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Critical Review

Does Gymnastics Training Inhibit Growth of Females?

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Objective: The increasingly dominant performance of smaller-sized female gymnasts and increased magnitude of training beginning at an early age have prompted public and medical concerns, especially from an auxological perspective. The objective of this review is to determine if gymnastics training inhibits growth of females.

Data Sources: An extensive research of MedLine (PubMed interface) along with cross-referencing was conducted using the Text and MeSH words "gymnastics" in combination with "growth," "maturation," "body height," "body weight," and "growth plate." Our analysis is limited to English articles only.

Study Selection: All published studies that included data related to the research questions were included.

Main Results: Although data from three historical cohort studies indicate that female gymnasts are short even before they begin training, clinical reports and cohort studies do suggest that some female gymnasts experience attenuated growth during training followed by catch-up growth during periods of reduced training or retirement. There is conflicting evidence whether the "catch-up" is complete. There were no studies reporting prevalence or incidence of inadequate growth. Three cohort studies provide evidence of reduced growth but training was not partitioned from other confounding factors in the gymnastics environment. Although there is a paucity of studies examining the link of dietary practices with diminished growth in female gymnasts, a review of related dietary literature indicates the potential for insufficient energy and nutrient intake among female gymnasts.

Conclusions: Elite level or heavily involved female gymnasts may experience attenuated growth during their years of training and competition followed by catch-up growth during reduced training schedules or the months following retirement. However, a cause–effect relation between gymnastics training and inadequate growth of females has not been demonstrated.

Key Words: Gymnastics—Growth—Maturation—Body height—Body weight—Growth plate.

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INTRODUCTION

In response to the increased difficulty of skills and routines practiced and performed, women's gymnastics has evolved to favor a slender, prepubescent physique. Top-level female gymnasts today are shorter, lighter, and later-maturing than their predecessors 30–40 years earlier.[1] They begin training between the ages of 5–7 years and are often involved in strenuous, year-round training by age 10. During the periadolescent years, top-level female gymnasts may train 24–36 hours per week, 4–6 hours per day, and up to 12 months per year.[2,3] Although it is possible that small size and late maturation are due to self-selection for gymnastics,[4] it is also possible that growth is retarded as a result of inadequate nutrition for level of activity, particularly during the periadolescent period.[5–7] Additionally, it is believed that repetitive compression stress may result in premature femoral and tibial epiphyseal fusion, thus contributing to decreased leg growth in female gymnasts.[7–9] Therefore, this review critically evaluates the available evidence on whether gymnastics training inhibits growth of females.

METHODS AND MATERIALS

We searched MedLine from 1966–present (PubMed interface) using the Text and MeSH words "gymnastics," in combination with "growth," "maturation," "body height," "body weight," and "growth plate" (Table 1). Overall, there were 266 hits. Of 77 relevant titles, we reviewed the 55 reports with data central to our question. Additional articles and related information were found using cross-referencing.

Although most reports with relevant data were published articles, eight were published abstracts or conference proceedings. We acknowledge that these reports may provide less reliable or complete information than published articles.

Throughout this article, auxology is defined as the

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TABLE 1. *MedLine search strategy from 1966–present using a combination of MedLine subject headings (MeSH) and textwords (tw)*

Step		Search strategy	No. of hits
	1	Gymnastics (MeSH and tw)	636
	2	Growth (MeSH and tw)	456,918
	3	1 and 2	115
	4	Maturation (tw)	46,337
	5	1 and 4	30
	6	Body height (MeSH and tw)	15,576
	7	1 and 6	32
	8	Body weight (MeSH and tw)	170,668
	9	1 and 8	67
	10	Growth plate (MeSH and tw)	2,921
	11	1 and 10	22
Total number of hits			266

* All references pertain to publications in English.

study of growth.[10] Growth refers to increases in stature and weight, and related changes in body proportions and composition, and maturation refers to the timing and tempo (rate) of progress toward the mature state.[11] Maturation is often viewed in the context of skeletal (skeletal age [SA]), somatic (age at peak height velocity [PHV]) and sexual (secondary sex characteristics) maturation.[11]

We defined "inadequate growth" using National Center for Health Statistics (NCHS)/Centers for Disease Control and Prevention (CDC)/World Health Organization (WHO) criteria. Briefly, inadequate growth is defined as a value below the fifth percentile,[12] and growth faltering as a downward trend of growth indices across two major percentile lines.[12,13]

RESULTS

Auxological Studies

Our review of the literature uncovered 3 case reports, 18 cross-sectional, and 14 cohort studies with relevant data. Most of these studies were descriptive; however, 3 cross-sectional and 3 cohort studies investigated potentially causal relations between gymnastics training and the growth of female gymnasts.

Case Reports

Three case reports provide limited but longitudinal data by comparing a gymnast to her genetically identical siblings (Table 2).[5,14–16] Although it is difficult to infer causation from case data, these results suggest decreased growth during sport, but that catch-up growth does occur following retirement from the sport. In addition, menarche for the gymnast occurred more than 1 year after the siblings for a triplet gymnast,[5] 31 months later for an Israeli twin,[14,15] and 4.5 years later for an Australian twin.[16] Of note, the normal average difference for menarche in monozygotic (MZ) twins is 4 months.[17] These delays may be due to the physical stresses of training, or because of poor nutritional status. In the study using triplets,[5] the gymnast's energy expenditure (EE) was estimated to be approximately 2,900 kcal, but energy intake (EI) was only 2,300 kcal, based on 4-day diet records. The lower body weight and percent body fat in the gymnast compared with the siblings at baseline support the findings of energy imbalance.[5,14]

Cross-Sectional Studies

A brief summary of cross-sectional studies is shown in Table 3. Sample sizes range from 7 to 668 gymnasts, representing club level through international level of competition and training. Indices of maturity including skeletal age,[18–21] age at menarche,[18,22–28] and secondary sexual characteristics [18,22,23,29] occur significantly later in female gymnasts than control subjects. Female gymnasts have less fat mass than controls,[19,22,23,30–33] and are also significantly shorter and lighter for their age, with differences most pronounced among older, advanced level gymnasts.[18,23,25,31,32,34] In contrast, the relationship between gymnasts' sitting height and stature does not differ significantly from nonathletes.[24,28,31] These results should be viewed cautiously for two reasons. First, averaging data may remove important, relevant, and essential information. For example, not all elite gymnasts are late maturing; in fact, some actually have a normal or earlier-than-average pubertal development.[4,24] Second, cross-sectional studies provide no direct evidence of the sequence of events. Thus, it is not clear whether gymnastics training underlies the small size and later maturation of females, or whether these are selection factors for their sport.

In general, impaired growth and maturation are typically confirmed by assessing circulating hormones and growth factors. Comparisons of Dutch gymnasts and swimmers reveal lower levels of estrone and androstenedione in prepubertal gymnasts, but not in the early pubertal gymnasts.[35] Comparison of Dutch gymnasts with lean girls and small girls of the same chronological age and stage of maturation indicates lower luteinizing hormone (LH), 17-β-estradiol, and higher follicle-stimulating hormone (FSH).[36] Suboptimal levels of estradiol and serum leptin have been discovered in elite German female gymnasts.[20] Low insulin-like growth factor-1 (IGF-1) levels are reported in female gymnasts relative to controls[29,37–39]; however, this finding is equivocal.[19,40]

Several cross-sectional studies explored possible determinants of the growth and maturation characteristics of female gymnasts. Bernink et al.[22] found no difference between height and socioeconomic status of gymnasts and controls. Theintz et al.[18] documented the tendency of female gymnasts to be the children of short parents with later-than-average puberty. Peltenburg et al.[23] reported a relation between training duration per week and growth and maturation characteristics in swimmers, but not gymnasts.

Prospective and Historical Cohort Studies

A brief summary of cohort studies is shown in Table 4. Studies range in duration from 6 months to 7 years, but most studies are short in duration and therefore limited in estimating growth velocities.[4] Most gymnasts did not exceed 20 hours per week training (range: 6–36 hr/wk). Again, competitive female gymnasts generally demonstrate an auxological pattern of slow growth and later maturation compared with reference groups,[8,41–50] per-

TABLE 2. *Case studies: growth and maturation of female gymnasts*

Study	Topic	Subjects	Measures	Important findings			
Tveit-Milligan et al.[5]	Clinical report of the growth and maturation of triplet sisters	3 F, 11.5 yrs; gymnast trains 20–26 hrs/wk	Height, weight, Tanner stages, AOM, skinfolds	Age 11.5	Gymnast	Sister 1	Sister 2
				Height (cm)	150.2	154.9	149.8
				Weight (kg)	43.6	55.6	48.8
				Fat (%)	10.5	22.0	23.0
				Age 13*			
				Height (cm)	160.4	159.8	154.6
				Weight (kg)	57.2	66.5	54.7
				Fat (%)	15.1	24.5	—
				AOM	12 yr 10 mos	11 yr 3 mos	11 yr 9 mos
				*Gymnast retired at 12 yr 4 mos			
Constantini et al.[14,15]	Clinical report of the growth and maturation of MZ twin females	2 F, 13.5 yrs; gymnast trains 25 hrs/wk; sister plays basketball 6–8 hrs/wk	Height, weight, Tanner stages, skinfolds	Age 13.5	Gymnast	Sister	
				Height (cm)	148.0	154.0	
				Weight (kg)	38.4	43.5	
				Fat (%)	8.2	17.0	
				At maturity*			
				Height (cm)	155.0	156.0	
				Weight (kg)	48.4	—	
				AOM	14 yr 7 mos	12 yr	
				*Gymnast retired at 14 yr 6 mos due to injury			
Bass et al.[16]	Clinical report of the growth and maturation of MZ twins	2 F, 26 yrs; both girls began gymnastics training at age 8	Height, menarche		Gymnast 1	Sister	
				Age of retirement	18.0	12.0	
				Final height (cm)	161.9	165.8	
				AOM	18 yr	13 yr 6 mos	

MZ, monozygotic; AOM, age of menarche.

haps not unlike other short normal slow-maturing children.[51]

None of the cohort studies report incidence of growth inadequacy. However, Malina[52] plotted the percentile position of mean/median heights and weights of female gymnasts from Europe, South Africa, and the United States relative to U.S. reference data (i.e., NCHS/CDC/WHO charts).[52,53] The data on gymnasts were derived from both cross-sectional and longitudinal studies and vary between ≤P10 and P50. However, more recent samples of top-level gymnasts are shorter and lighter and tend to cluster around P10.[19,24,52] This suggests that there were instances of inadequate growth among the gymnasts studied (i.e., <P5). This may be normal short stature; however, in routine screening, these girls would be evaluated for pathology related to their short stature.[13,53]

Three prospective cohort studies report gymnasts' height relative to predicted height. In one study, final height of Swiss gymnasts[8] was not documented but inferred to be reduced based on the predicted value derived from the degree of epiphyseal closure. Predicted adult stature, however, is not as reliable and valid an observation as measured adult stature. Polish gymnasts ended up 1–8 cm shorter than predicted from midparental height equations, whereas six of eight controls were 1–7 cm taller than expected.[42] Similar findings were found among 6 of 22 Swedish gymnasts, and the growth spurt typically occurred in periods of reduced training, often connected with injuries.[41]

Two prospective cohort studies report reduced growth in female gymnasts. Compared with swimmers, Swiss gymnasts had stunted growth of leg length.[8] The choice of swimmers as controls, however, may have resulted in bias because the swimmers were taller than average and appeared to have protracted growth of their legs, thus accentuating the difference between the two groups.[7] In contrast, Australian gymnasts had a shorter sitting height and leg length at baseline (see Figure 1), but only the deficit in sitting height increased during 2 years' follow-up.[44] Continued measurement of gymnasts who retired during this period revealed accelerated trunk velocity

TABLE 3. *Cross-sectional studies: growth and maturation of female gymnasts*

Study	Topic	Subjects	Measures	Important findings
Beunen et al.[34]	To study somatic profiles of gymnasts	23 F gymnasts, mean age 16.6 yrs	AOM, SA	AOM for gymnasts (n = 13) is 15.1 compared with 12.8–13.0 for Belgian reference samples; SA was later, on average, by 1.5 yrs
Bernink et al.[22]	To compare height and maturation in relation to socioeconomic status	78 F gymnasts, mean age 11.5 yrs (train 6.5 hrs/wk) 52 F swimmers (mean age 12.2 yrs) 116 F controls (mean age 11.9 yrs)	Height, Tanner stages, AOM, socioeconomic status	Gymnasts are shorter (P37) than swimmers (P85) and controls (P51); gymnasts are also later-maturing; no positive relationships between socioeconomic status and height or later maturation were found
Peltenburg et al.[23]	To study differences in growth and maturation among gymnasts and controls	668 F gymnasts (train 4.1 to 6.7 hrs/wk) 98 F swimmers 298 F controls	AOM, Tanner stages, height, weight, parental height	Menarche was later in gymnasts by 1–2 years compared with swimmers and controls; gymnasts are, on average, shorter and lighter, (especially after 10 yrs of age)
Peltenburg et al.[35]	To determine if later onset of puberty in gymnasts is modulated by a low estrone level due to low body fat	46 F gymnasts, ages 11–12 yrs (train 6.2–6.8 hrs/wk) 37 F swimmers, ages 11–12 yrs	Height, weight, Tanner stages, plasma levels of hormones	In prepubertal children the levels of estrone, testosterone, and androstenedione were lower in gymnasts than swimmers; however, in the early pubertal group these hormone levels were no longer different
Broekhoff et al.[31]	To compare gymnasts and controls on various morphological measures	18 F gymnasts, mean age 13.3 yrs (train 20–36 hrs/wk) 18 F controls, mean age 13.4 yrs	Stature, weight, fat mass	Gymnasts were significantly shorter, lighter, and had smaller amounts of fat mass, both in absolute terms and in proportion to total body weight ($p < 0.05$)
Haywood et al.[26]	To compare body composition in swimmers and gymnasts	121 F gymnasts 55 F swimmers	Height, weight, skinfolds	Swimmers are taller and heavier ($p < 0.001$) than gymnasts; there was no significant difference in percent body fat
Caldorone et al.[32]	To determine whether gymnastics favors girls who are small	52 F gymnasts, ages 11–15 yrs	Height, weight, sitting height, skinfolds, SA	SA (14.2) of gymnasts is proportional to CA (14.0); height and weight are lower than reference standards; sitting height/stature ratio was 50.8%
Theintz et al.[18]	To compare parental growth and maturation of gymnasts and swimmers	34 F gymnasts, mean age 12.6 yrs (train 15–25 hrs/wk) 19 F swimmers, mean age 12.6 yrs 25 F controls, mean age 12.9 yrs	Height, weight, and pubertal growth of parents and reference groups	Parents of gymnasts were significantly lighter and shorter than those of swimmers and controls; recalled menarche was also significantly later in mothers of gymnasts than in mothers of swimmers and controls
Jahreis et al.[39]	To study hormonal changes induced by gymnastics training	9 F gymnasts, mean age 11.5 yrs	IGF-1, cortisol, T3, T4, DHEA-S	IGF-1 concentration of gymnasts is below age-dependent norm of girls with delayed SA; however, IGF-1 levels decreased by 25% over 3 days of training
Benardot et al.[33]	To evaluate anthropometric and body composition of jr elite gymnasts	100 F gymnasts, ages 7–10 yrs 46 F gymnasts, ages 11–14 yrs	Height, weight, skinfolds	7–10 yr old gymnasts were at P48 for height; however, the 11–14 yr old gymnasts were at P20 for height
Claessens et al.[24]	To determine the growth and maturity status of elite gymnasts	201 F gymnasts, mean age 16.5 yrs (train 25 hrs/wk)	AOM, height, weight, SA	Gymnasts are shorter and lighter with differences most apparent after 17 years; AOM in gymnasts is 15.2 versus 13.2 in Flemish reference sample; SA is delayed 0.9–1.4 yrs
Caine et al.[21]	To determine prevalence of radial stress injuries	39 F gymnasts, mean age 11.8 yrs	SA	SA is 12.1 yrs compared with 12.8 yrs in controls ($p < 0.001$)

TABLE 3—*(Continued)*

Study	Topic	Subjects	Measures	Important findings
DeRidder et al.[36]	To explore the relation between physical factors and pubertal development	79 F gymnasts, mean age 11.8 yrs (train 20.8 hrs/wk) 10 lean girls 12 small girls, mean age 11.0 yrs	Tanner stages, height, weight, plasma levels of various hormones	Female gymnasts were significantly shorter than lean schoolgirls ($p < 0.05$) and had significantly lower LH, E2, and T-plasma levels than nonathletic schoolgirls ($p < 0.05$)
Lindholm et al.[28]	To investigate delayed puberty and skeletal development	19 F gymnasts, mean age 20.9 yrs	AOM, height, weight, sitting height, BMD, BMC	AOM for gymnasts is 14.8 yrs compared with 12.1 for controls ($p < 0.001$); gymnasts are shorter ($p > 0.01$); however, sitting height/stature ratio is the same ($p = 0.53$)
Nichols et al.[29]	To compare hormonal status of gymnasts, swimmers, and controls	10 F gymnasts ages 9–14 yrs (train 16–20 hrs/wk) 10 F swimmers 10 F controls	Height, weight, plasma levels of IGF-1 and estradiol	Gymnasts are shorter ($p < 0.002$) and lighter ($p < 0.01$) than swimmers and controls; IGF-1 was lower in gymnasts than controls ($p < 0.01$)
Bale et al.[25]	Compare distance runners, gymnasts, and anorexic individuals	10 F runners, mean age 13.6 yrs 10 F anorexics, mean age 14.7 yrs 20 F gymnasts, mean age 13.3 yrs (train > 14 hrs/wk)	Height, weight, skinfolds, AOM	Gymnasts are shorter than age 13–14 references; gymnasts and runners had higher lean body mass than anorexics; anorexics had highest % body fat and fat mass ($p < 0.05$)
Weimann et al.[20]	To determine if there is a relation between leptin and delayed puberty	22 F gymnasts, mean age 13.6 yrs (train 22 hrs/wk)	Height, weight, Tanner stages, plasma levels of LH, IGF-1, FSH, estradiol, IGFBP-1, menarche, skinfolds	Leptin levels correlated with fat mass, which was lower in gymnasts ($r = 0.06$; $p = 0.005$); adjustment of serum leptin levels for pubertal stage and BMI or % body fat reveals low levels of leptin
Weimann et al.[19]	To evaluate the influence of gymnastics training prepubertally	22 F gymnasts, mean age 13.6 yrs (train 22 hrs/wk)	Height of gymnasts and parents, weight, Tanner stages, predicted height	SA was delayed on average 1.7 yrs; menarche was later than norms by 2.3 yrs; nutritional intake was 16% of German nutrition recommendations; height and weight fell below P12

AOM, age of menarche; SA, skeletal age; IGF, insulin-like growth factor; LH, luteinizing hormone; BMD, bone mineral density; BMC, bone mineral content; FSH, follicle-stimulating hormone; BMI, body mass index; DHEA-S, dehydroepiandrosterone-sulphate.

(i.e., the sitting height became more similar to the control group) in the peripubertal (>10 years of age) but not the prepubertal (<10 years of age) girls.[44]

The results of three studies[54–56] indicate that familial and constitutional factors do play an important role in the selection and sorting processes of women's competitive gymnastics. Historical cohort data indicate: 1) female gymnasts are shorter than girls representing other competitive sports long before selection,[54,55] 2) top-level gymnasts were shorter than less competitive or recreational gymnasts prior to participation in gymnastics,[54,56] and 3) parents of nationally selected gymnasts are, on average, smaller.[54]

Energy Imbalance

Mean energy intakes in prepubertal and adolescent female gymnasts are generally lower than national recommendations by approximately 275–1,200 kcal,[30,57–67] although other reports indicate that prepubertal gymnasts may have adequate intakes.[47,57] The more consistent findings of inadequate intakes in adolescents versus prepubertal gymnasts may be explained by the older gymnasts' need to restrict food intake to maintain the slender, prepubertal physique.[14,30,39,42,50,59,67–70] This hypothesis is supported by frequent reports of individual energy restriction among advanced competitive level female gymnasts.[30,58–66,68,71] In addition to low EI, young female gymnasts have inadequate intakes of essential micronutrients that impact growth and skeletal development,[72–74] most notably zinc,[63,64,71] iron[58,64,65,71,75] and calcium.[19,30,59,63,64,71]

Although limited, there are data to suggest that the low EI of female gymnasts is insufficient to support normal growth and vigorous training. Total energy intake of Flemish gymnasts was only 90% of Dutch RDA (range 65–119%) at baseline, and decreased to 80% (range 51–92%) over 4 years, and was associated with a decrease in percentile scores for weight.[45] Energy intake of Australian gymnasts was less than controls, continued to decrease over time as training load increased, and was associated with increasing deficits in height and a delay in skeletal maturation.[44]

TABLE 4. *Cohort studies: growth and maturation of female gymnasts*

Study	Topic	Subjects	Measures	Important findings
Salmela[50]	To prospectively study (2 seasons) the morphological characteristics of gymnasts	14 F elite gymnasts (train 26 hrs/wk)	2 measurement occasions; height, weight, segment lengths, breadths, circumferences, and proportions	Most measures increased, but skinfolds and upper arm girth decreased; mean heights are well below P5 on both measurement occasions
Haywood[48]	To prospectively study (1 yr) the strength and flexibility of gymnasts	30 F club-level gymnasts, ages 12.3–14.5 yrs (train 6.8–8 hrs/wk)	Height, weight, AOM, skinfolds, strength, and flexibility	13/30 gymnasts reached menarche by 14.5 yrs, on average; gymnasts were at P25 for height and weight
Peltenburg et al.[54]	To retrospectively study the growth patterns from 1–11 yrs of age	197 F gymnasts (recreational, young talented, and older talented) 63 F swimmers 102 F controls	Height, weight, parents' height, socioeconomic status	Gymnasts were already smaller from age 1 and became smaller with increasing age; among the 3 gymnastic groups, the older talented had the lowest values; parents of gymnasts were smaller; no relations to socioeconomic status were found
Ziemilska[42]	To prospectively study (7 yrs) the growth and maturation of gymnasts	9 F elite gymnasts, ages 10–12 yrs (train 20–30 hrs/wk)	Height, weight, height predictions, Tanner stages, training volume and intensity	In contrast to controls (taller than predicted), all but one gymnast were shorter than predicted; gymnasts also grow more slowly and have a later PHV than controls; gymnasts' AOM is 1.5 years earlier than their mothers
Theintz et al.[8]	To prospectively study (2–3.7 yrs) whether gymnastics training could alter growth potential	22 F gymnasts, mean age 12.3 yrs (train 22 hrs/wk) 23 F swimmers, mean age 12.3 yrs (train 8 hrs/wk)	Height, weight, sitting height, leg length, skinfolds, Tanner stages, SA	Decrease in mean height ($p < 0.001$) predictions with time and a decrease in height standard scores ($p < 0.001$) of gymnasts; in contrast, these measures did not change in the case of swimmers
Lindholm et al.[41]	To prospectively study (5 yrs) the relation between pubertal and gymnastic training	22 F gymnastics selected for elite training, ages 11–14 yrs (train 10–20 hrs/wk) 22 F controls	Height, weight, Tanner stages, estimated final height	Gymnasts grow more slowly than controls; average AOM is 14.5 in gymnasts compared to 13.2 in controls; growth spurt often occurred during periods of reduced training and in accordance with injuries; 6/21 gymnasts ended up 3.5–7.5 cm shorter than expected
Baxter-Jones and Helms[43]	To prospectively study (3 yrs) the influence of training on growth	81 F gymnasts (train 11–16 hrs/wk) 60 F swimmers 81 F tennis players	Height, weight, AOM of athletes and their mothers	Gymnasts were below average in height until 17 yrs and had a later AOM (14.3 versus 13.0) than controls; there was a positive correlation between AOM of gymnasts and their mothers
Tanghe et al.[56]	To study prospectively (4 yrs) the relation between training and bone growth	13 F top-level gymnasts 10 F recreational gymnasts	Height, weight, sitting height, SA, leg length	High performance group is shorter than the recreational group at all age levels; however, leg and arm lengths are the same
Zonderland et al.[45]	To study prospectively (3–4 yrs) the energy intake and growth status of female gymnasts	13 F top-level gymnasts (train 15 hrs/wk)	Height, weight, SA, 7-day food records	Energy intake was 75% of Dutch RDA at baseline and continued to decrease to 67% by the third measurement occasion ($p \leq 0.05$); at the same time, height decreased from P36 to P30; weight decreased significantly over time ($p \leq 0.05$)
Bass et al.[46]	To study prospectively (1 yr) growth and training of female gymnasts	45 F gymnasts, mean age 10.4 yrs (train 15–36 hrs/wk 35 F controls, mean age 9.3 yrs	Height, weight, bone age, BMD, Tanner stages	At baseline, gymnasts are shorter than controls due to reduced sitting height ($p < 0.05$) and femur ($p < 0.08$) and tibial ($p < 0.05$) lengths; during a 1 yr follow-up these deficits increased, especially sitting height ($p < 0.001$)
Courteix et al.[49]	To study prospectively (1 yr) somatic development of female gymnasts	14 F gymnasts, mean age 11.3 yrs (train 12–15 hrs/wk) 21 F controls, mean age 11.0 yrs	Height, weight, SA, Tanner stages	Gymnasts were shorter and lighter than controls and there was a tendency toward a greater delay in SA in gymnasts; however, differences were not statistically significant

TABLE 4—*(Continued)*

Study	Topic	Subjects	Measures	Important findings
Nickols-Richardson et al.[47]	To study prospectively (1 yr) changes in BMD in gymnasts and controls	9 F club-level female gymnasts, mean age 10.0 yrs (train 12–15 hrs/wk) 9 F controls, mean age 10.1	Height, weight, 3-day diet record, 7-day physical activity recall	There was no difference in energy intake between groups and this did not change over time; although athletes were matched on height and weight and age, gymnasts had lower fat mass and percent body fat on all measurement occasions
Damsgaard et al.[55]	To study retrospectively the effect of genetic factors on the stature of children participating in competitive sports	30 F gymnasts, ages 9.4–13.5 yrs (train 4–17 hrs/wk) 64 controls, ages 9.4–13.0 yrs (train 2–14 hrs/wk)	Birth date, birth weight, standing height, weight at ages 2–4 years, height of parents	Significant differences in height between gymnasts and controls ($p < 0.0004$) and these differences were evident at ages 2–4 ($p < 0.002$); the type of sport and hours trained per week had no effect on height standard deviation scores
Bass et al.[44]	To study prospectively (2 yrs) the effects of gymnastics training on growth and skeletal development	83 F gymnasts, ages 5.6–15.6 yrs (train 8–36 hrs/wk) 110 F controls, ages 6.9 to 16.6 yrs	Tanner stages, SA, height, sitting height, weight, leg length, 3-day diet records	At baseline, SA was delayed by 1.3 yrs and increased with years of training; there were deficits in standing and sitting height and leg length in gymnasts at baseline and only the deficit in sitting height increased during the study period ($p < 0.001$); in 13 gymnasts followed for 12 months after retirement, growth in sitting height accelerated resulting in a lessening of the deficit in sitting height ($p < 0.01$)

AOM, age of menarche; PHV, peak height velocity; BMD, bone mineral density; DEXA, dual X-ray absorptiometry; SA, skeletal age.

It is important to note that estimating dietary intakes is difficult and lacks precision.[19,76,77] Therefore, it remains possible that the negative energy balance observed in several reports[5,57,58,70,78–80] may be the result of underestimation of energy intakes.[19,57]

DISCUSSION

The results of this review indicate that some elite level or heavily involved female gymnasts experience attenuated growth during their years of training and competition followed by catch-up growth during periods of reduced training or retirement from gymnastics. However, the available evidence does not point to a specific cause for this growth disturbance.

Inadequate Growth Among Female Gymnasts

None of the studies reviewed report prevalence or incidence of inadequate growth among female gymnasts. However, the catch-up growth observed during reduced training schedules[41,69,81] or the months following retirement[5,14–16,44] provides evidence that growth is affected in some instances. This is also supported by the cross-sectional and cohort studies showing decreased height and weight for age,[24,50,52] decreased height compared with predicted height from midparental height equations,[41,42] lower levels of hormones and serum growth factors,[20,29,37–39] and evidence from two case reports and one cohort study linking inadequate diet with growth disturbance in female gymnasts.[5,14–16,44] However, this supporting evidence should be interpreted in the context of the methodological limitations associated with the estimation procedures used in these studies.[4,13,19,57] Although catch-up growth does occur, the evidence is inconclusive whether normal height is achieved.[5,14–16,28,44] Observations of reduced growth may not be specific to gymnasts, as catch-up growth has also been documented in other athletes once training was reduced.[82,83]

Strength of Evidence

A purpose of this review was to evaluate critically the available evidence on whether gymnastics training inhibits growth of females. Although only randomized controlled trials can absolutely provide cause–effect conclusions, they are obviously not a feasible alternative to answer the current question. The cohort design was the strongest design used to address the question; however, the nature and extent of exposure was not clearly defined in these studies as a basis for determining cause. Rather, training was routinely described in terms of hours per week, with little consideration of the intensity (elements per minute, biomechanical loads, or skill difficulty) or energy cost of training.

Table 5 lists criteria that suggest associations are not coincidental but indeed represent cause and effect.[84] The table shows that the available evidence for cause does

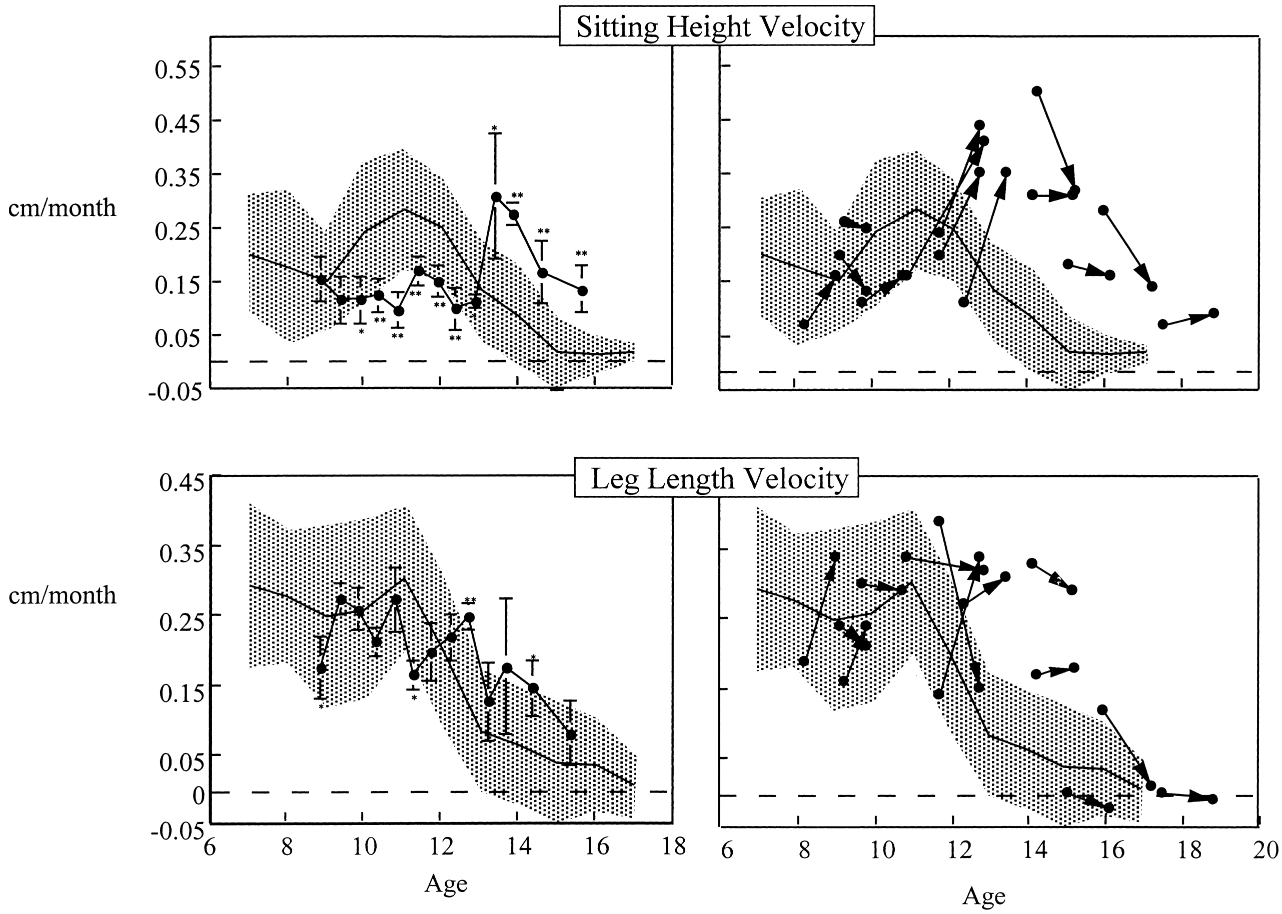

FIG. 1. Sitting height and leg length velocities. The left panel shows the growth velocity of sitting height and leg length measured every 6 months for 2 years in 21 active gymnasts (mean ± SEM, closed circles) and 110 controls (mean ± 1 SD, shaded areas). The right panel shows "catch-up" growth in sitting height in 13 recently retired gymnasts. Growth velocity in sitting height and leg length was calculated during the 12 months before and the 12 months after retirement (arrowheads). *p < 0.05; **p < 0.001 gymnasts relative to controls. [Adapted with permission from Bass et al.[44]]

not, in general, satisfy the epidemiological criteria for causation. It is plausible that gymnastics training blocks the expression of statural growth by competitively removing the necessary nutritional support for growth, as demonstrated in animal studies.[85–88] However, if training is a factor, it must be partitioned from the genetic predisposition of the gymnasts studied as well as dietary and other factors in the gymnastics environment that may negatively influence growth and maturation of females.[4]

Clinical Implications

Despite the "normal" short stature of gymnasts, we feel that any patient who falls behind in growth, across two major percentiles of the growth chart, should undergo a complete evaluation for underlying pathology, even when height is not below the fifth percentile.[13] This could be normal short stature, but the clinical criterion would warrant assessment. Because growth is an active process, growth velocity charts should also be used in determining the normality of growth.[89] Growth monitoring should start early in the "careers" of budding gymnasts so as to establish individual "norms" for comparison purposes.

In contrast to the upper extremity, our search uncovered little data on growth plate injuries involving the lower extremity (LE) of female gymnasts.[90–92] However, given the relatively high incidence of LE injury in female gymnasts,[92] the potential for premature femoral and tibial epiphyseal fusion secondary to injury is a concern. It seems unlikely that physeal injury would result in a reduction in adult stature, although leg length discrepancy resulting from unilateral physeal injury might be an outcome. Any indication of pain around a joint may be the symptom of significant growth plate changes, which require accurate diagnosis, adequate treatment, and specific recommendations about return to activity.

Directions for Further Study

Epidemiological investigation is required to establish or refute a cause–effect relation between gymnastics training and inadequate growth in females. Descriptive studies are needed to provide information on the frequency of inadequate growth among female gymnasts. The incidence and any long-term sequelae of LE physeal injuries should also be investigated. Analytical research is needed to elucidate the temporal sequence of possible

TABLE 5. *Evidence that an association is cause–effect*

Criterion	Comments	Evidence
Temporality	Cause precedes effect	Several studies[5,8,14–16,46] provide limited but longitudinal evidence of reduced growth and delayed maturation of female gymnasts during training followed by catch-up growth during reduced training or retirement from gymnastics
Strength	Large relative risk	No studies report a relative risk or odds ratio showing an association between cause and effect.
Dose–response	Larger exposures to cause associated with higher rates of the disease	The volume and intensity of training have not been related statistically to prevalence or incidence of growth failure; however, in one study energy intake was the only independent predictor of growth velocity.[46]
Reversibility	Reduction in exposure associated with lower rates of the disease	Catch-up growth following reduction in gymnastics training or retirement from the sport are well-documented[5,14,16,41,46]; however, confounding may explain a reversible association.
Consistency	Repeatedly observed by different persons, in different places, circumstances, and times	While evidence for reduced growth is provided, it is not known whether the cause is training per se or some other factor associated with the gymnastics environment (e.g., diet, psychological stress).
Biologic plausibility	Makes sense, according to biologic knowledge at the time	In animals, exercise has been shown to block statural growth by competitively removing the necessary nutritional support for growth.[84–87]
Specificity	One cause leads to one effect	The absence of specificity (i.e., one cause/one effect) is not necessarily a major strike against the hypothesized relation; however, it is evident that if training is a factor, its effects must be partitioned from constitutional and other components of the gymnastics environment before causality can be established.[4]
Analogy	Cause–effect relationship established for a similar exposure	Pugliese et al.[88] described growth failure and impaired maturation in a group of children ages 9–17 years who regularly restricted calories due to fear of obesity. After nutritional and psychiatric counseling, the patients resumed adequate caloric intake with resultant increased linear growth and sexual development.

risk factors in relation to the development of inadequate growth. Particular attention should be given to sample size and power determination.[12] Attempts should also be made to continue to follow girls who "drop out" or otherwise retire from gymnastics, since the contrast with athletes continuing in the sport may provide useful insight.

Analytical data should probably be collected biannually and include training volume and intensity, nutritional state, energy expenditure (doubly labeled water technique), body segment proportions, pubertal stage and bone age, midparent and target height, and predicted adult height. Social and psychological factors may also be important for explaining inadequate growth in some instances. In the gymnastics environment, one or more of the following social or psychological factors may interact with marginal caloric status and vigorous exercise to alter growth and maturation: maintaining body weight when the natural course is to gain, year-long training and frequent competitions, parental involvement and expectations, and perhaps coaching styles and demands.[4,12,93,94] In addition to providing information on possible causes of inadequate growth, these data are also important to narrowing the differential diagnosis of growth failure.

CONCLUSIONS

Elite level or those gymnasts involved in heavy training regimens may be at risk for adverse effects on growth and maturation. This effect is often but not necessarily always reversed after retirement.

A cause–effect relation between gymnastics training and inhibited growth of females has not been demonstrated.

If training does negatively influence growth, it must be partitioned from the genetic predisposition of the gymnasts studied and other confounding factors in the gymnastics environment.

The growth of female gymnasts should be plotted regularly on a standard chart (NCHS/CDC/WHO) commencing before puberty. If height and/or weight falls below the 5th percentile, or if there is a displayed tendency for a patient to fall off her predicted curve, a complete diagnostic evaluation is indicated.

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