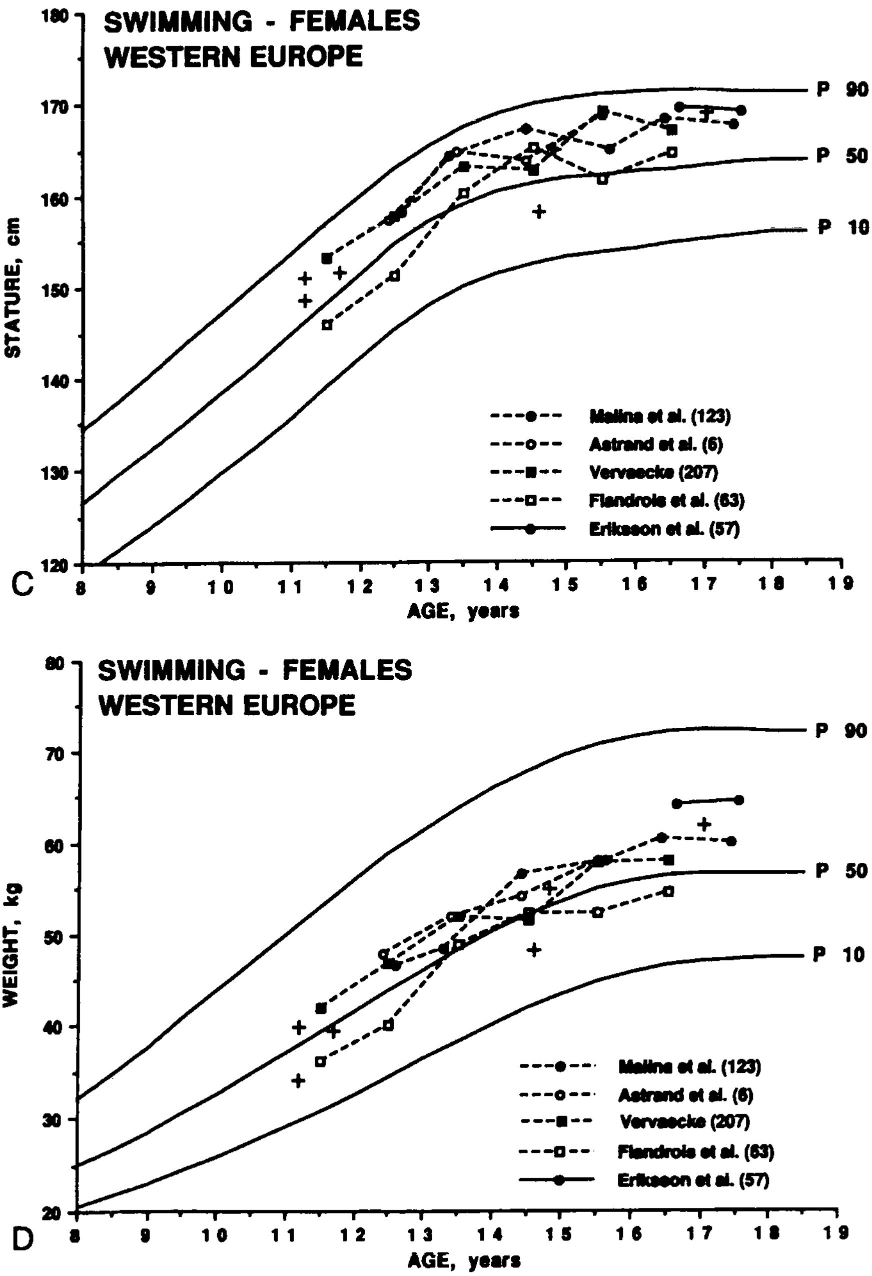

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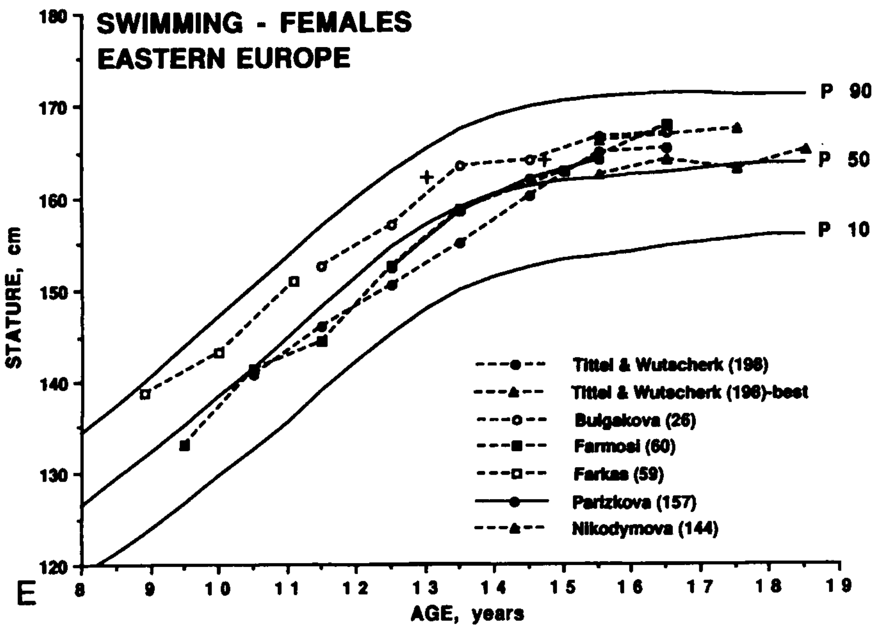

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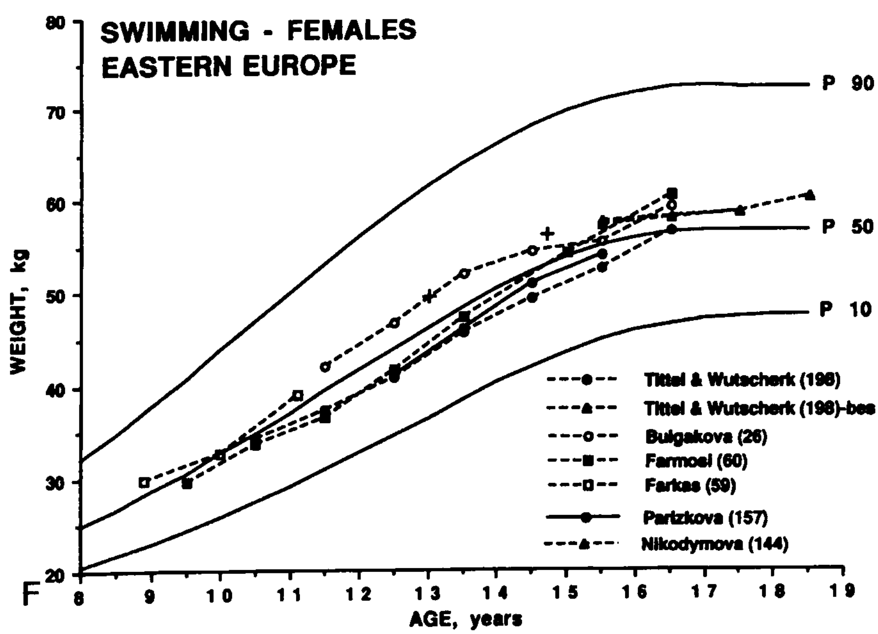


F

Less extensive data for secondary sex characteristics indicate similar breast and pubic hair development in age-group swimmers 8–15 years and nonswimmers [15, 129]. Estimated median ages at menarche (probit) for status quo samples of age-group swimmers from several elite programs in California, Indiana, and Texas and for an independent sample in Austin, Texas, were 13.1 ± 1.1 years and 12.7 ± 1.1 years, respectively (Malina, unpublished), which are similar to the median age for the general U.S. population. In an early study of 30 elite Swedish swimmers 11.9–16.4 years, all but one girl (12.3 years) attained menarche; the age at menarche for the remaining 29 was 12.9 ± 1.1 years [6]. On the other hand, more recent retrospective estimates of age at menarche in elite university swimmers are considerably later, 14.3 and 14.4 years [113, 181]. This issue is discussed later in the review.

Among age-group swimmers under 12 years, the more successful tended to be advanced in SA [191] and more mature in breast and pubic hair development [9]. On the other hand, in small samples (n=7 per group) of national and junior national qualifiers 15–18 years of age, the former had slightly lower breast and pubic hair ratings than the latter, even though the national qualifiers were older by 0.4 years [129].

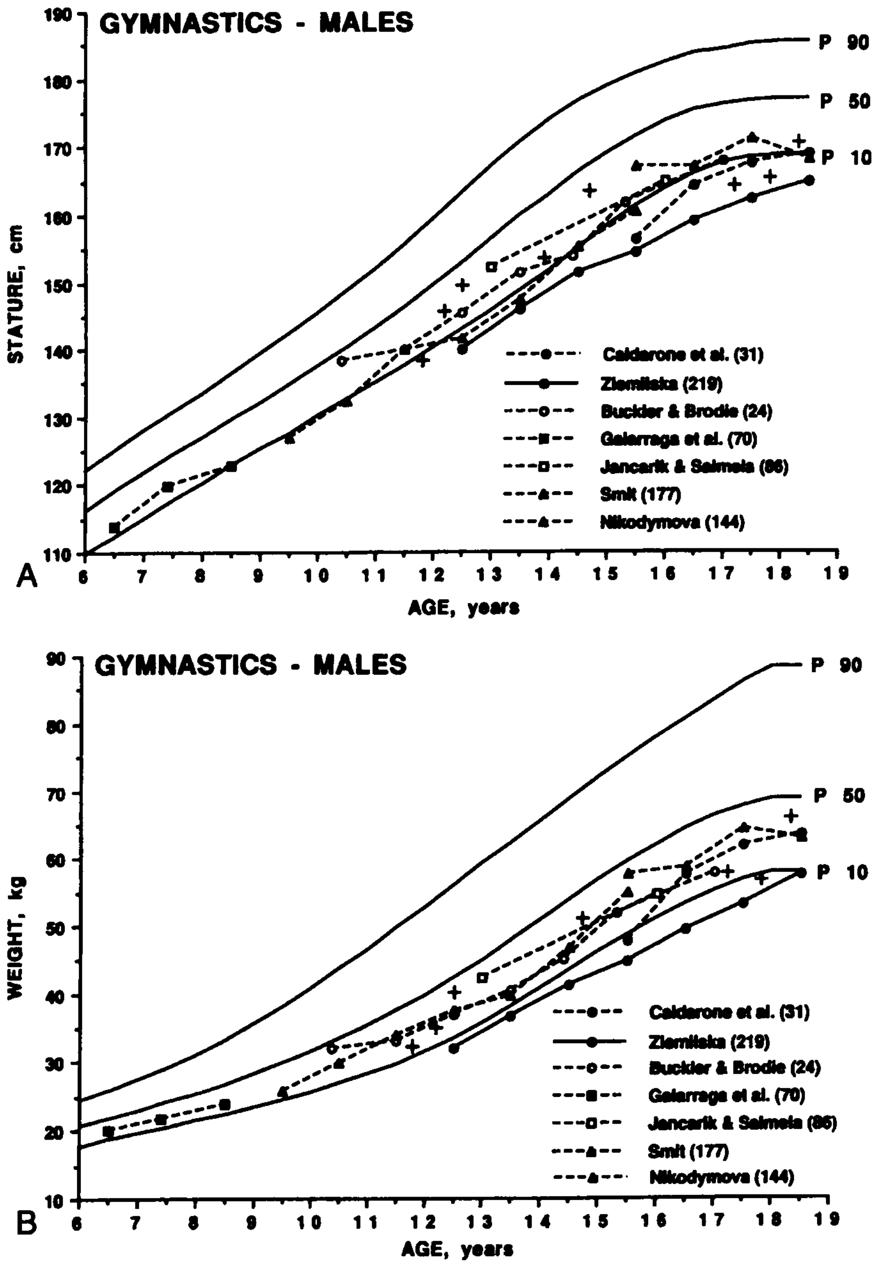
Diving

Mean statures of male U.S. Junior Olympic divers are consistently below P 50 from 11–18 years, while weights are below P 50 from 11–15 years and at P 50 from 16–18 years [122]. A combined sample of U.S., Canadian, and Mexican junior national team members [179] has similar statures and weights, except in the oldest age group, when they are shorter and lighter. Among females, mean statures of U.S. Junior Olympic divers are slightly but consistently below P 50 [122]. Weights are also slightly below P 50 from 10–14 years, but are at P 50 from 15–18 years. The combined sample of U.S., Canadian, and Mexican junior national team members [129] are shorter than U.S. divers but have similar body weights. Single-year growth velocities for statures of both male and female Junior Olympic divers were within the range of reference data, and the estimated median age at menarche (probit) was 13.6 years ± 1.1 years [122].

Gymnastics

MALES. Statures of male gymnasts tend to cluster around P 10 of the reference data, while weights, with one exception, vary between P 50 and P 10 (Fig. 13.6, *left*). SAs are plotted relative to CAs for several samples of gymnasts in Figure 13.7 (*top*). The trend indicates no clear pattern in childhood, 6–8 years [70], but a delay of 1–2 years during adolescence [69, 91, 154]. The SA-CA difference also appears to be rather constant during this time. Data on secondary sex characteristics are consistent with those for skeletal maturation [24, 219].

FIGURE 13.6
Statures and weights of male gymnasts (left) *and female gymnasts from Europe* (center) *and the Americas* (right). *Individual points: males [5, 22, 69, 86, 131, 154, 156, 174]; females, Europe [15, 58, 149, 180, 190, 206, 220]; females, Americas [5, 22, 33, 80, 106, 131, 140, 215].*



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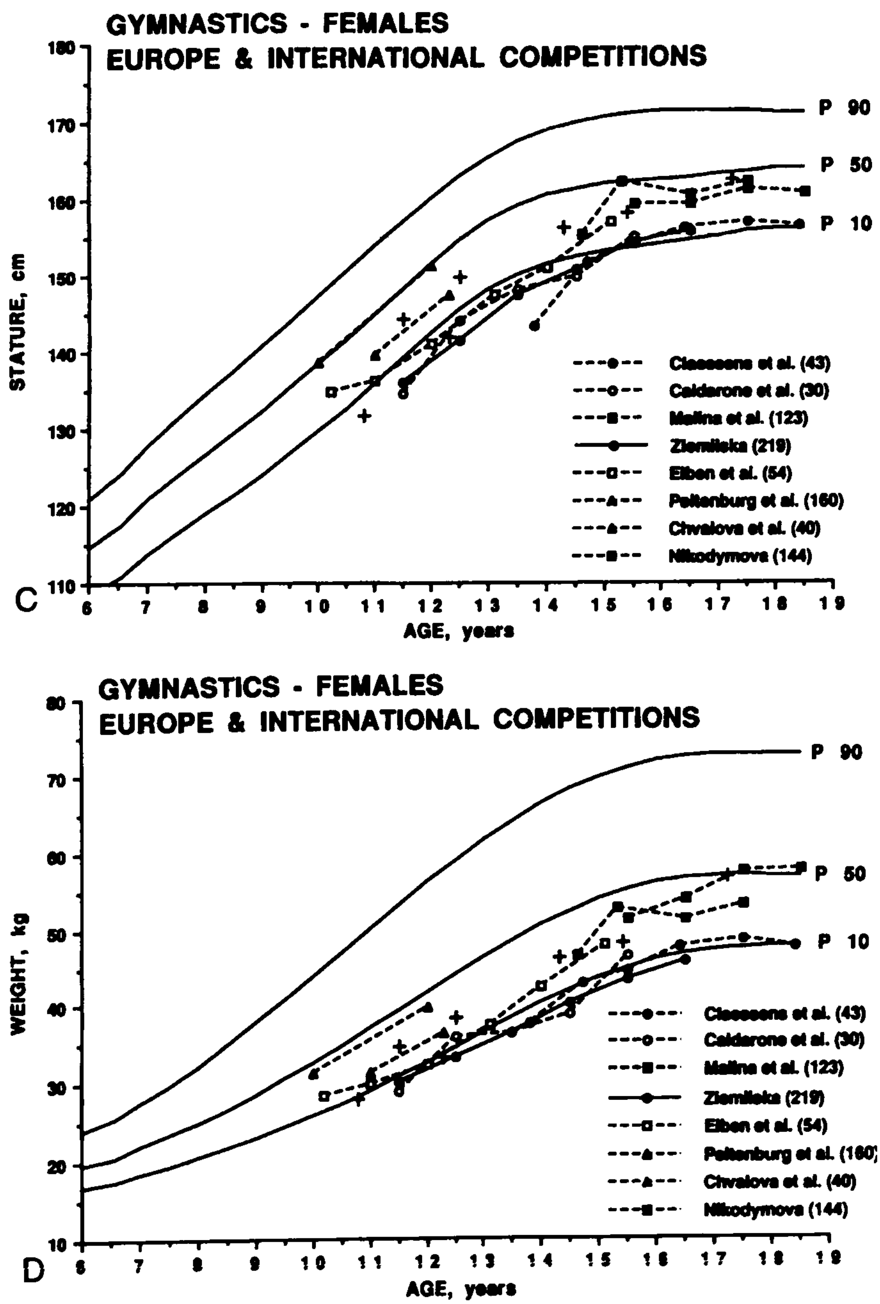

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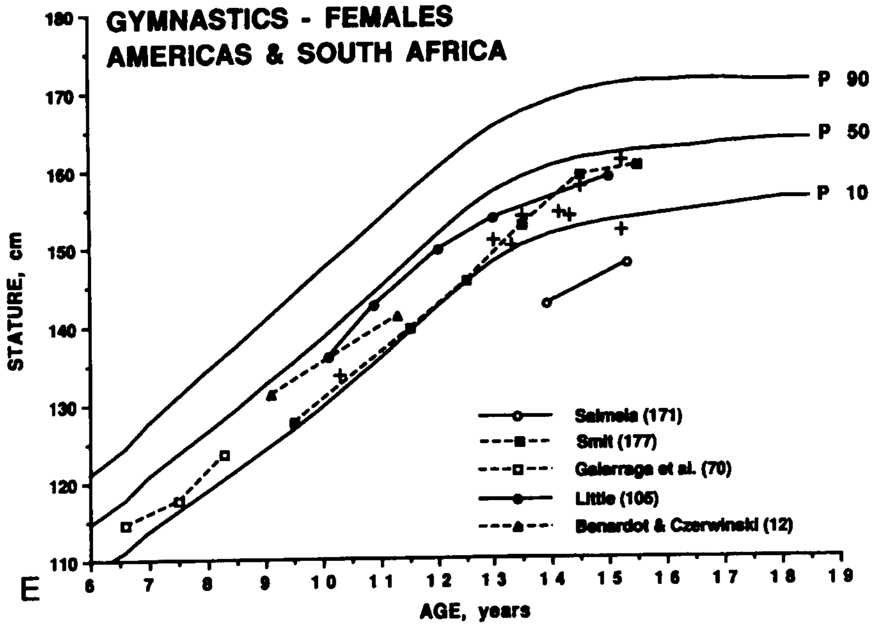


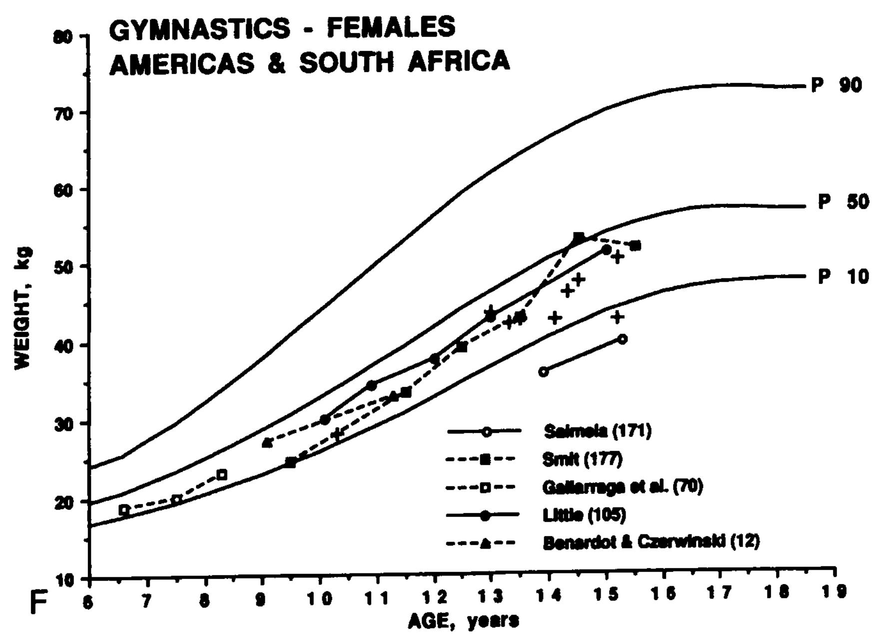
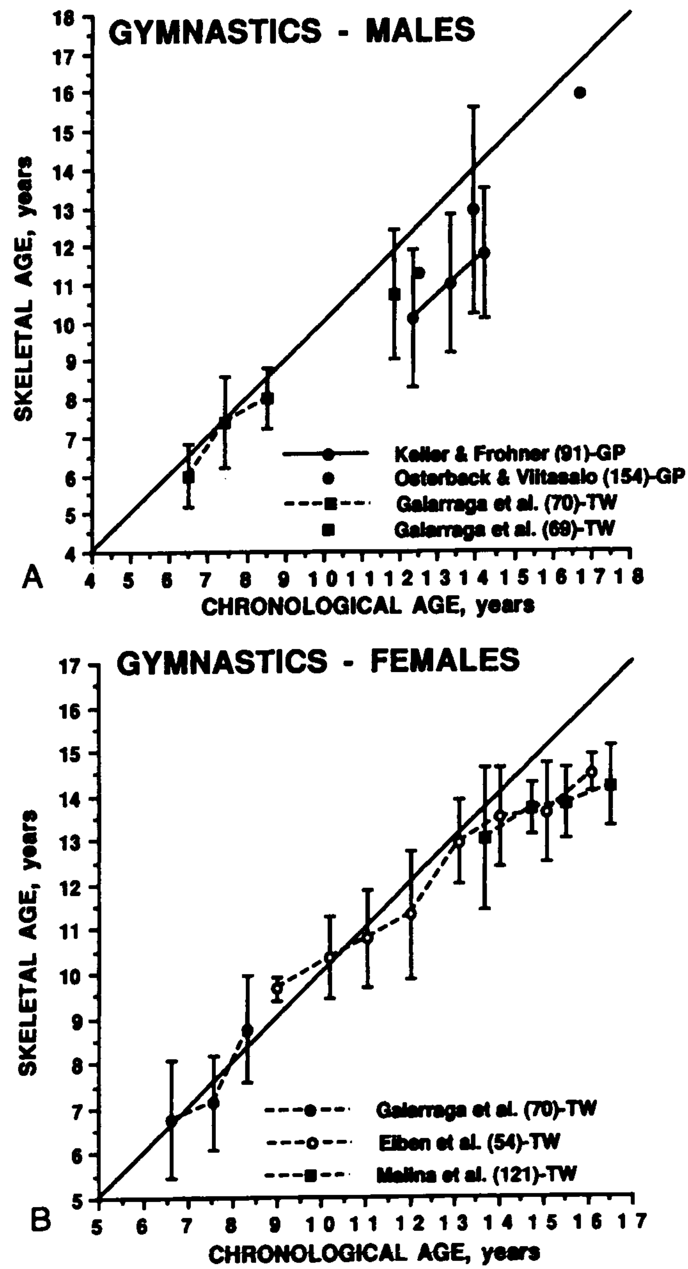


FIGURE 13.7
Skeletal age versus chronological age in male (top) *and female* (bottom) *gymnasts.*



FEMALES. Data for female gymnasts are more extensive; the data are grouped for convenience: Europeans and samples from international competitions, and the Americas and South Africa. Statures and weights of gymnasts in international competitions and from Europe vary between P 50 and P 10, but most are nearer P 10 (Fig. 13.6, *center*). The earliest data are from the 1950s [144] and participants in the Mexico City, Munich, and Montreal Olympic Games, 1968–1976 [123]. More recent samples of gymnasts of the same age, 14–18 years, are shorter and lighter. This is especially apparent in participants in the 1987 world championships [43], who have statures and weights that fall on P 10. A secular trend toward smaller statures and lighter weights has thus occurred in samples of world class female gymnasts.

Statures and weights of gymnasts from the Americas and South Africa also vary between P 50 and P 10, with the exception of a small sample of elite Canadian gymnasts [171] who are well below P 10 (Fig. 13.6, *right*). In contrast to European gymnasts, statures and weights of gymnasts from the Americas do not cluster at P 10.

The skeletal maturation of female gymnasts shows a pattern similar to that for males (Fig. 13.7, *bottom*). Cross-sectional data indicate no clear pattern of SA-CA differences during childhood, 6–10 years [54, 70]. Subsequently, SA tends to lag relative to CA through about 16 years [54, 121, 189, 190]. Note that skeletal maturity of females is attained at 16.0 years in the TW method. Athletes who have already attained skeletal maturity are not included in the calculations; they are simply classified as adult. SAs of gymnasts older than 16–18 years also tend to be delayed, but group statistics are biased by the exclusion of those who already are skeletally mature [121]. In contrast, a sample of 24 Czechoslovak gymnasts observed at 12.4 and 16.5 years had SAs (local adaptation of the GP method) that were equivalent to CAs on each occasion [150].

Data on breast and pubic hair development of gymnasts are consistent with those for skeletal maturation [15, 160, 219], and more talented gymnasts are more delayed in sexual maturation than those at the local club level [160]. Age at menarche is also quite late. Prospective studies of highly trained Polish (n=9) and Swiss (n=11) gymnasts gave mean ages at menarche of 15.1 ± 0.9 [219] and 14.5 ± 1.2 [190] years, respectively. Status quo estimates for Hungarian gymnasts [54] and participants at the 1987 world championships [43] were 15.0 ± 0.6 and 15.6 ± 2.1 years, respectively. The latter sample did not include girls under 13 years of age, so the estimate is likely biased toward an older age.

Tennis

Statures of young male Italian [50], Finnish [134], and U.S. [28] tennis players tend to be below P 50, while weights are at P 50. However, two samples of Czechoslovak players 12–13 years [40, 101] are considerably taller and also heavier. The late adolescent Chilean national players [52] are shorter than P 50, but just as heavy. In nine Finnish tennis players, SAs and CAs did not differ [134].

Data for young female tennis players are quite limited, given the popularity of the sport. Statures are generally above P 50, especially in adolescence, while weights are near P 50 [28, 40, 52, 101, 187]. A sample of Czechoslovak tennis players (n=14) observed at 14.3 and 17.1 years had SAs that did not differ from their CAs on each occasion [150].

Figure Skating

Young figure skaters of both sexes tend to have statures and weights that are well below the respective reference medians, males [97, 167, 214] more than females [52, 68, 97, 100, 167, 169, 176, 214]. Four of the five samples of males have statures at or below P 10. Evidence from gonadal hormone assays in both sexes [214], and skeletal and sexual maturation in girls [150, 151] indicates later maturation in figure skaters.

Skiing

Statures and weights of male skiers vary about the respective reference medians [38, 52, 97, 159, 168, 178, 182]. In contrast, statures of female skiers are generally above the median, while weights are at the median [97, 159, 182], with the exception of the 10- and 17-year-old samples of Canadian skiers [168, 216], who are consistently shorter and lighter. Growth rates for stature (cm/yr) and weight (kg/yr) of Finnish skiers 10–14 years of age followed over two years were similar to local control subjects [159].

Cycling

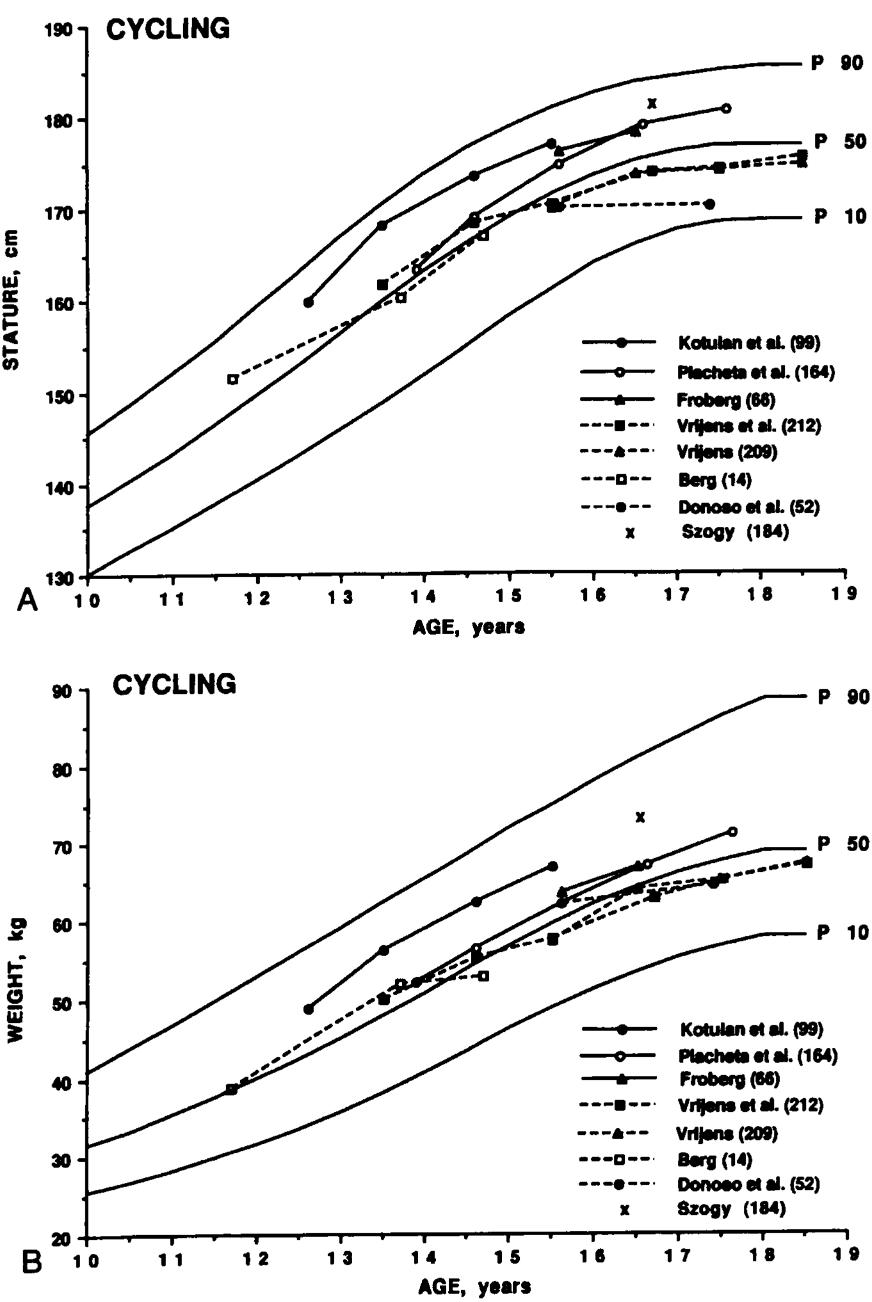
Statures of male cyclists are variable, especially in late adolescence (Fig. 13.8). However, longitudinal samples from Czechoslovakia [99, 164] and Denmark [66] are above P 50 and taller than cross-sectional samples from Belgium [209, 212], who are at or below P 50. Body weights are less variable, and most cluster about P 50, although the three longitudinal samples are slightly heavier throughout. Cyclists of the Chilean national team [52] are the shortest, especially in late adolescence, but they have similar weights.

Six select Czechoslovak cyclists followed longitudinally from 12 to 15 years had SAs that were consistently advanced relative to CAs, and an earlier estimated age at PHV, 12.9 ± 0.4 years [99]. In contrast, cross-sectional samples of Belgian cyclists had equivalent SAs and CAs [210].

Rowing/Canoeing

Limited data for males indicate statures and weights greater than the respective reference medians [52, 97, 99, 216, 218]. Eleven select Czechoslovak rowers followed longitudinally from 12 to 15 years had SAs in advance of CAs, and the degree of advancement increased with age [99]. Their estimated age at PHV, 13.5 ± 0.5 years, was earlier than in control subjects by about one year. Mixed-longitudinal data for Polish female

FIGURE 13.8
Statures and weights of male cyclists.



rowers 11–14 years enrolled in a sports school are similar to those for males, i.e., taller and heavier than the respective reference medians (Malina, unpublished).

Wrestling
The limited data for prepubescent wrestlers are variable [44, 170]. Mixed-longitudinal data for Polish boys 11–14 years, in a sports school, indicate statures and weights greater than the respective reference medians (Malina, unpublished). In contrast, cross-sectional data for U.S. wrestlers 14–18 years indicate statures that are generally less than P 50 and weights that are at or below P 50 [46, 83, 90, 186, 196]. Finnish wrestlers were delayed in SA, and the delay was greater in younger (CA 12.1 years, SA-CA = –0.9 years) than in older (15.7 years, SA-CA = –0.3 years) wrestlers [154].

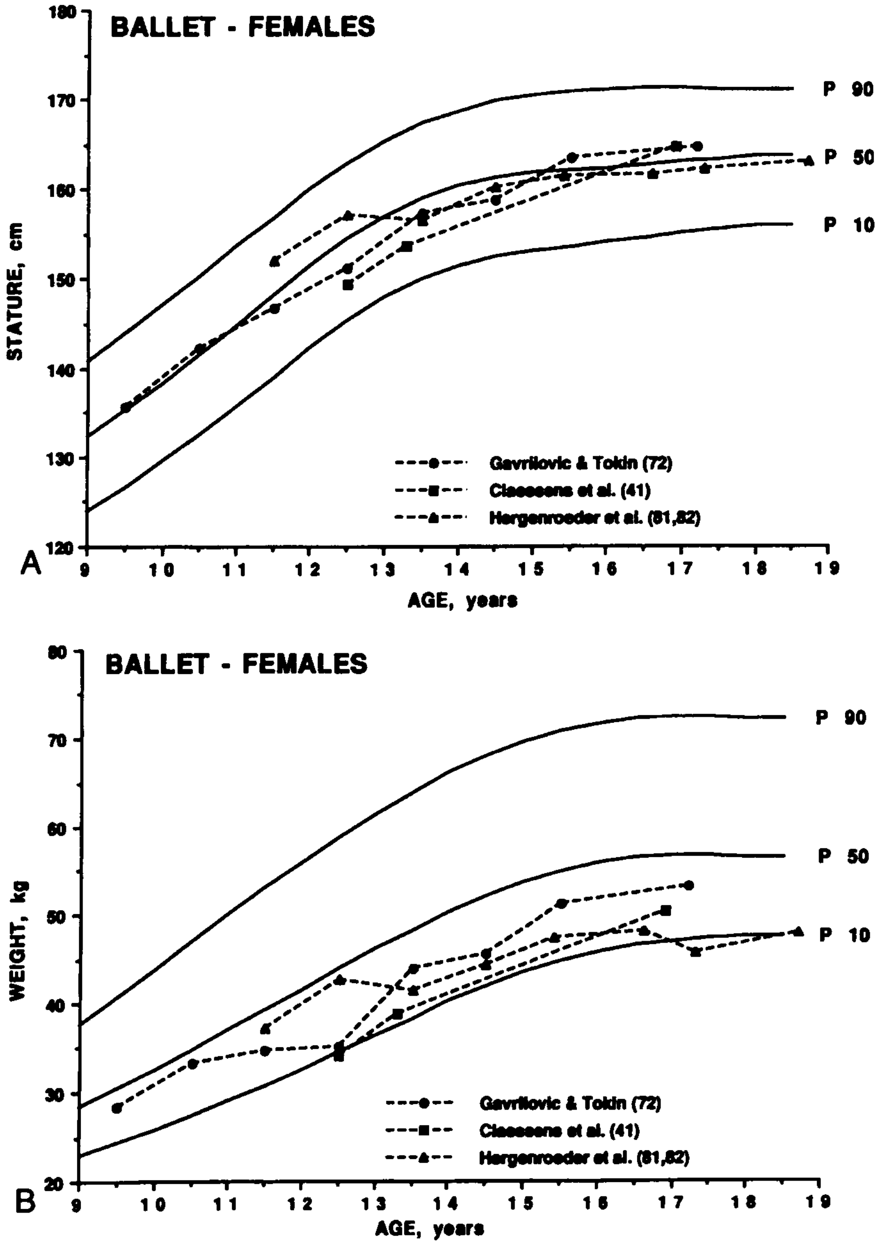
Weight Lifting
Statures of weight lifters 13–18 years are slightly below P 50 in early adolescence, but move toward P 10 in late adolescence [39, 64, 133, 135, 199]. In contrast, body weights, with few exceptions, are generally above the reference median. SAs of four 12-year-old Finnish weight lifters were delayed by about 0.5 years [135].

Ballet
FEMALES. Data for children and youth training in ballet are available primarily for females (Fig. 13.9). Statures of Yugoslav and U.S. dancers are near P 50, while those of younger Belgian dancers are below P 50, and that of older dancers is at P 50. In contrast, weights are below P 50, approximating P 10 at some ages. Late adolescent U.S. dancers have weights at P 10. The data of Warren [213] for select dancers (which are reported only graphically) indicate a similar pattern.

Maturation data for female ballet dancers are variable. Among a select group of Belgian ballerinas 11.8–13.6 years of age, 19 of 22 dancers had TW SAs that were within ± 1 year of CAs [41]. In contrast, 15 dancers, 12–15 years of age, training to become professional dancers in New York had SAs (method not specified) classified as delayed [213]. Only one of the 22 Belgian dancers had attained menarche [41]. Prospective data for the New York dancers indicated a mean age at menarche of 15.4 ± 1.9 years [213]. The New York sample was also quite delayed in breast and pubic hair development. Status quo estimates for two samples attending ballet schools in Novi Sad, Yugoslovia, gave median menarcheal ages of 13.6 and 14.1 years, which were later than local reference data by about one year [71, 72].

MALES. Small samples of Belgian (n=8) and U.S. (n=7) male ballet dancers 12–15 years of age had mean statures and weights below the reference medians [Claessens and Beunen, unpublished; 81, 82]. Four Belgian dancers (18.1 years) had a mean stature at P 50 but a mean weight at P 10, while U.S. dancers 16.7 (n=10) and 18.8 (n=11) years had statures

FIGURE 13.9
Statures and weights of female ballet dancers.



and weights at and above the respective medians. Six of the eight Belgian dancers had SAs (TW) within ± 1 year of CAs.

DOES TRAINING FOR SPORT INFLUENCE GROWTH AND MATURATION?

It is often assumed that regular physical activity, including training for sport, is important to support normal growth and maturation. Some have suggested that sport training may have a stimulatory or accelerating influence on growth and sexual maturation; more often, however, concern is expressed about potential negative influences of intensive training on growth and maturation, moreso in females than in males [114]. Others have suggested that regular training in swimming, track, ballet, and speed skating before menarche causes the late sexual maturation in these athletes [35, 65, 76, 213]. Concern about the potential influence of training for sport on the sexual maturation of girls was highlighted in a recent report of the American Medical Association and the American Dietetic Association [3, p. 4] which cautions:

> Some fitness programs may be detrimental to adolescents if they mandate prolonged, strenuous exercise and/or very low body fat to maximize their competitive edge . . . These regimes may delay sexual maturation, decrease bone growth and ultimate height. . .

In light of these views, how can the available data for young athletes in a variety of sports be interpreted?

GROWTH IN STATURE. Gymnastics is the only sport that presents a profile of short stature in both sexes. Figures skaters of both sexes and male divers and weight lifters also present, on average, short statures, though data are not extensive. Some samples of female ballet dancers indicate shorter stature during early adolescence, but late adolescent statures do not differ from the reference median. On the other hand, athletes of both sexes in other sports have, on average, statures that equal or exceed the reference median. And, in many of these sports, training is as intense as, or more intense than, training in gymnastics, figure skating, and ballet.

The data for gymnasts must be considered in the context of extremely selective criteria applied to this sport, including selection at an early age for small body size and physique characteristics associated with later maturation [8, 79]. The short stature of gymnasts is also familial. Their parents are significantly shorter than those of swimmers and nonathletes [161, 189]. Retrospective growth data also indicate that select gymnasts had statures that were about one standard deviation score below average by 2 years of age, long before they were nationally selected; recreational and locally select gymnasts were also smaller, about one-half of a standard deviation score, by 2 years of age [161]. The short stature is also related to later skeletal and sexual maturation; data on the age at PHV for gymnasts are not available. Longitudinal observations on elite East German male gymnasts from 12 to 14 years indicate similar gains in SA, CA, and stature, leading the authors to conclude that the delayed growth and maturation are "more a sequelae of selecting than caused by the influence of sports activities" [91, p. 18]. It is thus difficult to implicate the stress of training as the causative factor in the slower growth and smaller size of gymnasts.

Diet is a potentially confounding factor. For example, young East German female 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" [85, p. 98]. This may be chronic mild undernutrition. Other factors that may interact with marginal caloric status and perhaps altered eating habits merit closer attention. These may include the psychological and emotional stress associated with maintaining body weight when the natural course of growth is to gain, year-long training (often before school in the morning and after school in the late afternoon), frequent competitions, altered social relationships with peers, and perhaps overbearing and demanding coaches.

Gymnasts of both sexes are often described as having relatively short legs for their stature [24] or as having been selected for short limbs [85]. It is also suggested that growth rate of leg length is stunted in highly trained gymnasts [8, 190], leading to disproportionately short legs and short stature. However, cross-sectional data for several samples of male and female gymnasts, including three from international competitions, indicate sitting height/stature ratios that are quite similar to reference data for European and American white youth [30, 31, 43, 123, 219]. Although gymnasts are absolutely shorter, the results suggest similar proportional relationships of the legs and trunk relative to nonathletes. Longitudinal data that span late childhood through late adolescence are necessary to satisfactorily address this issue.

The size attained by athletes of both sexes in other sports does not appear to be affected by intensive training. Available longitudinal studies indicate mean statures that maintain their position relative to the reference values over time, and several short-term studies indicate growth rates in stature that are within the range of rates observed in the nonathlete population [115, 122, 159, 173].

MATURATION. Short-term longitudinal studies of boys and girls in several sports [91, 99, 150, 172] indicate similar gains in both SA and CA, which would imply no effect of training on skeletal maturation. Although methods for estimating PHV vary, the available data indicate no effect of training on the age at PHV in boys in several sports [11, 67, 95, 99, 114]. There are presently no corresponding estimates of age at PHV of young female athletes.

Sexual maturation data are more available for young female than male athletes. The data, however, are largely cross-sectional, so inferences about the effects of training are hazardous. Prospective studies of female gymnasts [190, 219] and ballet dancers [213] indicate later ages at menarche. Status quo estimate for Hungarian [54] and world class [43] gymnasts give a similar late age at menarche, while those for girls in Yugoslav ballet schools [71, 72] are earlier. The late menarche and late attainment of adult stature in select ballet dancers [213] is similar to the pattern of growth characteristic of late-maturing children [119]. Like gymnastics, ballet has rigid selection criteria that place an emphasis on thinness and linearity [78], and significant numbers of young ballerinas have eating problems [76].

Later mean ages at menarche are commonly reported for late adolescent and adult athletes [16, 18, 111, 113, 119]. Standard deviations are about one year or more; hence, it is important to note that not all athletes experience menarche late. These data are retrospective and are thus limited to some extent by error of recall. Status quo data for Hungarian [54] and world class [43] gymnasts and Junior Olympic divers [122] are generally consistent with the retrospective data, but status quo estimates for track athletes [61] and age-group swimmers (Malina, unpublished) are earlier than retrospective estimates. It is especially evident in swimmers. Data for young swimmers, Olympic swimmers, and national level swimmers from several countries, collected in the 1950s–1970s, indicate mean ages at menarche that approximate the mean of the general population [111]; however, university level swimmers from elite programs in the U.S. in the mid-1980s had mean ages at menarche of 14.3 and 14.4 years [113, 181]. This trend probably reflects enhanced opportunities for girls in swimming. In the 1950s–1970s, it was common for female swimmers to retire by 16–17 years of age. With the advent of Title IX legislation in the U.S., many universities added and/or improved their swim programs so that more opportunities were available. Also, later-maturing age-group swimmers, catching-up to their peers in size and strength in late adolescence, probably experienced more success in swimming and persisted in the sport. Another factor may be change in the size and physique of female swimmers. A comparison of university level female swimmers in the late-1980s with those in the mid-1970s indicated that the former were taller and more linear (Malina, unpublished), a physique characteristic of later maturers.

The later recalled mean ages at menarche of athletes in a variety of sports and correlations with years of training before menarche are often used to infer that training prior to menarche "delays" this physiological event. Association does not imply a cause-effect sequence between training and sexual maturation. Further, athletes who take up regular training in a sport after menarche are excluded. Other factors known to influence menarche also need to be considered. For example, there is a familial tendency for later maturation in athletes. Mothers of ballet dancers [23] and university level athletes in several sports [125] attain menarche later than mothers of nonathletes, and sisters of elite swimmers [181] and university athletes [125] attain menarche later than average. Ages at menarche of the mothers and sisters are not as late as those of the athletes. Mother-daughter and sister-sister correlations in families of athletes are similar to those for the general population [125]. Another factor is number of siblings in the family. Girls from larger families tend to attain menarche later than those from smaller families, and the estimated magnitude of the sibling number effect is similar in athletes and nonathletes [113].

In adequately nourished individuals, sexual maturation is a genotypically mediated process. Linearity of physique is associated with later maturation in both sexes, and some sports select for this characteristic of body build. Dietary practices associated with an emphasis on thinness or an optimal weight for performance may possibly influence growth and maturation, especially if they involve energy deficiency for prolonged periods. The demands of training compete with those of growth and maturational processes for available energy. Psychological and emotional stresses associated with training and competition are additional concerns. Nevertheless, if training for sport is related to later menarche, it most likely interacts with or is confounded by other factors, so that the specific effect of training per se may be impossible to extract. In the vast majority of athletes, intensive training for sport has no effect on growth and maturational processes.

ACKNOWLEDGMENTS

I would like to thank the following colleagues for providing raw data and/or unpublished data for use in this review: Gaston Beunen and Albrecht Claessens of the Catholic University of Leuven, Claude Bouchard of Laval University, Albert Hergenroeder and William Klish of the Baylor College of Medicine, Georges Lariviere of the University of Montreal, Michael Little of the State University of New York at Binghamton, and Joel Stager of Indiana University.

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