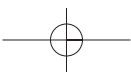
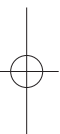
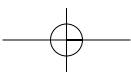
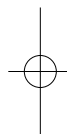
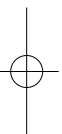
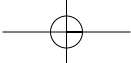


# Part 1

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## Growth, Maturation, and Physical Performance





# Chapter 1

## Growth and Biologic Maturation: Relevance to Athletic Performance

GASTON BEUNEN AND ROBERT M. MALINA

Growth refers to measurable changes in size, physique and body composition, and various systems of the body, whereas maturation refers to progress toward the mature state. Maturation is variable among bodily systems and also in timing and tempo of progress. The processes of growth and maturation are related, and both influence physical performance.

Chronologic age (CA) is the common reference in studies of growth and performance. However, there is considerable variation in growth, maturity, and performance status among individuals of the same CA, especially during the pubertal years.

Interrelationships among growth, maturation, and performance during childhood and adolescence are the focus of this chapter. It specifically considers:

- 1 Age-, sex-, and maturity-associated variation in physical performance;
- 2 Growth and maturity characteristics of young athletes;
- 3 The influence of training on growth and maturation; and
- 4 Matching of opponents for sport.

### Overview of growth and performance

#### Somatic growth

Growth in stature is rapid in infancy and early childhood, rather steady during middle childhood, rapid during the adolescent spurt, and then slow as adult stature is attained. This pattern of growth (size-attained and rate) is generally similar for body weight and other dimensions with the exception of

subcutaneous fat and fat distribution. The growth rate of stature is highest during the first year of life then gradually declines until the onset (take-off) of the adolescent growth spurt (about 10 years in girls and 12 years in boys). With the spurt, growth rate increases, reaching a peak (peak height velocity, PHV) at about 12 years in girls and 14 years in boys, and then gradually declines and eventually ceases with the attainment of adult stature (Tanner 1962, 1978; Malina *et al.* 2004). There is evidence for a small mid-growth spurt in childhood in stature and probably in other dimensions in many, but not all, children (Malina *et al.* 2004; see Chapter 31). Daily, half-weekly, or weekly measurements of length and height indicate that growth is episodic rather than continuous over short periods (Lamp1 *et al.* 1992), although "mini growth spurts" superimposed on a continuous growth pattern have been suggested (Hermanussen *et al.* 1988).

#### Physical performance

Physical performance is commonly measured as the outcome (product) of standardized motor tasks requiring speed, agility, balance, flexibility, explosive strength, local muscular endurance, and static muscular strength.

Isometric strength increases linearly with age during childhood and the transition into adolescence in both sexes. At approximately 13 years, strength development accelerates considerably in boys (adolescent spurt), but continues to increase linearly in girls through about 15 years with less evidence for a clear adolescent spurt, although data

## 4 CHAPTER 1

vary among specific strength tests. Sex differences in strength are consistent, although small, through childhood and the transition into adolescence. Thereafter, the differences become increasingly larger so that at the age of 16 years and later only a few girls perform at the same level as the average boy. Among Belgian youth, for example, the median arm pull strength of 17-year-old girls falls below the corresponding third percentile for boys (Beunen *et al.* 1989). Strength is related to body size and muscle mass, so that sex differences might relate to a size advantage in boys. During childhood and adolescence boys tend to have greater strength per unit body size, especially in the upper body and trunk than girls, but corresponding sex differences in lower extremity strength are negligible. In fact, isometric strength in boys and girls increases during childhood and adolescence more than predicted from height alone (Asmussen & Heeboll-Nielsen 1955). The disproportionate strength increase is most apparent during male adolescence, and is greater in the upper extremities than in the trunk or lower extremities (Asmussen 1962; Carron & Bailey 1974).

Performance in a variety of standardized tests such as dashes (speed), shuttle runs (agility, speed), vertical and standing long jumps and distance throw (coordination and explosive strength), flexed arm hang and sit-ups (local muscular endurance), and beam walk and flamingo stand (balance) also improve, on average, from childhood through adolescence in boys. The performances in girls increase until the age of 13–14 years, with little subsequent improvement, although some more recent evidence suggests that the plateau for some motor tasks has shifted to a slightly older age. The growth pattern for flexibility differs. Mean scores in the sit and reach are stable or decline slightly during childhood, increase during adolescence, and reach a plateau at about 14–15 years in girls and decline from childhood through mid-adolescence and then increase in boys (Haubenstricker & Seefeldt 1986; Beunen & Simons 1990; Malina *et al.* 2004).

Performances of girls fall, on average, within 1 standard deviation (SD) below average performances of boys in late childhood and early adolescence, with the exception of softball throw for distance. However, after 14 years average performances of girls are

consistently beyond the bounds of 1 SD below the means of boys in most tasks. In contrast, girls are more flexible than boys at virtually all ages (Beunen *et al.* 1989; Malina *et al.* 2004).

Correlations between somatic dimensions and performance in motor tasks during childhood are generally low (0 to about 0.35). Performance in tasks in which the body is projected (jumps and dashes) correlates negatively and performance in tasks in which an object is projected (throws) correlates positively with body mass. Correlations during adolescence are of the same magnitude and in the same direction as during childhood (Malina 1975; Malina *et al.* 2004).

Most fitness test batteries include a direct or indirect estimate of aerobic power. Absolute aerobic power ( $\dot{V}O_{2\max}$ , L·min<sup>-1</sup>) increases from childhood through adolescence in boys, but reaches a plateau at 13–14 years of age in girls. Before the age of 10–12 years,  $\dot{V}O_{2\max}$  of girls reaches about 85–90% of the mean values of boys, but after the adolescent spurt average  $\dot{V}O_{2\max}$  in girls reaches only 70% of mean scores in boys (Krahenbuhl *et al.* 1985; Armstrong & Welsman 1994; Malina *et al.* 2004).

The dependence of aerobic power on body size during growth is indicated in the growth curve of relative aerobic power (i.e., per unit body mass, mL·kg<sup>-1</sup>·min<sup>-1</sup>). The values are rather stable throughout the growth period in cross-sectional samples of boys (Krahenbuhl *et al.* 1985), but trends in longitudinal samples suggest a decline through adolescence (Mirwald & Bailey 1986). On the other hand, relative  $\dot{V}O_{2\max}$  decreases systematically with age in girls (Krahenbuhl *et al.* 1985; Mirwald & Bailey 1986; Armstrong & Welsman 1994). Sex differences in relative  $\dot{V}O_{2\max}$  are generally smaller than in absolute  $\dot{V}O_{2\max}$ , with girls reaching 80–95% of boys' values. Several authors demonstrated that expressing  $\dot{V}O_{2\max}$  to body mass may confound the understanding of changes in oxygen uptake with growth and maturation (see Chapter 5). Power functions, allometric equations, and multilevel modeling have been used more recently. Results are mixed because of the various techniques used, the age ranges considered, and sample bias (Armstrong & Welsman 1994). When size and mass are included in the scaling, mass exponents close to the theoretical

scaling coefficient of  $k = 0.67$  are obtained (Armsstrong & Welsman 1994).

### Adolescent spurts in performance

Most data for performance are derived from cross-sectional samples which are inadequate for quantifying the timing and tempo of the adolescent growth spurt. Individuals pass through adolescence at their own pace and consequently have their growth spurts over a wide range of CAs, the so-called time-spreading effect (Tanner 1962). Only longitudinal or mixed longitudinal data properly analysed provide adequate information about tempo and timing of spurts in a variety of characteristics.

In addition to documenting the occurrence of growth spurts per se in performance, the timing of the spurts is ordinarily viewed relative to the timing of PHV (i.e., relative to a biologic milestone) rather than to CA. This serves to reduce the time spread along the CA axis and provides more specific information about the timing and magnitude of adolescent spurts in other body dimensions than height and in performance. Note that this concept was first realized by Boas (1892).

In such analyses, individual velocities for a body dimension or performance item are aligned on the individual's PHV so that growth rates are viewed in terms of years before and after the individual's PHV, regardless of the age at which PHV occurred. A mean constant velocity curve is obtained from these individual values in which the aligned individual values are combined. When mathematical functions are used, the mean-constant curve is obtained by fitting the function to each individual, estimating the constants for each individual, and then averaging the constants to yield the curve.

Longitudinal data show well-defined adolescent spurts in strength, several motor performances, and absolute aerobic power of boys. Corresponding data for girls are less extensive and show a spurt in absolute aerobic power while data for strength are variable.

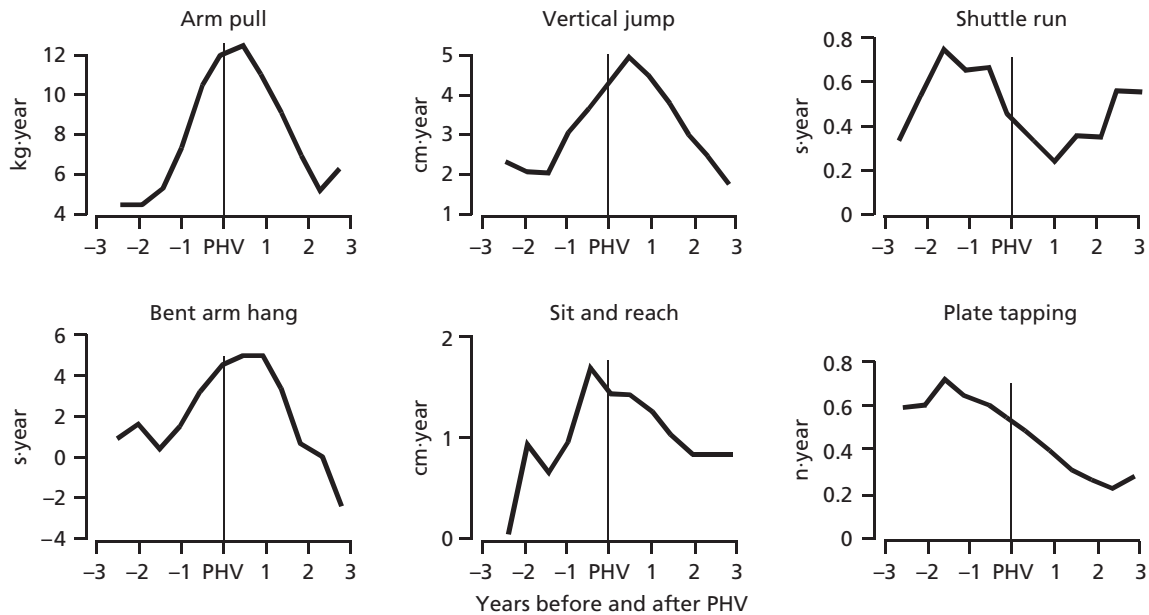
The male adolescent spurt in static strength occurs about 0.5–1.0 year after PHV and is more coincident with peak weight velocity (PWV) (Stolz & Stolz 1951; Carron & Bailey 1974; Kemper & Verschuur 1985; Beunen *et al.* 1988; Beunen & Malina 1988).

The strength spurt (arm pull) of Dutch girls occurs at about the same time as in boys, 0.5 years after PHV. Peak strength (arm pull) gain in boys is, on average, about  $12 \text{ kg}\cdot\text{year}^{-1}$  compared to  $6 \text{ kg}\cdot\text{year}^{-1}$  in girls. Among California girls, however, a composite strength score of four tests shows an inconsistent pattern; the spurt in strength preceded PHV in about 40% of the girls, coincided with PHV in 11%, and followed PHV in 49% (Faust 1977).

Half-yearly velocities for six performance tasks in Belgian boys are summarized in Fig. 1.1. On the average, peak velocities in static strength (arm pull), explosive strength (vertical jump), and muscular endurance (bent arm hang) occur after PHV. The adolescent spurt in these characteristics appears to begin about 1.5 years prior to PHV and reach a peak 0.5–1.0 year after PHV. In contrast, maximum velocities in speed tests (shuttle run and plate tapping) and flexibility (sit and reach) occur before PHV. The lower age limit in the Leuven Growth Study of Belgian boys, 12 years of age, does not permit an accurate estimate of the onset of the spurts in flexibility and speed. Results for small samples of Spanish boys ( $n = 18\text{--}27$ ) and girls are generally consistent with those observed for Belgian boys. The data for Spanish girls ( $n = 25\text{--}35$ ) are consistent with the trends for Belgian boys for strength and power, but the flexibility and speed tasks show peak gains after PHV which is in contrast to the findings in Belgian boys (Heras Yague & de la Fuente 1998). Data for girls are limited; however, when performance is related to age at menarche, which occurs on average after PHV, there is no tendency for motor performance to peak before, at, or after menarche (Espenschade 1940).

An overview of the timing in strength and motor performance relative to PHV, PWV, and peak strength velocity (PSV) is given in Table 1.1. Because PWV and PSV follow PHV, it is obvious that maximum velocities in running speed (shuttle run), speed of limb movement (plate tapping), and flexibility (sit and reach) also precede PWV and PSV. Maximum velocities in strength and muscular endurance follow PWV and coincide with PSV. The evidence thus indicates that during adolescence boys are first stretched (spurt in stature) and then filled-out (spurt in muscle mass, weight, and strength).

## 6 CHAPTER 1



**Fig. 1.1** Median velocities of several tests of strength and motor performance aligned on peak height velocity (PHV) in the Leuven Growth Study of Belgian Boys. Velocities for the performance items are plotted as years before and after PHV. Drawn from data reported by Beunen *et al.* (1988).

**Table 1.1** Timing of maximum observed velocities of several motor performance items relative to adolescent spurts in stature, body weight and arm pull strength in Belgian boys (after Beunen *et al.* 1988).

Performance	Height spurt			Weight spurt			Strength spurt		
	Precedes	Coincides	Follows	Precedes	Coincides	Follows	Precedes	Coincides	Follows
Arm pull			×			×			
Vertical jump			×			×		×	
Plate tapping	×			×			×		
Shuttle run	×			×			×		
Sit & reach	×			×			×		
Bent arm hang			×			×		×	

Absolute  $\dot{V}O_{2\max}$  ( $L \cdot \min^{-1}$ ) shows a clear adolescent spurt in both sexes in samples of Belgian and Canadian children (Mirwald & Bailey 1986; Geithner *et al.* 2004). Estimated peak velocities are greater in boys ( $1.01 L \cdot \min^{-1} \cdot \text{year}^{-1}$  in Belgian boys and  $0.41 L \cdot \min^{-1} \cdot \text{year}^{-1}$  in Canadian boys) than in girls ( $0.59 L \cdot \min^{-1} \cdot \text{year}^{-1}$  in Belgian girls and  $0.28 L \cdot \min^{-1} \cdot \text{year}^{-1}$  in Canadian girls). Note, however, that in the Belgian sample  $\dot{V}O_{2\text{peak}}$  reached a plateau or declined after reaching a maximal value. Corresponding data for Dutch (Kemper 1985),

German, and Norwegian (Rutenfranz *et al.* 1982) adolescents, although not analyzed in the same manner, suggest a similar trend. On average,  $\dot{V}O_{2\max}$  begins to increase several years before PHV and continues to increase after PHV.  $\dot{V}O_{2\max}$  per unit body mass ( $mL O_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ), on the other hand, generally begins to decline 1 year before PHV and continues to decline after PHV. The decline reflects the rapid changes in stature and body mass so that, per unit body mass, oxygen uptake declines during the growth spurt. The significance of relative

aerobic power as expressed per body weight or other body dimensions can be questioned because the relationships between aerobic power and several body dimensions and systemic functions during growth are complex. Relative aerobic power masks the sex-specific changes in body composition, size, and function. Changes in relative aerobic power during adolescence probably reflect changes in body composition and not changes in aerobic function, which increases at this time. Power functions, allometric equations, and multilevel modeling have been used to scale changes in aerobic function during adolescence (Armstrong & Welsman 1994; Beunen *et al.* 2002; see Chapter 5). Although  $\dot{V}O_{2\text{peak}}$  is associated with biologic maturity status after controlling for height and weight (Armstrong & Welsman 2000), studies utilizing multilevel modeling do not provide at present additional information about changes in  $\dot{V}O_{2\text{peak}}$  normalized for height and/or weight relative to the timing of the adolescent growth spurt.

### **Maturity-associated variation in performance**

Individual differences in maturity status at a given age and in the timing of the adolescent spurt influence growth status and performance. Moreover, youth who are successful in sport tend to differ, on average, in maturity status and rate compared with the general population. It is thus important to review maturity-associated variation in performance.

Variation in maturity status influences body dimensions, composition and proportions, and also performance. The effect of variation in maturity status can operate through associated variation in body size and/or composition and through a direct influence on performance. Maturity-associated variation in somatic growth is discussed in more detail elsewhere (Malina *et al.* 2004). The subsequent discussion focuses on the influence of variation in maturity status on performance, summarizing first correlational analyses and then comparisons of youth of contrasting maturity status.

Correlations between skeletal age (SA) as one indicator of maturity and several indicators of motor

performance, including tests of speed, flexibility, explosive strength or power, and muscular endurance, range from low to moderate in children and adolescents (Espenschade 1940; Seils 1951; Rarick & Oyster 1964; Beunen *et al.* 1981b, 1997a; Malina *et al.* 2004). Static strength is positively correlated with SA at all ages in pre-adolescent boys and girls, while muscular endurance (functional strength or dynamic strength) is negatively correlated to SA in adolescent girls 11–13 years and boys 12–13 years of age. The negative associations reflect the negative influence of body weight at this time. In boys, from 14 years onwards all gross motor abilities are positively associated with SA. The greater strength that accompanies male adolescence compensates for the higher body weight so that from 14 years positive associations are apparent between SA and muscular endurance.

More comprehensive analyses considering the interactions of CA, SA, height, and weight indicate that variation in maturity status influences performance indirectly. Among children 7–12 years of age, skeletal maturity status influenced strength and motor performance mainly through its interaction with size and body mass (Katzmarzyk *et al.* 1997). Among 6- to 11-year-old girls, SA by itself appeared only sporadically among the predictors of performance (Beunen *et al.* 1997a). Among adolescent boys, CA and SA by themselves or in combination with height and body mass accounted for a small percentage (0–17%) of the variance in speed, flexibility, explosive strength, and muscular endurance, but for static strength the explained variance was as high as 58% (Beunen *et al.* 1981b). The corresponding analyses of adolescent girls indicated a significant influence of the interaction between SA and body size on static strength (up to 33% of explained variance), but relatively little influence (generally, less than 10%) on motor performance (speed, flexibility, explosive strength, and muscular endurance). By inference, the results may suggest an important role for variation in neuromuscular maturation as a factor influencing performance during childhood. Skeletal maturity perhaps does not reflect neuromuscular maturation and probably exerts its influence on performance through associated variation in somatic features.

## 8 CHAPTER 1

In a longitudinal analysis of boys and girls of contrasting maturity status (Jones 1949; see also Malina *et al.* 2004), early maturing boys had higher muscular strength than late maturing boys at all ages between 11 and 17 years, while early maturing girls performed only slightly better than late maturing girls only in early adolescence (i.e., 11–13 years of age). Subsequently, there were no differences in strength among girls of contrasting maturity status. Associations among various maturity indicators and measures of static or isometric strength have consistently documented a positive relationship between maturity status and strength in boys and girls (Clarke 1971; Carron & Bailey 1974; Beunen *et al.* 1981b; Bastos & Hegg 1986; Malina *et al.* 2004).

Motor performances (vertical jump, sit and reach, shuttle run, plate tapping) of early maturing boys grouped by age at PHV, are, on average, better than those of average and late maturing boys of the same age from 12 to 18 years, with the exception of the flexed arm hang (Lefevre *et al.* 1990). Controlling for body size reduces some of the differences between adolescent boys of contrasting maturity status, but the advantage for early maturing boys persists in strength and power tasks compared to speed tasks (Beunen *et al.* 1978). Among adolescent girls, on the other hand, maturity-associated variation in performance is not consistent among tasks and from age to age (Beunen *et al.* unpublished data [see Malina *et al.* 2004]; Little *et al.* 1997).

Some evidence for boys suggests the performance advantage associated with early maturation disappears at adult age (Lefevre *et al.* 1990). Performances of 30-year-old men grouped on the basis of their age at PHV do not significantly differ for static strength (arm pull), muscular endurance of the lower trunk (leg lifts), running speed (shuttle run), and flexibility (sit and reach). However, early maturers still perform better at 30 years for speed of limb movement (plate tapping), while late maturers perform better in muscular endurance of the upper body (bent arm hang) and explosive strength (vertical jump). The results also indicate that late maturing males improve significantly in performance between 18 and 30 years, more so than early or average maturing males (Lefevre *et al.* 1990).

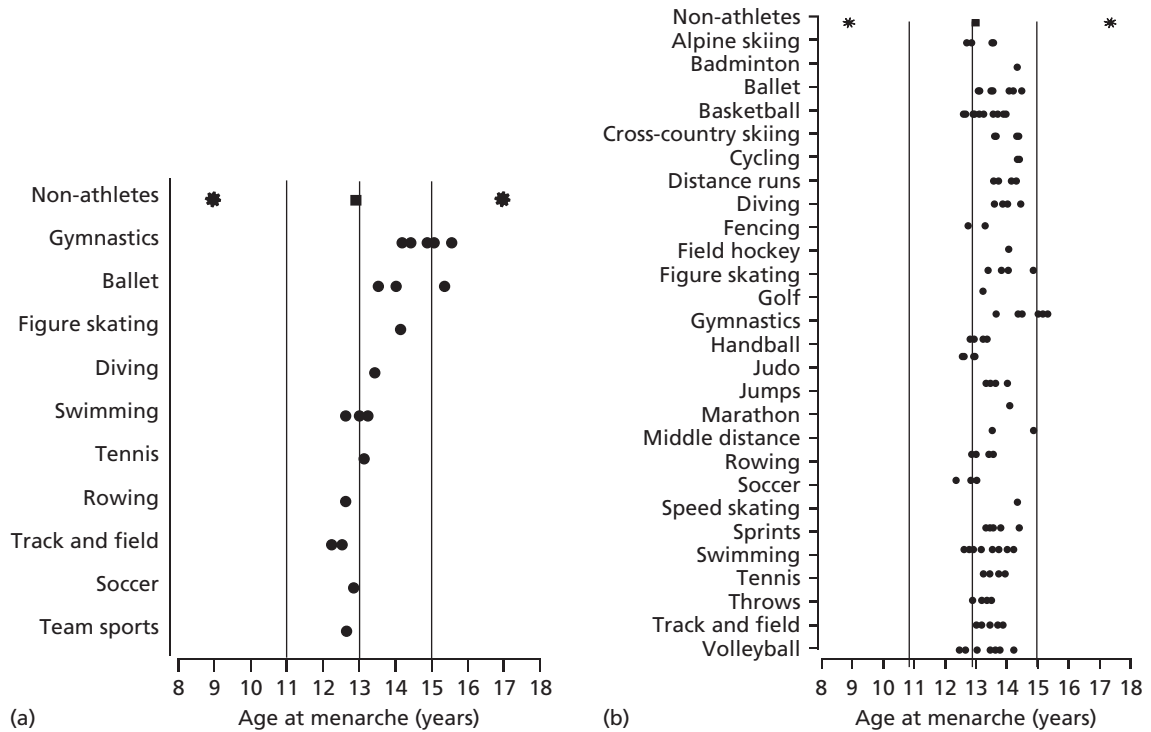
Skeletal maturation and absolute aerobic power are significantly related. The correlations are higher (0.89) when a broad age range, 8–18 years, is considered (Hollmann & Bouchard 1970) compared to a narrower range, 8–14 years (0.55–0.68; Labitzke 1971). When  $\dot{V}O_{2\max}$  is expressed per kilogram body mass, correlations are not significant (Hollmann & Bouchard 1970; Labitzke 1971; Savov 1978; Shephard *et al.* 1978). Non-significant and generally lower associations are apparent between several indices of submaximal performance capacity and maturity status, except around the growth spurt in boys when correlations are higher (Hebbelinck *et al.* 1971; Kemper *et al.* 1975; Bouchard *et al.* 1976, 1978). In a national sample of Belgian girls, submaximal power output (PWC) at heart rates of 130, 150, and 170 beats·min<sup>-1</sup> is significantly related to skeletal maturation. The correlations generally increase with age and reach a maximum between 11 and 13 years (Beunen 1989).

Early maturing boys have, on average, a higher absolute  $\dot{V}O_{2\max}$  than late maturing boys except in late adolescence. A similar trend is evident for early and late maturing girls, but the differences are smaller than in boys. On the other hand, relative  $\dot{V}O_{2\max}$  is higher in late maturers of both sexes (Kemper *et al.* 1986; Malina *et al.* 1997). This observation most probably reflects the higher absolute and relative fatness of early maturing girls. However, among boys, early maturers have an absolutely larger fat-free mass and relatively less fat mass than late maturers. The better relative  $\dot{V}O_{2\max}$ , expressed per kilogram body mass, of late maturers more likely reflects the rapid growth of body mass with advancing maturation, so that oxygen uptake per unit body mass becomes progressively less. Allometric analyses indicate that early maturing boys have higher coefficients for body mass and height compared with average and late maturing boys. In girls from 11 to 14 years the increase in  $\dot{V}O_{2\text{peak}}$  is not associated with increases in body mass or stature (Beunen *et al.* 1997b; Malina *et al.* 2004).

### Maturity status of elite young athletes

The biologic maturity status of athletes has been studied rather extensively, especially age at menarche.





**Fig. 1.2** Mean ages at menarche in athletes grouped by sport. (a) Prospective and status quo studies. (b) Retrospective studies. Assuming a mean age at menarche of  $13.0 \pm 1.0$  years for non-athletes, about 95% of girls will attain menarche between 11.0 and 15.0 years of age. These ages are indicated by vertical lines in the figure; the range of reported ages at menarche in a large sample of university students who were non-athletes, 9.2–17.2 years of age, is also indicated with asterisks.

The subject has been reviewed by Beunen (1989), Malina (1983, 1994a, 1998a, 2002), and Malina *et al.* (2004). Studies of young athletes have a number of limitations. First, the definition of an athlete is vague and a wide variety of skill and competitive levels are represented. Second, young athletes are a highly selected group, not only with regard to skill and performance level, but also with regard to size and physique. The selection may be made by the individual, parents, coach, influential others, or some combination of these. Third, earlier maturation is intrinsically related to growth in size and both are associated with performance. Finally, athletic performance is influenced by many factors, many of which are not biologic.

Age at menarche is the maturational landmark most often studied in elite athletes (Malina 1983, 1991, 1998b, 2002). Mean ages at menarche based

on longitudinal and status quo studies of adolescent athletes, and on retrospective ages at menarche of older adolescent and young adult athletes are summarized in Fig. 1.2. Data collected by questioning adolescent athletes are limited (Fig. 1.2a). Most samples of adolescent athletes have mean or median ages at menarche within the normal range, but mean ages for samples of adolescent gymnasts, ballet dancers, figure skaters, and divers tend to be later than those of athletes in other sports. It should be noted that the samples of adolescent athletes are rather small, which suggests that more data are needed. Mean recalled ages at menarche for late adolescent and young adult athletes are more extensive (Fig. 1.2b). The majority of mean ages are above 13.0 years, but variation within and between sports is apparent. The retrospective data for gymnasts, divers, ballet dancers,

and soccer players are generally consistent with the longitudinal or status quo data (Fig. 1.2a). Differences between ages at menarche in younger and older athletes in a given sport merit attention. For tennis, rowing, track and field, and swimming the longitudinal or status quo data show earlier ages at menarche than the retrospective data. Allowing for error of recall associated with the retrospective method, data suggest that late adolescent and young adult athletes in these sports tend to attain menarche later than athletes involved in the same sports during the circumpubertal years (prospective and longitudinal data). This trend is especially apparent in swimmers. Status quo and retrospective data indicate mean ages at menarche that approximate the mean of the general population; however, retrospective data for university level swimmers indicate later mean ages at menarche, 14.3 and 14.4 years. This trend reflects, in part, more opportunities for adolescent girls in swimming, most probably because of improved or additional swim programs at university level (Title IX legislation). A related factor is differential success of later maturing girls in the sport at more advanced competitive levels (Malina *et al.* 2004).

Data for other maturity indicators in female athletes are less extensive (Beunen 1989; Malina *et al.* 2004). Local level age group athletes and non-athletes do not differ in the distributions of stages 2–4 of breast and pubic hair development (Plowman *et al.* 1991). Gymnasts are not as advanced in both breast and pubic hair development compared with swimmers or control subjects of the same age, who do not differ from each other (Bernink *et al.* 1983; Peltenburg *et al.* 1984). Among 113 gymnasts competing at the 1987 World Championships at Rotterdam, the SA–CA difference was –1.9 years, indicating late maturation (Claessens *et al.* 1991). These observations are consistent with earlier reports documenting slower maturation in female gymnasts (Novotny & Taftlova 1971; Beunen *et al.* 1981a). In a small sample of ballet dancers ( $n = 15$ ) followed from 12 to 15 years, breast development occurred at later ages, while pubic hair developed at expected ages (Warren 1980). In contrast, among 30 girls training in rowing and light athletics in Polish sport schools (about 8–12 hours-week<sup>-1</sup>) and followed

longitudinally from 11 to 14 years, breast and pubic hair development, age at menarche (prospectively obtained), and estimated growth velocities did not differ from reference data for the general population (Malina *et al.* 1990).

With few exceptions, male athletes of different competitive levels in various sports are characterized by average or advanced biologic maturity status. Whatever the biologic maturity indicator used or the competitive level considered, the evidence points in the same direction (Beunen 1989; Malina 1998a, 2002; Malina *et al.* 2004). Boys average and advanced in maturity status tend to be overrepresented among young athletes. The most marked advancement in maturity status occurs in adolescence, which is probably a result of the size, physique, fat-free mass, and performance (strength, power, speed) advantages of the early maturers. This advantage is reduced as boys approach late adolescence or early adulthood, when late maturers catch up or even tend to outperform the early maturers (see above). In a select national sample of Belgian male track athletes, all 15- to 16-year-olds except one had an SA in advance of CA. Among 17- to 18-year-old athletes, about two-thirds had an SA equal to or in advance of that expected for CA, while one-third had an SA that was less than their CA (Malina *et al.* 1986). The statures of 16-year-old athletes advanced in SA, of 17- to 18-year-old athletes who had already attained skeletal maturity, and of 17- to 18-year-old athletes who had reached skeletal maturity did not differ, although athletes 16–18 years old advanced in skeletal maturity were heavier. Although the data are cross-sectional, the trend suggests catch-up in stature of those late in skeletal maturation, but persistent differences in body weight.

### Training and the growth and maturation of young athletes

Training refers to systematic, specialized practice for a specific sport or sport discipline for most of the year or to specific short-term experimental programs. Physical activity is not the same as regular training. The measurement, quantification, and specification of training programs by sport need further attention. Training programs are ordinarily

specific (e.g., endurance running, strength training, sport skill training) and vary in intensity and duration.

Many of the changes attributed to regular training, although not all, are in the same direction as those that accompany normal growth and maturation. It is difficult to partition training effects from those of normal growth and maturation in the currently available data. Many studies of young athletes tend to focus on training per se and overlook other factors that are capable of influencing growth and maturation. An obvious factor is selection; young athletes in many sports are rigorously selected for specific morphologic and maturational features. Allowing for these caveats, a discussion of training, growth, and maturation follows.

### **Growth in stature**

Longitudinal data for young athletes that span childhood and adolescence are extremely limited. Data for active and inactive boys followed from late childhood through adolescence indicate no differences in stature, while corresponding data for boys active in several sports indicate statures consistent with average to advanced maturity status (Beunen *et al.* 1992; Malina 1994a,b; Malina & Bielicki 1996). Longitudinal data for girls are less extensive. Girls regularly active in a variety of team and individual sports (track, rowing, swimming, basketball, volleyball) present a pattern of growth that is characteristic of average maturing individuals (Malina 1994a,b; Malina & Bielicki 1996). Young female athletes in a variety of sports tend to have less weight-for-height than non-athletes, suggesting a linear and lean build. There is, of course, variation by event and/or position within a sport. This is especially evident in track and field. Mean heights of adolescent female distance runners and sprinters 10–18 years of age tend to be at or above reference medians; mean weights of distance runners are consistently below the reference medians, while those of sprinters are generally quite close to the medians. Distance runners thus have less weight-for-height. Data for jumpers and throwers indicate greater heights in jumpers than throwers, and greater weights in throwers than jumpers. The heights of jumpers and throwers

often exceed the 90th percentiles; in contrast, mean weights of the throwers are close to or above the 90th percentiles, while those of the jumpers are at or above the reference medians (Malina 2004).

Available short- and long-term longitudinal data indicate mean statures that maintain their position relative to the reference values over time, which suggests that they are not apparently influenced by the regular training for sport. Short-term longitudinal studies of male and female athletes in a variety of sports (volleyball, diving, distance running, track, basketball, rowing, cycling, ice hockey) indicate growth rates within the range expected for non-athletes (Malina 1994a,b). Intensive training for distance running has received considerable scrutiny, but longitudinal data indicate growth rates in male and female runners similar to those for reference values for non-athletes (Eisenmann & Malina 2002; Malina 2004).

In the context of these short- and long-term longitudinal observations, and allowing for selective criteria in some sports, regular participation in sport and training for sport has no apparent effect on attained stature and rate of growth in stature. Nevertheless, it is consistently suggested that regular gymnastics training “blunts” growth velocities in female gymnasts with the inference that the adolescent growth spurt is also “blunted” (Theintz *et al.* 1993; Daly *et al.* 2005). These conclusions are based on samples of female gymnasts followed over short periods (2.0–3.7 years) that do not cover the age span needed to capture the adolescent growth spurt in individual girls (see below).

### **The adolescent growth spurt**

Age at PHV is not apparently affected by regular physical activity and training for sport. The observations for male athletes are consistent with the data for SA (i.e., ages at PHV tend to occur early or close to the average in male athletes). Available data for female athletes indicate ages at PHV that approximate the average (Malina *et al.* 2004). Longitudinal data for females in ballet, figure skating, and diving, sports in which later maturing girls commonly excel during adolescence, are insufficient to estimate ages at PHV. Samples of ballet dancers show shorter

statures during early adolescence, but late adolescent statures that do not differ from non-dancers (i.e., later attainment of adult stature) (Malina 1994a). This is a growth pattern characteristic of late maturers (Malina *et al.* 2004).

Data for gymnasts of both sexes indicate later ages at PHV (Malina 1999; Thomis *et al.* 2005). The parameters of the adolescent spurt in male and female gymnasts are similar to those for short, but healthy, late maturing children with short parents (Malina 1999). Nevertheless, it has been suggested that the adolescent growth spurt in female gymnasts is “blunted” or absent (Theintz *et al.* 1993; Daly *et al.* 2005). Note that the inference of growth “blunting” is not discussed for male gymnasts who, relative to reference data for males, are as short as and later maturing as female gymnasts (Malina 1994a, 1999). As noted, the duration of the studies of female gymnasts was not sufficient to accommodate the entire duration of the growth spurt which leads to biased estimates of PHV and age at PHV (Zemel & Johnston 1994). Individually fitted growth curves for 13 female gymnasts followed, on average, from 8.7 to 15.5 years, indicate a later age at PHV compared to a reference for the general population (Thomis *et al.* 2005). Estimated peak velocities of growth in height, leg length, and sitting height are only slightly less than in non-athletes and well within the range of normal variability (Malina *et al.* 2004).

### **Skeletal maturation**

Skeletal age does not differ between active and inactive boys followed longitudinally from 13 to 18 years (Beunen *et al.* 1992). In boys active in sport, SA and CA show similar gains prior to the adolescent spurt, but SA progresses faster than CA during the growth spurt and puberty in boys, reflecting their advanced maturity status. In a corresponding sample of girls active in sport, SA and CA progress at the same pace from late childhood through the growth spurt and puberty (Malina & Bielicki 1996). Although young athletes in several sports, including gymnasts of both sexes, differ in skeletal maturity status, short-term longitudinal observations indicate similar gains in both SA and

CA (Malina 1994a, 1998a). The data thus imply no effect of training for sport on skeletal maturation of the hand and wrist.

### **Sexual maturation**

The pubertal progress of boys and girls active in sport is similar to the progress observed in boys or girls not active in sport. The effect of training for sport on the sexual maturation of boys has not generally been considered. This may not be surprising because early and average maturation are characteristic of the majority of young male athletes. Wrestling is the primary sport among males that has an emphasis on weight regulation. The emphasis on weight control, however, is short term, and longitudinal observations over a season indicate no significant effects on maturation and hormonal profiles (Roemmich & Sinning 1997a,b).

Later mean ages at menarche in young gymnasts, figure skaters, and ballet dancers, and in late adolescent and adult athletes in many sports are often attributed to regular training for the respective sports (Malina 1983, 1991, 1998b, 2002). Although some data are prospective, the majority are status quo and retrospective, which does not permit establishment of causality. Many biologic and environmental factors are related to the timing of menarche (e.g., genotype, diet, family size, family composition and interactions, stress) (Clapp & Little 1995; Ellis 2004; Malina *et al.* 2004). Given the complexity of factors, it is essential that they be considered before inferring causality for training before and/or during puberty as a factor influencing the timing of menarche in presumably healthy adolescent athletes (Loucks *et al.* 1992; Clapp & Little 1995). The conclusion of a comprehensive evaluation of exercise and female reproductive health merits attention in this regard: “it has yet to be shown that exercise delays menarche in anyone” (Loucks *et al.* 1992, p. S288).

The available evidence thus suggests that regular training for and participation in sport do not affect growth in stature, the timing and magnitude of PHV, and skeletal and sexual maturation in young athletes. In contrast to the commonly used indicators of growth and maturation, systematic training has potentially beneficial effects on body composition

and specific tissues—skeletal (bone), skeletal muscle and adipose—but discussion of these is beyond the scope of this chapter (Malina *et al.* 2004). Functional effects of systematic training also have implications for performance. Resistance and aerobic training leads to improvements in muscular strength and maximal aerobic power, respectively, in youth of both sexes, while improvements in sport-related skills associated with sport-specific training have not been systematically evaluated although are often taken for granted (Malina *et al.* 2004).

### Matching opponents in youth sports

Youth sport programs are ordinarily structured into chronologic age categories. Given the wide range of variation in body size, body composition, biologic maturation, physical performance, skill, psychosocial characteristics, personality, and behaviour among children of the same age and especially in the transition from childhood to adolescence, attempts to equalize competition are often discussed and occasionally attempted. Nevertheless, size, maturity, strength, performance, and skill mismatches are rather common in spite of attempts to equate participants for competition. The potential competitive inequity and perhaps risk for injury associated with such mismatches are especially evident in contact and collision sports (for a classification of contact and collision sports see American Academy of Pediatrics 1988). Matching participants by size and biologic maturity has often been proposed as a means for reducing differences in size, strength, motor performance, and skill (e.g., Gallagher 1969; Seefeldt 1981; Caine & Broekhoff 1987).

### Matching criteria

Children and adolescents are ordinarily grouped for sport by CA and sex. As noted, interindividual variation in body dimensions, biologic maturity, body composition, physical performance, and skill is considerable within a single chronologic year (e.g., 10.0–10.99 years).

The limitation of CA for grouping youth was already recognized by Crampton (1908) and Rotch (1909). Although Crampton did not specifically refer

to sport (his focus was child labor), he advocated the use of “physiological age” based on the development of pubic hair; Rotch, on the other hand, advocated “anatomical age” based on X-rays of the carpals and indicated the potential utility of this approach for sport.

Sports vary with season of the year and this implies differential cut-off dates to define age for a given season. Participants born after the cut-off date are grouped in a younger age category than those born before the cut-off date. Moreover, coaches tend to select participants who are born in the months immediately after the cut-off date.

Although matching participants by size and/or biologic maturation is often proposed, matching by size or biologic maturity status independent of CA is misleading; CA, size, and biologic maturity status are highly interrelated. Matching by body mass is common in some sports (e.g., American football, weight lifting, judo, and wrestling). Weight categories are often quite broad so that mismatches are still possible. Moreover, some American youth football programs place weight limits on primary ball carriers (offensive players). The rationale for limiting body weight of ball carriers is that a markedly heavier athlete will not be able to run into a lighter athlete playing on defense. However, the weight limitation on ball carriers does not apply for any defensive position (i.e., a heavier player could run into a lighter player while making a tackle).

The most commonly used indicators of biologic maturity are secondary sex characteristics (see Chapter 31; Malina *et al.* 2004). An important issue is the invasiveness of the assessment of sexual maturity, although self-assessments are available. The question remains which indicators should be used (pubic hair, genital development in boys; pubic hair, breast development, or age at menarche in girls)? Although these indicators are correlated there is considerable variation in the tempo of the transition from one stage to the next stage and in the sequence of the stages and indicators (Malina *et al.* 2004). This variation presents a practical problem. If secondary sex characteristics are used to group participants, how are changes in status that occur during a season taken into consideration? It is likely that some participants will change in status quite quickly over a

season whereas others will remain in the same stage leading again to potential mismatches.

SA is the best single indicator of biologic maturity because it spans childhood and adolescence (Tanner 1962; Malina *et al.* 2004). However, it requires an X-ray of the hand and wrist with, although minimal, exposure to radiation. It is certainly not to be recommended for use on a large scale in youth sports. An alternative could be to use percentage of adult height as a criterion, which implies the prediction of mature height, or the prediction of maturity-offset from age at PHV (see Chapter 31). Similar variability in tempo of biologic maturation in SA, percentage of mature height and maturity offset can be expected as for secondary sex characteristics, which presents a practical problem for the matching process.

While matching based on secondary sex characteristics, SA, or other valid indicators of biologic maturity may be a practical tool for equitable matching in youth sports, it may not necessarily be accurate or valid for matching opponents on behavior and psychologic factors. A younger physically mature athlete may be matched with older athletes, who are biologically similar but psychologically more mature and tactically more proficient as a result of longer experience. Potential psychologic effects associated with moving up (e.g., increased competitive stress, behavioral insecurity) or moving down (e.g., drop-out, lower self-esteem) associated with maturity matching also need to be considered (Hergenroeder 1998; Kontos & Malina 2003).

The prudent implementation of matching using a combination of physical size and maturity, as well as psychologic, behavioral, and other factors, needs to be more systematically evaluated. In spite of being logistically difficult to implement, a matching system, if implemented properly, may be beneficial to equalizing competition, to maintaining interest in participation, and to reducing potential for injury (Kontos & Malina 2003).

In the context of national or international competition in early entry sports (e.g., gymnastics, diving, tennis, and figure skating) the issue of CA and biologic age limits needs careful evaluation. Should biologic age limits be imposed (e.g., skeletal age of 15 years)? Such changes may be desirable for the

sake of the health and well-being of the children involved.

### Challenges for future research

Longitudinal or mixed longitudinal studies of growth and performance (strength, motor, aerobic, anaerobic) on sufficiently large samples of female adolescents are needed. Mixed longitudinal studies are recommended because information can be collected over a shorter period, but such studies need to be carefully planned to include cohorts that are followed over a short period but are selected so that they overlap in time (Goldstein 1979). Control for test or learning effects needs to be built into the study design (van't Hof *et al.* 1976).

The impact of intensive training on saltatory growth (Lampl *et al.* 1992) and/or mini-growth spurts (Hermanussen *et al.* 1988) needs evaluation.

Muscular strength and endurance and aerobic power show well-defined adolescent spurts in boys. Can performance be enhanced by training during the spurts? This question implies that knowledge about somatic growth and maturation be incorporated into experimental studies of various training programs.

There is need for prospective longitudinal studies of youth training for different sports from the prepubertal years through puberty. Such studies should include a variety of somatic, maturity, and performance characteristics together with specific information about training programs, nutrition, and hormonal secretions.

For issues that require invasive methods, animal models that closely replicate the human situation may permit experimental control of intervening variables.

The genetic determination of physical performance capacities and genotype–environment interactions (training, physical activity, nutrition) needs study in children and youth.

In the context of national or international competitions in early entry sports (e.g., gymnastics, diving, tennis, and figure skating), the issue of age limits—chronologic and/or biologic—needs consideration. Should biologic age limits be imposed? Such changes may be desirable for the sake of the health and well-being of young athletes.

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## 16 CHAPTER 1

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