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Growth Retardation in Artistic Compared with Rhythmic Elite Female Gymnasts

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We studied 129 female rhythmic gymnasts (RG) and 142 female artistic gymnasts (AG) who participated in the 1999 Gymnastics World Championship for RG in Osaka, Japan, and the 1999 and 2001 Gymnastics World Championships for AG in Tianjin, China (n = 48), and Ghent, Belgium (n = 94), respectively.

RG were taller than average, with a mean height SD score above the 50th percentile, whereas AG were relatively short, with a mean height SD score below the 50th percentile. Both RG and AG followed their respective reported target height SD score, which was above the 50th percentile for the RG and below the 50th percentile for the AG. The RG followed a growth pattern that was higher than their reported target height, whereas AG exhibited a negative growth pattern. RG and AG weighed less than the population mean, with the mean weight for age below the 50th percentile for both groups. RG were taller than AG ($t = 17.15$; $P < 0.001$), with a higher reported target height SD score ($t = 6.44$; $P < 0.001$), a greater Δ height-reported target height ($t = 2.74$; $P < 0.001$), and a lower mean body fat ($t = -11.83$; $P < 0.001$) and body mass index ($t = -10.73$; $P < 0.001$) than AG. AG started their training at an earlier age than RG ($t = 4.13$; $P < 0.001$). Using multiple regression analysis, actual height SD score was independently influenced positively by weight SD score for both RG ($b = 0.421$; $t = 4.317$; $P < 0.001$) and AG ($b = 1.404$; $t = 16.514$; $P = <0.001$), and by reported target height only for RG ($b = 0.299$; $t = 3.139$; $P = 0.002$), and negatively by body mass index only for AG ($b = -0.80$; $t = -9.88$; $P < 0.001$).

In conclusion, in elite female AG, a deterioration of growth potential was observed, whereas in RG the genetic predisposition to growth was preserved. (*J Clin Endocrinol Metab* 87: 3169–3173, 2002)

BEGINNING AT A young age, rhythmic gymnasts (RG) and artistic gymnasts (AG) performing at a high agonistic level are exposed to high levels of physical and psychological stress from many hours of intense athletic training and competitions. The detrimental effects of these factors on growth, skeletal maturation, and pubertal development have been documented in individuals involved in a variety of sports (1–5). Individual sports impart unique influences on biological maturation that are related to the heterogeneity of the sport-specific demands of training and the stage of growth and sexual maturation of the individual athlete.

RG and AG participate in two distinct sports within the area of gymnastics. Their programs include specific gymnastics and require specific and different skills. In AG, although anthropometric measurements and prospective growth predictions appear within normal limits (6–9), a decrease in mean height predictions with time has been observed that could ultimately result in lower final adult height (10). We have previously reported that stress and physical training have profound effects on growth and pubertal development of elite female RG (11). Despite the observed significant delay in both skeletal maturation and pubertal development, the same athlete group of elite RG after a longitudinal follow-up was shown to compensate the loss of pubertal growth spurt by a late acceleration of linear growth. Despite the delay in skeletal maturation, genetic predisposition of growth was not only preserved, but even exceeded (12).

The aim of the present study was to compare somatometric data of RG and AG of high agonistic level and determine the impact of their gymnastics participation on growth. This study is unique in character, because all variables were measured on the field of competition.

Subjects and Methods

Data for this study were obtained during the 1999 Rhythmic Gymnastics World Championships in Osaka, Japan (n = 129), and the 1999 and 2001 Artistic Gymnastics World Championships in Tianjin, China (n = 48), and Ghent, Belgium (n = 94), respectively. The study was conducted under the authorization of the International Federation of Gymnastics and the European Union of Gymnastics. Informed consent was obtained in accordance with Article 7 of the medical organization of the official International Federation of Gymnastics competitions. The Medical Authority of the International Federation of Gymnastics is authorized to function as an institutional review board for human research subjects. All athletes participated voluntarily under the authorization of the heads of their national delegations. The study included 129 elite RG and 142 elite AG, aged 11–23 yr, from 28 countries that represented all continents. Data concerning RG obtained from different populations have been reported recently (11).

The study protocol has been published elsewhere (11, 12). 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 breast and pubic hair development according to Tanner's stages of pubertal development (13).

The laboratory investigation included determination of body composition by a portable apparatus (Futrex 5000, Futrex, Inc., Gaithersburg,

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

MD) that estimates percentage body fat and total body water based on infrared analysis (11, 12, 14). The accuracy and precision of the near infrared analysis has been validated to be equivalent to the standard methods of body composition assessment by skinfold measurements (15) and bioimpedance assessments (16).

All athletes completed a questionnaire that included questions on personal (onset of breast and pubic hair development, age of menarche, onset and intensity of training, number of competitions per year) and family data (paternal and maternal heights, maternal age of menarche). It is to be noted that the athletes knew very well the accurate height of their parents and the data of the onset of their menarche, as well as the year of the maternal and sisters' menarche. The reported target height (TH) in centimeters was estimated using the midparental height as an index of genetic predisposition to adult height. The equation used for reported TH was: TH = (father's height − 13 + mother's height)/2 (1).

Statistical analysis

Height and weight were expressed as the SD score of the mean height and weight for age, according to Tanner's standards (17). The SD score was also calculated for reported target height. The Pearson product moment correlation coefficient, with two-tailed test of significance, was used to assess all studied relationships. A multiple regression analysis (ANOVA) was used to ascertain the independent predictive value of each parameter proven to be significant according to Pearson correlation coefficient. The independent sample t test, with 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).

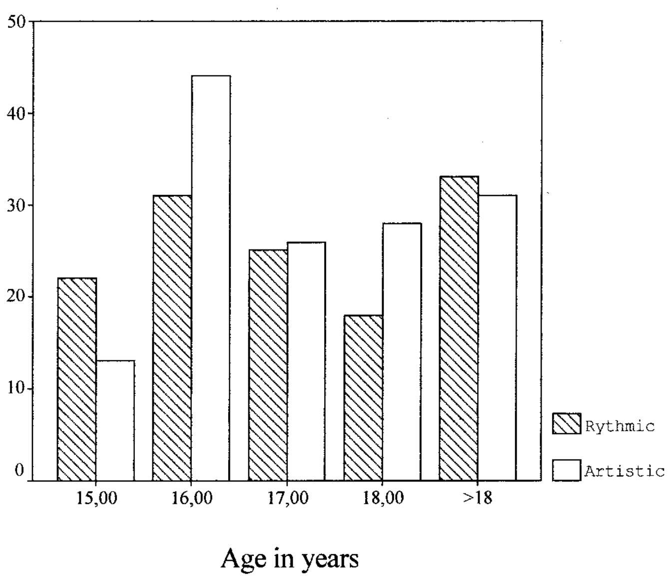

FIG. 1. Distribution according to chronological age.

Results

The age distribution of RG and AG ranged from 11–23 yr. The higher incidence was between 15 and 17 yr (Fig. 1).

Anthropometric characteristics

The mean values for collected and derived data are shown in Tables 1 and 2, respectively, and the height and weight SD score for each age group is shown in Fig. 2. As we reported previously (11, 12), RG were taller than average, with mean height SD score above the 50th percentile, whereas AG were well below the 50th percentile (Fig. 2). Both RG and AG followed their respective target height SD score, which was above the 50th percentile for RG and below the 50th percentile for AG (Table 1). However, the RG followed a growth pattern that was slightly higher than their reported target height, whereas the AG followed a growth pattern that was lower than their predicted genetic predisposition (Table 2). Both RG and AG had low weights compared with the population mean, with the mean weight for age below the 50th percentile for both groups (Fig. 2).

Sexual maturation

The distribution of pubertal development according to age, is shown in Fig. 3 for breast development (Tanner's stages I–V). The age of first breast and pubic hair development is presented in Table 1. Although AG presented pubarche later than RG (see Table 5), it is to be noted that both RG and AG follow the same pattern of pubertal development.

The age of recalled menarche was 15.2 ± 1.4 yr for RG and 15.2 ± 1.2 yr for AG. Concerning RG, 118 athletes responded to the questionnaire, from which 33 (28.65%) had not reached menarche yet. In AG, the number of athletes without menarche reached 34.8% (47 of 135). These differences were not

TABLE 1. Demographic, training, and parental weight data of examined RG and AG

Variable	RG		AG	
	Mean	SD	Mean	SD
Age (yr)	17.1 (n = 129)	1.4	17.3 (n = 142)	1.9
Height (cm)	166.3 (n = 129)	4.6	154.4 (n = 142)	6.6
Mother's height (cm)	165.3 (n = 121)	5.4	162.3 (n = 126)	5.8
Father's height (cm)	178.0 (n = 121)	7.0	172.9 (n = 126)	6.2
Weight (kg)	47.3 (n = 129)	4.8	47.2 (n = 142)	6.9
BMI (kg/m^2)	17.1 (n = 129)	2.1	19.7 (n = 142)	1.9
Body fat (%)	13.1 (n = 122)	4.9	20.6 (n = 140)	5.3
No. of competitions/year	7.6 (n = 116)	3.1	8.0 (n = 134)	4.4
Training intensity (h/wk)	31.2 (n = 118)	9.6	31.9 (n = 134)	10.6
Onset of training (yr)	7.7 (n = 116)	2.2	6.4 (n = 125)	2.4
Menarche (yr)	15.2 (n = 85)	1.4	15.2 (n = 88)	1.2
Reported onset of breast development (yr)	13.4 (n = 105)	1.6	13.6 (n = 113)	1.4
Reported onset of pubic hair development (yr)	12.7 (n = 109)	1.5	13.0 (n = 120)	1.3

TABLE 2. Derived height and weight data of examined RG and AG

Variable	RG		AG	
	Mean	SD	Mean	SD
Height SD score	+0.70 (n = 129)	0.8	−1.27 (n = 142)	1.1
Reported target height (cm)	165.0 (n = 121)	4.7	161.1 (n = 124)	4.7
Target height SD score	+0.48 (n = 121)	0.8	−0.18 (n = 125)	0.8
Δ Height-target height SD score	+0.10 (n = 121)	0.9	−0.89 (n = 125)	1.9
Weight SD score	−0.95 (n = 129)	0.6	−0.92 (n = 142)	0.7

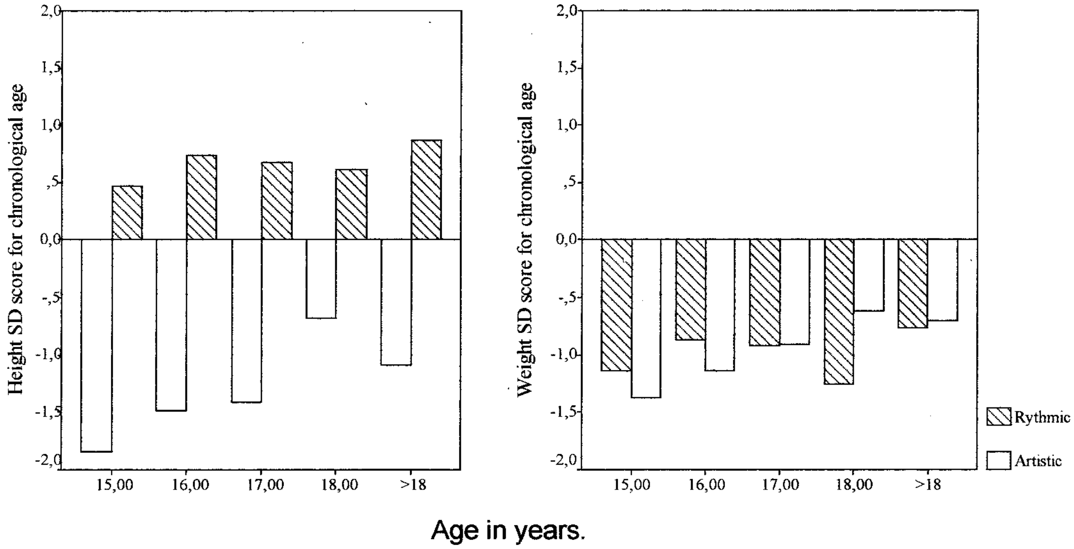

FIG. 2. Height SD score and weight SD score for chronological age.

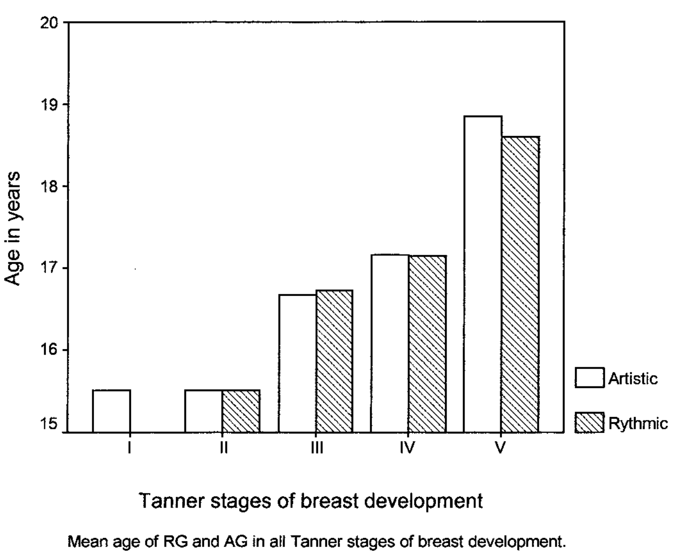

FIG. 3. Tanner stages of breast development.

significant ($\chi^2 = 1.37$) as a whole, as well as when analyzed by age. It should be mentioned that from those without menarche yet, 33 RG and all 47 AG were older than 15 yr of age, so the final age of menarche is anticipated to be even more delayed.

Relationships

Height SD score correlations for RG and AG are presented in Table 3.

A multiple regression analysis was used to ascertain which of the above parameters had independent value in predicting height SD score for both RG and AG (Table 4). The actual height SD score was independently influenced positively by weight SD score for both RG (b = 0.39; t = 4.46; $P < 0.001$) and AG (b = 1.43; t = 21.05; $P = <0.001$) and by target height (b = 0.33; t = 4.13; $P < 0.001$) only for RG and negatively by body mass index (BMI) (b = −0.81; t = −12.38; $P < 0.001$) only for AG.

All anthropometric, sports-related parameters and growth data of RG and AG were compared, and their correlation coefficients are presented in Table 5. Both gymnastics groups were of similar age and of similar age distribution (Fig. 1).

RG were taller than AG (t = 16.77; $P < 0.001$), with a higher reported target height SD score (t = 6.41, $P < 0.001$), a greater Δ height-target height (t = 6.35; $P < 0.001$), and a lower mean body fat (t = −11.92; $P < 0.001$) and BMI (t = −10.69; $P < 0.001$) than AG. AG started training at an earlier age than RG (t = 4.12; $P < 0.001$).

Discussion

RG and AG exhibit a specific pattern of growth characterized by general similarities, but also striking and important differences. Although both groups had lower weights than the age-related population mean, RG were taller and AG were shorter than the population mean for their respective age groups. It is generally accepted that both sports are characterized by a moderate but significant delay in growth and pubertal development (8, 10, 11, 18).

TABLE 3. Height SD score for RG and AG: correlation coefficients

Variable	RG	AG
Target height SD score	n = 121, r = 0.34, $P < 0.001$	n = 124, r = 0.30, $P = 0.001$
Δ Height-target height SD score	n = 121, r = 0.51, $P < 0.001$	n = 124, r = 0.77, $P < 0.001$
Weight SD score	n = 129, r = 0.46, $P < 0.001$	n = 142, r = 0.78, $P < 0.001$
BMI (kg/m^2)	n = 129, r = 0.13, $P = 0.128$	n = 142, r = 0.37, $P < 0.001$
Body fat (%)	n = 122, r = −0.51, $P = 0.122$	n = 139, r = −0.18, $P = 0.033$
No. of competitions/year	n = 115, r = −0.15, $P = 0.115$	n = 133, r = 0.06, $P = 0.470$
Intensity of training (h/wk)	n = 117, r = 0.13, $P = 0.162$	n = 133, r = −0.30, $P = 0.001$
Onset of training (yr)	n = 113, r = −0.34, $P = 0.719$	n = 125, r = −0.16, $P = 0.078$
Menarche (yr)	n = 117, r = 0.26, $P = 0.006$	n = 87, r = −0.12, $P = 0.255$
Reported onset of breast development (yr)	n = 104, r = −0.14, $P = 0.164$	n = 112, r = −0.10, $P = 0.278$
Reported onset of pubic hair development (yr)	n = 108, r = −0.10, $P = 0.293$	n = 119, r = −0.16, $P = 0.078$

TABLE 4. Actual height for examined RG and AG: multiple regression analysis (ANOVA)

Variable	RG	AG
Target height SD score	b = 0.33, t = 4.13, $P < 0.001$	b = 0.05, t = 1.38, $P = 0.172$
Weight SD score	b = 0.39, t = 4.46, $P < 0.001$	b = 1.41, t = 19.91, $P < 0.001$
BMI		b = −0.79, t = −11.46, $P < 0.001$
Body fat		b = −0.01, t = −0.11, $P = 0.920$
Intensity of training		b = −0.03, t = −0.74, $P = 0.463$
Menarche	b = 0.11, t = 1.24, $P = 0.22$	

TABLE 5. Comparative auxologic data between RG (n = 129) and AG (n = 143): correlation coefficients

Variable	t	*P*
Age (yr)	1.29	0.200
Height SD score	16.77	<0.001
Target height SD score	6.41	<0.001
Δ Height-target height SD score	6.35	<0.001
Weight SD score	−0.43	0.710
BMI (kg/m^2)	−10.69	<0.001
Body fat (%)	−11.92	<0.001
No. of competitions/year	−0.89	0.380
Intensity of training (h/wk)	−0.53	0.600
Onset of training (yr)	4.12	<0.001
Menarche (yr)	1.14	0.900
Reported onset of breast development (yr)	−1.14	0.210
Reported onset of pubic hair development (yr)	−2.51	0.013

RG present a reported target height SD score well above the 50th percentile, whereas AG were markedly below the 50th percentile. Both groups are exposed to similar highly intensive training conditions. On the other hand, each sport is characterized by specific athletic requirements that favor a particular optimal somatotype. A short-limbed individual would have a greater mechanical advantage in artistic gymnastic performance, whereas a long-limbed individual could benefit from a similar advantage in rhythmic gymnastics. Indeed, performance scores in elite female AG are negatively correlated with the degree of fatness or endomorphy of the individual (19). It is reasonable, therefore, for trainers (coaches) to select those individuals who best match the appropriate anthropometric criteria for each sport. The sport-specific selection criteria for artistic gymnastics suggests that a short stature with relatively short limbs, broad shoulders, and narrow hips is derived from genetic predisposition rather than a result of the specific sport activity (20). These observations are in concordance with the present data concerning the genetic predisposition for final height in the examined gymnasts. Although reported target height tends to be overestimated and therefore should be used with caution, the same procedure for data collection was used for both RG and AG.

Genetic predisposition, however, cannot fully explain the observed differences in stature between RG and AG. In this study, RG grow slightly taller, and AG grow considerably shorter than their genetic predisposition. Nevertheless, in RG, multiple regression analysis of the reported target height revealed an independent positive influence on actual height, whereas in AG this effect was actually lost. These findings are probably related to the specific conditions of training and performance in AG, as well as to their particular somatotype. Low body fat in RG could actually protect premature fusion of the epiphyses due to less substrate for steroidal aromatization in adipose tissue. Growth plates are submitted to abrupt and repetitive vertical forces that, especially in the lower limbs, could lead to premature fusion of the epiphyses in the healing process. Indeed, radiologic lesions at the hand and wrist of AG have been shown to result in overuse lesions of the growth plates, producing a negative end-organ effect (21). In a recent study (22), shorter leg length in AG was attributed to genetic predisposition, but reduced sitting height was worsened with continuous training activity and was considered to be a consequence of vigorous exercise that could be reversed with the cessation of gymnastics training.

Growth is a complex process, whereas gene expression is maximally achieved only when favorable conditions operate throughout the entire period of growth (23). The effect of stress and intensive physical training on growth is related to the combined effects of exercise intensity, exercise frequency, and exercise duration. Intensive athletic training of 18 h/wk for a long period of time is able to attenuate growth (23). Indeed, in the examined AG, the intensity of training had a negative impact on actual height SD score. Nevertheless, the observation that training in AG starts at a younger age compared with RG could be an additional factor in the observed deterioration of growth.

We have previously shown that RG exhibit a specific pattern of growth and pubertal development and that, despite the observed delay in skeletal maturation and pubertal development, the final height was not affected. Recent data from a longitudinal prospective study suggest an adequate compensatory catch-up growth phenomenon resulting from pubertal delay, with a recovery of growth potential (12). It is well established that the removal of factors associated with growth restriction results in growth for a longer than usual period, and is seen as an increased height velocity for chronological age (24). If bone maturation progresses slowly over a long period of time, then the achieved final height will be above the initially expected final height (24). In our examined sample of RG and AG, puberty started and progressed similarly for both RG and AG, thus excluding any discrepancies either in the onset of puberty or during pubertal development as the cause of the observed deterioration of growth in AG. Will AG present an adequate compensatory catch-up growth phenomenon resulting in a recovery of growth potential as puberty will progress? A large prospective study on the growth pattern of elite AG should be done to answer these critical questions.

In conclusion, this study confirms previous studies (1, 12) reporting the profound effects of intensive physical training in elite female RG and suggests that genetic predisposition to growth is not only preserved, but even exceeded. In contrast, in AG a deterioration of growth potential has been observed. Importantly, our findings add fuel to the idea that early initiation of elite-level training regimens may negatively impact on skeletal development and growth. The observed deterioration of growth in AG needs further evaluation to facilitate the improvement of standard training regimens that can reduce potential health risks in these elegant athletes.

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