The influence of intensive physical training on growth and pubertal development in athletes

Neoklis A. Georgopoulos,1 Nikolaos D. Roupas,1 Anastasia Theodoropoulou,2 Athanasios Tsekouras,2 Apostolos G. Vagenakis,2 and Kostas B. Markou2

1Division of Reproductive Endocrinology, Department of Obstetrics and Gynecology, University of Patras Medical School, University Hospital, Patras, Greece. 2Division of Endocrinology, Department of Medicine, University of Patras Medical School, University Hospital, Patras, Greece

Address for correspondence: Neoklis A. Georgopoulos, Division of Reproductive Endocrinology, Department of Obstetrics and Gynecology, University of Patras Medical School, University Hospital, Rio-26500, Patras, Greece. neoklisg@hol.gr

Genetic potential for growth can be fully expressed only under favorable environmental conditions. Although moderate physical activity has beneficial effects on growth, excessive physical training may negatively affect it. Sports favoring restricted energy availability, in the presence of high energy expenditure, are of particular concern. In gymnastics, a different pattern in skeletal maturation and linear growth was observed, resulting in an attenuation of growth potential in artistic gymnasts (AG), more pronounced in males than in females. In female rhythmic gymnasts (RG), the genetic predisposition to growth was preserved owing to a late catchup growth phenomenon. In all other sports not requiring strict dietary restrictions, no deterioration of growth has been documented so far. Intensive physical training and negative energy balance alter the hypothalamic pituitary set point at puberty, prolong the prepubertal stage, and delay pubertal development and menarche in a variety of sports. In elite RG and AG, prepubertal stage is prolonged and pubertal development is entirely shifted to a later age, following the bone maturation rather than the chronological age.

Keywords: athletes; gymnasts; growth; pubertal development; skeletal maturation; bone acquisition

Introduction

Somatic growth and biological maturation are dynamic processes regulated by a variety of genetic and environmental factors. Changes in body composition, in body proportions, in skeletal maturation, and in pubertal development constitute indispensable components in the evaluation of the growth process, complementing the traditional aspect of the assessment of stature as the main focus of growth evaluation. Thus, growth and physical maturation should be regarded as a complex, and dynamic process, including a large variety of molecular and somatic changes.

Genetic predisposition to growth can be fully expressed only under favorable environmental conditions.1 Environmental factors can act independently or in combination to modify the individual genetic potential. Athletic training when exerted during childhood and adolescence has a huge impact on physical growth and pubertal maturation. There is strong evidence that regular physical activity is important for good body function and development. At the same time, there is a growing concern regarding the influence of stress and intensive physical training on general health. Beginning at an early age, athletes performing at a high competitive level are exposed to high levels of physical and psychological stress resulting from many hours of intense training and competitions. The damaging effects of these factors on somatic growth, skeletal, and pubertal maturation, have been described in individuals performing a variety of sports. Individual sports exert unique influences on biological maturation, depending on the sport-related specific character, technical skills and training methods and the stage of growth and sexual maturation of the individual athlete. Therefore, the whole picture is
extremely complex and should be approached with extreme caution and responsibility.

**Somatic growth in athletes**

The major factor influencing linear growth is genetic predisposition. Both adult final height and the rate of growth are greatly influenced by genetic factors. Studies involving twins, revealed that the average difference in final height between monozygotic twins was less than 3 cm, compared to 12 cm for dizygotic twins. Final height is best correlated to target height (midparental height) especially when parents are not of disparate heights. Environment and heredity continuously interact throughout the entire period of growth. Children with similar genetic potential are expected to reach comparable final height under optimal environmental conditions. On the other hand, children with the same genetic background exposed to entirely different environmental conditions, can end up with a different adult height. Furthermore, children of parents from underdeveloped areas, born and raised in industrialized countries, present taller as adults, compared to their target height. In industrialized countries, an increase in height has been documented, attributed to the improvement in socioeconomic conditions.

Growth and maturation are complex processes and genetic predisposition is achieved only when favorable conditions exist during the entire period of growth. Major environmental factors that may alter somatic growth are intensive physical exercise and stress. The impact of stress and intensive physical training on growth depends on the combined effects of intensity, frequency, and duration of exercise. Intensive athletic training of 18 hours per week is capable of attenuating growth. Although moderate physical activity has beneficial effects on growth, as it is associated with cardiovascular benefits and favorable changes in body composition, extensive physical training may negatively affect growth, especially during puberty. The effect of intense physical training on growth and maturation depends on a variety of factors, including the type of physical training, the age of training initiation, and the intensity of training. Each sport requires a specific type of exercise and is characterized by unique athletic demands that favor a particular optimal somatotype.

The period of maximum training during the growth process is of particular importance. For example, in female gymnasts, the greatest physical exertion coincides with the period of pubertal development, whereas in male gymnasts, the maximum training is required toward the end of puberty. Over the past few decades, the demands of high competition level have increased the intensity of training within the same sport. For example, it is known that gymnasts are trained much more intensely nowadays than previously, usually 26–32 hours per week compared to 15 h during the seventies and 20 h during the eighties.

Sports that require a strict control of energy input in combination with a high energy output are of particular concern. Thus, it is not reasonable to generalize when trying to evaluate the particular effects of the activity of each sport on somatic growth. The major sports that require intensive physical training during childhood and adolescence are mainly gymnastics (both Rhythmic and Artistic), and to a lesser extent swimming, rowing, wrestling, track and field athleticism, and tennis.

Rhythmic gymnasts (RG) and artistic gymnasts (AG) are two distinct groups within the field of gymnastics. They include different training methods, athletic performance objectives, and require specialized and distinct skills. 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 artistic gymnasts are negatively correlated with the degree of fatness or endomorphy of the individual. Therefore, trainers (coaches) expectedly select individuals that best match certain anthropometric criteria for each sport. The sport-specific selection criteria for artistic gymnastics imply that a short stature with relatively short limbs, broad shoulders, and narrow hips is due to determined genetic predisposition, rather than a result of the specific sport training and performance. Thus, genetic predisposition should always be considered when studying the impact of gymnastics on growth.

**Artistic gymnasts**

Until recently, AG anthropometric measurements and prospective growth predictions appeared within normal limits. In all these reports, the adult
height of AG remained proportional for the reported target height despite the method used to estimate predicted adult height. Another prospective study documented a reduction of growth potential and a decrease in mean height predictions over time, in a smaller group of AG. However, in another study by the same group evidence was provided that the predicted adult height was not reduced in AG, demonstrating the inherent inaccuracy of height predictions. Although these data provide useful information, no definite conclusions should be made until adult height has been attained.

In a large cross-sectional study, we have shown that female AG were shorter and lighter than average, with mean height and weight SD scores below 0 (the 50% percentile), following their respective target height SD score, which was also below 0. However, the actually measured height was lower than their target height. The major factors negatively affecting height in AG were low weight, low body fat, and intensity of training.

The majority of previously reported data referred only to female AG. We, therefore, evaluated comparatively both male and female AG. At the time of examination, although both female and male AG were shorter than their age-related population mean, female AG showed a greater height deviation from their age-related population mean. Male AG presenting with a height closer to their age-related population mean, had a genetic predisposition toward a much higher final height than female AG. As a result, the difference between target height and actual height SD score (ΔTarget height – Actual height SD score) was greater in males than in females. Considering these data, it is reasonable to assume that in AG the growth process in males might be more susceptible to the detrimental effects of intensive physical training.

For both sexes, current measured height was correlated positively to target height, indicating that genetic predisposition to growth, although altered, was not disrupted. In the group of athletes—of both sexes—that have reached their final adult height, final height failed to meet their genetic predisposition, providing additional evidence for growth attenuation in AG.

### Rhythmic gymnasts

In RG, female RG were taller and thinner than average for age, with height velocity SD score for each age group above 0 (50% percentile) for all ages. Interestingly, although linear growth in normal girls comes to an end by the year of 15, in RG growth continued up to the age of 18. Their final adult height was identical to the estimated predicted height at first evaluation, and higher than the genetically determined target height, denoting that genetic potentials to final height was not only achieved, but even exceeded. Furthermore, target height was the only independent parameter proved to positively influence height velocity, therefore genetic predisposition remained the main driving force for the observed efficient catch-up growth. Comparing AG with RG leads to the conclusion that their reported target height SD score was similar to their own measured heights (above 0 for the RG and below 0 for the AG), indicating once more the determining role of genetic predisposition and preselection. RG followed a growth pattern that was higher than their reported target height, whereas AG exhibited a lower growth pattern.

In conclusion, studies in gymnasts performing at the highest competitive level, documented a deterioration of growth potential in AG, more pronounced in males than in females; whereas, in female RG, the genetic predisposition to growth was not only preserved, but even exceeded.

### Other sports

In all other sports, no deterioration of growth has been reported. In swimmers, probably due both to preselection bias by trainers and to high energy input, the currently measured height was well above the population mean. Another longitudinal study, found no impact of regular intensive physical training on the final height of female swimmers and tennis players. In young distance runners, mean height for both males and females approximates the reference medians and estimated height velocities are, on average, similar to age and sex-specific population means. Girls training for approximately 12 hours per week in sports including rowing, track, and swimming for an average of 4 years during puberty, revealed no difference in height velocity compared to the population means, although a tendency toward a slightly later peak height velocity was noted. Female swimmers training for 8 hours per week presented, after a follow-up of 2–3 years, normal heights and normal height velocities compared to their population means, whereas AG training
for 22 hours per week showed significantly lower growth velocities.\textsuperscript{13} Assessment of anthropometric data of elite junior tennis players, revealed significantly taller top ranked, compared to lower ranked, female tennis players.\textsuperscript{25} No difference in growth has been found between seasonal wrestlers and controls as all changes in dietary intake, body composition, and muscular strength were reversed during the post seasonal period.\textsuperscript{26} Growth rate was assessed as normal in a large cohort of school wrestlers, although no information was provided whether or not a lower growth rate was observed during the sport season followed by a catch-up growth during the nontraining season.\textsuperscript{27} Anthropometric characteristics showed that male rowers were similar in most aspects to a student control sample, whereas data on a large sample of elite junior rowers showed a tendency toward a taller height, more pronounced among finalists compared to nonfinalists, indicating the influence of preselection bias.\textsuperscript{28,29}

In conclusion, intensive physical training and athletic performance at high level did not negatively affect somatic growth in all sports not requiring strict dietary restrictions leading to energy imbalance. The attention should be drawn to elite AG of both sexes, engaged in highly strenuous competitions.

**Pubertal development in athletes**

Growth specifically refers to increase in body size, whereas maturation includes the progress leading to the biologically mature state. Thus, growth cannot be fully evaluated without determining the timing and tempo of biological maturation. Puberty is a dynamic period of development with rapid changes in body size, shape, and composition. The onset of puberty corresponds to a specific biological age, as determined by skeletal maturation, and namely, a bone age of 13 years for boys and 11 years for girls.\textsuperscript{30} Prolonged intensive physical training has great impact on skeletal maturation, leading to a significant delay in bone age compared to chronological age. As in the general population, pubertal development in highly trained athletes seems to follow bone age rather than chronological age.\textsuperscript{31} However, genetic predisposition and variation among individuals should always be considered. Specific sports favor the early matures, whereas others, such as gymnastics, offer advantage to the later developing individuals. Therefore, any assessment of sexual maturation must take into account the biological indicators of bone age and peak height velocity.

Delayed pubertal development and sexual maturation has been observed in a variety of sports, mainly gymnastics, dancing, and long-distance running.\textsuperscript{32} The documented delay is determined by the type, the frequency, the intensity, and the duration of exercise and is more pronounced in sports requiring strict dietary restrictions that result in higher energy expenditure in the presence of a deficient energy input. In the case of gymnasts performing in the high competitive level of the Olympic games, delayed menarche has been noted, compared to high school, college, and club-level athletes.\textsuperscript{7} Young girls or adolescents engaged in sports requiring training less than 15 hours per week do not show menstrual disturbances or delay in sexual maturation.\textsuperscript{33}

In elite RG and AG, the prepubertal stage was prolonged and pubertal development was shifted to a later age, retaining a normal progression rate.\textsuperscript{15–18} Expectedly, the progression of puberty followed the bone age rather than the chronological age.\textsuperscript{16,17} It is to be underlined that for both RG and AG, pubertal progression, although delayed, was not prolonged. Normal girls require an average of 1.96 ± 0.93 years (mean±SD) for their breast development to progress from Tanner stage II to Tanner stage IV.\textsuperscript{34} A comparable period of time was observed for both RG and AG in our study. Therefore, pubertal maturation was entirely shifted to a later age, maintaining a normal rate of progression.

The major factor responsible for the delay in the onset of breast and pubic hair development in both sports was low body weight. Low body weight reflects an energy deficit, prominent in both sports, as a result of intensive physical training (high energy expenditure) on the one side and caloric under-nutrition (low energy input) on the other. Gymnasts indeed are subject to a significant energy drain, occurring early in prepubertal age, and are highly motivated to achieve low body weight consistent with their sports requirements for a thin somatotype.

On the other hand, in ballet dancers under high-energy drain and low-diet intake, a delayed thelarche and a normal pubarche were noted.\textsuperscript{35} This implies that independent central mechanisms are involved in triggering these aspects of pubertal development. Indeed, breast development and subsequently menarche are related to estrogen levels,
whereas pubarche is mainly related to adrenal androgen production. In conditions of energy imbalance and consequent reduction in adipose tissue mass, estrogen production is decreased and breast development and menarche are delayed. It is the onset, the duration, and the extent of energy deficit that determine the degree of involvement in all aspects of pubertal development. Indeed, ballet dancers with a normal pubarche start their training at the age of 8–9 years of age with only 3.5–7.3 hours per week, whereas the RG and AG we examined started their training at the age of 6.4–7.7 years of age with more than 30 hours of training per week.

Female athletes involved in a large variety of sports, including runners, swimmers, tennis players, ballet dancers, and gymnasts, present a well-documented delayed menarche. In RG, menarche was significantly delayed compared to their mothers and not trained sisters, an observation arguing against a genetic predisposition toward delayed menarche.

It is well known that a minimum weight, for height and a critical lean, to, fat mass ratio is required for menarche. According to Frisch theory, the attainment of a critical percentage of body fat lowers the metabolic rate and induces a sensitization of the hypothalamus to gonadal steroids. Indeed, leptin and estrogen production by the adipose tissue play a central role in triggering menarche. These adjustments reflect a natural adaptation of the body to high energy demands. In AG and RG, low body fat, low body weight (low energy input), and prolonged intensive physical training (high energy output) were the major factors influencing menarche. Low body weight, however, remained the most significant factor in delaying the onset of puberty. It is to be noted that in both RG and AG, older athletes without menarche presented lower height, weight, and BMI compared to their contemporaries with menarche.

In conclusion, in RG and AG intensive physical training and negative energy balance prolong the prepubertal stage and delay pubertal development, by regulating the hypothalamic pituitary set point at puberty, without affecting the duration of the pubertal process.

**Conclusions**

Genetic predisposition to growth can be fully expressed only under favorable environmental conditions. Moderate physical exercise has beneficial effects on growth as it is associated with cardiovascular benefits and favorable changes in body composition. Conversely, extensive physical training may attenuate growth, especially during puberty.

The effect of stress and intensive physical training on growth and maturity is related to the combined effects of age of exercise onset, exercise intensity, exercise frequency, and exercise duration.

Sports that require a strict control of energy consumption, combined with a high-energy expenditure, are of particular concern. In gymnastics of the highest competitive level, a delay in skeletal maturation was observed, leading to a deterioration of growth potential in AG, more pronounced for males than for females, whereas in female RG the genetic potential for growth was finally achieved by compensation via a late catch-up growth phenomenon. In all other sports not requiring strict dietary restrictions, no deterioration of growth has been documented.

Intensive physical training and negative energy balance, by modulating the hypothalamic pituitary set point at the expected time of puberty, prolong the prepubertal stage and delay pubertal progression in a variety of sports.

In elite RG and AG, prepubertal stage was prolonged and pubertal development was entirely shifted to a later age, following the bone age rather than the chronological age and maintaining a normal rate of progression. Female athletes present a well-documented delayed menarcheal age, compared to their mothers and nontrained sisters.

**Conflicts of interest**

The authors declare no conflicts of interest.

**References**


Growth in athletes


