Journal of Strength and Conditioning Research, 2004, 18(3), 625–629

STRENGTH ADAPTATIONS AND HORMONAL RESPONSES TO RESISTANCE TRAINING AND DETRAINING IN PREADOLESCENT MALES

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ABSTRACT. Tsolakis, C.K., G.K. Vagenas, and A.G. Dessypris. Strength adaptations and hormonal responses to resistance training and detraining in preadolescent males. *J. Strength Cond. Res. 18(3):625–629. 2004.*—Ninteen untrained preadolescent males (11–13 years old) were randomly placed into an experimental trained group (STG, $n = 9$) and a control group ($n = 10$). Informed consent was obtained from the children and their parents. The STG was submitted to a 2-month resistance-training program (6 exercises, 3 × 10 repetitions maximum [RM], 3 times per week), followed by a 2-month detraining program. The effectiveness of the resistance program was determined by measuring pre- and posttraining and detraining differences in isometric and isotonic (10RM) strength and hormonal responses in testosterone (T), sex hormone binding globulin, and free androgen index (FAI). Their maturation stage was evaluated according to Tanner. Significant posttraining isometric strength gains (17.5%) and mean T and FAI value increases ($p < 0.05$–0.001) were observed in STG. Detraining resulted in a significant loss (9.5%, $p < 0.001$) of isometric strength whereas the hormonal parameters of STG remained practically unaltered. The relative (Δ%) postdetraining hormonal responses correlated significantly with the respective isometric strength changes. In conclusion, the resistance training induced strength changes independent of the changes in the anabolic and androgenic activity in preadolescent males. Further research is needed to fully clarify the physiological mechanisms underlying the strength training and detraining process.

KEY WORDS. strength training, isokinetic training, androgens, untrained boys

INTRODUCTION

The physiological muscle-growth changes in boys during the early stages of puberty are attributed mainly to the increase in boys' androgen levels (10). These changes are usually observed after the age of 11, correlate with developmental-stage changes, and are considered significant in the functional growth of muscle tissue (20,21, 40).

Many individuals in their preadolescent period increasingly participate in systematic resistance-training programs that, if all basic principles of design and safety are followed, lead to an increase in muscular strength (6), improve health, and prevent possible exercise-related injuries (20) attributed to muscle weakness and muscle-strength imbalance during development (28). Although the mechanisms that produce these changes in adolescents have been thoroughly researched (18, 25, 34, 37), little research exists regarding preadolescents.

Among adults, strength gains induced by resistance training are attributed mainly to neurological adaptations in the early stages of training and domination of muscle hypertrophy over time (25). Neuromuscular performance in adults decreases slowly during detraining via reversible neurological and hormonal adaptations (13, 26). Regarding children, the changes in strength are attributed to neurological factors (34), whereas muscle hypertrophy is much more limited than it is in adolescents (11, 24). Consequently, the probable decrease in strength gains during detraining is mainly attributed to reduced neuromuscular activation and reduced motor coordination (6).

Data on the influence of prolonged resistance training and detraining on androgen levels of adults are contradictory because of inherent methodological differences of the relative studies (1, 12, 15, 16); however, there is a relative lack of similar information about preadolescent males (23, 25). Therefore, we investigated the influence of a short, 2-month, supervised, progressive resistance-training program with isotonic equipment and a 2-month detraining program on strength adaptations, serum hormones testosterone (T), sex hormone binding globulin (SHBG), and free androgen index (FAI) in Greek preadolescents who lacked any previous training experience.

METHODS

Nineteen untrained high school boys, 11–13 years of age, were placed randomly into 2 groups: an experimental trained group (STG, $n = 9$) and a control group (CG, $n = 10$). The subjects' personal characteristics are given in Table 1. They participated voluntarily after learning the purpose of the study and the potential risks associated with a strength-training program and after obtaining their parents' written consent. The University of Athens, Department of Physical Education, approved the study. Their subjects' maturation stage was evaluated according to Tanner (36) on the basis of external genitals and pubic hair development. All subjects were classified as late stage 1 or early stage 2 and confirmed by their serum concentrations of T (38), which reflected also their preadolescent status (36). Before their selection, all subjects underwent medical evaluation (preparticipation sports examination) to exclude those with chronic diseases, orthopedic limitations, or other inhibiting factors.

Experimental Approach to the Problem

Our study intended to determine whether a short resistance-training program and detraining of equal duration could influence strength levels and relative hormonal factors in sedentary preadolescent boys.

The STG was submitted to a 2-month resistance-training program. The training-program variables were de-

Table 1. Anthropometric characteristics of STG and CG (mean ± SD).*

Groups	*n*	Age (y)	Height (cm)	Weight (kg)	% Body fat
STG	9	11.78 ± 0.84	152.18 ± 5.91	43.02 ± 9.5	14.05 ± 3.11
CG	10	12 ± 0.82	156.82 ± 8.68	43.18 ± 10.74	12.74 ± 2.64
STG vs. CG**		NS	NS	NS	NS

* STG = experimental group; CG = control group; NS = not significant.
** Independent T-test.

signed according to the basic principles described by Kraemer and Fleck (19). Every training session included 3 sets of a predetermined 10 repetitions maximum (RM) of 6 different exercises for the upper body in a variable-resistance machine (supine bench press, wide grip cable, pull-downs, biceps curl, triceps extensions, seated row, overhead press). The exercise program was designed for the upper extremities because children's arms are proportionally weaker than their legs (29, 31), and in this context, the subjects might have been capable of greater strength gains after the end of the training protocol. The subjects were allowed a 1-minute rest between each set and a 3-minute rest between each of the 6 different exercises. The duration of the training sessions was about 60 minutes 3 times per week (48 hours between each training session). Each session was supervised by a coach and included a warm-up of about 10 minutes with jogging, static stretching, and light exercises of the involved muscle groups and approximately 5–8 minutes of stretching to cool down. The subjects were submitted to a test (10RM) every 15 days to readjust the training effort. The training period was followed by a 2-month detraining period during which the subjects did not participate in any training program except their school physical education classes. Before the beginning of the 2-month training at the end of the second month and at the end of the detraining period, blood samples were obtained from the antecubital vein in resting conditions (subjects remained seated for 10–15 minutes on arrival at the laboratory) for hormonal determination. The CG was not subjected to resistance training but followed similar anthropometric test and blood assay protocols. No injuries resulted from the training sessions. Few subjects complained of delayed muscle pain and limited range of motion in the initial 3 sessions, which disappeared after the first week of training followed by extra stretching exercises.

Measurements

Isokinetic Strength. A specially designed strain guage loaded upper extremity dynamometer was used to measure the pre- and postexercise concentric strength of the elbow flexion in the right arm. Each subject was placed in an adjustable seat fastened with 3 special belts which helped the immobilization of the chest, shoulder and back. The isometric strength of the elbow flexion at a 90° angle was recorded.

After a satisfactory warm-up with mild exercises and stretching of muscle groups of the upper extremities and body, each subject performed 3 maximal efforts lasting approximately 3 seconds with a 60 second interval between. The subjects were informed of the procedure before the efforts, and each maximal effort was reinforced by verbal encouragement. The best of the three efforts were retained for further analysis.

Isotonic Strength. Each subject's 10RM was determined on elbow flexion with adjustable dumbbells. The start position during isokinetic testing was 40° of elbow flexion. After a satisfactory warm-up with a light weight (1.5 kg), the 10RM was found within 3–4 trials and was measured within 0.5 kg (the maximum weight that could be lifted 10 times correctly without any other muscle-group support). An adult instructor could identify when the upper arm was not immobilized and when the try was not through the full predetermined range of motion. The rest interval between trials was 1 minute.

Blood Tests. After 2 days of rest and 12 hours of fasting, approximately 5 ml of blood was drawn from a forearm (antecubital) vein with a gauge needle 21-G × 1.5-in. vacutainer, set up between 0830 and 0900 hours, to avoid the influence of the diurnal variations in serum hormones. The blood was allowed to clot at room temperature (22° C) and the serum was separated by centrifugation at 3,000*g* for 15 minutes and stored at −30° C until analyzed (within 30 days). Testosterone was determined by a commercial RIA kit Direct Testosterone I^{125} (Farmos ORION Diagnostica, Finland). Intra- and interassay variations were 4.6% and 4.9% and the assay sensitivity was 0.30 nmol/L. The specificity was very good with minor cross-reactions. Sex hormone binding globulin was determined by IRMA method (Farmos). Intra- and interassay variations were 3.2% and 5.5% with a sensitivity of 0.5 nmol/L. All samples for T and SHBG were determined in duplicate (as well as the standard curve), and high- and low-quality control sera were included in the test. Duplicate values were very satisfactory (T, $r = 0.96$; SHBG, $r = 0.98$).

Finally, the FAI counted using the type (Farmos):

$$\text{FAI} = \frac{\text{concentration of total T (nmol/L)}}{\text{concentration SHBG (nmol/L)}} \times 100$$

Anthropometry. All 19 subjects were measured for height, weight, and tricep and subscapular skinfolds. The last measurements were taken with a Harpenden skinfold caliper (17). All anthropometric and body composition measurements were taken on all 3 occasions by the same investigator, who was previously controlled for his test-retest reliability ($r > 0.92$).

Statistical Analyses

Pre-, post-, and detraining values for all measured variables were compared via a 2-way analysis of variance (ANOVA) (2 × 3) with repeated measures. Post hoc analyses included 1-way repeated-measures ANOVA and independent Bonferoni tests. T-test for independent variables were used for comparison of the means of the hormonal parameters examined between the STG and the CG. Pearson product moment correlation was used to ex-

Table 2. Hormonal concentrations and ioskinetic strength of STG ($n = 9$) and CG ($n = 10$) (mean ± *SD*).†

Variables	Group	Pretraining	Posttraining	Detraining
T (nmol/L)	STG	4.9 ± 5.7	10.9 ± 6.2*	10.7 ± 7.6**
	CG	6.1 ± 4.45	6.6 ± 4.05	7.2 ± 3.98***
SHBG (nmol/L)	STG	69 ± 30.9	61.5 ± 42.2	78.2 ± 50.5
	CG	64.2 ± 21.84	73.7 ± 25.7	65.1 ± 23.3
FAI	STG	15.6 ± 26.1	28.49 ± 33.5***	22.7 ± 27.4[a]
	CG	12.7 ± 15.1	12.1 ± 13.6	14.6 ± 15.6
Isometric strength (kg)	STG	85.11 ± 8.26	100.16 ± 8.39*	90.64 ± 7.60*
	CG	83.06 ± 6.95	83.94 ± 7.13	84.60 ± 7.01
Isotonic strength (kg)	STG	3.22 ± 1.62	4 ± 1.54	3.80 ± 1.58
	CG	3.35 ± 0.85	3.60 ± 0.84	3.75 ± 0.71

* $p < 0.001$.
** STG values greater than CG values, $p < 0.05$.
*** $p < 0.05$ (1-way analysis of variance significance for pre-, post-, and detraining values; Bonferroni post hoc analysis).
† STG = experimental group; CG = control group; T = testosterone; SHBG = sex hormone binding globulin; FAI = free androgen index.

amine bivariate relationships between percentage changes (%Δ) in strength and the hormonal responses. The data in the tables are presented as mean ± *SD*. Significance in this investigation was set at $p \leq 0.05$.

RESULTS

The mean values of the hormonal variables are given in Table 2. Subjects who participated in the weight-training program exhibited 124% increase ($p < 0.001$) in the mean T concentration and 75% increase ($p < 0.05$) in the FAI values. The STG demonstrated significant isometric strength gains (17.5%, $p < 0.001$), whereas the CG showed no significant gains in any of the above-mentioned parameters.

At the end of the detraining period, the mean hormonal concentrations of the STG were not significantly different from the posttraining concentrations, whereas strength significantly decreased (9.5% $p < 0.001$). The mean detraining T concentration and the mean FAI values of the CG increased by 9% and 21% ($p < 0.05$). No significant differences were observed in any of the strength measurements between groups. Significant correlation was observed in the relative (Δ%) postdetraining changes between hormonal parameters (T, FAI; $r = -0.68$, $p < 0.05$) and isometric strength ($r = -0.91$, $p < 0.01$) in the STG.

DISCUSSION

The present study demonstrated that 2 months of a progressive, supervised resistance strength-training program in preadolescent boys resulted in significant increases in the level of T and FAI values and maintenance of posttraining changes after a 2-month detraining period. Isometric strength significantly improved but decreased significantly at the end of the detraining period toward untrained control values, suggesting that strength gains in children are impermanent and reversible. No significant association was observed between the relative changes in isometric or isotonic (10RM) strength and the changes in hormonal parameters during posttraining period. After the end of the detraining period, significant correlation was observed in the relative (Δ%) postdetraining changes between hormonal parameters (T, FAI; $r = -0.68$, $p < 0.05$) and isometric strength ($r = -0.91$, $p < 0.01$) in the STG.

The influence of resistance training on the strength of preadolescent boys has been extensively studied. It is generally accepted that it can successfully and safely increase muscular strength (2, 3, 20). In the present study, a significant improvement (17.5%) of their isometric strength was found. Although direct comparisons between investigations of the same age groups and duration are limited (9, 32), the magnitude of the strength gains observed in the present study was smaller and probably attributed to their different training frequency (9), intensity, and testing modality (9, 32).

Detraining in adults was characterized by a relative reduction of muscular strength through reversible neuromuscular and hormonal adaptations (13, 26). There is insufficient information about the changes in resistance-training–induced strength gains during detraining in preadolescents. Few studies (2, 8) investigated the effects of detraining with an inclusion of a CG to explain probable growth-related increases in strength. In our study, after 8 weeks of detraining, the trained subjects' strength decreased significantly by 9.5%, converging toward the control values, whereas the CG subjects showed no significant changes in strength during the same detraining period. Although the magnitude of the initial strength gain and the detraining duration could partly explain the reversible response of strength (2), other factors seem to be important as well. No significant correlation was observed between the initial strength and the respective strength loss, either in isotonic (10RM) or isometric strength for this STG. The STG maintained approximately 64% of the strength gained during training, probably because of the high intensity of the training program (20), which is an important factor related to the magnitude of the improvement of the muscular strength (4). The impermanent and reversible process of strength and the preserved hormonal gains during the detraining period could help coaches design in-season conditioning programs, though more details need to be examined regarding the point at where the studied parameters will regress to their pretraining values. No significant differences in strength between groups were found at the end of the detraining period. The nonsignificant strength gains occurred in the CG, which indicate the subjects' growth process, combined with the 9.5% significant decreases of the STG, were found to be consistent with the model proposed by Blimkie et al. (6) concerning the effects

of growth, resistance training, and detraining during childhood.

To our knowledge, little is known about the influence of resistance training upon androgen (T, SHBG, FAI) secretion and bioavailability in preadolescent boys (24, 32). Our previous work with this age group has demonstrated that resistance training significantly increased T and FAI levels of the STG (39), which could probably contribute as an additional stimulus to the anabolic process during the growth spurt of puberty. These increases could be associated with changes in the cybernetic mechanisms (hypothalamic neurons of gonadotropin-releasing hormone, pituitary gonadotrophins) of the hypopituitary-gonadal axis, which control the onset of puberty (35) and thus lead to acceleration of the rhythm of the growth and development (7), although such training of small duration could not permit any definite conclusion because the mechanisms do not influence the skeletal growth of the prepubertal boys (3). Obviously, more research is needed to clarify whether extension of the training period may influence the maturity status of the exercised subjects.

The results of our study, and especially the nonsignificant correlation between pre- and postrelative strength changes (Δ%) and anabolic hormones, may demonstrate a lack of a potential role of T in strength acquisition. Sale (33) pointed out that neural factors and the possible muscle-fiber transition of type II to more glycolytic profiles predominate on muscle hypertrophy in prepubescent children. In contrast, Mero et al. (23) reported significant correlation between hormones and force production after a much longer training period (12 months) of combined different training regiments. The significant postdetraining correlation between hormonal parameters and isokinetic strength could probably explain the magnitude of anabolic and catabolic process in adults (14, 16). Although information about detraining adaptations on preadolescent androgen levels is rare, the detraining period's significant association combined with the significant changes in T and FAI, which practically remained unaltered, probably shows the trainability status of the STG (30).

The concentration of T and SHBG in the STG remained within the reference values range (38) at the end of the training, which, in turn, shows that the strength training of this study had no adverse effect on the hormonal mechanisms operating in prepubescent boys. The lack of musculoskeletal injuries after the training period also showed that this applied, supervised, concentric resistance training does not appear to be a particularly risky activity in healthy children. Therefore, resistance training could be an effective part of the physical exercise programs for preadolescents (27), taking into account the interaction between the training adaptations and the potential physiological limits for each stage of development (20). Numerous questions remain regarding the influence of different combinations of the training factors (training mode, intensity, volume, duration) to obtain the optimal training regimen for specific improvement of strength and the role of strength training in inducing androgen responses on muscle hypertrophy or neuromuscular and motor coordination changes in these subjects.

We conclude that (a) the 2-months resistance training resulted in significant increases in mean hormonal levels (T, FAI) and in isometric strength of preadolescent boys and (b) the posttraining hormonal gains were preserved for 2 months, whereas isometric strength decreased significantly after the end of the detraining period.

PRACTICAL APPLICATIONS

The present data have important practical applications and may be useful to coaches and clinicians who take adequate information on the subjects' trainability status to design preventive or rehabilitative strength-training programs to reduce the risk of exercise-related injuries or to achieve optimal musculature, which helps and stabilizes the growing parts of the human kinetics mechanisms (22). Coaches and clinicians may also effectively design the strength-training variables related to the periodization, especially the appropriate length of rest between 2 training periods, or to the rehabilitation from sport-related injuries for this age group while considering the transient nature of the training response, which, in an in-season conditioning program, will result in inevitable and undesirable strength loss.

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Acknowledgments

We would like to thank all the participants and their parents for their enthusiastic contribution and patience shown during the project. We are also thankful to Dr. S. Chantzikonstantinou, professor of sports medicine, Department of Physical Education and Sports Science, University of Athens, for his comments; to Dr. D.A. Adamopoulos, M.D., Ph.D., chief endocrinologist, Helena Venizelos Hospital, for reviewing and correcting our manuscript; to Dr. A. Vagenas, assistant professor of statistics, Department of Physical Education and Sports Science, University of Athens, for his valuable advice; and to K. Tsolakis, director of Biochemistry Laboratory, Sotiria Hospital, for his expert technical assistance.

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