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ORIGINAL ARTICLE

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Hormonal responses to physical training in high-level peripubertal male gymnasts

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Abstract The effects of performing intensive training during growth remains controversial, with claims of negative effects upon growth and maturation purportedly due at least in part to a combination of hormonal disturbances and inappropriate nutrition. We examined the training-related responses of total testosterone (T), insulin-like growth factor-1 (IGF-1), cortisol (C) and diet in 16 peripubertal (pubertal stage ≤ 2) male gymnasts [mean (SD) age 10.5 (0.9) years, training 17.2 (5.6) h · week^{-1}] and 17 controls [mean (SD) age 9.6 (1.2) years] over a 10-month period. Fasted, resting morning blood samples (0730–0900 hours) were taken from all children on Monday, Wednesday and Friday during a single week towards the end of each of three phases of gymnastics training: routine development (RD), precompetition (PC) and strength conditioning (SC). Serum concentrations of T, C and IGF-1 did not differ between the groups at any time. The ratio between IGF-1 and cortisol was significantly reduced in gymnasts relative to controls during RD and SC training ($P < 0.05$), although no differences were detected for the T:C ratio. Diet did not correlate with any of the hormonal measurements, and no intergroup differences were found for the rate of growth in height. In summary, these results suggest that either the gymnastics training performed by these subjects was not intense enough to alter adrenal function, or that the gymnasts were well adapted to the training. In contrast, the reduction in the anabolic to catabolic balance represented by the IGF-1:C ratio is suggestive of a catabolic state, perhaps resulting from overstrain, insufficient recovery and/or inadequate caloric intake relative to energy output. While physical training during growth may induce a catabolic state, further research is needed to determine the biological significance of this finding, particularly with regard to growth and maturation.

Key words Children · Serum hormones · Physical training · Gymnastics

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Introduction

Early age entry into intensive physical training programs is a widespread phenomenon, with children as young as 5 or 6 years undergoing training programs of increasing intensity, often reaching 20–30 h · week^{-1} (Theintz et al. 1993). Although there have been several reports of late maturation and growth retardation in young athletes engaged in arduous physical training (Lindholm et al. 1994; Theintz et al. 1993; Ziemilska 1985), many children involved in such programs are selected on the basis of inherited physical or functional attributes, making it difficult to disentangle training-induced effects from those that accompany normal growth and development (Malina 1994).

Growth is regulated largely by the synergistic action of growth hormone (GH), insulin-like growth factor-1 (IGF-1), sex steroids, thyroid hormone and adequate nutrition. Despite some evidence in mature male athletes which suggests that the hypothalamo-pituitary-gonadal axis may be disturbed by intense training (Hackney et al. 1990; Wheeler et al. 1991), the limited data examining hormonal responses to exercise in male children and adolescents is conflicting. For instance, serum testosterone levels have been shown to either increase (Kraemer et al. 1992; Mero et al. 1990), remain unchanged (Fahey et al. 1979; Rowland et al. 1987) or decrease (Rich et al. 1992a) following acute and/or long-term physical training. Although exercise has been shown to stimulate GH release in adolescent boys (Zakas et al. 1994), several studies have found that circulating IGF-1 levels are lower in male and female adolescent athletes (wrestlers and gymnasts), presumably in response to training (Roemmich and Sinning 1977; Theintz 1994). Because nutritional status has also

been shown to have a profound effect on IGF-1 (Hintz et al. 1978; Smith et al. 1995), and exercise can produce a net caloric deficit, poor dietary practices combined with intensive training may have a significant impact on both anabolic and catabolic hormone secretion.

Alterations in the concentrations of specific anabolic and catabolic hormones are believed to reflect adaptive responses to the physiological and psychological stresses associated with training. In this vein, the measurements of both testosterone and cortisol have been used to indicate the anabolic:catabolic status of the body in response to exercise. A decrease in the concentration of testosterone and an increase in cortisol, or a reduction in the so-called testosterone:cortisol (T:C) ratio, is thought to indicate an increase in catabolic activity, and perhaps represent a state of overstrain or insufficient recovery (Urhausen et al. 1995). Since prepubertal growth is relatively sex hormone independent (Borer 1995), it is possible that other anabolic hormones operating throughout this period, such as GH and IGF-1, could be studied in conjunction with cortisol to gain some insight into the physiological stresses associated with training. Furthermore, since GH is released in a pulsatile fashion and its effects are largely modulated through the production of IGF-1, the ratio between IGF-1 and cortisol (IGF-1:C) may provide a more complete picture of the anabolic:catabolic status of the body in response to exercise during the growing years.

The purpose of the present study was to examine the interaction between exercise, diet, serum total testosterone, IGF-1 and cortisol in male gymnasts prior to puberty, to determine whether training has the potential to alter the normal progress of growth through modification of these factors. In addition, the IGF-1:C and T:C ratios were calculated as part of this process, to estimate the anabolic to catabolic status of the body in response to gymnastics training. Although it is common to assess training intensity on the basis of weekly hours and standard of competition, we also investigated the intensity of the actual training sessions to more accurately portray the demands placed upon young gymnasts.

Methods

Subjects

A group of 16 peripubertal male gymnasts [mean (SD) age 10.5 (0.9) years, height 133.9 (6.8) cm, body mass 30.8 (4.0) kg], training at least 10 $h \cdot week^{-1}$ [mean (SD) 17.2 (5.6)], were recruited from the Victorian Institute of Gymnastics and two feeder programs where high-level competitive gymnastics programs were offered. All gymnasts followed a similar training schedule in preparation for the same Domestic, State and National competitions. The length of participation in formal gymnastics training ranged from 2.3 to 6.2 years at the commencement of the study. A control group of 17 untrained normoactive children [mean (SD) age 9.6 (1.2) years, height 134.7 (7.2) cm, body mass 31.7 (4.9) kg] was recruited from local primary schools and was not limited to sedentary individuals, since it was felt that the sample should represent normal activity patterns in a similar biological age band.

All parents and children completed a health questionnaire, which included items relating to previous and current medical status, use of medications and past injuries. An activity questionnaire, modified from Grimston et al. (1993), was used to assess activity patterns during the previous and current year, with particular emphasis on whether the subjects were engaged in regular organized athletic activity and, if so, its frequency and duration. At each subsequent visit, all parents were questioned on an informal basis about the activities of their children during the preceding period. This process revealed that all control group boys engaged in school physical education classes, with none involved in any systematic physical training programs prior to, or during the study. The parents and coaches of the gymnasts completed a separate questionnaire and were interviewed regarding the age at which formal gymnastics training commenced and current weekly training hours. Years of training were calculated from chronological age minus starting age. Written informed consent was obtained from all parents prior to participation, following discussions which involved both the children and parents. All procedures were approved by the Royal Melbourne Institute of Technology Ethics Committee.

Physical characteristics and sexual maturity

The study was conducted over a 10-month period, with repeated measurements performed at 3- to 4-monthly intervals. Height was measured using a Harpenden anthropometer to the nearest 0.1 cm. Body mass was recorded to the nearest 0.1 kg using a portable digital scale and with each subject wearing light clothing without footwear. The maturity status of all of the children was assessed according to the development of pubic hair (self assessment of Tanner stage) and serum total testosterone levels. Each child, with the aid of one or both parents, used photographs and line drawings, together with appropriate descriptions of each stage of pubic hair development as described by Marshall and Tanner (1970), to select the appropriate level. This method has been shown to correlate significantly ($r = 0.65$–0.91) with physician-assessed pubertal status (Duke et al. 1980; Williams et al. 1988). Serum total testosterone levels were also used to assess sexual maturity. Research has shown that testosterone levels during growth tend to parallel changes in bone age, Tanner stage and testicular volume (August et al. 1972; Klein et al. 1996; Kletter et al. 1993). In the present study, subjects were considered to be peripubertal (pubertal stage ≤ 2) if serum total testosterone was ≤ 1.8 $nmol \cdot l^{-1}$ (Klein et al. 1996; Kletter et al. 1993).

Training intensity

In order to provide some indication of gymnastics training intensity, eight training sessions (range 3–4 h) encompassing three different phases of training were videotaped over a 10-month period. The three phases of the yearly training cycle included: routine development (RD), emphasising the development of routines and new movements for competition; pre-competition (PC), focusing on the refinement of routines for State and/or National competition; and strength/conditioning (SC), where emphasis was placed on general and apparatus-specific strength and conditioning work. On each occasion, only one member of the training group was followed for the entire session since all gymnasts followed a similar set of routines/activities. A stopwatch was used in conjunction with video recordings to determine the amount of time spent in each subdivision and/or task of training. Work to rest ratios were calculated from active time, which was considered to include time spent in the actual performance of a skill, calisthenic, warm-up or flexibility activity, and inactive time, which represented rest intervals and time used to move between activities.

Heart rates were monitored in parallel with the video recordings in four gymnasts during each training session for the PC and SC phases only (Sportstester 3000 Polar Electro Oy, Kempele, Finland). The heart rate transmitter was attached to the subject's trunk via adhesive tape to minimize movement, and was programmed to record heart rates every 15 s for the entire training session. Data were later downloaded by interface with a computer for analysis.

Blood sampling and hormone analysis

To explore the influence of training on anabolic and catabolic hormones, fasted resting blood samples (10 ml) were collected from an antecubital vein (0730–0900 hours) after an overnight fast on Monday, Wednesday and Friday of a single week towards the end of each of the three phases of gymnastics training (Fig. 1). To minimize discomfort, all children were provided with an anaesthetic cream (EMLA, Astra Pharmaceuticals) which was applied over the cubital region. Blood samples were immediately transferred into serum Vacuette tubes (Greiner Labortechnik) and allowed to clot at room temperature. Serum was separated by centrifugation and aliquots were stored at −80°C until assayed. All samples were assessed for serum total testosterone and cortisol by radioimmunoassay (Department of Clinical Biochemistry, Monash Medical Centre, Melbourne, Australia). Serum concentrations of IGF-1 (Monday samples only) were analysed using a double-antibody radioimmunoassay (Somatomedin-C Kit, Bioclone, NSW, Australia), following acid-ethanol extraction to release IGF-1 from its binding proteins. All samples were measured in duplicate. Intra-assay coefficients of variation for testosterone, cortisol and IGF-1 were 6.3%, 5.1% and 5.4%, respectively. Inter-assay coefficients of variation were 12.4% for testosterone, 14.6% for cortisol and 10.9% for IGF-1.

Dietary intake

To assess the adequacy of nutrient intake, 7-day weighed food diaries were completed by a subset of parents (13 gymnasts and 14 controls) during each phase of gymnastics training. All participants received a detailed verbal explanation, written instructions and practice in maintaining accurate dietary records. Subjects were instructed to eat normally during the period of diet recording and to be as accurate as possible in recording the amount and type of food or fluid consumed. Parents were requested to indicate how the food was prepared and to specify brand names when known. During school hours, teachers were requested to assist children in recording the food/fluid consumed. Data from the food records were analysed after consultation with a dietitian, using the DIET/3 software package (Xyris Software, Brisbane, Australia) which utilizes the Nuttab Australia database (Commonwealth Department of Health and Community Services, Canberra, 1992). Data for total energy (kJ/day), protein (g/day), carbohydrates (g/day) and fat (g/day) are reported herein.

Statistical analysis

All statistical analyses were performed using SPSS for Windows (Release 6.1, Norusis/SPSS, Chicago, Ill., USA). Data related to the physical and maturational characteristics of the subjects at the first data collection, in addition to diet, were analysed by Student's *t*-tests or analysis of covariance (ANCOVA), adjusted for chronological age. Changes in the anthropometric and hormonal agents were analysed using a 2 × 3 mixed design ANCOVA, in which chronological age and/or height were included as covariates. For all hormonal analyses, except IGF-1, a $\log_{10}$ transformation was performed on each data set for purposes of normalization. Significant group main effects and interactions were examined with a simple effects test. Individual pairwise comparisons using difference contrasts were used to assess significant time effects within each group. Pearson's product moment correlation coefficients were used to examine relationships of interest. Unless otherwise stated, the level of statistical significance for all statistical analyses was set at $P \leq 0.05$, and results are presented as the mean (SD).

Results

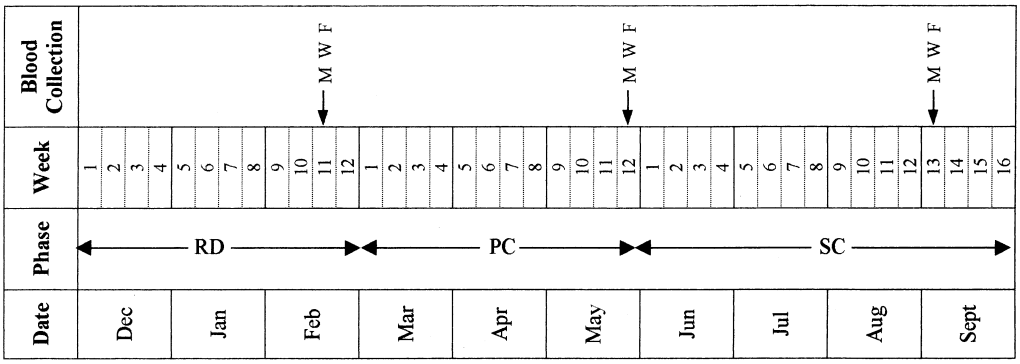
Physical characteristics and maturation

While gymnasts were found to be significantly older than controls ($P \leq 0.05$), no significant differences were found between the groups for sexual maturity (all subjects remained at pubertal stage ≤ 2 based upon serum total testosterone and Tanner stage). After adjusting for differences in chronological age, the gymnasts were found to be significantly shorter ($P \leq 0.01$) and lighter ($P = 0.05$) than control group children. However, no significant differences were detected between the groups for the rate of growth in height or body mass over the course of the study, although gymnasts remained significantly shorter than controls at each time point (Fig. 2).

Video and heart rate analysis

Results of the video analysis representative of each of the three phases of gymnastics training revealed that inactive time accounted on average for 63% of the total training time. This represented an average 1 min 43 s of rest or recovery for every minute of work. Inspection of the work:rest ratio for each phase of gymnastics training revealed that training was most demanding during the SC phase (1:1.44), followed by RD (1:1.78) and PC training (1:1.94).

Fig. 1 Training and blood collection (*RD* Routine development, *PC* Pre-competition, *SC* Strength/conditioning, *M* Monday, *W* Wednesday, *F* Friday) schedules during the experimental period



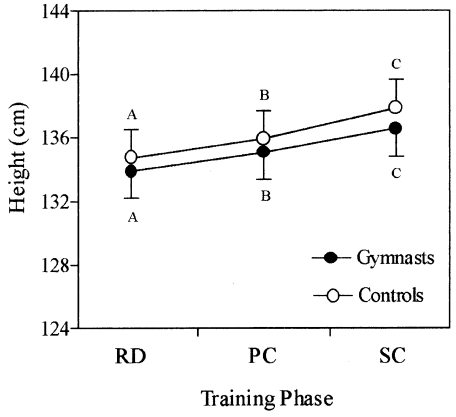


Fig. 2 Change in height of the gymnasts (*closed circles*; $n = 16$) and the controls (*open circles*; $n = 17$) across the three different phases of gymnastics training, RD, PC and SC . Values are the means (SEM). Like letters indicate significant difference ($P < 0.01$)

The mean heart rate for the five training sessions was 127.5 beats · min^{-1} (PC 126 beats · min^{-1}; SC 129 beats · min^{-1}). Since children have a maximum heart rate ranging from approximately 195 to 205 beats · min^{-1} (Rowland 1996), the gymnasts averaged between 60 and 65% of the maximum. Inspection of a typical heart rate pattern of a gymnast during training revealed transient peaks during manoeuvres on the high bar (158–184 beats · min^{-1}) and parallel bars (171–184 beats · min^{-1}), and even higher sustained rates during conditioning activities (maximum 200 beats · min^{-1}).

Serum hormones (cortisol, total testosterone and IGF-1)

Since no significant within- or between-group differences were observed for the weekly (Monday, Wednesday, Friday) serum cortisol or testosterone concentrations during any phase of gymnastics training, the values for each training phase were pooled for each group (Table 1). Subsequent analysis of the cortisol and testosterone data revealed that there were no significant group main effects nor group-by-time interactions. However, significant time effects were observed in both gymnasts and controls for serum cortisol. Further inspection revealed that cortisol levels were significantly higher in the gymnasts during the SC phase of training when compared to RD or PC training. A similar time effect was also observed in the control group (SC > RD). For serum concentrations of IGF-1, no significant group, time, nor group-by-time interactions were detected between the gymnasts and controls after adjustments were made for differences in age and height.

Anabolic:catabolic hormonal balance

Comparison of the anabolic:catabolic balance across the three phases of training revealed no significant group nor interaction effects for changes in the T:C ratio between the gymnasts and controls (Fig. 3). However, the T:C ratio decreased significantly from PC to SC training in the gymnasts. On the other hand, the IGF-1:C ratio (Fig. 4) decreased significantly in both the gymnasts (RD versus SC, $P < 0.01$; PC versus SC, $P < 0.001$) and the controls (RD versus SC, $P < 0.01$). More importantly, there was a significant group-by-time interaction ($P < 0.01$), with the magnitude of the decrease being significantly greater in the gymnasts compared with the controls following both RD and SC training (Fig. 4).

Since IGF-1 is essential for normal growth, its relationship with changes in height was examined in both gymnasts and controls. In neither group were any significant relationships found between the increase in height and either IGF-1 ($r = 0.15$–0.48) or the IGF-1:C ratio ($r = -0.13$–0.33) for any phase of training. In addition, training data (number of years and h · $week^{-1}$) for the gymnasts did not correlate significantly with IGF-1, cortisol, or the T:C or IGF-1:C ratios.

Diet

Due to the lack of difference in diet between the training phases for both gymnasts and controls, the results within each group were pooled. Although no differences were found between the gymnasts and controls for total energy [8446 (822) kJ versus 7554 (910) kJ], carbohy-

Table 1 Mean (SD) serum concentrations of cortisol, total testosterone and insulin-like growth factor-1 (IGF-1) across three different phases of gymnastics training, routine development (*RD*), pre-competition (*PC*) and strength conditioning (*SC*) in peripubertal male gymnasts and controls. Absolute means are presented, but significance tests are from analysis of covariance, adjusted for age (cortisol and testosterone) or age and height (IGF-1)

		Training phase		
		RD	PC	SC
Cortisol (nmol · l^{-1})	Gymnasts	431 (99)*	417 (68)*	569 (168)
	Controls	419 (118)*	471 (143)	524 (173)
Testosterone (nmol · l^{-1})	Gymnasts	0.64 (0.25)	0.68 (0.22)	0.76 (0.44)
	Controls	0.65 (0.34)	0.64 (0.36)	0.71 (0.46)
IGF-1 (ng/ml)	Gymnasts	140 (33)	153 (34)	135 (40)
	Controls	175 (49)	170 (65)	163 (52)

* Significantly different from SC value, $P < 0.001$

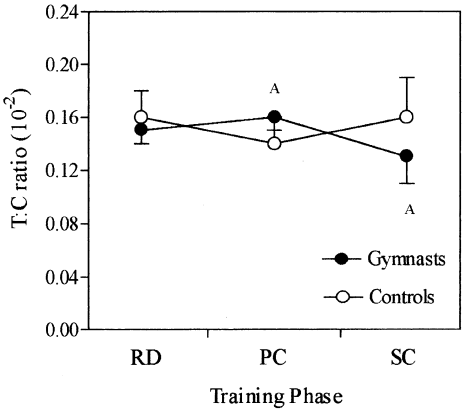


Fig. 3 Mean (SEM) testosterone (*T*):cortisol (*C*) ratio in gymnasts (*closed circles*; $n = 16$) and controls (*open circles*; $n = 17$) across three different phases of gymnastics training, RD, PC and SC. Like letters indicate significant difference ($^{A}P < 0.02$)

drate [268 (45) g versus 244 (33) g] or fat intake [75 (11) g versus 71 (9) g], the average protein intake of the gymnasts was significantly greater than controls [79 (18) g versus 62 (8) g, $P < 0.05$). No significant relationships were detected between either total energy or protein intake and serum IGF-1 or the IGF-1:C ratio in either group.

Discussion

The present study demonstrates that there were no significant differences in morning serum cortisol concentrations between high-level male gymnasts and normoactive children during three different phases of gymnastics training (RD, PC, SC). Although data on hormonal responses to exercise in prepubertal children are limited, the results of the present study are consistent with those of Rich et al. (1992b), who examined the acute serum cortisol response for 5 consecutive training days in eight trained male gymnasts and eleven untrained similarly aged controls (mean age 11.1 years). In the latter study, no significant differences were observed between gymnasts and controls immediately prior to or 30 min after gymnastics training at any time throughout the experimental period (Mon–Fri). Together, these results and those of the present study, indicate that either the gymnastics training was not intense enough to stimulate additional cortisol secretion, or that the gymnasts were well adapted to the training loads encountered. Although the heterogeneity of the training history of the gymnasts ($h \cdot week^{-1}$ and years training) could have contributed to the lack of a significant intergroup difference, Jahreis et al. (1991) found that morning serum cortisol levels did not change significantly in 16 peripubertal elite female gymnasts following 3 days of intensive training. However, the lack of a control group was a limitation of their study, since serum cortisol concentrations were very high [mean 824 (272) $nmol \cdot l^{-1}$] at the beginning of the investigation in the gymnasts, indicative of a long-lasting stress.

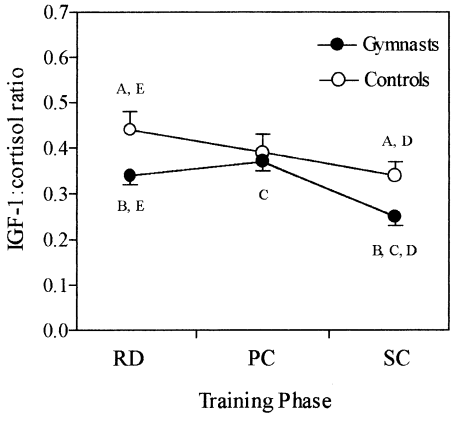


Fig. 4 Mean (SEM) insulin-like growth factor-1 (IGF-1): cortisol (C) ratio in gymnasts (*closed circles*; $n = 16$) and controls (*open circles*; $n = 17$) across three different phases of gymnastics training, RD, PC and SC. Like letters indicate a significant difference ($^{A\text{-}C}P < 0.001$; $^{D,\,E}P < 0.05$)

Previous research has indicated that the response of cortisol to exercise is dependent upon both the duration and intensity of the workload (Viru 1985). It has been suggested that the critical threshold above which circulating cortisol levels increase, corresponds to a duration of exercise of more than 20 min at approximately 60–70% of maximal oxygen consumption (Urhausen et al. 1995; Viru 1985). The video and heart rate data illustrate that gymnastics training was characterized by intermittent bursts of activity interspersed with equivalent or longer periods of rest and recovery. Although oxygen consumption was not assessed in the present study, gymnasts apparently derive a large proportion of their energy needs from anaerobic pathways, with a minor contribution from aerobic sources (Kirkendall 1985). In part support of this notion, the heart rates of the gymnasts in the present study only transiently exceeded the aerobic training threshold of approximately 160 $beats \cdot min^{-1}$ cited for prepubertal children (Shephard 1992). Although anaerobic exercise has also been shown to be a potent stimulus for eliciting an increase in cortisol concentrations (Buono et al. 1986; Elias et al. 1991), it appears that the intermittent short-duration bouts of exercise associated with the present training regime were not of sufficient intensity to elicit a large morning adrenocortical response in the male gymnasts, despite daily training sessions exceeding 3 h. The apparent lack of response may also be attributed to the fact that the diurnal variation in morning serum cortisol concentrations is much more pronounced than that in the afternoon (Hakkinen et al. 1988), which may have masked any exercise-induced alterations that had occurred. In addition, it has been suggested that cortisol levels may actually decrease following low-intensity physical activity (less than 50% of maximal oxygen uptake), presumably due to increased removal from the circulation or decreased adrenocortical activity (Viru 1985).

Despite the lack of a significant intergroup difference in serum cortisol, values increased significantly from RD to SC training in both gymnasts and controls. While the exact cause of this increase remains to be determined, evidence suggests that cortisol exhibits a seasonal variation, with higher values being reported during the winter months (Van Cauter et al. 1981). While this finding was limited to people living in the northern hemisphere, it is consistent with the results of the present study, since RD and SC training were performed during the summer and winter months, respectively.

In the literature, decreased levels of testosterone and increased levels of cortisol are said to be indicative of a disturbance in the anabolic:catabolic balance (Adercreutz et al. 1986; Urhausen et al. 1987; Vervoorn et al. 1991), which may be expressed in performance decrement. While few studies have examined the T:C ratio in response to training in children and adolescents, no significant differences were found in the present study between the highly active male gymnasts and normoactive controls over three different phases of gymnastics training, although the T:C ratio decreased from PC to SC training in the gymnasts. Rich et al. (1992b) found that the T:C ratio decreased in prepubertal male gymnasts compared with controls from the 1st (Monday) to the 3rd (Wednesday) day of gymnastics training, after which the ratio increased following a day's rest (Friday). However, since large day-to-day fluctuations were observed within the control group, the authors were unable to establish a direct link between training and a reduction in the T:C ratio. Given the prepubertal growth is relatively sex hormone independent (Borer 1995), calculation of the T:C ratio as a possible marker of training stress or overstrain may be of limited value during this period.

The other index of anabolism versus catabolism utilized in the present study was the serum IGF-1:C ratio. IGF-1 is growth hormone dependent, and because IGF-1 has a stable circadian serum concentration, single measurements are likely to prove useful as an appropriate measure of daily integrated GH secretion (Roelen et al. 1997). In the present study, the IGF-1:C ratio was significantly lower in the gymnasts compared with the controls during both RD and SC training. These phases were characterized by the lowest rest:work ratios, with SC training also distinguished by a regular 20–30 min cardiovascular conditioning period. When training volume and intensity were reduced prior to competition (PC), there was little difference in the IGF-1:C ratio between the groups, indicating that this ratio may be a sensitive indicator of current training demand and/or recovery in physically active children.

Although the present investigation appears to be the first to report the anabolic:catabolic balance using serum concentrations of IGF-1 and cortisol, when the IGF-1:C ratio was calculated from the data reported by Jahreis et al. (1991), who examined the hormonal changes associated with intense gymnastics training in 16 elite female gymnasts, a similar result was noted. At the conclusion of 3 consecutive days of strenuous physical training, the IGF-1:C ratio had decreased by 23%, from 0.30 to 0.23. In the present study, the IGF-1:C ratio decreased by 32% in the gymnasts, from PC to SC training. This may reflect overstrain or insufficient recovery, especially given that a decrease in the T:C ratio of greater than 30% has been described as an indicator of overtraining in adults (Aldercreutz et al. 1986; Vervoorn et al. 1991). The apparent decrease in the IGF-1:C ratio in the gymnasts in the present study is consistent with a catabolic state, although further research is required to determine the level, if one exists, at which a reduction in the IGF-1:C ratio reflects performance decrement.

Since the rate of growth did not differ between the groups throughout the study, and no relationship was detected between the change in height and the IGF-1:C ratio, it is tempting to speculate that gymnastics training prior to puberty does not have an adverse affect on growth in male children. However, caution must be exercised when making such an assumption, given the short observational period and the fact that the gymnasts had been training for a number of years prior to the investigation. While differences in physique are likely to reflect selection at a relatively young age, further long-term studies extending into puberty are needed to address the issue of whether training has the potential to alter growth in male gymnasts. Future studies should also examine the role of IGF-binding proteins, which modulate IGF action in both a positive and negative manner (Mohan and Baylink 1996), and have been shown to be negatively related to thigh muscle volume and maximal oxygen uptake in adolescent males and females (Eliakim et al. 1996, 1998), both indicators of physical fitness.

The reduction in the IGF-1:C ratio in the gymnasts in the present study was predominantly due to lower IGF-1 levels. Although the differences between the groups were not significant, other researchers measuring circulating IGF-1 concentrations in high-level female gymnasts reported significantly lower values when compared with other athletes and non-athletic controls (Jahreis et al. 1991; Nichols et al. 1995; Theintz 1994). Since a number of factors are known to regulate IGF-1 concentrations, it is difficult to ascertain whether alterations in IGF-1 are due to training, or to other intrinsic and/or extrinsic factors. Although serum levels of IGF-1 rise during puberty and are strongly correlated with markers of maturity, such as Tanner stage and bone age (Juul et al. 1994; Rosenfield et al. 1983), the lower values in the gymnasts could not be explained on the basis of delayed maturation since both groups were at a similar biological age (serum total testosterone and Tanner stage).

Nutritional status has also been shown to have a profound effect on serum IGF-1 levels. Several studies have suggested that IGF-1 levels are reduced in children with protein and/or caloric restriction (Hintz et al. 1978; Smith et al. 1995). In the present study, protein intake was significantly higher in the gymnasts, although no

intergroup differences were observed for total energy, carbohydrate or fat intake after adjustments were made for differences in chronological age. Although the average daily (kJ) intake for the gymnasts appeared to be adequate in terms of the Recommended Dietary Intakes (range 8100–9100 kJ/day) established by the National Health and Medical Research Council (Australia 1992) for light to moderately active children aged 8–11 years, Lindholm et al. (1995) estimated that the mean energy intake of young female gymnasts was, on average, 723 kcal (where 1 kcal = 4.19 kJ) less than their calculated energy need. While a direct comparison with female gymnasts is difficult given differences in training and competition requirements, one may speculate that the lower anabolic:catabolic balance observed in the gymnasts in the present study during periods of relatively intense physical training may have been associated with an imbalance between energy intake and output. Obviously, caution must be exercised when making such an assumption, since no attempt was made to assess the energy costs of daily gymnastics training.

In summary, the results of this study demonstrate that the daily 3-h gymnastics training sessions, regardless of phase, were either not intense enough to alter adrenal function, or that the gymnasts were well adapted to the training loads. Although the T:C ratio did not differ between gymnasts and controls at any time, the reduction in the IGF-1:C ratio in the gymnasts following periods of strenuous training is suggestive of a catabolic state, perhaps because of insufficient recovery or overstrain, which may be partly attributed to an imbalance between energy intake and output. Although it would appear that gymnastics training prior to pubertal onset does not alter growth, the IGF-1:C ratio may provide a useful tool for monitoring training demand in children undertaking regular strenuous physical training. Since low IGF-1 concentrations in children could lead to an attenuation of linear growth, further research is needed to establish the level, if one exists, at which a reduction in the IGF-1:C ratio has deleterious effects upon performance, growth, maturation and/or bone formation during adolescence.

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