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Does Elite Competition Inhibit Growth and Delay Maturation in Some Gymnasts? Quite Possibly

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Today, elite young gymnasts undertake training programs of progressive volume and intensity from an early age. For example, talented young female gymnasts often commence training at age 5 or 6 and train more than 20 to 30 hours per week year-round throughout childhood and adolescence. Despite the “normal” short stature of top-level gymnasts and the obvious health benefits of physical activity during growth, there is concern that elite level or those gymnasts involved in heavy training regimens may be at risk for adverse effects on growth and maturation. This concern has been the source of much debate in the literature and is complicated by the difficulties in distinguishing between the genetic predisposition to short stature and late or delayed maturation, and the effect of environmental factors such as nutrition and exercise that may influence growth and maturation.

The effect of gymnastics training on growth and maturation is often reported as averaged data: an approach that does not identify individual growth patterns. Finding no difference between groups is not proof that there is “in fact” no difference. Accepting the null hypothesis without the appropriate critical review of both the methodological and statistical power to detect differences is a flawed endeavor. We believe there is compelling “circumstantial” evidence to build a case that preparation for advanced gymnastics competition may place some children and youth at risk of reduced growth and delayed maturation.

Evidence of Adverse Effects on Growth and Maturation

Proponents of the position that gymnastics training has no apparent effect on growth and maturation of young athletes typically build their case on evidence that claims elite or high-level gymnasts were relatively small before they began training and that gymnasts who persist with their sport tend to be smaller and lighter than those who drop out. We agree that gymnasts are short and often have delayed maturation; the strict selection criteria of this sport identify individuals with familial short
stature, constitutionally delayed growth, or idiopathic delayed puberty. However, the question to be addressed is not whether gymnasts have short stature or late maturation but rather, does gymnastics training itself alter the tempo and rate of growth and maturation? That is, are some gymnasts growing and maturing differently than they would had they not undertaken training and participated in competitive gymnastics?

We believe that prolonged participation in high level gymnastics may place some young athletes at risk of reduced growth and delayed maturation. We acknowledge, however, that it is extremely difficult to establish causality between gymnastics training and reduced growth or delayed maturation because of the complex interaction between genetic and environmental factors. Many authors fail to recognize the possibility that various factors in the gymnastics environment, either alone or in combination with training, may negatively influence growth and maturation of young gymnasts. We now present the results of case, cross-sectional, and longitudinal studies placed in the context of the level of evidence and hence confidence to support our argument. Our stance on this pro argument is further supported by the explanation of the possible mechanisms acting in these circumstances.

Is Growth and Maturation Affected?

Case Reports

Case data are generally viewed as the weakest of research designs because they have no defined population and no comparison group. In the gymnastics literature, however, there are three important longitudinal case reports that compare a gymnast to her genetically identical siblings (4,16,41). Although it is difficult to infer causation from case studies, these particular studies may be viewed as a primitive form of case-control design and provide a rare model for isolating environmental from genetic effects which may shed light on etiology. These results show decreased growth during periods of training, and catch-up growth occurring following injury or retirement from the sport. Furthermore, sexual maturation was delayed in the gymnasts compared to their less active siblings: menarche occurred more than 1 year after the siblings for a triplet gymnast (41), 2.6 years later for an Israeli twin (17), and 4.5 years later for an Australian twin (4). The normal average difference for menarche in monozygotic twins (MZ) is 4 months (31).

Cross-Sectional Studies

Most of the data on growth and maturity characteristics of gymnasts are cross-sectional and confirm what one suspects; that indices of maturity including skeletal age, age at menarche, and secondary sexual characteristics occur significantly later in female gymnasts than control subjects. Female gymnasts have less fat mass than controls and are also significantly shorter and lighter for their age, with differences most pronounced among older, advanced level gymnasts (13). There are also cross-sectional data showing that male gymnasts are shorter than controls, with late or delayed maturation (30).

Comparison of the height of gymnasts relative to percentiles (or z-scores) of reference data provides a “snap-shot” of the prevalence of short stature. This could be “normal” short stature, but the clinical criterion would warrant assessment. We
reported that 14% of high-level pre-, peri-, and post-pubertal female gymnasts (training 20–27 hrs/wk) had short stature as indicated by height z-scores below −2 SD’s (18). In contrast, only 4.5% of non-elite competitive gymnasts training 7.5 to 22.5 hrs/wk had short stature (10).

The results from cross-sectional studies, however, must be placed in context of their limitations. First, averaging data may remove important information about the variability of growth and maturation characteristics among gymnasts. For example, not all elite female gymnasts are late-maturing. In fact, some actually have a normal or earlier-than-average pubertal development. 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 late maturation of females, or whether these are selection factors for their sport. Furthermore, the cross-sectional design does not allow for any interpretation other than gymnasts are short and generally have delayed maturation.

**Longitudinal Studies**

Longitudinal growth data offer more insight than cross-sectional data but still do not prove causation. The results of several short-term longitudinal studies demonstrate attenuated growth and delayed maturation in young female gymnasts involved in similar training regimens. For instance, high-level Swiss gymnasts (aged 12.3 ± 0.2 yrs) were reported to advance through puberty with little, if any acceleration in growth (40). However, since these gymnasts were followed for only two years, it is difficult to determine how many actually passed through puberty. Interestingly, the delay in skeletal maturation in these gymnasts did not worsen with continued training. Reduced skeletal growth during puberty was also reported in elite Swedish female gymnasts (aged 11–14 years) followed for five years (29). In elite Australian female gymnasts (aged 11.0 ± 0.4 yrs) followed for two years, the deficit in stature became greater with longer duration of training due to a shift to the right and blunting of the growth velocity curve (3). Skeletal maturation was delayed by 1.8 years in gymnasts and became more delayed (0.5 ± 0.1 yrs) after two years of training.

In male gymnasts, there is little evidence to support the notion that gymnastics training impedes growth or delays maturation. Two longitudinal studies in elite young male gymnasts report that gymnasts were shorter than controls at baseline, but height z-scores did not worsen during follow-up (20,25).

In these aforementioned studies, the reporting of average growth data along with mathematical modeling that produces average growth curves provide a “broad brush” approach to showing how a group is growing. However, this approach lacks the fine detail required to identify individuals at greatest risk. Thus, longitudinal data are most valuable when used to track individual gymnasts who are clinically delayed and/or who demonstrate growth faltering (where over time height is reduced by > −0.5 SD). We report that 19% of highly competitive pre- and peri-pubertal experienced growth faltering (18) (Figure 1). In our study of less competitive pre-, peri-, and post-pubertal gymnasts training 7.5 to 22.5 hours per week, we found that 35% of pre-pubertal gymnasts (7/20) showed evidence of growth faltering during 12 to 24 months follow-up; there was no evidence of growth faltering in peri- or post-pubertal gymnasts (10). These data indicate that some, but not all, gymnasts experience reduced growth. However, these data fall short of showing causation between training and growth faltering because the effect of environmen-
tal factors has not been isolated from the individual’s genetically determined tem-
poral pattern of growth and maturation.

The most convincing evidence for an adverse effect of gymnastic training on growth and maturation are the data on gymnasts who have retired or have time off due to injury. If participation in the sport has no effect on growth and maturation then it would follow that cessation of the sport would also have no effect on the tempo or rate of growth. However, this does not appear to be the case. Gymnastics coaches have long recognized that some gymnasts appear to experience catch-up growth following vacation periods or time off due to injury. Catch-up growth observed during reduced training schedules or following retirement is re-
ported in two cohort studies (3,29) and the case studies discussed earlier (16,41).

Figure 1 — Longitudinal changes in height z-scores in 41 highly competitive pre-, peri-, and post-pubertal female gymnasts relative to baseline height z-scores. Height z-scores decreased by greater than or equal to –0.5 SD’s in six gymnasts during follow-up (unpublished data).
Catch-up growth has also been documented in other athletes once training was reduced (27,42).

There is also evidence that reduced growth and subsequent catch-up growth is isolated to the sex steroid dependent acceleration of trunk growth, potentially resulting in site-specific deficits in height depending on the time of exposure (3,19) (Figure 2). For instance, several longitudinal studies have reported that the progressive deficits in stature in elite pre- and peri-pubertal female gymnasts were due predominantly to a greater increase in the deficit in trunk length (not leg length) (3,18). These results could be easily interpreted as normal late maturation—particularly when apparent in gymnasts who continued to train. However, the occurrence of catch-up growth (both accelerated growth above normal levels and/or

![Figure 2](image-url)  
*Figure 2 — The growth velocity in sitting height and leg length in 13 female gymnasts calculated 12 months before and 12 months after retirement (arrowheads). The shaded area represents the growth velocity of young healthy non-athletic girls (mean ± 1 SD). Adapted from Bass et al. (3).*
protracted growth) coincided with retirement or injury and not during training. This provides compelling evidence that it is the removal of environmental factors rather than the normal growth process that is operating in these circumstances.

Even if catch-up growth does occur, the evidence is inconclusive as to whether normal height is achieved (3,16,29,41). Long term cohort studies where final height is compared to predicted height provide evidence that final height may be compromised in some gymnasts (29,40,43). However, the comparison of final height to predicted height needs to be viewed in the context of the limited accuracy of predicted height estimates (7). Despite this, many gymnasts were 1 to 8 cm shorter than their mid-parental predicted height whereas the controls were taller than predicted (43). Final height estimates from the relative closure of the epiphysis are more accurate than mid-parental estimates; in Swiss gymnasts, final height was inferred to be reduced based on the predicted value derived from the degree of epiphyseal closure (40).

The Gymnastics Environment and Potential Risk Factors

Gymnastics “training” is just one of many factors in the gymnastics environment that either alone or in combination with other factors may negatively influence the growth and maturation of gymnasts. Other environmental factors that characterize the gymnastics environment that may also influence growth and maturation are nutrition and the psychological stress associated with year round training and competition at advanced levels. Growth plate injury may also influence bone length and stature. One or more of these factors may interact with the physical demands of training to adversely effect growth and maturation.

Physical Demands of Training

Training itself refers to systematic, specialized practice for gymnastics including learning and practicing the various elements and routines specific to gymnastics events and apparatus; warm-up and stretching, periodic dance and choreography, and occasional strength training. Training volume refers to number of days, hours, and elements practiced; training intensity refers to elements per minute, biomechanical loads, and difficulty ratings of skills practiced and performed (36). The dose of “gymnastics training” has rarely been defined and quantified or systematically related to the outcome of interest in most of the studies reviewed.

The evidence for gymnastics training being associated with reduced growth and delayed maturation has generally been limited to gymnasts involved in elite programs. In fact, it has been proposed that a training threshold (15 hours per week) exists where individuals may be at risk for attenuated growth. While further research is needed to explore such a threshold, the data available on sub-elite gymnasts training less than 15 hours per week indicates that growth does not appear to be affected (6,20).

There is no evidence to support the notion that long hours of training in isolation disturbs growth or maturation. Studies that do provide evidence of growth faltering involve cohorts of gymnasts who maintain low energy diets and who are involved in elite competitions that are likely to be associated with increased psychological stress due to increased training schedules and pressure to perform.
Nutrition

Adequate energy intake is essential for growing children and high levels of training naturally increase the need for energy and nutrients. It is estimated, for example, that gymnasts who train 4 hours per day undertake high levels of physical activity for about eight times longer than the average child (21). This may result in a need for an additional 400–700 kilocalories of energy intake daily (29,41). In the absence of sufficient nutrition to compensate for the increased level of activity, the energy demands of training may compete with those of the cellular processes underlying normal growth and maturation for available energy (8). This may be of particular concern during the adolescent growth spurt when about 15% of final height is typically gained and nutritional requirements increase.

In contrast to the increased caloric demands of gymnastics training, nutrition studies on female gymnasts consistently report mean energy intakes that are 275–1200 kilocalories lower than national recommendations (13). Although limited, there are also data to suggest that the energy intake of female gymnasts is insufficient to support normal growth and vigorous training (3,16,41,44). Female gymnasts also have correspondingly inadequate intakes of essential micronutrients such as zinc, iron, and calcium that may impact upon growth and skeletal development (2,13). Even after accounting for the differences in precision of the various forms of self-reported food intakes, it is clear that many elite female gymnasts eat too little.

There are also anecdotal accounts that indicate that some female gymnasts make conscious decisions to reduce food intake in order to maintain the slender, pre-pubertal physique which is associated with success in their sport (24,35). The evidence that inadequate dietary intakes are consistently reported in adolescent rather than pre-pubertal gymnasts supports these anecdotal accounts (13,16,24,35,43). There are frequent reports of energy restriction among advanced competitive level adolescent female gymnasts (13); a level that coincides with accelerated growth during the pubertal growth spurt; and a stage in growth and maturation that may be particularly sensitive to nutritional factors.

A potential consequence of chronic kilocalorie restriction in any child or adolescent is failure to grow and develop normally. The mechanism for how inadequate energy and nutrient intake negatively influences growth can be explained by the relationship between these factors and circulating concentrations of growth-related hormones. For instance, a negative energy balance is known to reduce the level of insulin-like growth factor (IGF-1) (37). Low levels of IGF-1 have been reported in young female gymnasts when compared with controls and swimmers (5,24,39), and were associated with negative energy balances and reduced growth rates in pre- and peri-pubertal female gymnasts (3). In contrast, no differences were detected in IGF-1 levels between pre- and early-pubertal male gymnasts and controls followed for 18 months (20). Because energy or protein restriction can lead to reduced IGF-1 levels, it is likely that the reported differences between male and female gymnasts are due to the poor dietary practices of the female gymnasts.

Psychological and Emotional Stress

Although it is difficult to identify or quantify stress-related influences upon growth, the existence of psychosocial correlates for short stature have been known for some time. Some recent evidence suggests that a history of anxiety in American
girls is associated with shorter self-reported young adult stature (34). Interestingly, there was no association in boys. Two other recent studies point to a relation between family conflict (domestic tension, divorce, separation or desertion) and short stature at age 7 in British girls and boys (33); and between familial distress and short final stature of Polish girls (22).

A component of the gymnastics environment that is most difficult to quantify is the psychosocial milieu that may include coaching style, parental pressure, intensive practices and demanding competitions, social isolation and lack of opportunities for social development, public display of skills and evaluation by others, and in some cases living and training away from home and family. Although gymnasts appear to have a remarkable ability to cope, this environment may be overwhelming for some gymnasts. There is some evidence that psychosocial stress may contribute to injury in female gymnasts (26); however, very little is known about the psychosocial effects of gymnastics participation on growth. Theintz et al. (38) reported that 3 of 27 highly trained Swiss gymnasts and 4 of 16 moderately trained swimmers were considered at risk for “a manifest mental disorder over time.” The majority of these young athletes presented with no psychological problems; however, 10 gymnasts presented with a global delay in psychological maturation, whereas no such case was observed among swimmers.

A discussion of psychosocial factors related to growth would be incomplete without considering eating disorders. As described earlier, some female gymnasts restrict food to maintain a slender, prepubertal physique. However, some elite level female gymnasts have developed frank eating disorders (35). An obvious concern associated with eating disorders in young gymnasts is risk of permanent growth deficits. A recent study involving early onset female anorexia nervosa (AN) patients indicates that patients developing AN before menarche have growth retardation at presentation, demonstrate catch-up growth with nutritional intervention, but do not reach their genetic height potential (28). Similar findings have been reported for adolescent male and female AN patients (1,32). To date, however, no comprehensive study has been undertaken on the prevalence and determinants of eating disorders in gymnasts.

**Injury and Growth**

The possibility of injury to the growth plate cartilage of young gymnasts has elicited concern from the medical community and others associated with gymnastics. The fear is that the tolerance limits of the growth plate may be exceeded by the mechanical stresses of landing forcefully from heights and/or by the repetitive physical loading associated with year-round training.

Reports on traumatic (acute) physeal injuries to gymnasts are limited to about a dozen reports and arise primarily from case series studies (11,15). These studies report on acute physeal injuries affecting a variety of skeletal sites in both the upper and lower extremities. Although this body of research provides little or no information on the incidence of these injuries, it does attest to the potential for acute injury-related growth disturbance in this population. The potential for acute lower limb growth plate injury is of particular concern given the high frequency of knee and ankle injuries among gymnasts (15). It is unlikely, however, that traumatic lower-extremity physeal injury would result in shortened adult stature, although leg length discrepancy resulting from unilateral injury might be an outcome.
Although incidence data are lacking, there are numerous clinical and cross-sectional reports which describe stress-related (chronic overuse) physeal injuries among gymnasts (11,15). Most of these reports relate to the distal radius physis, although stress injuries involving the olecranon, proximal humerus, distal ulna, and proximal tibia physes have also been reported. Notably, evidence of premature, partial, and complete epiphyseal closure of the distal radius in skeletally immature female gymnasts is presented in several recent case and cross-sectional studies (11,14). The evidence in these studies was provided by repeated roentgenographic evaluations that revealed bilateral discrepancies in radiographic status of the distal-radial growth plates in the involved and uninvolved extremities, and closure of the distal-radial growth plate preceding that of the ulna. An illustration of partial closure of the right distal radial physis in a 15-year-old female gymnast is shown in Figure 3 (23).

The body of the vertebra is subject to the same deforming factors that influence growth of the long bone. Repeated flexion of the trunk when landing from various heights may create biomechanical compression forces sufficient to damage the anterior aspect of the vertebral endplate in the thoracolumbar region (Th11/L3) and disrupt growth at this site (9). Disc degeneration may also result from excessive loading of the immature spine. Radiographic and MRI studies show a higher prevalence of radiographic irregularities (i.e., reduced disc height, disc degeneration, Schmorl's nodes, flattening or wedging of the vertebral bodies, and kyphosis) of the thoracolumbar spine in highly competitive gymnasts versus non-athletes and other athletes (12,15). It is likely that spinal height would be reduced if many of

![Figure 3 — An illustration of partial closure of the right distal radial physis in a female gymnast who presented with a symptomatic right wrist. Note that the distal physes in the right ulna and left radius and ulna are open (23).](image)
the discs/endplates are damaged. However, the incidence of these conditions among gymnasts and any long-term effects on vertebral or linear growth have not been determined.

**Synopsis**

We believe there is convincing evidence that implicates the combination of intense training and poor nutrition in reduced growth and delay of maturation in some elite- or advanced-level peri-adolescent female gymnasts. It is less clear if the psychological stress associated with training and competition is a significant factor in this pathology. There is evidence that acute or chronic physeal injury involving the extremities may involve growth sequelae in some cases; however, it is unlikely that these injury types will affect the temporal pattern of growth and maturation. On the other hand, spinal height may be somewhat compromised if many of the discs and/or endplates are damaged.

The data on male gymnasts are sparse and, with the exception of the limited literature on growth plate injury, do not indicate any adverse effects of gymnastics participation on growth and maturation. The differences between male and female gymnasts in these regards are likely due to differences in energy and nutrient intakes and training requirements. Also, male gymnasts often become involved in high volume, high intensity training at a later age than female gymnasts.

**Challenges for Further Research**

Clearly, individuals of the same age, undertaking the same or similar training schedules in the same environment are not responding in the same way. Thus, auxological epidemiology studies are needed to determine the frequency of short stature among gymnasts and the temporal sequence of possible risk factors in relation to the development of this condition. In particular, the role of nutrition needs to be elucidated. Long-term follow-up beyond training and into retirement is required to build a detailed picture of the sequence of events and the influence of training volume and intensity and dietary intakes.

There are few data to build a case on the effect of psychological stress on training and competing at a young age. These data need to be mapped and related to the gymnasts’ growth, development and performance. The incidence and any long-term sequelae of vertebral injuries/conditions, and physeal injuries involving the extremities, should also be determined.

**Conclusions**

A cause-and-effect relation between gymnastics training and reduced growth and delayed maturation has not been demonstrated, and likely never will be demonstrated because of the difficulties in designing such a study. However, it does not follow that inability to determine cause does not translate to demonstrating no effect. In fact, we have built a case that the opposite is true and that some (not all) gymnasts are at risk and experience reduced growth and delayed maturation. The sooner professionals in the field accept that participation in competitive gymnastics puts some children at risk of reduced growth and delayed maturation,
the sooner appropriate screening and monitoring of gymnasts in elite programs can be undertaken. Further, it will be an important paradigm shift from those in the field focusing on “is there an effect” to “what are the mechanisms and who is at risk.”

In a court of law, the prosecution would make this case a convincing one on “circumstantial evidence”—some female gymnasts are at risk of reduced growth and delayed maturation that may have long-term implications—and this should be enough to act upon. Coaches should be alerted to these findings to ensure informed decision-making related to the preparation of gymnasts for advanced levels of competition, and to help ensure the optimal growth, performance, and safety of these child athletes. Coaches should also recognize that no two gymnasts will respond identically to the same training loads and therefore training should be individualized as far as possible.

References


