Research paper

Growth velocity and final height in elite female rhythmic and artistic gymnasts

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ABSTRACT

PURPOSE: The aim of this study was to determine the impact of intensive training on adult final height in elite female rhythmic and artistic gymnasts. METHODS: The study included 215 rhythmic gymnasts (RG) and 113 artistic gymnasts (AG). RESULTS: AG were below the 50th percentile, while RG were taller than average. Final adult height was lower than target height in AG, while in RG, it exceeded target height. AG started training earlier than RG ($p<0.001$) and reported lower intensity of training ($p<0.001$). RG were taller than AG, with higher target height, greater Δ final height-target height and lower body fat and BMI ($p<0.001$). Using multiple regression analysis, the main factors influencing final height were weight SDS ($p<0.001$), target height SDS ($p<0.001$) and age of menarche ($p<0.001$) for RG, and weight SDS ($p<0.001$) and target height SDS ($p<0.001$) for AG. CONCLUSION: In both elite female RG and AG, genetic predisposition to final height was not disrupted and remained the main force of growth. Although in elite RG genetic predisposition for growth was fully preserved, in elite female AG final adult height falls shorter than genetically determined target height, though within the standard error of prediction.

Key Words: Adult height, Artistic gymnasts, Athletes, Final height, Growth, Growth velocity, Gymnastics, Rhythmic gymnasts

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Abbreviations-Acronyms:
SDS: Standard Deviation score
BMI: Body mass index
AG: Artistic Gymnasts
RG: Rhythmic Gymnasts
F.I.G.: International Federation of Gymnastics
U.E.G.: European Union of Gymnastics

INTRODUCTION

Rhythmic and artistic gymnastics are two distinct sports, each requiring very specialized skills. Artistic gymnastics is practised by both males and females, while rhythmic gymnastics is exclusively for female athletes. Rhythmic (RG) and artistic Gymnasts (AG) are exposed to high levels of physical and psychological stress during adolescence. The detrimental effects of these factors on growth, skeletal maturation, and pubertal development have been clearly documented in AG, leading to a significant late maturation.[1-5] Although prospective growth predictions, thanks to late catch-up growth, appear normal,[1-4] a decrease in height predictions with time was observed that could ultimately result in lower final adult height.[5] By contrast, in high level RG, despite the significant delay in skeletal maturation and pubertal development,[6] genetic predisposition of growth, as expressed by predictions of final adult height, was preserved.[7]

Data from the literature are controversial and difficult to compare. In RG no final impairment of growth has ever been documented. On the other hand, data in AG anthropometric measurements and prospective growth predictions appeared within normal limits,[4,8-11] while in other studies evidence for a reduction of growth potential and a decrease in mean height predictions over time was provided.[5,12] The results reported are derived from athletes at a different level of competition (college athletes, high performers, etc). Nevertheless, the increasing demand for ever higher performance levels has raised the intensity of training during the last 20-30 years. The International Federation of Gymnastics (F.I.G.) has therefore adopted this study designed to determine the particular pattern of growth as well as final adult height of elite female RG and AG athletes. The objective of the present study was to determine the pattern of pubertal growth velocity and adult final height in elite female gymnastics. From an original cohort of more than one thousand gymnasts studied cross-sectionally and partly previously published,[6,7-13] 328 who have reached final height during the 10-year follow-up period and have also reported parental data on height are included in this study.

SUBJECTS AND METHODS

The rational study was prospective and longitudinal, although the current analysis of data is cross-sectional. Data from 215 female RG and 113 female AG were obtained during the gymnastics competitions of European and World Championships for a period of 12 years (1997-2009). Gymnasts were National team members from 28 countries who represented all continents and all races. The mean age was 19.0 ± 1.6 for RG and 18.9 ± 1.7 for AG (Table 1). The study was conducted under the authorization of the F.I.G. and the European Union of Gymnastics (U.E.G.). Informed consent was obtained in accordance with article 7 of the medical organization of the official F.I.G. competitions. The medical authority of the F.I.G. 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 protocol has been published in previous studies.[6,13] Briefly, the study protocol included non-invasive clinical and laboratory investigations and the completion of a questionnaire. The clinical evaluation included height and weight measurements as well as assessment of breast and pubic hair development. The same physician measured both weight and height. Height was recorded as the mean of two consecutive measurements, to a standard physician scale. Breast and pubic hair development were assessed by a female physician (A.T.) according to Tanner's stages of pubertal development.[14] The laboratory investigation included determination of skeletal maturation and body composition. Body composition was determined by a portable apparatus (Futrex 5000, Futrex Inc., Gaithersburg, MD) which estimates body fat ratio and total body water based on infrared analysis.[15] Skeletal maturation was evaluated from an x-ray of the left hand and wrist, executed in a separate room under full body protection against radioactivity. All radiographs were evaluated blindly by two physicians and bone age was determined according to Greulich-Pyle standards.[16] Near-total skeletal maturation was considered when bone age was greater than 16 years of age. For those athletes whose radiographs showed near-total skeletal maturation (i.e. bone age >16 years), and for athletes over 18 years of chronological age irrespective of bone age, the measured height was

Table 1. Collected and derived data of examined rhythmic and artistic gymnasts. Data are expressed as mean ± SD, p values express differences between elite female RG and AG

Variables	Rhythmic gymnasts (n=215)		Artistic gymnasts (n=113)		
	Mean	SD	Mean	SD	p
Age (years)	19.0	1.6	18.9	1.7	=0.608
Mean final height (cm)	167.65	5.5	157.5	5.9	<0.001
Final height SDS	0.91	0.9	-0.79	0.9	<0.001
Mean Target Height (cm)	163.5	5.7	160.1	5.0	<0.001
Target height SDS	0.41	0.87	-0.35	0.84	<0.001
Δ Final - target height (cm)	4.11	5.27	-2.57	5.85	<0.001
Δ Final - target height SDS	0.7	0.9	-0.4	0.97	<0.001
Weight SDS	-0.52	0.9	-0.55	0.6	=0.738
BMI (Kg/m^2)	18.4	1.5	20.5	1.6	<0,001
Body fat (%)	14.7	5.0	16.4	4.99	0.007
No. of competitions/year	7.2	3.4	8.6	4.3	0.003
Training intensity (hours/week)	33.9	10.9	29.4	11.5	<0.001
Age of onset of training (years)	8.2	2.8	6.7	2.7	<0.001
Age of menarche (years)	15.6 (n=180)	1.9	15.5 (n=97)	1.6	=0.658

SDS: standard deviation score; BMI: body mass index

considered as final adult height only if two consecutive height measurements (spaced apart by at least one year) were equal i.e. did not differ.

All athletes completed a questionnaire that included questions on age of training commencement, the intensity of training, the number of competitions per year (as an index of exposure to stress), the age of menarche and several family data including paternal and maternal heights, etc. The reported target height in centimetres was estimated using the mid-parental height as an index of genetic predisposition to final height. The equation used for reported target height was: target height= (father's height-13+mother's height)/2 cm.[12] It is to be noted that target height is not an accurate estimation and rather reflects a range of probabilities within 1 SD from the mean. This represents a deviation of approximately a minimum of 5 cm[17] and a maximum of 8.5 cm in females,[18] in both directions. Height and weight were expressed as the standard deviation score (SDS) of the mean height and weight for age that represent the 50th percentile of normal values distribution, according to Tanner's standards.[19,14] The SDS was also calculated for reported target height.

Growth velocity was calculated after two consecutive height measurements of the same individual within a time period of 1 year ±3 months.

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STATISTICAL ANALYSIS

Two-tailed independent sample t-tests were used for comparison of data between the different groups. Pearson's two-tailed product moment correlation coefficient was used to evaluate the strength of correlation between the different variables. Multiple regression analysis was performed to ascertain the independent predictive value of each parameter proved to be significant according to Pearson's correlation coefficient. Significance level was set to 5%. All statistics were performed using SPSS for Windows, version 9.0.1 (Chicago, Illinois, 6061 USA).

RESULTS

Mean values for collected and derived data (including final height and weight SDS) for all examined AG and RG are shown in Table 1. As we have previously reported during the longitudinal follow-up of actual height SDS,[6,7] according to their final measured adult height, RG were taller than average with mean height SDS above the 50th percentile, while AG were well below the 50th percentile[12,13] (Figure 1). RG presented final height SDS that was slightly higher than their reported Target height SDS, while AG had final height SDS lower than their genetic predisposition, though within the standard error of prediction. Both RG and AG had low body weights compared to the population mean, with the mean weight for age falling below the 50th percentile for both groups (Figure 1).

Growth velocity mean values per chronological age for both RG and AG were obtained longitudinally and are presented cross-sectionally in Figure 2. Growth velocity SD score highest values were recorded at the age of 14 years for RG and at the age of 15 years for AG. It is of particular interest that, although height velocity in normal girls comes to an end by the age of 15, in our examined RG and AG it continues up to the age of 18.

As regards sexual maturation, all athletes who had reached final adult height were at Tanner stage V for breast development. The age of recalled menarche was similar in both groups: 15.6±1.9 years for RG, and 15.5 ±1.6 years for AG.

Results of the two-tailed independent sample t-tests comparing RG and AG on anthropometric, sports-related variables and growth data are presented in Table 1.

Results of the two-tailed independent sample t-tests comparing RG and AG on anthropometric, sports-related variables and growth data are presented in Table 1. RG were taller than AG [final height SDS 0.91±0.9 and final height (cm) 167.65±5.5 for RG compared to final height SDS -0.79±0.9 and final height (cm) 157.5±5.9 for AG] ($p<0.001$) with higher target height [target height SDS 0.41±0.87 and target height (cm) 163.5±5.7 for RG compared to target height SDS -0.35±0.84 and target height (cm) 160.1±5.0 for AG] ($p<0.001$), greater Δ final height-target height [Δ final height-target height SDS 0.7±0.9 and Δ final height-target height (cm) 4.11±5.27 compared to Δ final height-target height SDS -0.4±0.97 and Δ final height-target height (cm) -2.57±5.85] ($p<0.001$), lower mean body fat % [14.7±5.0 for RG compared to 16.4±4.99 for AG] ($p=0.007$) and Body Mass Index (BMI) (Kg/m^2) [18.4±1.5 for RG compared to 20.5±1.6 for AG] ($p<0.001$). AG started training at an earlier age than RG [8.2±2.8 years for RG compared to 6.7±2.7 years for AG] ($p<0.001$),

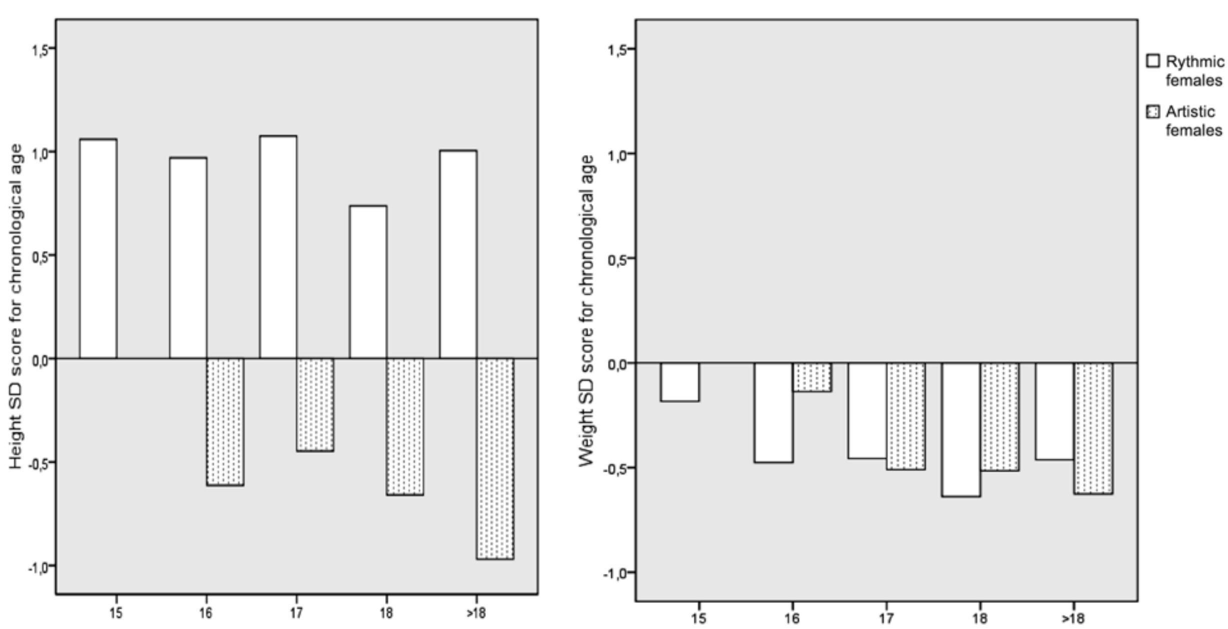

Figure 1. Final height SD score and weight SD score for elite rhythmic and artistic gymnasts.

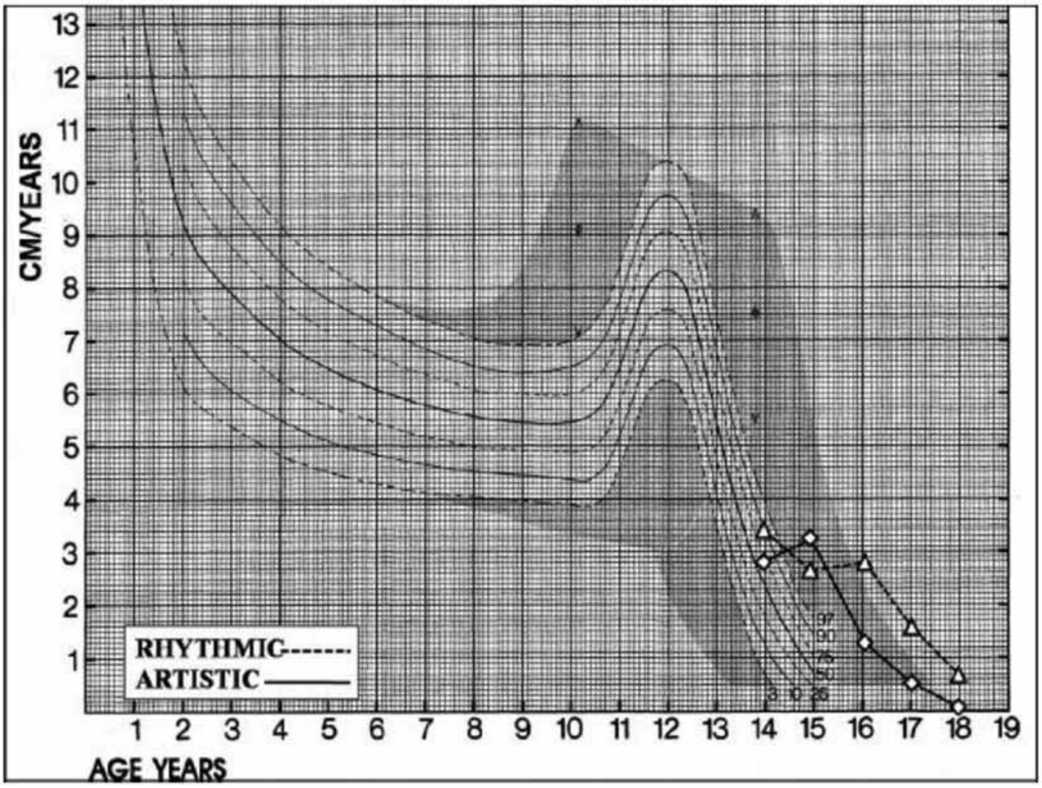

Figure 2. Mean values of height velocity per chronological age for elite female rhythmic and artistic gymnasts. Data were obtained from longitudinal measurements of the same individuals. Lines represent the 3rd, 10th, 25th, 50th, 75th, 90th and 97th percentiles of height velocity. The dark lines represent the height velocity of the examined gymnasts. The dark grey area includes the velocity curves of all children who have their peak velocities up to two standard deviations of age before and after this average age. The arrows and diamonds mark the 3rd, 50th and 97th percentiles of peak velocity when the peak takes place at these early limits.

and reported lower intensity of training 33.9±10.9 hours/week for RG compared to 29.4±11.5 hours/week for AG] ($p<0.001$).

CORRELATIONS

Correlations of final height SDS with target height SDS, Δ final height-target height SDS, Weight SDS, BMI, Body Fat ratio, the number of competitions per year, the intensity of training, the age of onset of training and the age of menarche, for RG and AG are presented in Table 2. Multiple regression analysis (MRA) was performed in order to ascertain which of the above parameters were independent predictors of final height SDS for both RG and AG (Table 3). All aforementioned variables, which have been significantly correlated with final height, were included in the MRA with the exception of BMI, excluded in order to avoid multicollinearity. The main factors influencing final height were weight SDS ($p<0.001$ for RG, $p<0.001$ for AG), target height SDS ($p<0.001$ for RG, $p<0.001$ AG), and age of menarche ($p<0.001$) for RG.

DISCUSSION

The results of the present study clearly demonstrate and strengthen our preliminary findings,[6,7] that female elite RG achieve normal final height in accordance with their genetic predisposition. In contrast, in female AG, a slight impairment of growth potential, albeit within normal limits, was observed.

The evidence for this slight impairment of growth comes from the noted differences between target height and actually measured final height (Δ final height-target height). Genetic predisposition to final height has been evaluated through the reported parental heights which may be considered biased. Although

Table 2. Final height standard deviation score for rhythmic and artistic gymnasts: Correlations coefficients

Variables	Rhythmic gymnasts (n=215)	Artistic gymnasts (n=113)
Target height SDS	n=215, r=0.52, p<0.001	n=113, r=0.464, p<0.001
Δ Final -Target height SDS	n=215, r=0.428, p<0.001	n=113, r=0.538, p<0.001
Weight SDS	n=215, r=0.280, p<0.001	n=113, r=0.774, p<0.001
BMI (Kg/m^2)	n=215, r=-0.047, p=0.587	n=113, r=0.256, p=0.008
Body fat (%)	n=215, r=-0.026, p=0.715	n=113, r=-0.200, p<0.048
No. of competitions/year	n=208, r=0.094, p=0.201	n=113, r=0.033, p=0.744
Intensity of training (hours/week)	n=206, r=0.33, p=0.658	n=113, r=-0.276, p=0.002
Age of onset of training (years)	n=211, r=-0.062, p=0.419	n=113, r=-0.006, p=0.954
Age of menarche (years)	n=175, r=0.181, p=0.016	n=95, r=-0.091, p=0.379

SDS: standard deviation score; BMI: body mass index

Table 3. Final height standard deviation score for examined rhythmic and artistic gymnasts: multiple regression analysis

Variables	Rhythmic gymnasts	Artistic gymnasts
Weight SDS	b=0.174, t=3.273, p=0.001	b=1.141, t=19.87, p<0.001
Target height SDS	b=0.527, t=8.432, p<0.001	b=0.137, t=3.307, p<0.001
Age of menarche	b=0.097, t=3.367, p=0.001	-
r^2	0.368	0.797

SDS: standard deviation score

the parental height is usually well recorded in the youngster's mind, knowing that their height is usually proportional to their parent's height, prediction of final height through target height is not an accurate estimation and rather reflects a range of probabilities within 1 SD from the mean. This represents a deviation of approximately a minimum of 5 cm[18] and a maximum of 8.5 cm in females,[19] in both directions. Indeed, in artistic gymnastics, the estimated difference in cm approaches this minimum deviation, while still remaining well within the error of the predication equation. In the event that the noted deviations from the reported target height were greater, then we would not be facing an impairment of growth potential but a true growth disorder. Therefore, the possibility of a slight impairment of growth potential, even when exhibited within the normal limits of growth, should be seriously taken into account.

In contemporary high power gymnastics, requirements for international records have driven the hours of training to more than 30 hours per week, compared to 15 h during the seventies and 20 h during the eighties. By contrast, local gymnastic activity at college or club level remains moderate and does not appear to negatively affect final height.[3,4,20] Erlandson et al reported prospective data from young, moderately trained female gymnasts showing that gymnasts followed the natural growth pattern of a late maturing individual resulting in a completely normal final height.[20] Athletic performance at the level of top champions, on the other hand, reflects the highest level of stress and intensive physical training to which gymnasts are exposed. To our knowledge, this is the first time that a slight impairment of adult final height has been documented in high competitive level elite contemporary artistic gymnastics, thus seriously prompting the demand for intervention on the part of the International Gymnastics Community for the protection of athletes' health.

The reason for the discrepancy between RG and AG in achieving the predicted final adult height is not readily apparent. The observed difference should be, at least in part, attributed to individual sport characteristics. Rhythmic and artistic gymnastics are two distinct sports within the field of gymnastics, requiring very different skills which favor a particular optimal somatotype. The athletic programme of rhythmic gymnastics resembles that of ballet, including performances with rope, hoop, ball and ribbon, while artistic gymnastics requires more vigorous athletics, such as uneven and parallel bars, vault, etc. A short-limbed individual would have a greater mechanical advantage in artistic gymnastic performance, while a long-limbed individual could benefit from a similar advantage in rhythmic gymnastics. Therefore, coaches out of necessity select individuals who best match the particular anthropometric criteria for each sport. The sport-specific selection criteria for artistic gymnastics implies that a short stature with relatively short limbs, broad shoulders and narrow hips is determined by genetic predisposition rather than as a result of the specific sport training and performance. Indeed, in our studied gymnasts, Target height SDS was over the mean for RG and below the mean for AG, implying a selection bias by coaches. Thus, genetic predisposition should always be considered when studying the impact of gymnastics on growth. In our study group, by excluding the selection bias using the difference between genetic predisposition and the finally achieved adult height (Δ final height-target height), the final height deficit exceeds that caused by early selection.

Although RG reported more training hours per week than AG, AG are exposed to more vigorous training, this often leading to lesions of the growth plates and frequent skeletal micro trauma, both to the lower and upper limbs.[21,22] In addition, imaging studies have identified evidence of injury to the wrist joint as a consequence of repetitive loading in a weight-bearing fashion, indicating that growth plates of the upper extremities are also significantly affected.[19,20] It is debatable whether these lesions could definitely affect growth. Some previously published reports rejected this outcome,[2,3,20,25,26] while others reported decreased sitting height in AG[5,6]. Therefore, overuse lesions of growth plates both in the lower and upper limbs might amount to an additional end-organ effect.[21-24]

Unfortunately sitting height was not assessed in this study. A subsequent study measuring this parameter will be needed in order to estimate the different effects of sports activity versus genetic predisposition.

It is interesting to note the greater intensity of training in RG as well as the older age of the onset of training. The fact that RG were exposed to less vigorous exercise activities and were older at the onset of training may be additional factors which protected this group from the detrimental effects of intense training. Of importance is not only the amount but also the nature of exercise activity as well as the time during early childhood development when sports activities are commencing.

We,[6,7,12,27] and others,[25,28] have previously shown that in RG and AG, intensive physical training and negative energy balance, by modulating the hypothalamic pituitary set point at puberty, prolonged the prepubertal stage and delayed pubertal development from Tanner stage II to Tanner stages IV and V, as well as menarche, which followed the retarded bone age rather than the chronological age. Gymnasts are known to be late maturers, experiencing a delayed acceleration of growth towards the end of puberty. Catch-up growth is defined as a height velocity above the statistical limits of normality for age, following a transient period of growth inhibition.[29,30] The ultimate success of catch-up growth largely depends upon the time of onset and the duration and speed of progression.[29] If bone maturation progresses slowly over a long period of time, then the achieved final height will be above the initially expected final height.[29] True catch-up growth occurs after removal of the environmental factor responsible for the disruption of maturation. Therefore, the late maturation which characterizes the observed pattern of growth in gymnasts misses the accelerated rate of true catch-up growth and mostly depends on the duration of the maturation process. This was observed in the present study in female RG where the prolongation of late maturation resulted in higher than predicted final height. In contrast, this did not apply to elite highly trained AG. Although a gain in actual height over time was evident in AG,[12,13] it got shorter during the pubertal growth spurt. This becomes obvious via observation of the progression of height velocity over time in RG versus AG. Elite RG presented an above average for age height velocity, starting from the age of 14 years, reaching a peak at the age of 16 and exceeding the age of 18 when, in a normal growing adolescent, linear growth is expected to be terminated.[7] This ultimate gain in height leads to a total preservation of genetic predisposition in the adult height of RG. Conversely, in elite female AG height velocity, although starting higher than in RG at the ages of 14-15, by following the normal growth pattern of a late maturer, was terminated by the age of 16-17, thus not allowing for a complete compensation of the shorter pubertal growth spurt.

Target height was one of the most important parameters influencing final adult height for all examined RG and AG; therefore, genetic predisposition (exceeded in RG and not fully achieved in AG) was not disrupted by the negative effects of intensive physical training. It is however to be emphasized that in RG, the observation that final adult height exceeded target height might simply reflect the tendency for higher adult stature among younger generations, this in turn mirroring the improvement of socio-economic conditions. In AG the difference between the predicted target height and the actual height measured in adulthood is less than 3 cm. Taking into account that the error within the prediction of target height is ±9cm, genetic predisposition remains the most important determinant of adult height in AG. The same importance was attributed to weight. Low body weight reflects the energy deficit evident in both sports as a consequence of intensive physical training (high energy output) and low caloric diet (low energy input). Gymnasts are indeed subjected to a significant energy drain occurring early in preadolescence and are moreover highly motivated to maintain a low body weight due to their sports requirements for a thin somatotype. In conditions of energy deficit and consequent adipose tissue reduction, estrogen production is decreased and skeletal maturation and pubertal development are delayed.[30,31] This is particularly evident in RG where, despite the normal height, low energy input leads to a significantly low body weight that accounts for the delay in both biological and skeletal maturation.[6,7] The particular growth pattern in RG with an additional increase in height after 16 years of age might be, at least partly, due to this deficit in weight. Although a certain somatometric phenotype in RG (taller and thinner than average) is related to success in performance,[32] the positive correlation between final height and weight denotes the careful monitoring of energy balance and adequate nutritional intake in RG.

This study has certain significant limitations. It is a field study, as all variables were determined during competitions, therefore additional determinations of other important anthropometric characteristics (such as sitting height, for instance) were not possible. The intensity of training was assessed through a questionnaire alone and expressed as hours of usual training per week; it was furthermore not determined on the field as the latter was not possible during the activities of major athletic competitions. Additional data concerning the critical prepubertal and early pubertal development are also lacking, as athletes participating in these high level competitions are older than 15 years of age. Finally, Target height estimations were not based on actually measured parental height and might be overestimated.

In conclusion, in both elite female RG and AG, genetic predisposition to final height was not disrupted and remained the main force of growth. Although in elite RG genetic predisposition for growth was fully preserved, in elite female AG final adult height falls shorter than genetically determined target height, though still within the standard error of prediction. Although this slight impairment of growth remains well within the normal limits, based on medical and psychological risks in general and further supported by the results of this study, the F.I.G. has decided to increase by one year the lower limits of age for participants in International Gymnastics competitions (including the Olympic Games). The ultimate goal of this intervention, the first ever in sports on behalf of athletes' health, is to discourage early intensive physical training during the critical years of prepubertal growth and to transpose the years of intensive training to a later period.

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Conflict of interest: *The authors have no financial relationships to disclose that are relevant to this article.*

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