Physical and pubertal development in young male gymnasts

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Gurd, Brendon, and Panagiota Klentrou. Physical and pubertal development in young male gymnasts. J Appl Physiol 95: 1011–1015, 2003. First published June 13, 2002; 10.1152/japplphysiol.00483.2003.—The purpose of this study was to evaluate the effect of intense training on physical growth and sexual maturation in young male gymnasts. Physical development, pubertal development, testosterone levels, energy expenditure, and relative body fat were examined in 21 circumpubertal male gymnasts (13.3 ± 0.3 yr) and 24 age-matched controls (13.5 ± 0.3 yr). Subjects completed a self-assessment of genital and pubic hair development with the use of the Tanner scale. All subjects were measured for height, weight, and salivary testosterone levels (T). The Physical Activity Questionnaire for Adolescents was used to estimate weekly energy expenditure in metabolic equivalents. Percent body fat (%BF) was assessed by using bioelectrical impedance analysis. Developmental stages and T, as well as height and weight, were not different between groups. Energy expenditure was significantly higher (P ≤ 0.05) and %BF was lower (P ≤ 0.05) in athletes than in controls, but lean body mass was not significantly different between groups. Energy expenditure was negatively correlated (P ≤ 0.05) with %BF but not related to T. Developmental stages were strongly (P ≤ 0.05) related to T but not to energy expenditure or %BF. It is concluded that, although there is a higher energy expenditure accompanying intense training in young male athletes, their body composition is not necessarily affected, and there is no determined effect on their physical and pubertal development.

intense training; testosterone; Tanner stages; energy expenditure; body composition

Puberty in humans is characterized by large hormonal changes resulting in both physical maturation (i.e., skeletal development and growth) and sexual maturation (growth of pubic hair and development in the genitalia). Intense training has been found to delay the onset of puberty in female individuals by altering normal hormonal development (27). This has led to delayed pubertal onset, delayed age at first menarche, and failure to develop mature skeletal structure (18). In male individuals, despite evidence that physical activity can also result in hormonal changes, there have been few studies that actually examined the relationship between training and the onset of puberty.

Puberty is triggered in male individuals by an increase in secretion of gonadotropin-releasing hormone from the hypothalamus. Gonadotropin-releasing hormone acts on the pituitary, stimulating the release of luteinizing hormone and follicle-stimulating hormone, which cause increased release of testosterone from the gonads. Testosterone continues to increase throughout puberty until it reaches adult levels and plays a key role in both physical and sexual maturation (22). Studies on traditional elite team sports have provided evidence that physical activity causes early onset of puberty in male individuals. Hale (12) found that a majority of participants in the Little League World Series were sexually mature for their age. Similarly, Cacciari et al. (4) found that competitive football players demonstrated early onset of pubertal growth and increased levels of serum testosterone and growth hormone compared with age-matched controls. Although these results do indicate early onset of puberty, the sports that were studied are sports that favor athletes who are more physically mature than other athletes of the same age.

Unlike athletes in team sports, young male individuals who participate in individual sports often train from an early age, providing a better model to examine the effects of physical activity on puberty. Studies by Elias and Wilson (9) and Hackney (11) on adults both found that endurance training resulted in decreased resting levels of circulating serum testosterone. Recent data showed that, although a 22% increase in training intensity caused a 9% increase in testosterone, after 2 wk of tapering, testosterone was significantly reduced to pretraining levels in 20-yr-old rowers (17). Carli et al. (5) found results that were in agreement with this: after 43 wk of swim training, pubertal athletes had testosterone levels that dropped below pretraining levels. Rich et al. (23) also found evidence that lowered testosterone with training after only 3 days of training in young gymnasts. Although they did not examine hormonal factors, Keller and Frohner (13) found that male gymnasts undertaking intensive training had reduced height and skeletal maturity relative to chronological age. These results suggest that decreased testosterone levels may result in delayed onset of puberty in male individuals, but, to date, there have been no studies that directly examine this relationship. In fact, it is possible that the decreased testosterone is a function of an increase in receptor binding, which would be a positive effect. Furthermore, the lack of a difference

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in growth rates, IGF-I, and diet between young male gymnasts and controls over a 10- to 18-mo period indicates that the short stature found in gymnasts may be due to selection bias rather than gymnastics training per se (6, 7)

The purpose of this research was to evaluate the effect of intense training during somatic growth and skeletal development on the onset of puberty in young male gymnasts. On the basis of the above evidence, it was hypothesized that after several years of training the increased energy expenditure by elite gymnasts would have resulted in lower levels of testosterone than in other boys of their age, leading to a delay in physical growth characteristics and markers of sexual maturation.

METHODS

Subjects. Twenty-one elite gymnasts (age 13.3 ± 0.3 yr) were recruited from competitive gymnastics clubs around Southern Ontario. To qualify for the experimental group, gymnasts had to be competing at a minimum of a provincial level and training at least 15 h/wk. Twenty-four age-matched boys (13.5 ± 0.3 yr) were recruited from recreational martial arts classes to participate as the control group. These boys were training not more than 2 h/wk. All subjects and their parents were informed of any risks that might result from participation, and informed consent was obtained before the study started. The experimental protocol was approved by the Brock University Research Ethics Board.

Protocol. Each participant was tested on one occasion at his gymnastic club or at the martial arts school. The testing was completed in the late afternoon before the subject’s regular activity session. During testing, subjects had their physical characteristics measured, completed a physical activity questionnaire, provided saliva samples, and completed a self-assessment of pubertal stages with the use of the Tanner scale. Before all tests, subjects were reminded that a self-assessment of pubertal stages with the use of the Tanner scale. Before all tests, subjects were reminded that a self-assessment of pubertal stages with the use of the Tanner scale.

Assessments. Height and weight were measured at the beginning of each testing session. Bioelectrical impedance analysis was used to estimate relative body fat (percent body fat (%BF)) with the interactance equipment (Quantum II, RJL Systems) by using the input variables of body frame size, height, mass, and sex (15).

Training sessions and training hours per week were recorded, and weekly energy expenditure [metabolic equivalents (MET/wk)] was calculated by using the Physical Activity Questionnaire for Adolescents (PAQ-A) (14). This instrument assesses the levels of moderate and vigorous activities in which older children engage. Energy expenditure was calculated as the rate of expenditure (in MET) listed for that activity (1) multiplied by the frequency of participation in a normal week and the average duration of participation in each episode of activity.

Pubertal maturation was self-reported by using the pictures of the Sexual Maturation Scale by Tanner (26). To reduce embarrassment, each subject went into a room by himself to complete the self-assessment. Once completed, the self-assessment was put into a plain folder by the subject and handed directly to the researcher present to maintain anonymity.

Salivary testosterone. One milliliter of unstimulated whole mixed saliva was collected from each subject by using cylinder-shape swabs placed in the mouth for 1 min. After sampling, the swabs were placed directly into plastic tubes. The samples were then centrifuged before freezing. The centrifuged saliva was maintained at −20 ºC until being assayed. No preservative was used in the collection tubes, and all saliva samples were collected in the early evening (around 6:00 PM). The subjects were asked not to consume any food or drink for at least 1 h before saliva collection. The saliva samples were analyzed in duplicate by a trained RIA technician experienced in saliva determinations. Testosterone was quantified by using a Coat-A-Count testosterone kit (Diagnostic Products, Los Angeles, CA) modified for saliva. Briefly, the saliva was submitted to a double ether extraction then preceded to RIA. To accommodate saliva, the calibrators were diluted 1:20 (vol/vol), and to further increase detectability at the low end of the curve a 5-ng standard was added, giving a range of 5–800 pg. For each assay tube, 200 µl of sample were pipetted into a polypropylene tube coated with antibody. One milliliter of 125I-labeled testosterone was added, and an extended incubation time of 22 h was used, at room temperature. After incubation, the tubes were decanted then counted for 60 s in an LKB 1272 gamma counter (Wallac, Turku, Finland). The antibody used in the assay is highly specific for testosterone with ≤5% cross-reactivity with dihydrotestosterone. The samples were analyzed in two separate runs. The sensitivities of the two assays were calculated to be 5 pg, and the intra-assay coefficients of variation were 14 and 6%, respectively, averaged across low, medium, and high pools. The mean of the two duplicates was considered the most reliable estimate of the testosterone concentration for each saliva specimen and was used for our statistical analysis throughout.

Data analysis. One-way ANOVA was used to determine differences between the gymnasts and controls for all of the variables tested. Pearson correlation analysis was used to examine possible relationship among variables. All data analyses were conducted by using SPSS 10 for Windows. A value of P ≤ 0.05 was accepted to indicate a significant result.

RESULTS

Table 1 presents a summary of the physical activity and training characteristics for gymnasts and controls. The gymnasts trained an average of 4.7 ± 0.4 sessions/wk for a duration of 18.7 ± 1.4 h/wk, which was significantly (P ≤ 0.05) higher than what was reported by the controls (Table 1). This difference in training contributed to 44% greater (P ≤ 0.05) energy expenditure per week by the gymnasts compared with the controls.

The gymnasts were slightly shorter and lighter than the controls, but these differences did not reach significance (Table 2). The gymnasts did, however, have significantly (P ≤ 0.05) lower relative body fat (Table 2). In terms of sexual maturation, there were no significant differences detected in testosterone levels between the gymnasts and controls.

Table 1. Energy expenditure and training volume for both the gymnasts and the controls

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gymnasts (n = 21)</th>
<th>Controls (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy expenditure, MET/wk</td>
<td>196.1 ± 4.8*</td>
<td>109.5 ± 3.6*</td>
</tr>
<tr>
<td>Training frequency, sessions/wk</td>
<td>4.7 ± 0.4*</td>
<td>1.2 ± 0.1*</td>
</tr>
<tr>
<td>Training duration, h/wk</td>
<td>18.7 ± 1.4*</td>
<td>5.8 ± 0.3*</td>
</tr>
</tbody>
</table>

Values are means ± SE; n, no. of subjects. MET, metabolic equivalents. *P ≤ 0.05.
DISCUSSION

The major finding of this study was that training in young male gymnasts did not significantly change resting salivary testosterone or alter the onset of puberty as determined by self-assessment of pubertal stages. Additionally, whereas the gymnasts had lower body fat and greater energy expenditure per week, there were no significant differences in height, weight, or lean body mass. Although significantly different between gymnasts and controls, relative body fat, energy expenditure, and training variables were not significantly correlated with physical growth or sexual maturation variables (Table 3).

Effects of training on physical maturation. Traditionally, gymnasts have been found to be shorter than nongymnasts either due to selection because of an advantage of shorter athletes in the sport or as a result of delayed puberty due to altered hormonal factors (19). In the present study, the height and weight of the gymnasts were similar to the age-matched controls. Previous studies found male gymnasts to be shorter than controls but concluded that gymnasts were shorter as a result of selection and not developmental delays (7, 13). Buckler and Brodie (3) found that gymnasts were shorter than average but were advanced in pubertal development for their age. Moreover, short stature in male gymnasts has been associated with a reduced leg length but not sitting height (7). According to the present findings, the physical characteristics were not significantly correlated with training volume, indicating that any differences observed in the physical characteristics of male gymnasts is a result of selection and not of training on physical development. This complements previous studies reporting no difference in growth rates and IGF-I over a period of 18 mo between normoactive children and young male gymnasts and concluding that the gymnasts were shorter due to selection bias (7). It is, however, unclear why in the present case selection did not lead to a group of shorter gymnasts.

In the present study, relative body fat (%BF) was measured by bioelectrical impedance analysis. Short- and long-term reproducibility of this method was reported as r = 0.999 for measurements taken in the same subject within 1 wk and as r = 0.977 for repeat measurements up to 1 mo (15). Recently, the validity and reliability of this method has been demonstrated successfully in children and adolescents (21, 25). Weekly energy expenditure (MET/wk) was calculated by using the PAQ-A. This questionnaire has demonstrated acceptable validity and reliability in 13- and 15-yr-old children (r = 0.15–0.64) (2, 14). This instrument is recommended to evaluate physical activity in adolescents because it identifies and quantifies most aspects of physical activity participation: type of activ-

Table 2. Physical characteristics and sexual maturation variables for both the gymnasts and controls

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gymnasts (n = 21)</th>
<th>Controls (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, cm</td>
<td>155.5 ± 2.3</td>
<td>162.5 ± 1.9</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>48.3 ± 2.7</td>
<td>54.4 ± 1.4</td>
</tr>
<tr>
<td>%Body fat</td>
<td>8.6 ± 0.1*</td>
<td>13.7 ± 0.7*</td>
</tr>
<tr>
<td>Lean body mass, kg</td>
<td>44.01 ± 1.5</td>
<td>46.9 ± 0.4</td>
</tr>
<tr>
<td>Testosterone, pg/ml</td>
<td>4.3 ± 5.8</td>
<td>38.2 ± 4.1</td>
</tr>
<tr>
<td>Genital development, Tanner stage</td>
<td>3.2 ± 0.2</td>
<td>3.5 ± 0.1</td>
</tr>
<tr>
<td>Pubic hair development, Tanner stage</td>
<td>3.5 ± 0.1</td>
<td>3.6 ± 0.1</td>
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</tbody>
</table>

Values are means ± SE; n, no. of subjects. *P ≤ 0.05.

Table 3. Correlation coefficients among variables

<table>
<thead>
<tr>
<th>LBM, kg</th>
<th>Ht, cm</th>
<th>%BF</th>
<th>EE, MET/wk</th>
<th>TF, sessions/wk</th>
<th>TD, h/wk</th>
<th>Genital Development, Tanner stage</th>
<th>Pubic Hair Development, Tanner stage</th>
<th>T, pg/ml</th>
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<tbody>
<tr>
<td>LBM, kg</td>
<td>0.71*</td>
<td>0.58*</td>
<td>−0.33</td>
<td>−0.55*</td>
<td>−0.66*</td>
<td>0.65*</td>
<td>0.55*</td>
<td>0.55*</td>
</tr>
<tr>
<td>Ht, cm</td>
<td>0.17</td>
<td>−0.18</td>
<td>−0.22</td>
<td>−0.41</td>
<td>0.72*</td>
<td>0.66*</td>
<td>0.67*</td>
<td>−0.23</td>
</tr>
<tr>
<td>%BF</td>
<td>−0.56*</td>
<td>−0.78*</td>
<td>0.78*</td>
<td>0.25*</td>
<td>0.19*</td>
<td>0.29</td>
<td>0.23</td>
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<tr>
<td>EE, MET/wk</td>
<td>0.71*</td>
<td>0.62*</td>
<td>0.16</td>
<td>0.27</td>
<td>0.38</td>
<td>0.18</td>
<td>0.20</td>
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<tr>
<td>TF, sessions/wk</td>
<td>0.27</td>
<td>0.93*</td>
<td>0.038</td>
<td>0.38</td>
<td>0.18</td>
<td>0.51*</td>
<td>0.63*</td>
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<tr>
<td>TD, h/wk</td>
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<tr>
<td>Testosterone, pg/ml</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.59*</td>
</tr>
</tbody>
</table>

LBM, lean body mass; Ht, height; %BF, percent body fat; EE, energy expenditure; TF, training frequency; TD, training duration; T, testosterone. *P ≤ 0.05.
ity, frequency, duration of participation, context of participation, and seasonal variation (2).

Although the present results differed from those of Buckler and Brodie (3) in terms of height and weight, both studies show significantly lower relative body fat in trained gymnasts. The correlation between energy expenditure (MET/wk) and body fat percent suggests that more physical activity could result in higher energy requirements and therefore less energy stored, but without nutritional intake data no specific conclusions can be made. Although in the past diet was not correlated with serum concentrations of testosterone, IGF-I, and cortisol in peripubertal male gymnasts, a reduction found in their ratio of IGF-I to cortisol after periods of strenuous training is suggestive of a catabolic state, which may be partially attributed to an imbalance between energy intake and expenditure (6). Furthermore, the lower body fat percent without a difference in weight suggests an increase in lean body mass in response to training in our subjects. This supports the results of Elias and Wilson (9), who found that exercise during puberty results in increases in lean body mass and decreases in body fat. However, these differences in energy expenditure and body composition were not found to significantly influence the physical and pubertal development of these athletes.

Training and testosterone. Previous studies have demonstrated both an increase in testosterone levels as a response to short-term training (4, 11, 20, 29) and a decrease in testosterone levels as a result of both short-term (23) and long-term training (10, 18). The cases where testosterone levels decreased after training involved prolonged endurance-type exercise (i.e., swimming), except in the study of Rich et al. (23), who found a decrease in testosterone after 3 days of gymnastics training. In that study, there was, however, an observed return toward preexercise levels after only 1 day of rest, suggesting that the observed changes may have only been transient. Very recently, it has been reported that after 2 wk of tapering testosterone was significantly reduced to pretraining levels in 20-yr-old male rowers (17). The same study (17) also showed that a 22% increase in training intensity caused a 9% increase in testosterone but that further increases of training volume by 25% resulted in no further changes in testosterone. The present study found no significant difference in resting testosterone levels between the gymnasts and the controls despite the large amount of training these gymnasts were involved in. These results are supported by those of Fahey et al. (10), who found that, although resting testosterone levels increased with pubertal stage, there were no observed differences after maximal exercise. Moreover, Daily et al. (6) found no difference in resting serum testosterone, IGF-I, and cortisol between peripubertal gymnasts and controls at any time during a 10-mo period. The data thus far, in addition to the absence of significant correlation between resting salivary testosterone levels and training volume (Table 3), suggest that gymnastics may cause transient or acute alterations in testosterone levels in male individuals but that these changes may not persist chronically.

Training and pubertal development. Past studies that looked at team sports concluded that physical activity resulted in advanced onset of puberty in male individuals (4, 12). These sports, however, favor young athletes who have matured early and are therefore stronger and faster than their less mature peers and the differences seen in these studies are related to selection and not developmental alteration (18). The present results support the hypothesis that training does not result in advanced onset of puberty and that these young athletes excel in team sports because of their early maturation.

Pubertal maturation in this study was assessed on the basis of self-reported staging. Although there are always limitations when maturation in youth is assessed by using self-report methods, self-assessment of sexual maturation has shown excellent agreement (κ = 0.81–0.91) with pediatrician assessment (8). Past and recent studies agree that the use of adolescent self-staging appears of value in studying puberty in adolescents (8, 24, 28). There is, however, relatively little literature on the effect of training on pubertal development as measured by pubertal stages. Larzon and Klinger (16) showed that intense training resulted in delays in pubertal onset, but this research was done on individual case studies and may not be relevant to the population as a whole. Hackney (11) found that gymnasts were delayed by 2 yr in the development of specific pubertal markers and concluded that this was a result of gymnastics selecting boys who were smaller and more likely to mature later, regardless of activity levels. This supports the present results suggesting that gymnastics training had no effect on the pubertal development of young male gymnasts.

In conclusion, this study indicates that intense gymnastics training may not necessarily influence the onset of puberty in male individuals. Although training does result in lower relative body fat and increased energy expenditure, there were no differences in height, weight, lean body mass, resting salivary testosterone, or pubertal development between the gymnasts and age-matched controls. Furthermore, body fat, energy expenditure, and training variables were not significantly correlated with physical growth or sexual maturation variables in this group. These findings suggest that gymnastics training in young male individuals does not appear to have significant effects on their resting testosterone and sexual maturation if body composition is within normal range.

REFERENCES


