# Physiological Characteristics of Young (9-12 Years) and Adolescent (≥13 Years) Rhythmic, Acrobatic, and Artistic Female Gymnasts

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**Background:** Elite gymnasts are exposed to high levels of physical stress, during both childhood and adolescence, with significantly late maturation and high injury prevalence. Here, we compare the physiological characteristics of female gymnasts in 2 age groups: young (9-12 years) and adolescent (≥13 years) in 3 disciplines of competitive gymnastics.

**Hypothesis:** Participants' physiological characteristics will differ by age group and by gymnastic discipline.

**Study Design:** Cohort study.

**Level of Evidence:** Level 2.

**Methods:** The study included 274 gymnasts, aged 11.8±1.9 years. Data collection included anthropometric measures, Tanner stage, and menarche age; ultrasound assessments were used to assess bone properties, including bone strength, skeletal age, and final-height prediction.

**Results:** Univariate analysis of variance showed age × discipline interactions for body mass index (BMI) percentiles ($F_{(2, 266)}=4.379$; $P=0.01$), skeletal age ($F_{(2, 241)}=3.808$; $P=0.02$), and final-height prediction ($F_{(2, 240)}=3.377$, $P=0.04$). Moreover, in both age groups, artistic gymnasts exhibited significantly higher BMI percentiles than rhythmic gymnasts ($P<0.05$). In the adolescent group, final-height prediction for rhythmic gymnasts was significantly greater than that of artistic gymnasts ($P<0.05$). Finally, in adolescent gymnasts, regression lines showed that skeletal age was lower than chronological age ($P<0.05$).

**Conclusion:** Artistic gymnasts were shorter than rhythmic and acrobatic gymnasts. Despite similar BMI and body fat, maturity patterns, and training-volume history, artistic gymnasts had lower bone-strength than rhythmic and acrobatic gymnasts. Combined with their high-impact and intensive training, this could increase their risk of musculoskeletal injuries.

**Clinical Relevance:** The current study may help athletic trainers and medical teams define "norms" for different age groups and gymnastic disciplines, based on what may be expected during the athletes' early and late maturation. This knowledge can be used to modify, individualize, and optimize training programs.

**Keywords:** anthropometric; bone properties; gymnasts; impact of training; puberty

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Highly intensive gymnastic activities, which include the repetition of extreme movements, require a specific body type, as is often reflected in the musculoskeletal development of gymnasts.[6,18] During maturation, pubertal development is accompanied by hormonal changes and rapid skeletal growth.[38] High-energy-consuming gymnastic training, coupled with the need to maintain body leanness during maturation, may lead to the reduced availability of energy and body fat, irregular hormonal cycles, late menarche, and menstrual disorders.[37] Furthermore, high loads on the immature musculoskeletal system may affect anatomical structure and function, such as changes in joint laxity and alterations in soft tissue metabolism.[38,37] Data suggest that female gymnasts tend to have reduced fat-masses and weight/height ratios, as well as a tendency to exhibit later maturation.[3,12,14,16] Combined, these factors might play a pivotal role in their high rates and risk of musculoskeletal injuries.[27,38]

Important parameters among gymnasts during puberty include bone strength and skeletal age.[4,11,13,35,36] On the one hand, intensive weightbearing gymnastic training may enhance bone-mineral density and bone strength in pre- and early-pubertal gymnasts.[4,11,13,35,36] On the other hand, some biomechanical studies show that extreme repetitive activities may impair bone properties and lead to accumulated bone microdamage, with an increased risk of injury that is related to such bone stress.[26,28] Furthermore, intensive physical training, particularly when accompanied by inadequate nutrition, may be associated with delayed maturation and reduced estrogen secretion, in turn leading to lower bone mass and strength, and even to delayed skeletal age compared with chronological age.[17,24]

Both prepubertal and adolescent gymnasts may present altered musculoskeletal characteristics that could impact their athletic abilities and sports performance.[38] However, whether these musculoskeletal changes are age- and maturity-dependent remains unknown. In addition, it is unclear whether physiological characteristics differ between rhythmic, acrobatic, and artistic gymnasts,[9,15,31] bearing in mind that all 3 disciplines require similar long and high-impact training hours, fit physiques, and lean body masses, with gymnasts in these fields also exhibiting relatively late pubertal development and a high prevalence of lower-extremity injuries.[21,23] The aim of the present study, therefore, was to compare the physiological characteristics of competitive female gymnasts, by age (young [9-12 years] and adolescent [≥13 years]), and by discipline (rhythmic, acrobatic, and artistic).

# METHODS

## Participants

A total of 274 female participants were included in the study, including rhythmic, acrobatic, and artistic gymnasts. All participants were competitive-level gymnasts who took part in at least 4 national or international competitions each year. The inclusion criteria required the gymnasts to have been fully active in all gymnastic training over the 3 months before the study, with <3 days absence from training due to pain, discomfort, or injury over the 3 months leading up to the study. The research study was approved by the Adi-Negev Rehabilitation Hospital Human Subjects Review Board, in accordance with the Helsinki Declaration. A written consent form was signed and submitted by each participant and by one of her parents (due to the participants' young age), and the gymnasts' rights and safety were protected throughout the study.

## Procedure

Each gymnast was assessed for anthropometric measures and pubertal stage. They were also assessed for bone strength and skeletal age using 2 different ultrasound devices. Skeletal age measurements were used for final-height prediction.

## Personal Details and Training Intensity

Data on the gymnast's age, training background, and intensity were collected, including the age at which they embarked on such training and the total number of practice hours per week.

## Pubertal Stage

The gymnasts completed the Tanner's Sexual Maturity Rating regarding breast development and pubic hair,[34] and were asked about their age of menarche.

## Anthropometric Parameters

Bodyweight and standing height were measured using standard scales and a stadiometer, and body mass index (BMI) and BMI percentiles were calculated. Body composition was assessed using the BC-545N device (TANITA Europe).

## Bone Strength

Tibial and radial ultrasound measurements were taken of the gymnasts' right-side bones, using the Sunlight Omnisense (Sunlight Medical), a quantitative ultrasonometry tool designed to measure speed-of-sound (SOS) at different skeletal sites, using the axial transmission method. SOS measurements are based on the principle whereby ultrasound waves propagate faster through bone than through soft tissue. The device consists of a main desktop unit and several small probes, designed to measure SOS at different sites. In this study, the measurement site for the tibia was defined as the midpoint between the medial-malleolus apex and the distal-patellar apex. The radius was defined as the midpoint between the elbow and the tip of the middle finger, parallel to the bone axis. The probe was moved across the mid-tibial and mid-radius plane, to seek the site with the maximal reading.[32]

## Skeletal Age and Final-Height Prediction

To determine the gymnasts' skeletal age and predict their final height, based on the ultrasound examination, the BAUSport (SonicBone) was used. This device is a small, portable bone sonometer, used to analyze 3 sites of the left hand: (1) the distal radial and ulnar secondary ossification centers of the epiphyses at the wrist; (2) the growth plate of the third metacarpal and the shaft of the proximal phalanx; and (3) the distal metacarpal epiphysis at the metacarpals. The device measures the speed of propagation through the bone of inaudible high-frequency waves of a short ultrasound pulse (m/s) and the distance attenuation factor (decay rate). With the use of these parameters, skeletal age was calculated (to the nearest 0.01 years) using an algorithm that was integrated into the BAUSport$^{T}$ software.[29,34] All ultrasound examinations were conducted by a trained professional, and in line with the manufacturer's manual. The examiner was blinded to the participants' gymnastic discipline, age, and pubertal status.

### Data Analysis

Univariate analysis of variance (ANOVA) (age × discipline) was conducted for each anthropometric measure and impact of training, using Bonferroni corrections for multiple tests. Chi-squared tests were used for categorical data such as Tanner's stages and menarche age. Regressions were used for presenting chronological age versus skeletal age separately for the 2 age groups and for the 3 disciplines. Statistical analyses were performed using SPSS Version 25.0, with the significance level being set at $\alpha \leq 0.05$ for all tests.

## RESULTS

The mean biological age of the 274 female gymnasts who participated in this study was 11.8±1.9 years. Moreover, 154 were rhythmic gymnasts, 60 were acrobatic gymnasts, and 60 were artistic gymnasts.

### Physiological Characteristics by Age Group and by Gymnastic Discipline

When conducting the univariate ANOVA, a significant age-group effect was seen for training impact (ie, the age at which the gymnastics began their training, and the number of training hours each week, during the current year and the previous year), anthropometric parameters (height, weight, and BMI) and for bone properties (radial bone-strength, tibial bone-strength, tibial Z-scores, skeletal age, and final-height prediction) ($P<0.05$). However, no age effect was found for BMI percentile or for fat percentage ($P>0.05$) (Tables 1 and 2).

A discipline effect was found for training impact, whereby a higher impact was seen in rhythmic gymnasts. A similar effect was also seen for anthropometric parameters, whereby lower BMI percentiles were seen among rhythmic and acrobatic gymnasts. Finally, such an effect was also found for bone properties, whereby greater tibial bone-strength and higher final-height prediction were seen among rhythmic and acrobatic gymnasts compared with artistic gymnasts ($P<0.05$). However, no discipline effect was found for height, weight, or BMI ($P>0.05$).

Age × discipline interactions were found for weight, BMI, and BMI percentile, with the latter being significantly higher in artistic gymnastics than in rhythmic gymnastics in both age groups. Interactions were also found for skeletal age and for final-height prediction, whereby in the adolescent group, final-height in rhythmic gymnasts was significantly greater than in artistic gymnasts.

### Bone Properties

Figure 1 presents regression lines for biological age, by discipline and by skeletal age. The lines appear separately for each age group. At 10.56 years, where the 2 lines intersect, the skeletal age of both groups was higher than their chronological age of 10.94 years. Yet at 16.0 years, the skeletal age of the adolescent group was lower than that of their chronological age, i.e., 15.35 years. No significant differences were found between the regression lines of the 3 gymnastic disciplines, indicating similar relationships between the participants' biological age and their skeletal age in all 3 gymnastic disciplines ($P>0.05$).

## DISCUSSION

The current study examined physiological characteristics, including anthropometric parameters, training impact, and bone properties, in female gymnasts from 2 age groups (young and adolescent) and from 3 disciplines (rhythmic, acrobatic, and artistic). The artistic gymnasts were found to be significantly shorter than the rhythmic and acrobatic gymnasts; however, a similar prevalence of being in the late pubertal stage was seen in both the rhythmic and the artistic gymnasts in the adolescent group, who also conveyed similar menarche ages and fat percentages. Furthermore, the BMI percentile of rhythmic gymnasts was found to be significantly lower than that of acrobatic and artistic gymnasts.

Studies tend to compare between gymnasts and other athletes, or with age-matched peers, with limited research comparing between gymnast disciplines.[7] The findings of the current study are in line with previous data, whereby body proportions, body compositions, and pubertal development among young gymnasts were compared with those of high-level athletes, the former's height was found to be below average, and their BMI and sum of skinfolds were lower than those of their age-matched peers.[3,12,35] Moreover, the mean weight-for-age in both rhythmic and artistic gymnastics has been found to be below the 50th percentile of the general population.[15] The findings of the current study are in line with previous data, whereby rhythmic and artistic gymnasts present a different somatotype compared with other athletes.[3,7,12,15,35] When body proportions, body composition, and pubertal development among young gymnasts were compared with those of high-level athletes, the former's height was found to be below average, and their BMI and sum of skinfolds were lower than those of their age-matched peers.[3,12,35] Furthermore, Georgopoulos et al[15] reported lower mean BMI and body-fat scores in rhythmic gymnasts than in artistic gymnasts.[15] Another study reported that national-level gymnasts were also found to have lower BMI and body-fat scores compared with age-matched nongymnasts, reflecting later growth and maturation in the former.[1]

Table 1. Physiological characteristics of participants by age group and gymnastic discipline

| | Young gymnasts aged 9-12 years | | | Adolescent gymnasts aged ≥13 years | | | |
|---|---|---|---|---|---|---|---|
| | Rhythmic (n = 101) | Acrobatic (n = 26) | Artistic (n = 48) | Rhythmic (n = 53) | Acrobatic (n = 34) | Artistic (n = 11) | Significance |
| Age | 10.6 ± 1.1 | 10.9 ± 1.0 | 10.5 ± 1.2 | 13.7 ± 1.2 | 14.2 ± 1.2 | 13.5 ± 0.7 | ***<br>$$; $$$<br>#; ##; ### |
| Training impact | | | | | | | |
| Age starting gymnastic training, years | 4.9 ± 1.5 | 5.6 ± 1.7 | 5.6 ± 1.8 | 5.5 ± 1.9 | 6.5 ± 2.1 | 6.5 ± 1.3 | *<br># |
| Hours per week in previous year | 18.9 ± 8.1 | 14.5 ± 6.3 | 14.9 ± 6.9 | 26.4 ± 10.8 | 17.9 ± 8.3 | 22.0 ± 5.3 | *<br>$$<br>#; ### |
| Hours per week in current year | 23.4 ± 9.5 | 17.1 ± 7.0 | 18.0 ± 6.6 | 29.2 ± 11.3 | 20.2 ± 9.0 | 23.2 ± 7.5 | *; **<br>$; $$<br>#; ##; ### |
| Anthropometric parameters | | | | | | | |
| Height, cm | 138.2 ± 19.2 | 134.8 ± 6.5 | 137.0 ± 7.3 | 154.8 ± 8.2 | 155.1 ± 7.4 | 148.1 ± 5.4 | $; $$$<br>#; ##; ### |
| Weight, kg | 31.0 ± 5.7 | 28.2 ± 3.6 | 31.8 ± 5.4 | 44.0 ± 9.1 | 45.6 ± 7.9 | 39.9 ± 6.2 | ***;<br>#; ##; ### |
| BMI, kg/m$^2$ | 16.0 ± 1.6 | 15.5 ± 1.1 | 16.9 ± 1.7 | 18.2 ± 2.6 | 18.8 ± 2.0 | 18.1 ± 1.7 | *; ***<br>#; ### |
| BMI percentile | 33 ± 22 | 25 ± 20 | 44 ± 21 | 34 ± 24 | 41 ± 22 | 41 ± 20 | *; ***<br>$; $$<br>## |
| Fat, % | 20.7 ± 2.3 | 19.4 ± 2.4 | 20.6 ± 2.1 | 21.7 ± 3.8 | 20.6 ± 3.3 | 20.8 ± 2.1 | # |
| Pubertal stage | | | | | | | |
| Menarche onset, y | 11.5 ± 0.7 | – | – | 12.3 ± 1.3 | 12.9 ± 1.2 | 13.0 ± 1.0 | |
| Menarche, % | 2.1 | 0 | 0 | 24.1 | 39.5 | 20.0 | #; ##; ### |
| Tanner stage 3-5, % | 3.1 | 0 | 2.2 | 32.8 | 61.8 | 26.7 | #; ##; ###<br>& |
| Bone properties | | | | | | | |
| Skeletal age, y | 10.7 ± 1.4 | 10.5 ± 1.7 | 11.0 ± 1.6 | 13.0 ± 1.3 | 14.2 ± 1.6 | 13.4 ± 1.3 | $$<br>#; ##; ### |

*(continued)*

Table 1. (continued)

| | Young gymnasts aged 9-12 years | | | Adolescent gymnasts aged ≥13 years | | | |
|---|---|---|---|---|---|---|---|
| | Rhythmic (n = 101) | Acrobatic (n = 26) | Artistic (n = 48) | Rhythmic (n = 53) | Acrobatic (n = 34) | Artistic (n = 11) | Significance |
| Predicted final-height, cm | 156.3 ± 6.1 | 153.6 ± 6.1 | 153.8 ± 5.0 | 161.6 ± 5.6 | 159.1 ± 5.6 | 153.9 ± 5.8 | $; $$$ #; ## |
| Radial strength | 3700 ± 103 | 3680 ± 96 | 3700 ± 101 | 3754 ± 118 | 3763 ± 108 | 3752 ± 81 | #; ## |
| Radius Z-score | 0.02 ± 1.00 | –0.05 ± 0.83 | 0.18 ± 0.86 | –0.04 ± 1.11 | 0.15 ± 0.88 | 0.25 ± 1.07 | $ |
| Tibial strength | 3548 ± 131 | 3554 ± 91 | 3501 ± 125 | 3616 ± 107 | 3620 ± 101 | 3526 ± 85 | $; $$$ #; ## |
| Tibia Z-score | 0.04 ± 1.13 | 0.10 ± 0.87 | –0.26 ± 1.05 | –0.30 ± 1.19 | –0.06 ± 0.81 | –0.86 ± 1.03 | *; *** $; $$$ #; ### |

*In the young group, significant differences ($P < 0.05$) were seen between rhythmic and artistic gymnasts (*), between rhythmic and acrobatic gymnasts (**), and between acrobatic and artistic gymnasts (***).
$In the adolescent group, significant differences ($P < 0.05$) were seen between rhythmic and artistic gymnasts ($), rhythmic and acrobatic gymnasts ($$), and between acrobatic and artistic gymnasts ($$$).
#Significant differences ($P < 0.05$) were seen between the 2 age groups, in rhythmic (#), acrobatic (##), and artistic gymnasts (###).
&Significant differences were seen between the 3 gymnastic disciplines in Tanner's stages 3-5 stages (chi-squared = 8.954, $P = 0.01$).

Consistent with the results of the current study, previous research found rhythmic gymnasts to be taller than average for their age compared with the artistic gymnasts, who were relatively short.[15,16] It has been suggested that, although rhythmic gymnasts may mature later than the general population, they tend to eventually be taller, with relatively lower weight-for-height, and with less fat mass.[3] Artistic gymnasts, on the other hand, tend to have relatively short limbs compared with rhythmic gymnasts, possibly providing the former with a mechanical-performance advantage.[7]

One especially interesting finding in this study is related to the height differences that were seen between the artistic gymnasts and the rhythmic ones; differences see only n in the adolescent group, not in the young one. Most gymnasts in the young group were prepubertal or in very early stages of puberty. It may be that the shorter final height of artistic gymnasts results from their reduced height-gains during puberty. This is consistent with Georgopoulos et al[17], who suggest that excessive physical training may negatively affect growth, especially during puberty. Previous studies suggest that competitive-level female gymnasts who undergo advanced and intermediate training tend to exhibit relatively slow growth-spurt patterns, with an altered tempo of growth and maturation. Their intensive physical training and negative energy balance may also modify the hypothalamic pituitary set point in puberty, while prolonging the prepubertal stage and delaying pubertal development and menarche, as seen in a variety of sports.[10]

However, the shorter height of artistic gymnasts during puberty, as seen in this study, may not necessarily be related to training volume (which is similar in both artistic and acrobatic gymnasts) or to reduced body fat (which is significantly higher among adolescent artistic gymnasts than among their younger counterpart). Alternatively, a more masculine body structure, ie, with shorter stature, may be associated with a competitive performance advantage, thereby presenting a genetic predisposition and leading to selection bias.[17] In contrast to our current results, Damsgaard et al[12] did not find a training-intensity effect on height, body composition, or pubertal development.

Skeletal maturation constitutes an essential component for growth evaluation,[16,17,37] with differences between skeletal and chronological ages likely stemming from multiple factors.[17,37] In the current study, no significant differences were seen between the gymnasts' skeletal and chronological age, in either the young group or by discipline. In the adolescent group, however, a lower skeletal age was seen compared with their chronological age. Previous studies show a delay of 1.3 to 1.8 years in skeletal maturation in prepubertal gymnasts

Table 2. Effects and interactions of age group and disciplines effect for training impact, anthropometric parameters, and bone properties

| | Age-group effect (*P* value) | Discipline effect (*P* value) | Age × discipline interactions |
|---|---|---|---|
| Training impact | | | |
| Age starting gymnastic training (y) | <0.01 | <0.01 | NS |
| Hours per week in previous year | <0.01 | <0.01 | NS |
| Hours per week in current year | <0.01 | <0.01 | NS |
| Anthropometric parameters | | | |
| Height (cm) | <0.01 | NS | NS |
| Weight (kg) | <0.01 | NS | $F_{(2, 267)} = 5.787$, $\eta^2 = 20.042$, $P < 0.01$ |
| BMI, (kg/m$^2$) | <0.01 | NS | $F_{(2, 266)} = 13.807$, $\eta^2 = 2.027$, $P = 0.03$ |
| BMI percentile | NS | 0.04 | $F_{(2, 266)} = 4.379$, $\eta^2 = 2.032$, $P = 0.01$ |
| Fat % | NS | 0.03 | NS |
| Bone properties | | | |
| Skeletal age (y) | <0.01 | NS | $F_{(2, 241)} = 3.808$, $\eta^2 = 2.031$, $P = 0.02$ |
| Predicted final-height (cm) | <0.01 | <0.01 | $F_{(2, 240)} = 3.377$, $\eta^2 = 2.027$, $P = 0.04$ |
| Radial strength | <0.01 | NS | NS |
| Radius Z-score | NS | NS | NS |
| Tibial strength | <0.01 | <0.01 | NS |
| Tibia Z-score | 0.03 | 0.04 | NS |

NS, not significant.

compared with the general population, with pubertal development tending to be in line with the athlete's skeletal rather than their chronological age.[14,16] It is believed that, in gymnastics, the intensive physical training, relatively low body-weight, and delayed maturation contribute to a significant delay in skeletal age compared with chronological age.[16,17,24] Specifically, in elite gymnasts, intensive training may be associated with the gymnasts' delayed age of menarche compared with other female family members.[14] In the current study, the final-height prediction was similar in both age groups; in contrast, among the rhythmic and acrobatic gymnasts, it was significantly lower in the young group than in the adolescent group. As such, the final-height predictions based on ultrasonography assessments, as conducted in this study, underestimated the height potential of young rhythmic and acrobatic female gymnasts, and should therefore be addressed with caution. Consistent with our findings, a previous study found correlations between the final height of artistic gymnasts and their skeletal-age height-prediction throughout maturation.[8] In contrast to our findings, however, the final adult height of rhythmic gymnasts has been found to be identical to the initial predicted height, and even higher than the participants' genetic target height.[17]

The current study indicates that the tibial bone-strength (Z-scores) of rhythmic and acrobatic gymnasts (in both young and adolescent groups) were almost the same as age-matched normally active controls. However, the bone strength of the artistic gymnasts in the adolescent group was weaker than their age-matched counterparts from the other 2 disciplines (Z-score, –0.86±1.03), and weaker compared with rhythmic and acrobatic gymnasts in both age groups. In athletes, high-impact loading activities have been shown to improve bone formation and bone-mineral density.[17] In rhythmic gymnasts who were prepubertal or entering puberty, the mechanical loading of high-intensity training actually had a beneficial effect on bone-mineral density accumulation.[35] A systematic review of the

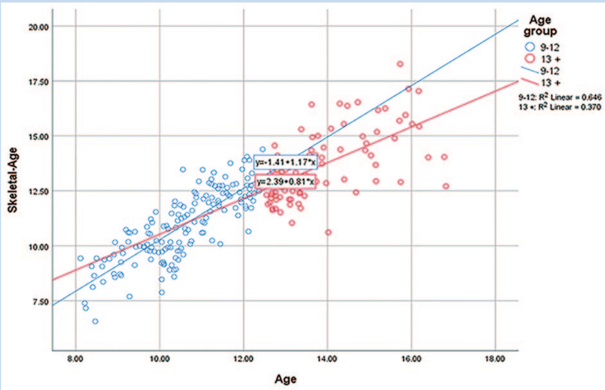


Figure 1. Regression lines for biological age by skeletal-age.

effects of gymnastic activities on bone accumulation during growth indicates that both rhythmic and artistic gymnasts present higher bone-mineral density and content values compared with untrained controls.[22] It has been suggested that their weightbearing activity has a positive influence on bone-mineral accrual, which may overcome the possible undesirable impact of a negative energy balance.[22] In contrast, however, the findings of the current study indicate reduced bone-strength in the artistic gymnasts compared with the rhythmic and acrobat gymnasts.

We suggest that this difference may not be related to BMI or fat mass, or to pubertal maturation or training volume; instead, it may stem from the different training types and intensities in which the participants take part. It might be that, in artistic gymnastics, the stressful bone impact is higher than the physiological bone limitation compared with the other 2 disciplines. A smaller tibial cortical bone shape was found in athletes compared with nonathlete controls when mechanical load exceeded the bone's microdamage threshold.[19] Repetitive activities (such as hopping and landing in gymnastics), with extreme bone stress and strain, were found to result in accumulated bone microdamage and reduced bone properties.[26] Additional research indicates that bones with reduced mineral density have reduced shock-absorption capabilities along the lower-limb kinematic chain.[5,20] The overloaded stress along the "weaker" bones may lead to accumulated microdamage, eventually resulting in injuries stemming from overuse, such as stress fractures.[5,26,28,39] Another explanation for our results could be related to the artistic gymnasts embarking on their training at a significantly later age than rhythmic gymnasts. Jürimäe and colleagues[22] demonstrated that even 1 year of specific gymnastics training starting in prepubertal years had a favorable effect on bone development in female gymnasts.

### Limitations

This study offers important insights into differences in anthropometric parameters, training impact, and bone properties in female gymnasts from different age groups and gymnastic disciplines. However, a number of research limitations should be addressed. First, data were only collected at 1 timepoint, and final-height prediction was based only on skeletal data gathered through ultrasound measurements. In addition, although all participants were within the same 2 age groups, differences were seen in the mean ages of the gymnasts by discipline, in both the young and the adolescent groups.

### Clinical Recommendations

Due to the limited data available on the growth and development of young gymnasts, parents, healthcare professionals, and, most importantly, the young girls themselves may be apprehensive about the possible negative impact of their participating in high-load training from a young age; such concerns may include their training possibly stunting their growth and limiting their final height, while altering their bone properties and increasing their risk of injury.[2] The current study reinforces the idea set forth in previous research, whereby gymnastic training does not appear to affect growth.[15,16] Since gymnasts may restrict their caloric intake to maintain low bodyweight, coaches should monitor and assess gymnasts carefully as a means for detecting early anomalies and preventing unhealthy weight reduction. Medical teams should also be aware that the systematic practice of gymnastics (eg, specific training volumes and loads, including repeated jumps, weightbearing exercises, and strength activities) during childhood and before menarche may actually have a positive impact on bone accumulation.[22,30,33,35] Finally, the findings of the current study may help clinicians, professional trainers, and medical staff define the "norms" for different age groups and for different disciplines among gymnastics, while identifying what can be expected during their early and late maturation. Such knowledge can be used to modify, tailor, and optimize gymnastic training by age and discipline.

## CONCLUSION

A review of the literature by Malina et al[25] from the Scientific Commission of the International Gymnastics Federation concluded that gymnastic training does not appear to attenuate pubertal growth and maturation, in relation to both the rate of growth and the timing and tempo of the growth spurt.[25] However, the main findings of the present study indicate that artistic gymnasts are shorter than acrobatic and rhythmic gymnasts, and that the greatest decrease in growth gain among artistic gymnasts may occur during puberty.

In addition, gymnast predicted final-height, based on skeletal age and measured during pre- and early-puberty, was found to underestimate height in the rhythmic and acrobatic groups. Finally, despite similar BMI and body fat, maturity patterns, and training-volume history, female artistic gymnasts exhibited lower bone-strength compared with their acrobatic and rhythmic peers. Combined with their high-impact and intensive training, this could increase their risk of musculoskeletal injuries.

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## REFERENCES


1. Akther M, Boby FA. Anthropometric profile of age level & national level female gymnasts in Bangladesh. *Int J Kinanthrop*. 2023;3(1):34-46.
2. Baxter-Jones ADG, Maffulli N. Intensive training in elite young female athletes. Effects of intensive training on growth and maturation are not established. *Br J Sports Med*. 2002;36(1):13-15.
3. Brown KA, Patel DR, Darmawan D. Participation in sports in relation to adolescent growth and development. *Transl Pediatr*. 2017;6(3):150-159.
4. Burt LA, Greene DA, Ducher G, Naughton GA. Skeletal adaptations associated with pre-pubertal gymnastics participation as determined by DXA and pQCT: a systematic review and meta-analysis. *J Sci Med Sport*. 2013;16(3):231-239.
5. Burt LA, Groves EM, Quipp K, Boyd SK. Bone density, microarchitecture and strength in elite figure skaters is discipline dependent. *J Sci Med Sport*. 2022;25(2):173-177.
6. Chandran A, Roby PR, Boltz AJ, Robison HJ, Morris SN, Collins CL. Epidemiology of injuries in National Collegiate Athletic Association women's gymnastics: 2014-2015 through 2018-2019. *J Athl Train*. 2021;56(7):688-694.
7. Claessens AL, Lefevre J, Beunen G, Malina RM. The contribution of anthropometric characteristics to performance scores in elite female gymnasts. *J Sports Med Phys Fitness*. 1999;39(4):355-360.
8. Claessens AL, Lefevre J, Beunen GP, Malina RM. Maturity-associated variation in the body size and proportions of elite female gymnasts 14-17 years of age. *Eur J Pediatr*. 2006;165(3):186-192.
9. Cugusi L, Manca A, Sarritzu S, et al. Risk factors associated with low back pain in competitive female gymnasts: a meta-analytic approach. *J Sports Sci*. 2020;38(22):2543-2552.
10. Daly RM, Caine D, Bass SL, Pieter W, Broekhoff J. Growth of highly versus moderately trained competitive female artistic gymnasts. *Med Sci Sports Exerc*. 2005;37(6):1053-1060.
11. Daly RM, Rich PA, Klein R, Bass S. Effects of high-impact exercise on ultrasonic and biochemical indices of skeletal status: a prospective study in young male gymnasts. *J Bone Miner Res*. 1999;14(7):1222-1230.
12. Damsgaard R, Bencke J, Matthiesen G, Petersen JH, Muller J. Body proportions, body composition and pubertal development of children in competitive sports. *Scand J Med Sci Sports*. 2001;11(1):54-60.
13. Falk B, Bronshtein Z, Zigel L, Constantini NW, Eliakim A. Quantitative ultrasound of the tibia and radius in prepubertal and early-pubertal female athletes. *Arch Pediatr Adolesc Med*. 2003;157(2):139-143.
14. Georgopoulos N, Markou K, Theodoropoulou A, et al. Growth and pubertal development in elite female rhythmic gymnasts. *J Clin Endocrinol Metab*. 1999;84(12):4525-4530.
15. Georgopoulos NA, Markou KB, Theodoropoulou A, Benardot D, Leglise M, Vagenakis AG. Growth retardation in artistic compared with rhythmic elite female gymnasts. *J Clin Endocrinol Metab*. 2002;87(7):3169-3173.
16. Georgopoulos NA, Markou KB, Theodoropoulou A, et al. Height velocity and skeletal maturation in elite female rhythmic gymnasts. *J Clin Endocrinol Metab*. 2001;86(11):5159-5164.
17. Georgopoulos NA, Markou KB, Theodoropoulou A, Vagenakis GA, Mylonas P, Vagenakis AG. Growth, pubertal development, skeletal maturation and bone mass acquisition in athletes. *Hormones (Athens)*. 2004;3(4):233-243.
18. Gram MCD, Clarsen B, Bø K. Injuries and illnesses among competitive Norwegian rhythmic gymnasts during preseason: a prospective cohort study of prevalence, incidence and risk factors. *Br J Sports Med*. 2021;55(4):231-236.
19. Hamstra-Wright KL, Bliven KC, Bay C. Risk factors for medial tibial stress syndrome in physically active individuals such as runners and military personnel: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49(6):362-369.
20. Ho KY, Cummins A, Khuu C, Parker S, Shepherd S. Comparisons of patellar bone mineral density between individuals with and without patellofemoral pain. *Knee*. 2020;27(3):846-853.
21. Jakše B, Jakše B, Čuk I, Šajber D. Body composition, training volume/pattern and injury status of Slovenian adolescent female high-performance gymnasts. *Int J Environ Res Public Health*. 2021;18(4):2019.
22. Jürimäe J, Gruodyte-Raciene R, Baxter-Jones ADG. Effects of gymnastics activities on bone accrual during growth: a systematic review. *J Sports Sci Med*. 2018;17(2):245-258.
23. Klentrou P, Plyley M. Onset of puberty, menstrual frequency, and body fat in elite rhythmic gymnasts compared with normal controls. *Br J Sports Med*. 2003;37(6):490-494.
24. Malina RM. Skeletal age and age verification in youth sport. *Sports Med*. 2011;41(11):925-947.
25. Malina RM, Baxter-Jones AD, Armstrong N, et al. Role of intensive training in the growth and maturation of artistic gymnasts. *Sports Med*. 2013;43(9):783-802.
26. Meardon SA, Derrick TR, Willson JD, et al. Peak and per-step tibial bone stress during walking and running in female and male recreational runners. *Am J Sports Med*. 2021;49(8):2227-2237.
27. Patel T, McGregor A, Fawcett L, et al. Coach awareness, knowledge and practice in relation to growth and maturation and training load in competitive, young gymnasts. *Int J Sports Sci Coaching*. 2021;16(3):528-543.
28. Popp KL, Frye AC, Stovitz SD, Hughes JM. Bone geometry and lower extremity bone stress injuries in male runners. *J Sci Med Sport*. 2020;23(2):145-150.
29. Rachmiel M, Naugolni L, Mazor-Aronovitch K, Koren-Morag N, Bistritzer T. Bone Age assessments by quantitative ultrasound (sonicbone) and hand X-ray based methods are comparable. *Isr Med Assoc J*. 2017;19(9):533-538.
30. Remmel L, Tillmann V, Tamm AL, Mengel E, Jurimae J. A longitudinal study of bone mineral accrual during growth in competitive premenarcheal rhythmic gymnasts. *J Sports Sci Med*. 2021;20(3):466-473.
31. Schärer C, Reinhart L, Hübner K. Age-related differences between maximum flight height of basic skills on floor, beam and vault and physical condition of youth female artistic gymnasts. *Sports (Basel)*. 2023;11(5):100.
32. Stanley RM, Jones RA, Cliff DP, et al. Increasing physical activity among young children from disadvantaged communities: study protocol of a group randomised controlled effectiveness trial. *BMC Public Health*. 2016;16(1):1095.
33. Tamolienė V, Remmel L, Gruodyte-Raciene R, Jürimäe. Relationships of bone mineral variables with body composition, blood hormones and training volume in adolescent female athletes with different loading patterns. *Int J Environ Res Public Health*. 2021;18(12):6571.
34. Tanner J, Whitehouse R, Cameron N, et al. *Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 Method)*. London: Saunders; 2001.
35. Võsoberg K, Tillmann V, Tamm AL, Maasalu K, Jürimäe J. Bone mineralization in rhythmic gymnasts entering puberty: associations with jumping performance and body composition variables. *J Sports Sci Med*. 2017;16(1):99-104.
36. Ward KA, Roberts SA, Adams JE, Mughal MZ. Bone geometry and density in the skeleton of pre-pubertal gymnasts and school children. *Bone*. 2005;36(6):1012-1018.
37. Weimann E. Gender-related differences in elite gymnasts: the female athlete triad. *J Appl Physiol (1985)*. 2002;92(5):2146-2152.
38. Wild CY, Steele JR, Munro BJ. Why do girls sustain more anterior cruciate ligament injuries than boys?: a review of the changes in estrogen and musculoskeletal structure and function during puberty. *Sports Med*. 2012;42(9):733-749.
39. Yung PS, Lai YM, Tung PY, et al. Effects of weight bearing and non-weight bearing exercises on bone properties using calcaneal quantitative ultrasound. *Br J Sports Med*. 2005;39(8):547-551.