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Growth and Skeletal Maturation in Male and Female Artistic Gymnasts

NEOKLIS A. GEORGOPOULOS, ANASTASIA THEODOROPOULOU, MICHEL LEGLISE, APOSTOLOS G. VAGENAKIS, AND KOSTAS B. MARKOU

Department of Obstetrics and Gynecology (N.A.G.), Division of Reproductive Endocrinology, and Department of Medicine (A.T., A.G.V., K.B.M.), Division of Endocrinology, University of Patras Medical School, University Hospital, Patras, 26500 Greece; International Gymnastic Federation (M.L., K.B.M.), CH 2740 Moutier, Switzerland; International Olympic Committee (M.L.), 1007 Lausanne, Switzerland; and International Federation of Gymnastics Medical Committee (M.L., K.B.M.), Lausanne, Switzerland

We studied 262 athletes who were 13–23 yr old. There were 93 male and 169 female artistic gymnasts (AG). This study is unique in character, because all variables were measured on the field of competition (24th European Championship).

Male AG had a higher height SD score than female (P < 0.001), with a higher reported target height SD score (P < 0.001), a higher predicted final height (P = 0.007), a lower Δ height − target height (P < 0.001), a less delayed bone age (P < 0.001), a greater body mass index (BMI) (P < 0.001), a lower mean body fat (P < 0.001), and an older age of onset of training (P < 0.001).

In a subgroup of athletes who had reached final height, male AG had a higher weight SD score than female (t = 4.322, P < 0.001), with a higher reported target height SD score (t = 18.9, P < 0.001), but a greater Δ final height − target height (t = 6.641, P < 0.001).

Height SD score was positively correlated to reported target height SD score (P = 0.009 and P = 0.006, respectively) and to weight SD (P < 0.001 and P < 0.001, respectively) for both male and female AG, as well as to BMI for female AG (P < 0.001), and negatively to Δ age − bone age (P < 0.001 and P = 0.003, respectively) and to predicted height SD score (P = 0.001 and P < 0.001, respectively).

Using multiple regression analysis, height SD score was positively correlated to predicted height SD score for both male (P < 0.001) and female (P = 0.005) AG, as well as to weight SD score (P < 0.001) for female AG and negatively to BMI (P < 0.001) for female AG and to Δ age − bone age (P < 0.001) for male AG.

In conclusion, a deterioration of growth in AG was observed. For both sexes, genetic predisposition to final height, although altered, was not disrupted. (*J Clin Endocrinol Metab* 89: 4377–4382, 2004)

OPTIMAL GROWTH DEPENDS upon a combination of genetic and environmental factors such as stress and intensive physical training (1). We have recently reported that stress and intensive physical training have profound effects on growth and skeletal maturation in female rhythmic gymnasts (2, 3), as well as female artistic gymnasts (AG) (4). In female AG, a deterioration of growth potential was observed, whereas in rhythmic gymnasts the genetic predisposition to growth was preserved. Despite the extensive literature, few data are available concerning growth, pubertal development, and skeletal maturation in male AG (5, 6), and even fewer comparative studies have been reported between male and female AG (7, 8). Gender-related differences in the evolution of puberty, the timing of the pubertal growth spurt, as well as the duration of pubertal development, in association with different sports-related somatotypes, could seriously influence growth and skeletal maturation.

The aim of this study was to evaluate the pattern of growth at different stages of puberty in elite male and female AG of high competitive level and to determine the impact of their gender-related differences on growth

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Abbreviations: AG, Artistic gymnasts; BMI, body mass index.

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Subjects and Methods

The study included 262 Caucasian athletes, aged 13–23 yr old, from 44 European countries, 93 male and 169 female AG, who participated in the 24th European Championship of Artistic Gymnasts held in Patras, Greece on April 2002.

The study was conducted under the authorization of the International Federation of Gymnastics (F.I.G.) and the European Union of Gymnastics. Informed consent was obtained in accordance with article 7 of the medical organization of the F.I.G. competitions, and all athletes participated voluntarily.

The study protocol has been published elsewhere (2, 3). Briefly, it included noninvasive clinical and laboratory investigations and the completion of a questionnaire. The clinical evaluation included height and weight measurements and assessment of pubic hair growth for both males and females according to Tanner's stages of pubertal development (9). Tanner stages for females have been determined by a female physician (A.T.) and for males by a male physician (K.B.M.). The descriptive stages for pubic hair growth are identical for both boys and girls (1).

The laboratory investigation included determination of body composition and skeletal maturation. Body composition was assessed by a portable apparatus (Futrex 5000; Futrex, Inc., Gaithersburg, MD), which is convenient for use in a field study and estimates percentage of body fat and total body water based on infrared analysis (10). This technique has been validated to be equivalent to the standard methods of body composition assessment by skinfold measurements (11) and bioimpedance assessment (12).

Skeletal maturation was evaluated from an x-ray of the left hand and wrist, obtained under full-body protection against radioactivity. Bone age was determined according to Greulich-Pyle standards (13). Near-total skeletal maturation was considered when bone age was greater than 16 yr of age for females and 18 yr of age for males (13). Prediction of adult height was calculated according to Bayley-Pinneau method, based on measured height and bone age, as assessed using the Greulich-Pyle standards. For those athletes whose radiographs showed near-total skeletal maturation and for those athletes over 18 yr of age, without bone age estimation, the measured actual height was considered to be the adult final height (n = 38).

All athletes completed a questionnaire that included questions on sports-related personal data (onset and intensity of training, number of competitions per year).

Statistical analysis

Height and weight were expressed as the SD score of the mean height and weight for age, according to Tanner's standards (9). Student's *t* test was used to study the sex-related differences. The Pearson product moment correlation coefficient, with the two-tailed test of significance, was used to assess all other studied relationships. A multiple regression analysis (ANOVA) was used to ascertain the independent predictive value of each parameter proved to be significant according to Pearson correlation coefficient. The independent sample *t* test, with the two-tailed test of statistical significance, was used to assess the power of all relationships within the two groups. Correlations with a critical value of $P < 0.05$ were considered significant. All statistics were performed using SPSS for Windows, version 9.0.1 (SPSS Inc., Chicago, IL).

Results

The chronological age distribution of male and female AG ranged from 13–23 yr. The higher incidence was between 17 and 18 yr for males and between 14 and 15 yr for females (Fig. 1). The age distribution according to skeletal maturation (bone age) is presented in Fig. 2. The higher incidence was between 17 and 18 yr for males and between 13 and 14 yr for females.

Anthropometric characteristics

The mean values for collected and derived data are shown in Table 1A and for sports-related data in Table 1B. Height and weight SD score for each age group are shown in Figs. 3 and 4, respectively. Both male and female AG were shorter than average, with mean height SD score below the 50th percentile (Fig. 3). Target height SD score was above the 50th percentile for male and below the 50th percentile for female AG (Table 1A). However, for both male and female AG their mean height SD score was lower than their predicted genetic predisposition (Table 1A).

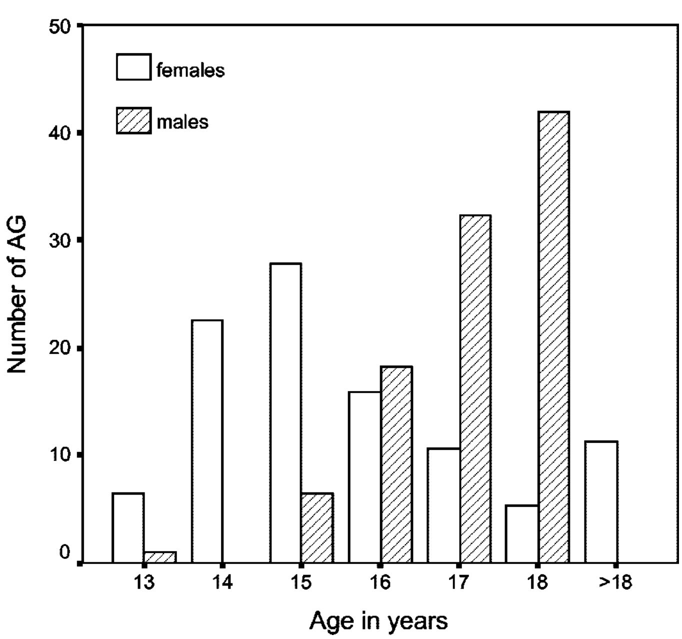

FIG. 1. Distribution of female and male AG according to chronological age.

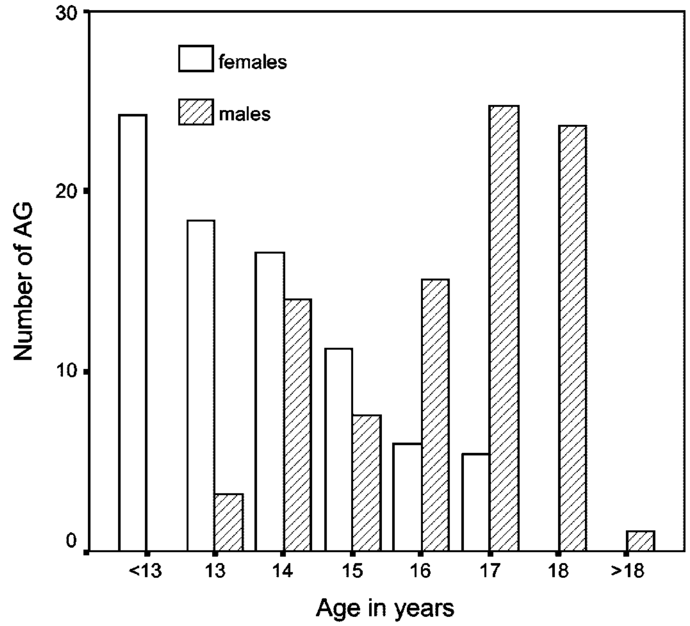

FIG. 2. Distribution of female and male AG according to bone age.

Both male and female AG had low weights compared with the population mean, with the mean weight for age below the 50th percentile for both groups (Fig. 4).

Data concerning final height from athletes whose radiographs showed near total skeletal maturation (males with bone age greater than 18 yr of age and females with bone age greater than 16 yr of age) and for those athletes over 18 yr of age, without bone age estimation, are presented in Table 2.

Sexual maturation

The distribution of pubic hair development according to age is shown in Fig. 5. Both male and female AG follow the same pattern of pubertal development as their mean ages in different stages of puberty are progressively increased without pubertal arrest. As expected, females had younger mean ages in all stages of pubertal development.

Relationships

All anthropometric, sports-related parameters and growth data of male and female AG were compared, and their correlation coefficients are presented in Table 1, A and B, and also for those athletes with final height in Table 2.

Male AG had a higher height SD score than females (t = 3.53, $P < 0.001$), with a higher reported target height SD score (t = 18.9, $P < 0.001$), higher predicted final height (t = 2.7, $P = 0.007$), lower Δ height − target height (t = −13.03, $P < 0.001$) and less delayed bone age (t = 5.78, $P < 0.001$). They also presented a greater body mass index (BMI) (t = 11.5, $P < 0.001$) and lower mean body fat (t = 14.95, $P < 0.001$). Female AG started training at an earlier age than males (t = 3.43, $P < 0.001$).

TABLE 1. Somatometric and sports-related data of male and female AG

A. Collected and derived somatometric data of male and female AG

	Age (yr)	Bone age (yr)	Δ Age − bone age	Height SDS	Weight SDS	Target height SDS	Predicted height SDS	PH-TH SDS	BMI (kg/m^2)	Body fat (%)
Female (n)	15.7 ± 2.0 (169)	13.4 ± 1.8 (138)	2.26 ± 2.2 (138)	−1.52 ± 1.1 (168)	−1.09 ± 0.7 (168)	−0.18 ± 0.7 (123)	−0.70 ± 0.9 (136)	−0.6 ± 0.9 (105)	19.0 ± 1.7 (168)	19.5 ± 4.2 (160)
Male (n)	16.9 ± 2 (93)	16.2 ± 1.6 (83)	0.76 ± 1.2 (83)	−0.97 ± 1.0 (93)	−0.13 ± 0.7 (93)	1.91 ± 0.7 (83)	−0.35 ± 0.8 (82)	−2.3 ± 0.8 (77)	21.5 ± 1.7 (93)	10.6 ± 5.0 (91)
P (t)	<0.001 (−5.03)	<0.001 (−11.99)	<0.001 (5.78)	<0.001 (−3.53)	<0.001 (−11.06)	<0.001 (−18.9)	0.007 (−2.7)	*P* < 0.001 (13.03)	<0.001 (−11.5)	<0.001 (14.95)

B. Sports-related data of male and female AG

	Age of onset of training (yr)	Competitions (no./yr)	Training (h/wk)
Female (n)	6.4 ± 2.4 (148)	7.7 ± 3.4 (148)	28.7 ± 8.6 (150)
Male (n)	7.4 ± 2.1 (90)	7.9 ± 3.2 (86)	26.8 ± 6.6 (92)
P (t)	<0.001 (−3.43)	0.701 (−0.385)	0.064 (1.86)

PH, predicted height; TH, target height. SDS, SD score.

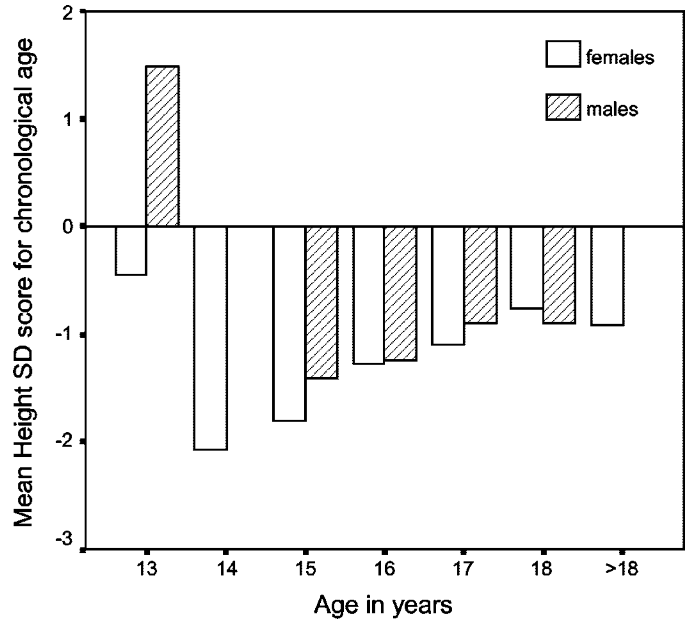

FIG. 3. Height SD score for chronological age.

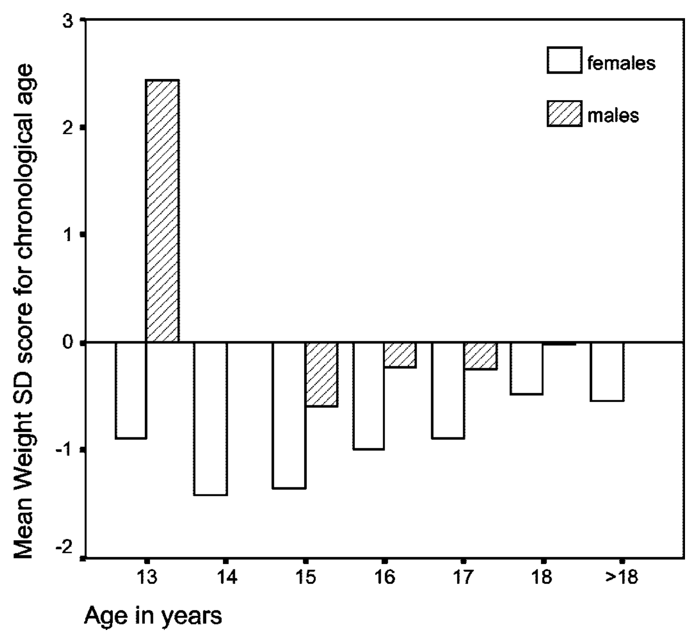

FIG. 4. Weight SD score for chronological age.

In the subgroup of athletes with final height, male AG had a higher weight SD score than females (t = −4.322, $P < 0.001$), with a higher reported target height SD score (t = −18.9, $P < 0.001$), but a greater difference between final height and reported target height (t = 6.641, $P < 0.001$). They also presented a greater BMI (t = 4.33, $P < 0.001$) and lower mean body fat (t = 5.81, $P < 0.001$).

Height SD score correlations to somatometric and sports-related data for male and female AG are presented in Table 3. Height SD score was positively correlated to target height SD score (r = 0.28, $P = 0.009$ and r = 0.25, $P = 0.006$, respectively) and to weight SD (r = 0.69, $P < 0.001$ and r = 0.82, $P < 0.001$, respectively) for both male and female AG, and

TABLE 2. Collected and derived somatometric and sports-related data of male and female AG with final height

	Age (yr)	Final height SDS	Weight SDS	Target height SDS	FH-TH SDS	BMI (kg/m^2)	Body fat (%)	Age of onset of training (yr)	Competitions (no./yr)	Training (h/wk)
Female (n)	19.5 ± 2.8 (22)	−0.89 ± 1.1 (22)	−0.55 ± 0.7 (22)	−0.03 ± 0.73 (16)	−0.39 ± 1.03 (13)	20.69 ± 1.73 (22)	18.32 ± 5.2 (20)	6.5 ± 3.2 (17)	7.7 ± 3.0 (17)	25.9 ± 9.1 (150)
Male (n)	17.7 ± 0.45 (16)	−0.73 ± 0.7 (16)	0.34 ± 0.52 (16)	1.97 ± 0.59 (14)	−2.50 ± 0.61 (14)	23.03 ± 1.5 (16)	9.27 ± 53.8 (16)	7.3 ± 2.5 (15)	5.9 ± 2.4 (15)	26.9 ± 9.0 (15)
P (t)	0.017 (2.5)	0.615 (−0.508)	0.001 (−4.322)	<0.001 (−18.9)	<0.001 (6.641)	<0.001 (−4.329)	<0.001 (5.814)	0.412 (−0.831)	0.085 (1.783)	0.774 (−0.289)

FH, Final height; TH, target height; SDS, SD score.

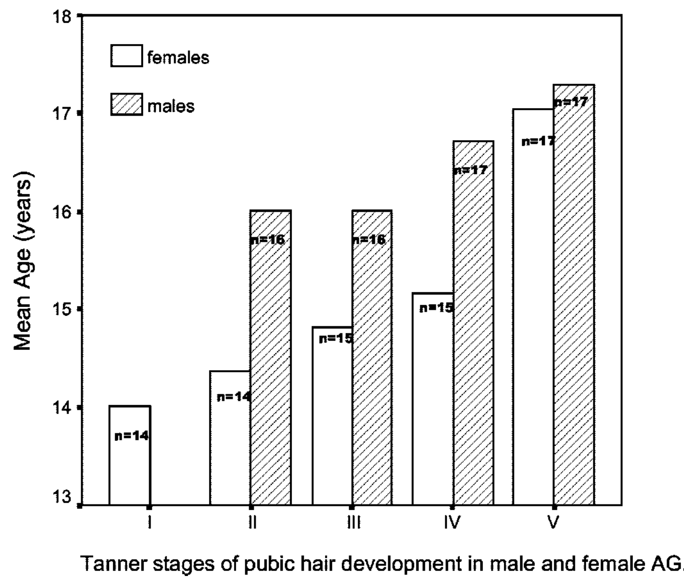

FIG. 5. Tanner stages of pubic hair development. Mean age of male and female AG in all Tanner stages of pubic hair development.

negatively to Δ age − bone age (r = −0.42, $P < 0.001$ and r = −0.41, $P = 0.003$, respectively) and to predicted height SD score (r = −0.36, $P = 0.001$ and r = −0.68, $P < 0.001$, respectively). Height SD score was also positively correlated to BMI in female AG (r = 0.49, $P < 0.001$).

A multiple regression analysis was used to ascertain which of the above parameters had independent value in predicting height SD score for both male ($r^2 = 0.563$) and female AG ($r^2 = 0.881$) (Table 4). Height SD score was positively correlated to predicted height SD score for both male (b = 0.599, t = 6.41, $P < 0.001$) and female (b = 0.170, t = 2.87, $P = 0.005$) AG, as well as to weight SD score (b = 1.320, t = 11.36, $P < 0.001$) for female AG and negatively to BMI (b = −0.650, t = −6.57, $P < 0.001$) for female AG and to Δ age − bone age (b = −0.686, t = −8.1, $P < 0.001$) for male AG.

Discussion

Both male and female AG exhibit a specific pattern of growth and skeletal maturation. Despite general similarities, sex-related differences have been noted. Both male and female AG were shorter and thinner than their age-related counterparts, and they showed a significant delay in skeletal maturation. Concerning these parameters, males, when compared with the age-related population means, were much shorter than lighter. However, in absolute values, the deficits in both height and weight were much more pronounced in females than in males. This observation could support the hypothesis that females are more vulnerable than males to detrimental effects of stress and intensive physical training on growth. Although artistic gymnastics performance shares many similarities for both males and females, it also needs different athletic requirements that favor a particular optimal somatotype (8). A short-limbed individual could benefit from a greater advantage in female artistic gymnastics, due to the specific instruments used for performance, which are different from those used in male artistic gymnastics. There-

TABLE 3. Height SDS correlations in male and female AG

	Δ Age − bone age	SDS weight	SDS target height	SDS predicted height	BMI (kg/m²)	Body fat (%)
Female height SDS	r = 0.41 $P = 0.003$ n = 138	r = 0.82 $P < 0.001$ n = 168	r = 0.25 $P = 0.006$ n = 123	r = −0.68 $P < 0.001$ n = 136	r = 0.49 $P < 0.001$ n = 168	r = 0.09 $P = 0.242$ n = 160
Male height SDS	r = −0.42 $P < 0.001$ n = 82	r = 0.69 $P < 0.001$ n = 93	r = 0.28 $P = 0.009$ n = 83	r = −0.36 $P = 0.001$ n = 81	r = 0.19 $P = 0.061$ n = 93	r = −0.50 $P = 0.64$ n = 91

SDS, SD score.

TABLE 4. Height SDS for examined male and female AG: multiple regression analysis (ANOVA)

Variable	Female ($r^2 = 0.881$)	Male ($r^2 = 0.563$)
Weight SDS	b = 1.320, t = 11.36, $P < 0.001$	
Predicted height SDS	b = 0.170, t = 2.87, $P = 0.005$	b = 0.599, t = 6.41, $P < 0.001$
Target height SDS	b = −0.025, t = −0.60, $P = 0.551$	b = 0.310, t = 0.36, $P = 0.723$
Δ Age − bone age	b = −0.030, t = −0.58, $P = 0.565$	b = −0.686, t = −8.1, $P < 0.001$
BMI	b = −0.650, t = −6.57, $P < 0.001$	—

SDS, SD score.

fore, no definite conclusion on growth characteristics of both sexes can be made without considering the possibility of a preselection bias. Indeed, male AG presented a reported target height SD score markedly above the 50th percentile, whereas female AG were well below the 50th percentile. The difference in genetic predisposition to final height reflects a selection of athletes by trainers based on the appropriate sex-related anthropometric criteria.

Considering the genetic predisposition, the pattern of growth for males and females can be summarized as follows: at the time of examination, both female and male AG were shorter than their age-related population mean. However, female AG presented a greater height deviation from their age-related population mean, with a greater delay in their skeletal maturation. On the contrary, male AG who presented a height closer to their age-related population mean have a genetic predisposition toward a much higher final height than female AG. Although this particularly tall reported target height in males could be an overestimation and should be considered with caution, it is reasonable to assume that, in male and female artistic gymnastics, the growth process in males might be more vulnerable to the detrimental effects of intensive physical training.

In previous studies in female AG, although cross-sectional height predictions of final height were not reduced (14), in a prospective study a reduction of growth potential and a decrease of height predictions with time were noted (15). In our study, in athletes who have not reached final height, predicted adult height, although lower than target height, is higher than the actual measured height for both sexes. It is therefore anticipated that, due to the delay in skeletal maturation, a late acceleration of linear growth will result in a regain of a percentage of growth lost through the delay in pubertal development. Catch-up growth is predicted to be more intense in females due to their greater delay in skeletal maturation. The ultimate success of catch-up growth will be difficult to perfectly predict from this early stage, because it largely depends on the time of onset, the duration, and the speed of progression (16). Therefore, more data to be obtained from this ongoing prospective study are needed to answer this critical question.

Actual height SD score correlations showed significant sex-related similarities as well as striking differences. For both sexes, actual measured height was correlated to target height, a finding indicating that genetic predisposition to growth, although altered, was not disrupted. For female AG, the most valuable independent predictive parameters proved to be weight SD score and BMI. This finding was previously reported for both female rhythmic gymnasts (2) and AG (4) and appears to be of no value for male AG. In females, fatness and BMI have been found to be more closely related to maturation stage than chronological age (17, 18). Higher BMI and body fat are associated with earlier pubertal development (18, 19), and the opposite are associated with pubertal delay (2, 20, 21). The percentage of body fat is significantly higher in girls than in boys and is perfectly correlated to the stage of pubertal development and to leptin levels both in gymnasts and in the nontrained population (22). None of the above observations are valid for males who during puberty, instead of increasing body fat, gain twice as much lean body mass as females (23).

The impact of stress and physical training on growth depends on a variety of factors, including the type of physical training, the time of onset, and the intensity of training. It is known that gymnasts are trained much more intensely nowadays than previously, usually 26–28 h per week compared with 15 h during the 1970s and 20 h during the 1980s. In females, the maximum training coincides with the period of pubertal development, whereas in males most of the efforts are required toward the end of puberty. Finally, sex-related differences in body composition play an additional role.

In conclusion, this study provides evidence for a growth deterioration in AG, more pronounced in males than in females. For both sexes, final height falls short of genetic predisposition. For female AG the most valuable predictive parameters for growth proved to be weight SD score and BMI.

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Address all correspondence and requests for reprints to: Apostolos G. Vagenakis, M.D., Department of Internal Medicine, Division of Endocrinology, University of Patras Medical School, University Hospital, Rio-26500, Greece. E-mail: Vag.inmd@med.upatras.gr.

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