Growth and Maturation of Adolescent Female Gymnasts, Swimmers, and Tennis Players

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ABSTRACT

ERLANDSON, M. C., L. B. SHERAR, R. L. MIRWALD, N. MAFFULLI, and A. D. G. BAXTER-JONES. Growth and Maturation of Adolescent Female Gymnasts, Swimmers, and Tennis Players. Med. Sci. Sports Exerc., Vol. 40, No. 1, pp. 34–42, 2008. Intensive training at a young age may adversely affect the growth and sexual maturation of female athletes, resulting in compromised adult stature. Purpose: To compare the somatic growth, sexual maturation, and final adult height of elite adolescent female athletes. Methods: Serial measures of height, sitting height, and breast and pubic hair development were taken on 81 gymnasts, 60 swimmers, and 81 tennis players between 8 and 19 yr of age. Menarchal age, parental heights, maternal menarcheal age, and number of training hours were also recorded. Final adult heights were obtained from a subsample of the athletes (N = 110). Results: Gymnasts were significantly shorter than tennis players and swimmers at all chronological ages during adolescence, and they attained menarche at an older age (P < 0.05). No significant differences were found in adult heights. During adolescence, no difference were found in standing height to sitting height ratios, leg length to standing height ratios, or sitting height to leg length ratios between sports (P > 0.05). Conclusion: The results from this study suggest that regular training did not affect final adult stature and that, when aligned by biological age, the tempo of sexual maturation was similar in these young athletes. Key Words: TRAINING, MENARCHE, PEAK HEIGHT VELOCITY, ADULT STATURE

To be successful at the international level of sport competition, it is believed that intensive training must begin before puberty (27). For example, in elite female artistic gymnastics, athletes normally peak in performance around 16 yr of age and are considered extraordinary if still competing internationally in their 20s. Thus, elite female gymnasts undertake training of progressive intensity and volume from an early age. Some gymnasts start training as young as 5 or 6 yr of age and can train 20–30 h wk–1 year-round throughout their childhood and adolescence (9). It has been suggested that this type of intensive training at such a young age could adversely affect the growth and biological maturation of young female athletes (1,9,10,14,31,33). However, this is a view disputed by others (6,32), because a cause-and-effect relationship between intensive training at a young age and reduced growth has not yet been demonstrated. To answer this question, the effects of environment must be isolated from those of genetic predisposition; this requires serial measurements in the same individual during childhood and into young adulthood, controlling for the confounders of normal growth and sexual maturation.

Adolescent female gymnasts are known to be shorter and less mature than other athletic populations and controls of the same chronological age (1,7,13,14,24). The question to be addressed is whether gymnastics training alters the tempo and timing of growth and biological maturation, resulting in reduced adult stature. Theintz et al. (31) longitudinally assessed standing height, sitting height, and leg length in gymnasts and swimmers between the ages of 12 and 14 yr. They concluded that gymnasts did not have a growth spurt in their lower extremities during adolescence, which resulted in compromised adult height; however, adult stature was predicted in this study, and a measure of final adult height was not performed. In contrast, it has been suggested that the short stature observed in elite gymnasts is partly attributable to selection of individuals with reduced leg length, and that it is trunk length rather than leg length that is compromised (1,10). The influence of intensive gymnastics training on trunk and lower-limb growth is, therefore, still controversial.

Most studies documenting biological maturity and growth of young athletes have been cross-sectional and retrospective in nature. Longitudinal studies on the growth of athletes are necessary to assess whether training affects final adult stature in elite-level athletes. The present study...
used data from a 3-yr mixed-longitudinal study during childhood and adolescence, together with a one-time follow-up measure of adult stature in young adulthood. The original study was designed to assess the somatic growth and sexual maturity of elite female gymnasts, swimmers, and tennis players. Swimmers, tennis players, and gymnasts were chosen for comparison because they have been shown to be involved in intensive training from a young age (2). We hypothesize that participation in gymnastics, swimming, and tennis training will not adversely affect the tempo of somatic growth and biological maturation in these young female athletes. Furthermore, we hypothesize that gymnastics, swimming, and tennis training does not have an effect on the attainment of adult stature.

**METHODS**

**Training of Young Athletes Study (1987–1992).** The subjects were drawn from a longitudinal study of childhood growth, maturation, and development initiated in 1987; this study has been described in detail elsewhere (2,4). In brief, elite age-grouped U.K. male and female participants were recruited into the Training of Young Athletes (TOYA) study (1987–1992). Subjects were randomly selected from a list of young British athletes provided by the governing bodies of four sporting organizations: The Lawn Tennis Association (LTA), the English Football Association (FA) (soccer), the Amateur Gymnastics Association (AGA), and the Amateur Swimming Association (ASA). The criteria for inclusion were current engagement in intensive training (thresholds were provided by each sport’s governing body) and/or past or expected future success at the national level of competition (5). Data on average weekly training hours were collected, using a self-report questionnaire at each visit. In total, 453 subjects (231 males and 222 females) were recruited. For the purposes of this paper, the swimmers and tennis players are being used as a physically active comparison group. All sporting groups are also compared against British reference standards (18).

The study used a mixed-longitudinal design. Five birth-year cohorts were selected to include prepubertal, pubertal, and postpubertal children through an entry age range of 9–18 yr (Table 1). During the course of the study, the composition of these cohorts remained the same. Because there were overlaps in ages between the cohorts, it was possible to estimate a consecutive 11-yr development pattern (9–20 yr) during adolescence from a 3-yr testing period. Annual measurements were taken during the three consecutive years from February 1988 to December 1990. The study received ethical approval from the joint ethical committee of the Hospital for Sick Children/Institute of Child Health, London, United Kingdom. Each child provided written assent, and written informed consent was obtained from the parents or guardians of all participants.

**TOYA follow-up study (2000).** In 2000, a follow-up questionnaire was mailed out to all original participants; the details are described elsewhere (5). In brief, 203 questionnaires (45.5%) were returned, 110 were from female respondents; of these, 38 were gymnasts (47%), 38 were tennis players (49%), and 34 were swimmers (60%). Table 1 illustrates the numbers of subjects in each chronologic age group for each sport, along with the numbers and ages of the subsample who participated in the follow-up study. Adult height data, collected in the follow-up study, were used to estimate the sample size required to find differences between the three sporting groups. When the sample size in each of the three groups (swimming, tennis, and gymnastics) was 34, a one-way analysis of variance had 80% power to detect
at the 0.05 level a difference in mean adult height characterized by a variance of means of 2.6 cm, assuming that the common standard deviation was 5.86 cm.

**Chronological age.** The chronological age of each subject was recorded to the nearest 0.01 yr by subtracting the decimal year of the subject’s date of birth from the decimal year of the day of testing. To create standardized age groups, subjects were classified into 12-month groupings at the time of measurement. For example, all children who were between 13.5 and 14.4 yr on the date of measurement were classified as 14 yr of age.

**Anthropometric assessment.** From 1988 to 1992, anthropometric measurements were conducted annually in accordance with the guidelines provided by Tanner and Whitehouse (29). All participants were measured by the same trained anthropologist. Stretch stature and sitting height were measured to the nearest millimeter with a Harpenden wall-mounted stadiometer (Holtian Ltd., Crosswell, UK). Leg length was calculated by subtracting sitting height from stature. All measurements were performed twice, and the results were averaged.

Mothers’ and fathers’ heights were either measured or self-reported during the initial study period, and athletes’ self-reported heights were collected at follow-up in 2000. All self-reported heights were adjusted for the tendency of individuals to overestimate height. The following equation was used: 2.316 + (0.955 × reported height in inches) (17). Parental heights were used to estimate each child’s predicted adult height, using the equation of Tanner (28): (father’s height (cm) − 12.7 cm) + (mothers height (cm))/2.

**Sexual maturity.** From 1988 to 1990, pubic hair and breast development were assessed annually by the same trained anthropologist, following standard procedures (28). At each testing occasion, girls were categorized into one of five stages of pubic hair growth (PH1–PH5) and breast development (B1–B5). To be eligible for inclusion in the maturity analysis, subjects were required to have consecutive annual measurements of pubic hair and breast development, permitting transition from one stage to another with no stages omitted. During the study and at follow-up, girls were asked whether they had experienced menses, and, if so, what date it had occurred. Age at menarche was calculated from date of menarche (month and year) and date of birth. The mother’s age at menarche (month and year) was also ascertained.

**Biological age.** The biological age of each subject was assigned on the basis of years from attainment of menarche. A biological age was then calculated by subtracting the chronological age at time of measurement from the chronological age at the attainment of menarche. Thus, a continuous measure of biological age was generated. Biological age groups were constructed using 1-yr intervals, such that the −1 age group included observations between −1.49 and −0.50 yr from menarche.

**Follow-up.** Follow-up measurements were obtained through a self-report questionnaire (22) in the fall of 2000, 10 yr after the conclusion of the initial study. The subjects were asked to report current height and were provided with detailed instructions of how to obtain accurate measurements. Subjects were further asked to recall age at menarche, thus providing additional information on the athletes who completed the original study before reaching this milestone of sexual development. Current sports involvement (yes or no) and date of retirement were also collected.

**Statistical analysis.** Measurements of stature were compared against British reference standards (18), z-values were calculated for adult stature, using reference standards for 19 yr of age (18). Descriptive statistics, means, standard deviations, and standard errors were calculated. Single-sample t-tests were calculated to compare adult height z-scores with the reference standards (z = 0). One-way analysis of variance (ANOVA) and Scheffe’s post hoc test were used to investigate whether there were significant differences between group means. Alpha level of significance was set at $P < 0.05$ (SPSS version 11.5, SPSS Inc., Chicago, IL).

**RESULTS**

**All participants.** The average age of entry into the sports were 6.2 (SD 1.5), 6.3 (SD 2.0), and 7.5 (SD 2.0) yr for gymnastics, swimming, and tennis, respectively. Intensive systematic training occurred 2–3 yr later at 8.5 (SD 1.6) yr in gymnasts, 9.2 (SD 2.0) yr in swimmers, and 9.5 (SD 1.9) yr in tennis players. Between 8 and 19 yr of age, gymnasts trained, on average, between 12.7 and 16.5 h wk$^{-1}$; swimmers trained an average of 10.0–13.5 h wk$^{-1}$, and tennis players trained an average of 7.0–11.5 h wk$^{-1}$. Most of the athletes’ parents had taken part in some kind of sport when young (83%); however, few had participated in their child’s chosen sport: 6% in gymnastics, 19% in swimming, and 35% in tennis. During the initial phase of the study (1987–1990), 27% of gymnasts, 14% of swimmers, and 12% of the tennis players retired from their sport at average ages of 15, 15, and 16 yr, respectively. At follow-up, 51% of subjects ($N = 56$) were still involved in their sport and actively training (26% of 38 gymnasts, 57% of 34 swimmers, and 77% of 38 tennis players). For the 49% of subjects who were no longer involved in their sport, the average age of retirement was 17.5 (SD 4.1) yr in gymnasts, 18.5 (SD 2.5) yr in swimmers, and 19.0 (SD 3.2) yr in tennis players.

Menarcheal age, maternal menarcheal age, parental statures, and predicted target heights for the initial sample (1988–1990; $N = 222$) are summarized in Table 2. Twenty-eight percent of gymnasts had attained menarche in 1988, 38% of the sample had attained menarche in 1989, and 38% in 1990. Sixty percent of swimmers had attained menarche in 1989, 70% in 1989, and 85% in 1990. Fifty-one percent of swimmers had attained menarche in 1988, 62% in 1989, and 70% of the sample had attained menarche in 1990.
age of menarche in relation to age of retirement from sport was also calculated (age at retirement minus age at menarche), and it was found that in 84% of gymnasts (3.1 ± 3.8 yr), 96% of swimmers’ (4.9 ± 2.4 yr) and 100% of tennis players’ (5.9 ± 3.6 yr) attainment of menarche preceded retirement, on average by 4.4 (SD 3.6) yr. Actual age at attainment of menarche was found to be significantly older in gymnasts compared with that of swimmers and tennis players (P < 0.05). Mothers of gymnasts had a significantly older age at menarche than did the mothers of tennis players or swimmers (P < 0.05). Fathers of gymnasts were significantly shorter than the fathers of the tennis players (P < 0.05) but not the fathers of the swimmers (P > 0.05). The mothers of gymnasts were significantly shorter than the mothers of tennis players and swimmers (P < 0.05). Gymnasts’ predicted target heights were significantly shorter than the predicted target heights of tennis players and swimmers (P < 0.05).

The mean chronological age of attainment of each breast stage (B2–B5) is shown in Figure 1A. There was no significant difference between athlete groups in the mean chronological age at which they attained B2, B3, or B4 (P > 0.05). However, gymnasts reached B5 at a significantly older chronological age than did tennis players and swimmers (P < 0.05). Likewise, there were no significant differences in the average chronological age of entry into PH2, PH3, and PH4 between the three groups of athletes, but gymnasts reached PH5 at a significantly older chronological age (P < 0.05). When sexual development was aligned to years from menarche (Fig. 1B), there were no significant differences in the biological age of entry into the breast or pubic hair stages, including B5 and PH5 (P > 0.05).

**Follow-up participants.** In the follow-up cohort, no significant differences were found between predicted target heights and attained adult heights (P < 0.05), nor were sport groups differences found. The correlation between predicted and attained adult height in this sample of athletes was r = 0.60 (P < 0.05). There were no significant differences between predicted target heights of individuals with follow-up data and those without (P > 0.05). The age at menarche, adult height, target height, and z-score for adult height of the follow-up participants are shown in Table 3 (N = 110). This subgroup of gymnasts attained menarche at a significantly older age than tennis players (P < 0.05). There were no significant difference in adult height between the three athlete groups (P > 0.05). It was also found that the adult statures did not differ significantly between those who had retired in adolescence and those who continued to participate in any of the sports (P > 0.05). The normalized z-values significantly differed from zero; thus, on average, all three groups of athletes demonstrated

| Table 2. Descriptive statistics of mother’s and child’s age at menarche, parental stature, and predicted target heights between sporting groups. |
|-----------------|-----------------|-----------------|
|                | Gymnasts        | Swimmers        | Tennis          |
| Age at menarche (yr) | 65 14.49*(1.47) | 57 13.32 (1.36) | 75 13.29 (1.36) |
| Mother’s height (cm) | 79 159.91*(5.60) | 76 163.12 (5.36) | 80 162.77 (4.96) |
| Father’s height (cm) | 79 170.77*(7.09) | 55 173.35 (5.26) | 80 174.39 (6.15) |
| Target height (cm) | 79 158.99*(4.92) | 55 161.92 (4.19) | 80 162.23 (4.29) |
| Mother’s age at menarche (yr) | 69 13.68*(1.58) | 49 13.02 (1.37) | 67 12.90 (1.45) |

*Gymnasts significantly (P < 0.05) different from swimmers and tennis players.

b Gymnasts significantly (P < 0.05) different from tennis players only.

Menarche data were not obtained for all individuals.

FIGURE 1—Mean chronological age (A) and mean biological age (B) at each stage of breast and pubic hair development of the three groups of athletes. B2, breast stage two; PH2, pubic hair stage 2; MEN, menarche.

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adult heights that were greater than the 50th percentile for the British reference population.

Figure 2 shows the age-related stature development for the follow-up participants during the original study time period. When compared with standard growth curves, gymnasts were below average height (50th percentile) at all chronological ages during the growth period up to 16 yr of age. In contrast, female swimmers and tennis players were all well above the 50th percentile for height during the same growth period. No significant differences were found between the tennis players’ and swimmers’ heights at any chronological age ($P > 0.05$). Gymnasts were significantly shorter than swimmers and tennis players at 14, 15, and 17 yr of age ($P < 0.05$). At 16 yr of age, gymnasts were significantly shorter than tennis players.

Figure 3 shows stature aligned to biological age (years from attainment of menarche) for the follow-up participants. There were no significant differences in stature among the three groups at any biological age ($P > 0.05$).

Figure 4 illustrates the development of leg length and trunk length across biological ages (years from menarche) for the follow-up group. There were no significant differences in the development of leg length and trunk length at any of the biological ages ($P > 0.05$). The only exception was at 3 yr after menarche, where the gymnasts had, on average, a significantly shorter leg length than the swimmers ($P < 0.05$).

Figure 5 shows sitting height to standing height, leg length to standing height, and sitting height to leg length ratios across biological ages for the follow-up sample. There were no significant differences in the aforementioned ratios at any biological age ($P > 0.05$).

**DISCUSSION**

The effect of sport training on normal growth and biological maturation of female athletes is still a matter of debate. It is a common belief that moderate physical activity is beneficial to growth; however, when it is practiced intensively from an early age, and over a long period of time, concerns arise (14,20,31,33). This study explored the development of stature and sexual development through childhood into early adulthood, in elite-aged tennis players, swimmers, and gymnasts, to shed light on whether intensive physical training alters the development of normal growth and biological maturation.

Sexual maturity. It has been suggested that in females, intensive physical training can suppress reproductive function and, thus, influence growth (19,31). Generally
children enter breast stage 2 around 10.5 yr of age and pubic hair stage 2 shortly thereafter, around 11 yr of age, although there is a large range of normal variation (28). We found that gymnasts entered breast and pubic hair stages 2–4 at similar ages to tennis players and swimmers, and this is in agreement with previous work (16). However, in the present study we found that the average ages of entry of

FIGURE 4—Development of (A) leg length and (B) sitting height in the follow-up sample of athletes from three sports aligned to biological age (years from menarche). Means and standard errors of mean (SEM) are shown at each biological age. * Significant difference between gymnasts and swimmers ($P < 0.05$).

FIGURE 5—Ratios of (A) sitting height to standing height, (B) leg length to standing height, and (C) sitting height to leg length in the follow-up sample of athletes from three sports aligned to biological age. Means and standard errors of the mean (SEM) are shown at each biological age.
gymnasts into breast and pubic hair stages 5 were significantly older than those of swimmers and tennis players, suggesting that the tempo of growth is slower in gymnasts than in tennis players or swimmers during this later stage of sexual maturation. However, although training could be altering this tempo, it is also possible that later-maturing athletes are persisting with the sport, whereas earlier maturers are dropping out, resulting in an older average age for reaching this stage of sexual development. When pubic hair and breast development were aligned to biological age (years from menarche), there was no significant difference in the biological age of entry into the stages (B5 and PH5) between athlete groups. This suggests that gymnastics training does not alter the tempo of sexual maturation; however, timing of the events in chronological years is different. A limitation of this data set is the lack of data on swimmers in the early stages of sexual maturation (i.e., B2 and PH2); this is a reflection of the older chronological age and earlier maturity of this athlete group. The lack of a control group of nonathletes also makes the interpretation of our results problematic, because all of our subjects are involved in intensive training, and, thus it is not possible to distinguish whether training per se is having an independent effect on the timing of growth.

Menarche. The data presented in the following section are a summary of data previously presented by Baxter-Jones et al. (3). Swimmers’ and tennis players’ average ages at menarche were similar to the median age of menarche (13 yr) in contemporary British girls born between 1982 and 1986, whereas gymnasts’ average age at menarche was much later (34). Furthermore, the gymnasts’ age at menarche was significantly older than for swimmers and tennis players. The older age at menarche observed in elite gymnasts is congruent with findings by other investigators (8,12,30). However, when interpreting these results, it is important to consider other factors known to influence menarcheal age. For example, there is a familial tendency for later maturation in some groups of female athletes (26). In confirmation, we found that mothers of gymnasts had a significantly older age at menarche than did mothers of swimmers and tennis players. We have previously reported (3) that gymnasts were found, on average, to attain menarche 0.81 yr after their mothers, swimmers 0.44 yr after, and tennis players 0.25 yr after. The difference between the age in attainment of menarche between mothers and daughters was significantly ($P < 0.05$) greater in gymnasts than in tennis players; although these differences were, on average, less than 1 yr, it is noticeable that the mother–daughter menarcheal age is double that of swimmers and triple that of tennis players, perhaps suggesting that additional factors, such as training, could be causing this effect. Mother and daughters also followed the same trend in the timing of menarche, with mothers of tennis players attaining menarche at the earliest age, followed by swimmers and then gymnasts. Furthermore, in this sample of female athletes, we previously found a positive correlation between menarcheal age of mother and daughter of $r = 0.2$ for gymnasts and tennis players and $r = 0.3$ for swimmers ($P < 0.05$) (3). This is consistent with the results of Malina et al. (25), who found a mother–daughter correlation of 0.25 in gymnasts. These can be considered fairly strong correlations in that mother–daughter correlations do not normally exceed $r = 0.50$, because mothers and daughters only have one half of their genes in common. Although these results suggest that the later menarche commonly observed in athletes is, to some extent, familial, the alternative explanation that training is having an effect cannot be ruled out. We also calculated the time period between achieving menarche and retiring from the sport, and we found that in the majority of cases (92%) menarche had occurred before retirement, again suggesting that the effects of training were likely not causing menarche to be delayed.

Stature. Swimmers’ heights were above the 50th percentile of the reference population throughout the growth period. Other reports (4,15,31) have shown that child and adolescent swimmers are, on average, taller than the average population. The statures of tennis players were also, on average, above the 50th percentile, in accordance with previous literature (23). The development of stature in gymnasts showed a similar growth pattern to that of swimmers and tennis players. Although gymnasts’ heights were below 50th percentile from 9 through 16 yr of age, by 19 yr of age they were above the 50th percentile. This is a typical pattern of growth shown by late matures when their data are plotted against reference percentiles that represent growth of an average child experiencing maturation at an average age. The results during adolescence are consistent with previous observations that, on average, gymnasts are considerably shorter than reference populations if maturational status is ignored (2,11). This finding could be interpreted to suggest that training is altering the normal growth of gymnasts. However, we also found that the fathers of gymnasts were significantly shorter than the fathers of tennis players, and the mothers of gymnasts were significantly shorter than the mothers of tennis players and swimmers. Therefore, girls successful in gymnastics have a familial (genetic) tendency for short stature. This finding and the previous observation that gymnasts are shorter than average long before systematic training has started (15) suggest that normal statural growth may not be altered by gymnastic training.

It has been suggested that intensive gymnastics training may stunt growth, thereby reducing adult height (14,31). The results from this study do not support this statement, because, on average, gymnasts were shown to have adult heights similar to the adult 50th percentile. However, this finding could be an artifact of the small sample size. A limitation of this study is the low number of follow-up responses (52.5% of females) to the questionnaire, and the fact that adult height was self-reported. This would indicate that our sample size may be too small, and it is possible that the null hypothesis was accepted when it was, in fact, false,
Although our sample size calculations indicate that a sample of 34 per group should be adequate enough to detect differences at the 0.05 level of significance. However, caution is advised in interpreting this result. What is indisputable is that gymnasts, on average, were not found to be below average stature, which suggests that their height did not seem to be compromised.

Although no significant differences were found between the predicted heights of athletes who were followed up compared with those who were not, the variability associated with using prediction equations to estimate adult stature should be noted. In the follow-up subjects, the mean difference between actual and predicted adult heights was 1.7 (SD 6.1) cm. Previously, it has been shown that the prediction of adult height using this method was within ±8.5 cm 95% of the time (28). Given this large range of error, it is possible that the follow-up sample had different final adult heights from those who were not followed up. There was also no difference between those athletes who provided follow-up and those who did not, with regard to birth weight, father’s height, mother’s age at menarche, age at menarche, height, weight, breast stage, and pubic hair at any measurement occasions. Importantly, in the follow-up subjects, there was no significant difference between predicted target height and adult stature attained for all athlete groups, showing that gymnasts, swimmers, and tennis players had all fulfilled their potential for adult height (Table 3).

**Growth in stature and biological maturity.**

Previous studies (9,10,14,20,21,31,33) that have concluded that stature is stunted by regular gymnastics training did not control for normal variation in the timing and tempo of biological maturation. Thus, the consistently observed reduced stature in gymnasts could probably be related to the fact that, on average, gymnasts are late matures. In the present study, the average height of gymnasts during the initial phase of the study (1998–1990) decreased between 18 and 20 yr of age (Fig. 2). It is very unlikely that gymnasts were losing height during this time period; it is much more likely that the shorter and later-maturing athletes were remaining in the sport, whereas the average and early-maturing individuals were dropping out.

Caine et al. (10) and Bass et al. (1) conclude that gymnastics training results in a reduction in growth of the trunk, whereas Theintz et al. (31) conclude that gymnastics training resulted in reductions in growth of the legs, resulting in reduced adult stature. However, the former study did not align its subjects by biological age but, rather, chronological age. This is problematic because, as stated earlier, gymnasts are, on average, late matures, and thus their leg length to sitting height ratio would be different than the ratio of an average or early-maturing individual. The latter study (31) accounts for biological maturation, but the gymnasts were not followed to adult height; therefore, it is impossible to infer that adult height was compromised. In the present study, we aligned individuals to biological age (years of menarche), followed them to adulthood, and found no significant difference in sitting height to standing height, leg length to standing height, or sitting height to leg length ratios between the three athlete groups. These findings are consistent with recent evidence (32) that female gymnasts showed a clearly defined adolescent growth spurt in leg length and trunk leg 1 yr later than a reference population. The same authors also found that peak leg length velocity occurred earlier than peak sitting height velocity, which is consistent with data for other samples (32).

**CONCLUSION**

The small sample size at follow-up, and the implication regarding inadequate power, means that the conclusions reached by this study must be interpreted accordingly. Regular intensive training did not seem to affect attained adult stature; however, because of limitations in the study design, the effects of training on the timing of sexual maturation could not be answered. What was observed was that swimmers’ and tennis players’ average development of stature, breast development, and pubic hair development were characteristic of early-maturing individuals, whereas gymnasts demonstrated characteristics of late-maturing individuals, suggesting that tempo of growth was not being compromised by training. Because gymnastics training did not seem to compromise adult height, it is likely that gymnasts and other athletes are selected into participating in the sport most suited to their body size, which was, in turn, related to their maturity status.

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**REFERENCES**
