Artistic Versus Rhythmic Gymnastics: Effects on Bone and Muscle Mass in Young Girls

G. Vicente-Rodriguez[1,2]
C. Dorado[1]
I. Ara[1,2]
J. Perez-Gomez[1]
H. Olmedillas[1]
S. Delgado-Guerra[1]
J. A. L. Calbet[1]

Abstract

We compared 35 prepubertal girls, 9 artistic gymnasts and 13 rhythmic gymnasts with 13 nonphysically active controls to study the effect of gymnastics on bone and muscle mass. Lean mass, bone mineral content and areal density were measured by dual energy X-ray absorptiometry, and physical fitness was also assessed. The artistic gymnasts showed a delay in pubertal development compared to the other groups ($p < 0.05$). The artistic gymnasts had a 16 and 17% higher aerobic power and anaerobic capacity, while the rhythmic group had a 14% higher anaerobic capacity than the controls, respectively (all $p < 0.05$). The artistic gymnasts had higher lean mass ($p < 0.05$) in the whole body and the extremities than both the rhythmic gymnasts and the controls. Body fat mass was 87.5 and 61.5% higher in the controls than in the artistic and the rhythmic gymnasts ($p < 0.05$). The upper extremity BMD was higher ($p < 0.05$) in the artistic group compared to the other groups. Lean mass strongly correlated with bone mineral content ($r = 0.84$, $p < 0.001$), and multiple regression analysis showed that total lean mass explained 64% of the variability in whole body bone mineral content, but only 20% in whole body bone mineral density. Therefore, recreational artistic gymnastic participation is associated with delayed pubertal development, enhanced physical fitness, muscle mass, and bone density in prepubertal girls, eliciting a higher osteogenic stimulus than rhythmic gymnastic.

Key words
Physical fitness · children · exercise · training · hypertrophy

Introduction

Bone is responsive to exercise during prepubescence in boys and girls [1,20,33]. Therefore, the prepubertal years are an opportune time to increase bone density through exercise to attain the highest bone mineral peak. Since residual benefits can be maintained into adulthood [29], exercise before puberty may reduce fracture risk after menopause [1].

Considering that high-impact, weight-bearing exercise seems to be particularly associated with the increase in bone mineral density (BMD) [20], most of the investigations studying bone mass accrual in girls have been carried out with an artistic gymnast population [5,7,23]. Ground reaction forces during artistic gymnastic participation are close to 10 times body mass in prepubertal children [8]. This high impact loading has been associated with greater BMD in the whole body [1,5], spine and lower extremities [1,23]. However, all the latter studies had in common not only the high-impact during gymnastics participation, but also the high training volumes, in most of the cases up to 15 hours per week. Nevertheless, the question of sport participation should be faced from a realistic point of view. These huge volumes of exercise are unrealistic for most girls whose sports participation is only recreational. We have reported a remarkable

Affiliation
[1] Department of Physical Education, University of Las Palmas de Gran Canaria, Las Palmas, Spain
[2] Department of Physiatry and Nursing, University of Zaragoza, Zaragoza, Spain

Correspondence
German Vicente-Rodriguez, PhD · Departamento de Educación Física · Campus Universitario de Tafira ·
35017 Las Palmas de Gran Canaria · Canary Island · Spain · Phone: + 34 928 45 88 96 ·
Phone: + 34 976 40 03 38 (3 01) · Fax: + 34 928 45 88 67 · E-mail: gvicente@arrakis.es; gervicen@unizar.es

Accepted after revision: May 22, 2006

Bibliography
Int J Sports Med 2007; 28: 386 – 393
DOI 10.1055/s-2006-924397
ISSN 0172-4622

enhancement of femoral bone mineral content and areal density in prepubertal boys with just 3 hours of football (soccer) participation per week [31]. What remains unanswered is whether these osteogenic benefits attained with high volumes of artistic gymnastics participation are also achievable with recreational participation in artistic gymnastics.

Although rhythmic and artistic gymnastics are two different sports within the same area of gymnastics, these two types of gymnastics are quite different in terms of sport skills. Therefore, the physiological adaptations elicited by artistic and rhythmic gymnastics on bone tissue are likely different. While physical training has been associated with delayed skeletal maturation and pubertal development in elite rhythmic gymnasts [13], the effect of rhythmic gymnastic participation on bone mass and density in prepubertal girls remains unknown.

Lean mass has been largely associated with bone mass [12, 30, 31, 34], however, despite the fact that long-term exercise training may produce neuromuscular adaptations in children [24], it is not known whether exercise training may produce muscular hypertrophy in prepubertal girls. It also remains unknown if muscle hypertrophy is or is not associated with a greater bone mass in prepubertal girls.

Therefore, the main aim of the present study was to test the hypothesis that recreational participation in gymnastics is associated with enhanced bone mass and areal density in prepubertal girls. A second aim was to determine if artistic and rhythmic gymnastic training present different bone tissue adaptations in response to the regular participation in these sports already at a prepubertal age.

Materials and Methods

Subjects

Thirty-five prepubertal girls (Tanner 1 – 2) from different schools and sport clubs from the island of Gran Canaria agreed to enroll in the study. Both parents and children were informed about the aims and procedures of the study, as well as the possible risks and benefits. The study was performed in accordance with the Helsinki Declaration of 1975 as regards the conduct of clinical research and was approved by the Ethical Committee of the University of Las Palmas de Gran Canaria. Written informed consent was obtained from subjects and their parents.

The subjects were divided into three groups depending on their physical activity patterns. Thirteen were ascribed to the rhythmic group, 9 to the artistic group and the other 13 composed the control group. Active girls had been participating in either rhythmic or artistic gymnastics at least 3 times a week for at least one year. The rhythmic gymnasts trained 15 h/week (3.3 yr ± 1.2 with one month summer holiday per year). The artistic gymnasts trained 12 h/week (3.4 yr ± 2.8 with 3 months summer holidays per year). However, the physical activities practiced by the controls were limited to those included in the compulsory physical education curriculum (2 weekly sessions of 45 minutes each). The control group subjects did not participate in any kind of sports other than occasional children's games at least one year prior to the start of the study. The girls completed a medical and physical activity questionnaire, and their parents gave additional medical information. Information regarding physical activity, past injuries, medication and known diseases was obtained from every subject. Subjects were specifically asked to give their usual daily intake of dairy products to estimate the daily intake of calcium.

Pubertal status assessment

Tanner pubertal status was determined by auto-evaluation, a method of recognized validity and reliability [9].

Physical fitness

Anaerobic capacity. A 300-meter running test was used to estimate the anaerobic capacity, because the anaerobic capacity is the first determinant of performance in maximal all-out efforts eliciting exhaustion between 30 and 60 seconds [2]. The test was performed on a 400-m track, and timings were measured manually. The girls were asked to run the 300 m as fast as possible.

Running speed test. The time needed to cover 30 meters (T_{30}) was measured with photoelectric cells (General ASDE, Valencia, Spain) because this test has predictive value for BMC and BMD in prepubertal boys [33]. The timer is automatically activated when the subject crosses the first cell and every 5 meters thereafter. The girls were motivated to run as fast as they could, and the best performance achieved in three trials separated by at least a 1-min rest period was taken as the representative value of this test.

Aerobic maximal power. The maximal oxygen uptake ($\dot{V}O_{2max}$) was estimated using a maximal multistage 20-m shuttle run test as devised by Luc Leger [19]. Subjects were required to run back and forth on a 20-m course and be on the 20-m line at the same time that a beep is emitted from a tape. The frequency of the sound signals increases in such a way that running speed starts at 8.5 $km \cdot h^{-1}$ and is increased by 0.5 $km \cdot h^{-1}$ each minute. The length of time the subjects were able to run was recorded to calculate the $\dot{V}O_{2max}$. The maximal multistage 20-m shuttle run test has been shown to be valid and reliable for the estimation of the $\dot{V}O_{2max}$ [19].

Dynamic strength. The forces generated during a vertical counter movement jump (CMJ) were measured with a plate force (Kistler 9281B, Winterthur, Switzerland). The CMJ starts from a standing position allowing for counter movement, with the intention of reaching knee bending angles of around 90° just before impulsion. The jumping height (Hj), the take of velocity, the peak force (Fp, being Fp = maximal force-body mass), the positive impulse, the instantaneous maximal velocity ($I_{max}V$), the instantaneous maximal power ($I_{max}P$) and the mean power of the concentric phase (MP) generated were determined in the best of three trials.

Bone and lean mass

The bone mass and lean mass (body mass – [fat mass + bone mass]) were measured using dual-energy X-ray absorptiometry (DXA) (QDR-1500, Hologic Corp., Software version 7.10, Waltham, MA, USA). DXA equipment was calibrated using a lumbar spine phantom and following the Hologic guidelines. Subjects

Table **1** Subjects' age, anthropometrics, body composition and physical fitness related variables (mean ± SD)

Variables	*Rhythmic*	*Artistic*	*Controls*	*N*
Age (year)	10.4 ± 0.72	9.7 ± 1.50	9.9 ± 0.72	13–9–13
Height (cm)	138.8 ± 6.13	$133.6^b \pm 6.00$	141.4 ± 5.41	13–9–13
Body mass (kg)	$31.6^a \pm 3.24$	$29.8^b \pm 4.20$	36.5 ± 5.41	13–9–13
Lean mass (kg)	23.2 ± 2.88	22.6 ± 3.00	23.9 ± 2.16	13–9–13
%BF	$21^a \pm 6.13$	$19^b \pm 4.20$	28.8 ± 7.21	13–9–13
BMI	$16.4^a \pm 1.44$	$16.6^b \pm 1.20$	18.2 ± 2.16	13–9–13
Fat mass (kg)	$6.5^a \pm 2.16$	$5.6^b \pm 1.80$	10.5 ± 3.97	13–9–13
V_{30} *(m · s⁻¹)*	4.97 ± 0.42	4.96 ± 0.32	5.04 ± 0.32	13–9–13
V_{300} *(m · s⁻¹)*	$0.40^a \pm 0.04$	$0.41^b \pm 0.02$	0.35 ± 0.05	13–9–13
$\dot{V}O_{2max}$ $(ml \cdot kg^{-1} \cdot min^{-1})$	51.14 ± 2.40	$55.10^b \pm 7.0$	47.46 ± 5.31	13–9–13

%BF: percentage of body fat; BMI: body mass index; V_{30}: velocity in 30-m running speed test; V_{300}: velocity in 300-m running test; $\dot{V}O_{2max}$: maximum oxygen uptake. $^a p < 0.05$ between rhythmic and control groups; $^b p < 0.05$ between artistic and control groups

were scanned in supine position and the scans were performed in high resolution. Lean mass (g), fat mass (g), total area (cm^2), and BMC (g) were calculated from total and regional analysis of the whole body scan. BMD ($g \cdot cm^{-2}$) was calculated using the formula BMD = BMC · area^{-2}. The regional analysis was performed as described elsewhere [3]. Lean mass of the limbs was assumed equivalent to the muscle mass.

Two additional examinations were conducted to estimate bone mass at the lumbar spine and proximal region of the femur. Bone mineral content and density values of the femoral neck, greater trochanter, inter-trochanteric, and Ward's triangle subregions are also reported.

The laboratory precision error for the regional analysis of the whole body scan, as defined by the coefficient of variation (CV) for repeated measurements in young volunteers, was 0.4, 0.7, 3.1, and 1.0, respectively, for the BMC, BMD, fat mass and lean mass at the whole body; and 1.4, 2.4, 5.2, and 1.4 at the extremities [4].

Statistical analysis

Mean and standard deviation (SD) are given as descriptive statistics. Differences between groups were established using ANOVA. The chi-square test was applied to check the similarity of the Tanner stages distribution between groups. Analyses of covariance (ANCOVA) were performed to evaluate differences in bone, lean mass and physical fitness related variables, entering height and body mass as covariates. The reason for using these covariates is based on evidence identifying height and body mass as influential factors on the growing skeleton [11,27]. Additionally, bivariate correlation and linear stepwise multiple regression was applied to identify the relationship between physical fitness, lean mass, fat mass and bone mass variables. To test the similarity of slopes and intercepts of these relationships, the corresponding *t*-test was applied for the model: $Y_{ij} = \alpha_i + \beta_i X_{ij} + \varepsilon_{ij}$ for $i = 1,2$ (1 = active, 2 = controls) and $j = 1, \ldots n_1$ being ε_{ij} i.i.d. random variables following a distribution $N(0,\sigma_1)$. SPSS package (SPSS, Inc., Chicago, IL, USA) for personal computers was used for the statistical analysis. Significant differences were assumed when $p < 0.05$. Statistical size and power are also reported.

Results

Physical characteristics

The subject's age, anthropometric and body composition data are summarized in Table **1**. The girls of the artistic gymnastics group where thinner and shorter than the controls ($p < 0.05$). Also, rhythmic gymnasts were thinner than the controls ($p < 0.05$), but no differences were found in body weight or height between rhythmic and artistic gymnasts. The body fat mass was comparable between gymnasts, but the controls showed a 87.5% and 61.5% higher body fat mass than the artistic and the rhythmic gymnasts, respectively ($p < 0.05$). No significant differences between groups were observed in daily calcium intake, which was above the recommended dietary allowances (RDA) (1300 mg of calcium intake per day in 10-year-old children). All subjects had a Tanner value ≤ 2. However, the artistic gymnasts showed a significant delay in pubertal development compared to both the rhythmic gymnasts and the controls, as reflected by the Tanner frequency distribution (Tanner 1: 77.8% vs. 23.1% and 15.4%; Tanner 2: 22.2% vs. 76.9% and 84.6%, respectively; $p < 0.05$), even after control for age differences. The rhythmic gymnasts and the controls were similarly developed.

Physical fitness

Overall, both artistic and rhythmic gymnasts had similar physical fitness, and both groups of athletes had better physical fitness than their matched controls. Even after accounting for the differences in body mass and height, the artistic gymnasts achieved better results in dynamic strength-related variables than rhythmic gymnasts and controls (Table **2**). The artistic gymnasts had a 16% higher $\dot{V}O_{2max}$ and a 17% higher anaerobic capacity than the control girls ($p < 0.05$; size = 0.30 and 0.35 and power = 0.73 and 0.79, respectively; Table **1**). The rhythmic gymnasts had a 14% higher anaerobic capacity than the control girls ($p < 0.05$; size = 0.24 and power = 0.70, Table **1**). No differences were found in the 30-m running speed between groups.

Table **2** Subjects' jumping height (Hj), take of velocity, peak force (Fp), positive impulse, instantaneous maximal velocity ($I_{max}V$), instantaneous maximal power ($I_{max}P$) and mean power of the concentric phase (MP) generated during the best vertical counter movement jump (mean ± SD)

Variables	*Rhythmic*	*Artistic*	*Controls*
Hj (cm)	18.4 ± 0.4	24.0^{a,b} ± 0.7	17.3 ± 0.320
Take off velocity ($m \cdot s^{-1}$)	1.898 ± 0.115	2.162^{a,b} ± 0.210	1.833 ± 0.104
Fp (kp)	44.9 ± 0.6	50.9 ± 1.0	46.0 ± 0.5
Positive impulse ($kp \cdot s^{-1}$)	6.42 ± 0.21	7.15^{a,b} ± 0.38	6.26 ± 0.19
$I_{max}V$ ($m \cdot s^{-1}$)	1.995 ± 0.118	2.231^{a,b} ± 0.213	1.959 ± 0.108
$I_{max}P$ (W)	1090 ± 3	1235^{a,b} ± 5	1066 ± 3
MP (W)	671 ± 2	733 ± 4	637 ± 2

^{a}p < 0.05 between artistic and rhythmic gymnasts; ^{b}p < 0.05 between artistic gymnasts and control subjects

Table **3** Body weight-, height-, and age-adjusted bone mineral density (BMD) from the whole body, femoral, and lumbar scans (mean ± SD)

BMD ($g \cdot cm^{-2}$) ***Whole body scan***	***Rhythmic***	***Artistic***	***Control***
Whole body	0.815 ± 0.05	0.833 ± 0.05	0.823 ± 0.06
Head	1.357 ± 0.14	1.370 ± 0.14	1.420 ± 0.15
Pelvic	0.810 ± 0.06	0.812 ± 0.06	0.819 ± 0.07
Arms (mean)	0.530 ± 0.04	0.575^{a,b} ± 0.04	0.542 ± 0.04
Dominant arm	0.531 ± 0.04	0.571^{a} ± 0.04	0.542 ± 0.04
Contralateral arm	0.530 ± 0.04	0.578^{a,b} ± 0.04	0.541 ± 0.04
Legs (mean)	0.866 ± 0.06	0.877 ± 0.05	0.863 ± 0.06
Dominant leg	0.854 ± 0.06	0.866 ± 0.06	0.861 ± 0.06
Contralateral leg	0.877 ± 0.06	0.888 ± 0.06	0.865 ± 0.06
Spine regions			
Lumbar (mean L_1-L_4)	0.676 ± 0.07	0.708 ± 0.07	0.663 ± 0.07
Femoral regions			
Proximal femur (mean)	0.724 ± 0.07	0.756 ± 0.07	0.730 ± 0.08
Femoral neck	0.715 ± 0.07	0.732 ± 0.07	0.699 ± 0.08
Trochanter	0.606 ± 0.06	0.626 ± 0.07	0.613 ± 0.07
Inter-trochanteric zone	0.781 ± 0.08	0.819 ± 0.08	0.809 ± 0.09
Ward's triangle	0.693 ± 0.11	0.713 ± 0.11	0.665 ± 0.12

^{a} Differences between the rhythmic and the artistic gymnast and, ^{b} between the artistic gymnast and the controls at level of p < 0.05

Body composition

The artistic gymnasts had significantly higher lean mass (p < 0.05; size = 0.14 – 0.24 and power = 0.60 – 0.83) in the whole body and extremities than both the rhythmic gymnasts and the controls after adjusting for differences in body mass, height, and age (Fig. **1**).

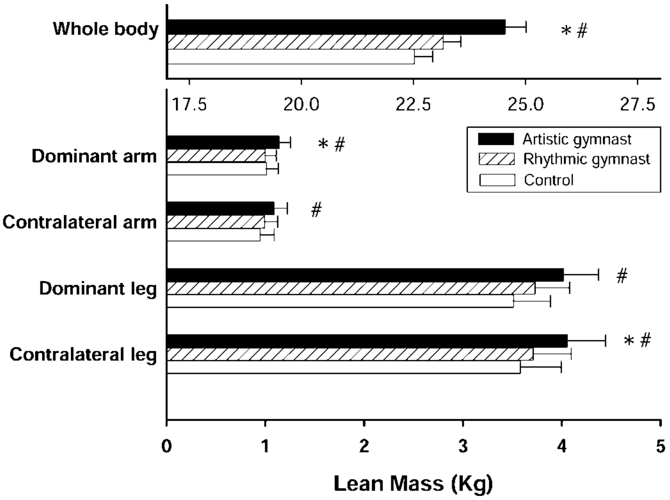

Fig. **1** Body mass-, height-, and age-adjusted lean mass from the whole body scan in the artistic gymnast, the rhythmic gymnasts and the controls (mean ± SD). * p < 0.05 between the artistic and the rhythmic gymnasts. $^{\#}$ p < 0.05 between the artistic gymnasts and the controls.

Body mass-, height-, and age-adjusted total, appendicular and axial BMC was similar between the three groups, except the femoral neck BMC that was higher in the rhythmic gymnasts compared with the artistic gymnasts and the controls (3.0 ± 0.4 vs. 2.6 ± 0.3 and 2.6 ± 0.4 g, p < 0.05). The mean upper extremity BMD was significantly higher in the artistic than in the rhythmic gymnasts or the controls (p < 0.05; size = 0.10 – 0.20 and power = 0.40 – 0.73, Table **3**). Dominant arm BMD was similar between the artistic gymnasts and the controls, but lower in the rhythmic gymnasts than in the artistic gymnasts, while the contralateral arm BMD was significantly higher for the artistic gymnasts compared with both the rhythmic gymnasts and the controls (both p < 0.05; size = 0.12 – 0.22 and power = 0.47 – 0.80, Table **3**). Interestingly, when we analyzed side-to-side intragroup BMD asymmetries (Fig. **2**), artistic gymnasts had significantly higher contralateral upper and lower extremity BMD (p < 0.05); rhythmic gymnasts had significant higher contralateral lower extremity BMD (p < 0.05); but no side-to-side differences in BMD were observed in the control group.

Relationship between soft tissues and bone mass and density

When all subjects were combined in a single group, the strongest correlation was found between whole body BMC and total lean mass (r = 0.84, p < 0.001), while whole body BMD weakly correlated with total lean mass (r = 0.45, p < 0.001). Surprisingly, when the artistic group was analyzed separately, there was no relationship between total lean mass and BMD, while the correlation between lean mass and BMC remained elevated (r = 0.80, p < 0.001). Fat mass did not correlate with any bone mass related variable. Multiple regression analysis showed that total lean mass explains 64% of the variability in whole body BMC but only 20% of the variability in whole body BMD at this age.

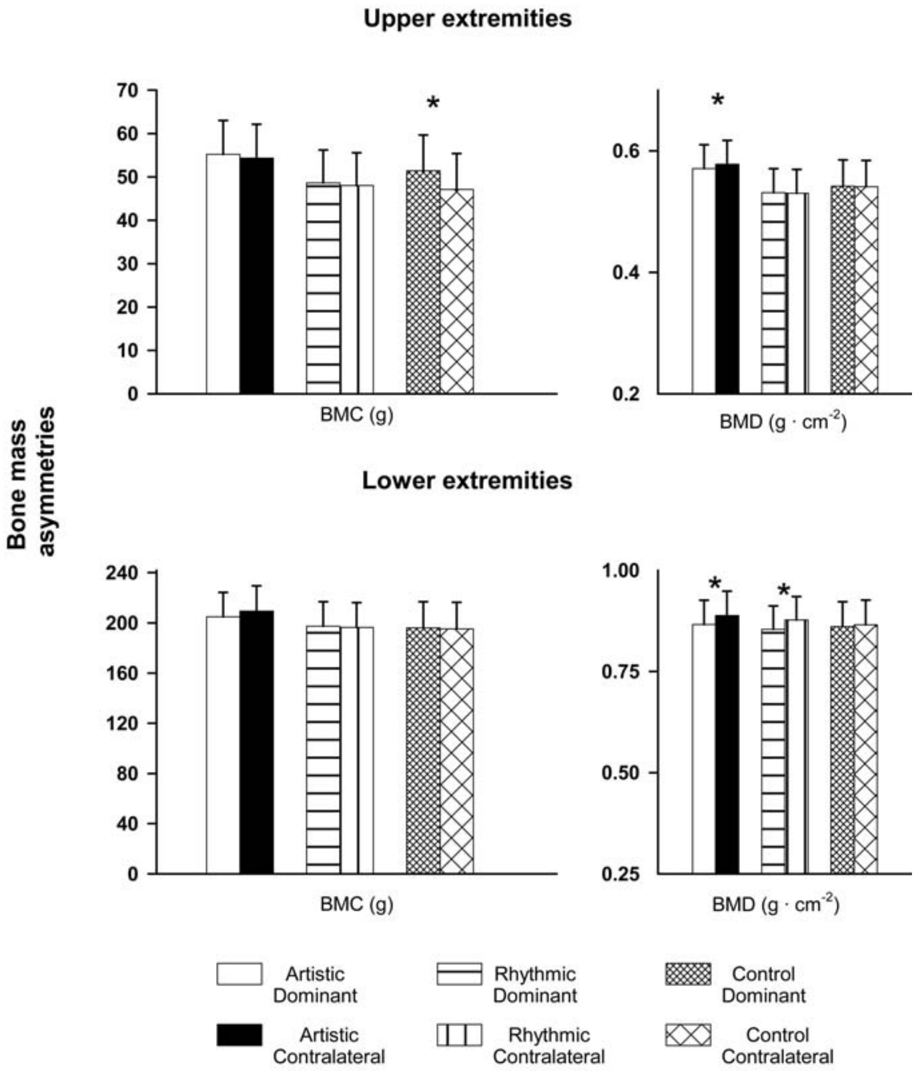

Fig. **2** Side-to-side bone mineral content (BMC) and areal density (BMD) asymmetries in the artistic gymnast, the rhythmic gymnasts and the controls (mean ± SD). * $p < 0.05$.

Discussion

This study shows that recreational participation in artistic gymnastics is associated with enhanced muscle mass and upper extremities BMD compared to either age-matched rhythmic gymnasts or sedentary counterparts.

High volume impact loading has been associated with 8 – 20% greater whole body and regional bone mineral density in prepubertal artistic gymnasts compared with controls [1,5,10]. A major difference between the present investigation and previous studies is the volume of exercise. Our gymnasts devoted just 12 hours per week to training and competitions compared to the 15 to 34 hours per week in other studies [1,5,10]. Consequently, the gymnasts studied by Dyson et al. [10] had between 8 and 20% more BMD than their matched controls in the whole body, lumbar spine, femoral neck and distal radius, after accounting for differences in bone size. Cassell et al. [5] reported a 8% higher whole body BMD adjusted for body weight than the controls. In addition, Bass et al. [1] observed 11.5% higher arms BMD in prepubertal gymnasts compared to matched counterparts. In the present investigation, the artistic gymnasts exhibited 6% higher upper extremity BMD than the controls, after accounting for differences in body mass, height, and age. This higher BMD in the upper extremities of the artistic gymnasts likely reflects the adaptations elicited by the high strains withstood by the arms and wrists in many specific figures of this sport [1]. In addition, often they use their non-dominant arm first to break the movement before the final stabilization with both arms. Possibly, for that reason, the non-dominant arm BMD of the artistic gymnasts was 7% and 9% higher than the non-dominant arm BMD of the controls and the rhythmic gymnasts, respectively. The latter implies that the impact loadings present in the artistic gymnastic participation surpass the threshold for a mechanical stimulation of osteogenesis in the upper extremity of prepubertal girls. In contrast, the rhythmic gymnasts did not show such an increase in upper extremity BMD compared to their maturation matched sedentary controls after adjustment for age, height and body mass.

In contrast to the findings of Dyson et al. [10] and Bass et al. [1], but in agreement with Cassell et al. [5] and Robinson et al. [26], who studied adult female gymnasts, no significant differences in lumbar spine BMD were observed between our gymnasts and controls. Altogether, these studies and the present investigation show that artistic gymnastic participation at prepubertal ages is associated with increased bone mass in loaded regions, the effect being more accentuated as the number of hours devoted to exercise increases.

A novel component of this study was the comparison of the two main kinds of gymnastics: artistic and rhythmic. Rhythmic gymnasts and controls showed similar BMC and BMD values in all regions. Compared to controls, the rhythmic gymnasts had lower body mass due to a lower fat mass, while lean body mass was the same in both groups. Therefore, despite their low BMI, the BMC and BMD values do not seem negatively affected in the rhythmic gymnasts. One reason may be that a major determinant of bone mass in growing children is lean body mass and, particularly, muscle mass [31]. As illustrated in Fig. **1**, the rhythmic gymnasts and controls had similar muscle mass in the extremities. Another possibility is that the increased fat mass of the controls could have had a positive influence on their bone metabolism. Obese people have less fracture risk than thinner counterparts and obesity has been associated with increased bone mineral density in adults [21]. Several studies suggest that fat mass effect on bone mass may be mediated by hormonal factors such as sex hormones, insulin and leptin [14,28]. *In vitro* studies have shown a direct stimulation of osteoblast differentiation and matrix mineralization by leptin [14,28]. However, in contrast to what has been observed in adults [25], we have not found any relationship between fat mass and bone mass variables. The latter is in agreement with the idea that lean mass has an important role during pubertal growth, while fat mass likely exerts a greater influence on female bone metabolism after the menarche [31,34]. However, more experiments will be needed to clarify definitively if fat mass, by increasing estrogen or by other mechanisms, may have an osteogenic influence on growing bone.

Despite the fact that estrogens have been considered a key endocrine regulator of bone metabolism promoting bone mass during puberty [6], animal experiments have shown that in postpubertal female rats, bone is less responsive to loading than in ovariectomized rats or in male rats of similar age [16]. In agreement with Jarvinen et al. [16], our data show that prepubertal bone is rather responsive to loading and support previous studies showing that female athletes who started their career before the puberty spurt may benefit from a greater osteogenic response to loading than the athletes who started their career after the menarche [1,15,17]. An alternative explanation for the lack of enhancement of BMC or BMD in the rhythmic gymnasts compared to the controls is that this kind of gymnastic participation is not strenuous enough to elicit physiologically relevant changes in bone metabolism. In fact, while artistic gymnastics is characterized by a great number of impacts, rhythmic gymnastics exercises are based more on smooth movements, with occasional jumps over a yielding surface which may dampen the impacts and, hence, the strains withstood by the bones. This idea is strengthened by the fact that the artistic gymnast showed enhanced upper extremity BMD, even when the rhythmic gymnasts trained five hours per week more than the artistic group. Therefore, as the main difference between both disciplines is the intensity of their actions, this may also be the factor that causes the differences in bone mass.

There is a paucity of information on the effects of sports participation on muscle mass in prepubertal and young children [24,31–33]. Ramsay et al. [24] observed that 20 weeks of strength training increased maximal dynamic, isokinetic and isometric strength in prepubertal boys. This study indicates that similar effects are possible in girls, since the artistic gymnasts exhibited greater dynamic strength than rhythmic gymnasts and controls, as reflected by the attainment of a 30–39% higher height in the countermovement jumps than both the rhythmic gymnasts and the controls, respectively.

However, Ramsay et al. did not find changes in muscle cross-sectional areas as measured by computerized axial tomography [24]. Thus, those increases in strength were interpreted as independent of hypertrophic mechanisms, and they were explained as the results of adaptations in the neural activation of muscles [24].

In contrast, in the present study we have seen that body weight-, height-, and age-adjusted lean mass was 6% and 9% higher in artistic gymnast than in rhythmic gymnast and controls, respectively. Lean mass of the lower extremity is equivalent to the extremity muscle mass [18]. So our data indicates that artistic gymnastic participation may elicit muscle hypertrophy in prepubertal girls.

Morris et al. [22] showed that changes in lean mass accounted for 10–58% of the variability in BMD acquisition in prepubertal girls who completed a 10-month exercise intervention program. In agreement, in the present investigation, we report a close relationship between lean mass and BMC in all scanned regions. However, the correlation between lean mass and BMD is weak, and nonexistent in the artistic gymnast group. Moreover, the higher level of contralateral arm BMD of the artistic gymnast remained elevated after accounting for lean mass, suggesting that this higher BMD is likely the result of the osteogenic effect of the impact loading associated with artistic gymnast participation. The latter implies that, in this case, exercise exerts an osteogenic effect independent of the effect of muscle mass as happens in prepubertal boys [5,33]. In contrast to this finding and what we have previously observed in boys [33], young female handballers also showed higher BMD than matched controls. This difference however, disappears after accounting for arm muscle mass, suggesting that this enhanced BMD could be directly explained by the higher muscle mass [32]. Thus, in the handballers, exercise exerts an indirect effect on bone mass throughout the enhancement of muscle mass, or at least, we could not distinguish an independent effect of exercise on bone as we have seen here and previously in boys [33]. This may be because the exercise intensity could be lower in handball girls than in artistic gymnasts or boys. Therefore, the relationship between lean mass and bone mass could also be different depending on the exercise volume and intensity during growth. Taking all this into consideration, it seems that low impact exercise may exert an indirect effect on bones through the increase of muscle mass, but when exercise crosses a determined intensity threshold or it generates high impacts, it becomes an independent factor affecting bone mass during prepubertal years, independently of its effects on muscle mass.

Limitations

The DXA scanner measures areal bone mineral density ($g \cdot cm^2$). To circumvent these limitations, the effect of body size on areal BMD determinations was taken into account by adjusting it for body mass, height, age, final age and sexual maturation.

Self-selection could be another limitation of the study since the strongest girls with greater muscle mass and bone mass could choose to enroll in sport activities because their condition facilitates greater achievement and success, which may positively reinforce participation in sports. Similarly, it is possible that genetic factors, which establish the potential for muscle and bone masses development, also accounted for some of the effects reported here. However, the higher BMD of the artistic gymnasts, despite the lower maturational development, the side-to-side comparisons and the fact that the BMC and BMD of the head (a non-loaded region) were similar in all the groups (data not shown), while the loaded regions increased significantly more in the artistic gymnasts than in the rhythmic gymnasts and control girls, suggests that a cause-effect relationship between high loading exercise participation and muscle and bone mass exists.

Conclusions

Recreational artistic gymnastic participation is associated with a delay in pubertal development, but also with muscle hypertrophy and enhanced bone mineral density in prepubertal girls. Participation in artistic gymnastic could then elicit a higher osteogenic stimulus in prepubertal girls than participation in rhythmic gymnastic. Our study also indicates that artistic gymnastic participation promotes muscle hypertrophy and exerts an independent osteogenic effect, which may or may not be related to the gain in muscle mass in prepubertal girls. However, many questions remain unanswered, i.e., if the bone of girls is less responsive to loading when the exercise starts during the estrogen repleted period compared to that started before puberty, or whether fat mass has a protective effect on growing bone by increasing estrogen or by other related mechanisms. In addition, longitudinal studies are needed to verify whether the high values of BMD observed, in this population, translates into an enhanced peak bone mass and lower fracture risk at old age. Out-of-school sport participation in modalities with a high impact load should be encouraged even before the growth spurt to promote bone mass acquisition and muscle mass hypertrophy in girls.

Acknowledgements

Special thanks are given to José Navarro de Tuero for this excellent technical assistance. This study was supported by Ministerio de Educación, Cultura y Deportes (AP2000-3652), Universidad de Las Palmas de Gran Canaria, Gobierno de Canarias (PI2000/067), Consejo Superior de Deportes (27/UNI10/00), and Ministerio de Ciencia y Tecnología (BFI2003-09638 and FEDER).

References

[1] Bass S, Pearce G, Bradney M, Hendrich E, Delmas PD, Harding A, Seeman E. Exercise before puberty may confer residual benefits in bone density in adulthood: studies in active prepubertal and retired female gymnasts. J Bone Miner Res 1998; 13: 500 – 507

[2] Calbet JA, De Paz JA, Garatachea N, Cabeza De Vaca S, Chavarren J. Anaerobic energy provision does not limit Wingate exercise performance in endurance-trained cyclists. J Appl Physiol 2003; 94: 668 – 676

[3] Calbet JA, Dorado C, Diaz-Herrera P, Rodriguez-Rodriguez LP. High femoral bone mineral content and density in male football (soccer) players. Med Sci Sports Exerc 2001; 33: 1682 – 1687

[4] Calbet JA, Moysi JS, Dorado C, Rodriguez LP. Bone mineral content and density in professional tennis players. Calcif Tissue Int 1998; 62: 491 – 496

[5] Cassell C, Benedict M, Specker B. Bone mineral density in elite 7- to 9-yr-old female gymnasts and swimmers. Med Sci Sports Exerc 1996; 28: 1243 – 1246

[6] Compston JE. Sex steroids and bone. Physiol Rev 2001; 81: 419 – 447

[7] Courteix D, Lespessailles E, Peres SL, Obert P, Germain P, Benhamou CL. Effect of physical training on bone mineral density in prepubertal girls: a comparative study between impact-loading and non-impact-loading sports. Osteoporos Int 1998; 8: 152 – 158

[8] 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: 1222 – 1230

[9] Duke PM, Litt IF, Gross RT. Adolescents' self-assessment of sexual maturation. Pediatrics 1980; 66: 918 – 920

[10] Dyson K, Blimkie CJ, Davison KS, Webber CE, Adachi JD. Gymnastic training and bone density in pre-adolescent females. Med Sci Sports Exerc 1997; 29: 443 – 450

[11] Faulkner RA, Bailey DA, Drinkwater DT, McKay HA, Arnold C, Wilkinson AA. Bone densitometry in Canadian children 8 – 17 years of age. Calcif Tissue Int 1996; 59: 344 – 351

[12] Forwood MR, Bailey DA, Beck TJ, Mirwald RL, Baxter-Jones AD, Uusi-Rasi K. Sexual dimorphism of the femoral neck during the adolescent growth spurt: a structural analysis. Bone 2004; 35: 973 – 981

[13] Georgopoulos N, Markou K, Theodoropoulou A, Paraskevopoulou P, Varaki L, Kazantzi Z, Leglise M, Vagenakis AG. Growth and pubertal development in elite female rhythmic gymnasts. J Clin Endocrinol Metab 1999; 84: 4525 – 4530

[14] Gordeladze JO, Drevon CA, Syversen U, Reseland JE. Leptin stimulates human osteoblastic cell proliferation, de novo collagen synthesis, and mineralization: impact on differentiation markers, apoptosis, and osteoclastic signaling. J Cell Biochem 2002; 85: 825 – 836

[15] Heinonen A, Sievanen H, Kannus P, Oja P, Pasanen M, Vuori I. High-impact exercise and bones of growing girls: a 9-month controlled trial. Osteoporos Int 2000; 11: 1010 – 1017

[16] Jarvinen TL, Kannus P, Pajamaki I, Vuohelainen T, Tuukkanen J, Jarvinen M, Sievanen H. Estrogen deposits extra mineral into bones of female rats in puberty, but simultaneously seems to suppress the responsiveness of female skeleton to mechanical loading. Bone 2003; 32: 642 – 651

[17] Kannus P, Haapasalo H, Sankelo M, Sievanen H, Pasanen M, Heinonen A, Oja P, Vuori I. Effect of starting age of physical activity on bone mass in the dominant arm of tennis and squash players. Ann Intern Med 1995; 123: 27 – 31

[18] Kim J, Wang Z, Heymsfield SB, Baumgartner RN, Gallagher D. Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry method. Am J Clin Nutr 2002; 76: 378 – 383.

[19] Leger LA, Mercier D, Gadoury C, Lambert J. The multistage 20-meter shuttle run test for aerobic fitness. J Sports Sci 1988; 6: 93 – 101

[20] Lehtonen-Veromaa M, Mottonen T, Nuotio I, Heinonen OJ, Viikari J. Influence of physical activity on ultrasound and dual-energy X-ray absorptiometry bone measurements in peripubertal girls: a cross-sectional study. Calcif Tissue Int 2000; 66: 248 – 254

[21] Lindsay R, Cosman F, Herrington BS, Himmelstein S. Bone mass and body composition in normal women. J Bone Miner Res 1992; 7: 55 – 63

[22] Morris FL, Naughton GA, Gibbs JL, Carlson JS, Wark JD. Prospective ten-month exercise intervention in premenarcheal girls: positive effects on bone and lean mass. J Bone Miner Res 1997; 12: 1453 – 1462

[23] Nickols-Richardson SM, Modlesky CM, O'Connor PJ, Lewis RD. Premenarcheal gymnasts possess higher bone mineral density than controls. Med Sci Sports Exerc 2000; 32: 63 – 69

[24] Ramsay JA, Blimkie CJR, Smith K, Ganer S, MacDougall JD, Sale DG. Strength training effects in prepubescent boys. Med Sci Sports Exerc 1990; 22: 605 – 614

[25] Reid IR. Relationships among body mass, its components, and bone. Bone 2002; 31: 547 – 555

[26] Robinson TL, Snow-Harter C, Taaffe DR, Gillis D, Shaw J, Marcus R. Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. J Bone Miner Res 1995; 10: 26 – 35

[27] Slemenda CW, Miller JZ, Hui SL, Reister TK, Johnston CC. Role of physical activity in the development of skeletal mass in children. J Bone Miner Res 1991; 6: 1227 – 1233

[28] Thomas T, Gori F, Khosla S, Jensen MD, Burguera B, Riggs BL. Leptin acts on human marrow stromal cells to enhance differentiation to osteoblasts and to inhibit differentiation to adipocytes. Endocrinology 1999; 140: 1630 – 1638

[29] Uzunca K, Birtane M, Durmus-Altun G, Ustun F. High bone mineral density in loaded skeletal regions of former professional football (soccer) players: what is the effect of time after active career? Br J Sports Med 2005; 39: 154 – 157; discussion 154 – 157

[30] Vicente-Rodriguez G, Ara I, Perez-Gomez J, Dorado C, Calbet JAL. Muscular development and physical activity are major determinants of femoral bone mass acquisition during growth. Br J Sports Med 2005; 39: 611 – 616

[31] Vicente-Rodriguez G, Ara I, Perez-Gomez J, Dorado C, Serrano-Sanchez JA, Calbet JAL. High femoral bone mineral density accretion in prepubertal football players. Med Sci Sports Exerc 2004; 33: 1789 – 1795

[32] Vicente-Rodriguez G, Dorado C, Perez-Gomez J, Gonzalez-Henriquez JJ, Calbet JA. Enhanced bone mass and physical fitness in young female handball players. Bone 2004; 35: 1208 – 1215

[33] Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I, Serrano-Sanchez JA, Dorado C, Calbet JA. Enhanced bone mass and physical fitness in prepubescent footballers. Bone 2003; 33: 853 – 859

[34] Young D, Hopper JL, Macinnis RJ, Nowson CA, Hoang NH, Wark JD. Changes in body composition as determinants of longitudinal changes in bone mineral measures in 8- to 26-year-old female twins. Osteoporos Int 2001; 12: 506 – 515