Neuromuscular adaptations following prepubescent strength training

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ABSTRACT

OZMUN, J. C., A. E. MIKESKY, and P. R. SURBURG. Neuromuscular adaptations following prepubescent strength training. *Med. Sci. Sports Exerc.* Vol. 26, No. 4, pp. 510–514, 1994. Underlying mechanisms of prepubescent strength gains following resistance training are speculative. The purpose of this investigation was to determine the effects of 8 wk of resistance training on muscular strength, integrated EMG amplitude (IEMG), and arm anthropometrics of prepubescent youth. Sixteen subjects (8 males, 8 females) were randomly assigned to trained or control groups. All subjects (mean age = 10.3 yr) were of prepubertal status according to the criteria of Tanner. The trained group performed three sets (7–11 repetitions) of bicep curls with dumbbells three times per week for 8 wk. Pre- and posttraining measurements included isotonic and isokinetic strength of the elbow flexors, arm anthropometrics, and IEMG of the biceps brachii. Planned comparisons for a 2 × 2 (group by test) ANOVA model were used for data analysis. Significant isotonic (22.6%) and isokinetic (27.8%) strength gains were observed in the trained group without corresponding changes in arm circumference or skinfolds. The IEMG amplitude increased 16.8% ($P < 0.05$). The control group did not demonstrate any significant changes in the parameters measured. Early gains in muscular strength resulting from resistance training by prepubescent children may be attributed to increased muscle activation.

YOUTH, MUSCULAR STRENGTH DEVELOPMENT, PROGRESSIVE RESISTANCE EXERCISE, MUSCLE HYPERTROPHY, WEIGHT TRAINING

It is generally accepted that, following certain guidelines, prepubescent youth can successfully and safely experience increases in muscular strength following a resistance training program (9,11,12,17,18,20). However, the underlying causes of such strength gains remain unclear. With adult subjects it has been demonstrated that strength training results in neural adaptations that allow for enhancement of the motor unit activity patterns (4,8,10,15). This is particularly evident during the first few weeks of a strength training program (10). In preadolescents, however, the role of neuromuscular adaptations is not as clear.

Only one study has attempted to directly address the issue of neural adaptation to strength training in prepubescent children. Blimkie et al. (2) isotonically strength trained prepubescent children for 10 wk. The training resulted in significant increases in isometric and isotonic strength. However, no significant changes were noted between the exercise or control subjects in muscle cross-sectional area as determined by computerized tomography. While not statistically significant, a trend was noted toward an increase in motor unit activation as determined by interpolated twitch.

Although there is evidence indicating neural involvement in strength gains in older subjects, results from the few studies involving prepubescent children is equivocal. Therefore the purpose of this investigation was to examine the effects of an 8-wk weight training program on muscle strength and integrated EMG activity in prepubescent youth.

METHODS

Subjects. Sixteen male and female children between the ages of 9 and 12 yr and from the same elementary school participated in the study. Age and gender data are given in Table 1. Males and females were combined as they demonstrate a fairly similar rate of increase in muscular strength during the prepubertal years (1). Written informed consent was obtained from a parent or legal guardian of each subject prior to data collection. Each child received a preparticipation medical examination for the purposes of determining pubertal status of the subjects via Tanner's five-stage protocol (19), and to screen for any orthopaedic conditions that would restrict the subject from participating in a weight training program.

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TABLE 1. Age and gender of subjects.

Group	Mean Age (yr)	SD	Range	Gender
Control	10.0	0.43	9.4–10.8	Males, $N = 5$ Females, $N = 3$
Trained	10.5	0.55	9.8–11.6	Males, $N = 3$ Females, $N = 5$

Based on pubic hair and breast development, all subjects were classified as prepubescent, and none had any restrictive orthopedic conditions.

Isokinetic strength. The Kin-Com III (Chattecx Corp., Chattanooga, TN) isokinetic dynamometer was used to measure pre- and posttraining concentric elbow flexion strength of the right arm. Each subject was familiarized with the testing apparatus and procedures prior to test administration. The subject was seated in an armless chair with feet suspended, eliminating the possibility of force production from the lower extremities. A back pad (90° from seat) and three belts (one lap and two shoulder belts) were used to prevent posterior movement of the elbow and extraneous movements of the chest, shoulders, and back. The axis of the dynamometer resistance arm was aligned with the lateral epicondyle of the humerus. Dynamometer settings and chair positioning measures were taken for each subject to ensure the same setup during posttesting. Correction for gravity was determined by the Kin-Com, which had the capacity to weigh the subject's arm and adjust for the weight.

Concentric elbow flexion strength was measured through an 80° arc ranging from the start position of 40° of elbow flexion to the end position of 120° of flexion at $90°\cdot s^{-1}$. Concentric muscle contractions were measured instead of eccentric contractions in an effort to reduce the risk of muscle soreness and/or injury (7). All isokinetic strength measures were corrected for limb mass. Each subject performed three practice trials (submaximal effort) followed by five maximal efforts with a 1-min rest separating each effort (4,10). Prior to each maximal effort, the subjects were instructed to do their very best and to pull as hard as they could. Instructions initiating each trial and verbal encouragement during each effort were standardized using an audio cassette tape (6). Average force measurements were determined for each maximal contraction. Average force measurements allowed for the measuring of force exertion throughout the range of motion and coincided with the IEMG readings.

Isotonic strength. Elbow flexion isotonic strength was determined after the isokinetic testing using a weighted dumbbell. While still secured in the dynamometer chair, the subject's one repetition maximum (1RM) was determined when performing an elbow flexion (arm curl) exercise. Subjects performed three practice trials with a light (≤2.3 kg) weight followed by a maximum of five test trials to determine 1RM. The dumbbell weight chosen for the initial test trial was determined by the amount of force pounds exerted at approximately 85° during isokinetic testing (the 85° position represents one of the weakest points through the elbow flexion range of motion). The start position, as during isokinetic testing, was 40° of elbow flexion. The rest interval between trials was 1 min.

Electromyography. Electromyographic (EMG) data were collected during each isokinetic test trial using silver-silver chloride bipolar surface electrodes (Beckman). Electrode impedance was below 1 kOhms. The electrodes were placed longitudinally along the belly of the biceps brachii. Inter- electrode distance was 2 cm. Placement site for electrodes was determined using the site location technique for a bicep skinfold measurement (5). EMG signals were amplified and filtered using a Grass P15 preamplifier. Filtered EMG signals were fed online to a computer via an A/D board (Data Translation DT2801A), rectified, and integrated via computer software.

Anthropometric measures. Anthropometric measures administered included upper arm circumference and skinfolds of the bicep and tricep. Upper arm circumference was determined using a Gulick tape following the protocol described by Callaway et al. (3). Biceps and triceps skinfolds were obtained using Lange Skinfold Calipers following the protocols described by Harrison et al. (5). The mean of three measures was used for both arm circumference and skinfolds. Both pre- and posttesting measures were performed by the same experienced technician.

Training. Upon completion of the initial testing, subjects were randomly assigned to either a trained (T) or control (C) group. Subjects in the T group participated in a strength training program for the right elbow flexors. The T subjects trained three times per week for 8 wk with at least 1 d of rest between successive training sessions. Each subject sat in a chair that did not interfere with a flexion or extension movement of the right arm. A dumbbell was grasped by the right hand. One repetition consisted of an elbow flexion motion performed through a full range of motion with the forearm supinated. Each subject was encouraged to maintain a consistent velocity for all repetitions. Movements were performed in the sagittal plane. Each training session was closely supervised both to provide encouragement and to ensure subjects were using good exercise technique. Training sessions began with two warm-up sets of seven repetitions using dumbbells weighing 0.45–1.4 kg. Following the warm-up, three training sets were performed using a weight that could be lifted 7–10 times. When the subject could perform 11 repetitions, the weight was increased (18). The weight increment or decrement was 1.4 kg. The initial training load for each subject was determined by trial and error, beginning with lighter weight and gradually increasing resistance until the number of repetitions fell within the minimum-maximum range (14).

The C subjects played table games three times per week for the 8-wk period. The table game sessions were of the same duration as the weight training sessions.

Statistical analysis. A subject by trial analysis of variance was conducted to determine if differences existed between pretest isokinetic strength testing trials. Analyses of variance procedures involved planned comparisons for a 2 × 2, test session by group model for each of the dependent variables.

RESULTS

Descriptive characteristics of the subjects are shown in Table 1. The results from the subject by trial ANOVA indicated that a significant trial effect was found ($P < 0.05$) with the measurement of isokinetic strength. The results of a Tukey test determined that trial 1 was significantly different from trials 2, 4, and 5. This difference may have reflected a learning factor. To reduce this possible learning effect only trials 2–5 were used for statistical analysis with the dependent measure of isokinetic strength. Because the measurement of each trial of IEMG activity coincided with corresponding isokinetic strength trials, only trials 2–5 were used for statistical analysis with this dependent measure, as well.

Subjects who participated in a weight training program exhibited 27.8% increase ($P < 0.05$, Fig. 1) in isokinetic strength. No significant isokinetic strength gains were experienced by the control group (↑ 15.5%).

The effects of weight training on isotonic strength were similar to the results found with isokinetic testing. The trained group demonstrated significant isotonic strength gains (22.6%, $P < 0.05$) while the control groups showed no significant isotonic strength gains (3.8%, Fig. 2).

There was a significant increase in neural activity from pretest to posttest scores in the trained subjects (16.8%, $P < 0.05$). The control group showed no significant change in IEMG following the intervention time period (↓ 6.0%, Fig. 3).

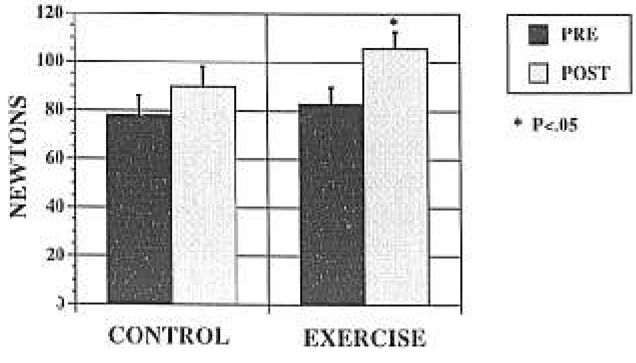

Figure 1—Isokinetic strength means and standard errors for the average of four maximal trials at 90°·s^{-1}.

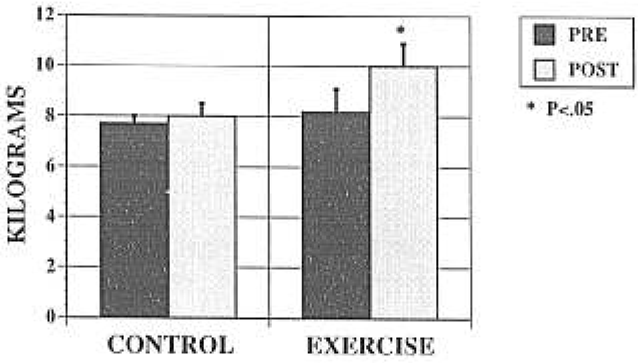

Figure 2—Isotonic strength means and standard errors for 1 RM effort.

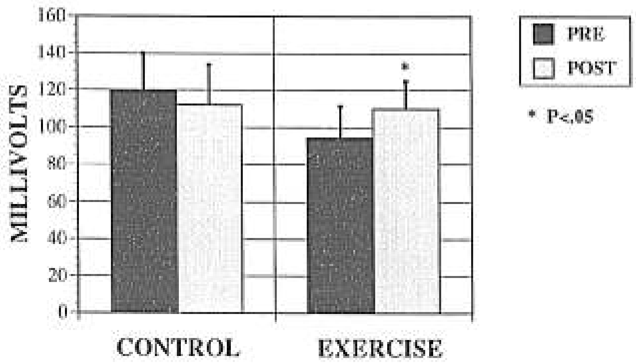

Figure 3—IEMG means and standard errors for the average of four maximal effort trials during isokinetic testing.

There were no significant changes in upper-arm circumferences or skinfolds in either the trained or control groups (Table 2).

DISCUSSION

Early investigations which displayed evidence of neuromuscular involvement in strength enhancement incorporated IEMG methodology (8,10). Komi et al. (8) discovered a 38% increase in IEMG activity of the involved limb with adolescent subjects following a 12-wk isometric training program. These results are comparable to the 16.8% IEMG increases observed in the trained subjects of this study. In the Komi et al. investigation, circumference measures of the trained limb did not increase significantly, placing the central focus on neural involvement rather than muscle hypertrophy in regard to strength gains early in a strength training program. Similar anthropometric results from this investigation were obtained. An analysis of upper-arm circumference and skinfold measurements showed that strength training had not caused a statistically significant increase in arm size or change in composition. The unaltered change in arm circumference and skinfold measures in the trained group would imply that hypertrophy of muscle did not accompany the strength gains. Increases in IEMG activity com-

TABLE 2. Means and standard errors of anthropometric measures on separate test sessions.

Variable	Group	Pretest M	Pretest SE	Posttest M	Posttest SE
Arm	C	22.56	(1.46)	22.38	(1.51)
Circumference (cm)	T	23.73	(1.45)	24.03	(1.57)
Tricep	C	15.31	(3.04)	15.35	(3.04)
Skinfold (mm)	T	17.67	(2.86)	18.58	(3.20)
Bicep	C	8.92	(2.34)	8.91	(2.07)
Skinfold (mm)	T	9.43	(1.98)	9.97	(2.06)

C = control; T = trained.
* $P < 0.05$.

bined with a lack of arm/muscle size increase have been demonstrated consistently in other investigations with adult subjects (10,16) and associated with neurological adaptations.

With prepubescent subjects, Blimkie et al. (2) used a method of measurement referred to as interpolated twitch technique to examine underlying mechanisms of strength increases following training. The interpolated twitch technique involves delivering a single supramaximal stimulus to the nerve of a muscle engaged in a maximal voluntary contraction. The amount of torque or force exerted beyond that which is registered from the voluntary contraction gives an indication of the percent of motor unit activation. As discussed earlier, the trained subjects increased significantly in strength following their prescribed training. Analysis of the interpolated twitch technique data indicated that there was a trend toward an increase in motor unit activation as a result of training.

Using a different method of measuring motor unit activity, the results from this investigation support the findings of Blimkie et al. An increase in isokinetic and isotonic strength following training was accompanied by an increase in IEMG activity with prepubescent subjects. These corresponding strength and IEMG increases may reflect an enhancement in motor unit recruitment, improvement in the firing rate of activated motor units, or alteration of EMG firing patterns (13). Sale (14) suggests that although data are limited children appear to resemble adults in motor unit activation ability.

An interesting observation from this investigation was the percentage increase difference that occurred between the isokinetic and isotonic strength gains of the trained subjects when compared with the changes noted with the control group. The isotonic strength gain difference was 6.5% greater than the isokinetic strength gain difference. This discrepancy may reflect a learning effect with isotonic training. As the isotonic training method was analogous to the testing method, the trained group was more familiar with the equipment and required movements.

Additionally, it was noted that, although not statistically significant, there was a 6% decrease in IEMG with the control group. This decrease coincided with a nonsignificant increase in isokinetic strength of this group. These results are probably in line with normal variability for this population. However, it may be speculated that if the control group had maintained pretest IEMG values during posttesting a greater increase in isokinetic strength would have been observed. Such an increase, if corresponded to the 6% change in IEMG, would still remain considerably lower than the isokinetic changes seen in the trained group.

The removal of surface electrodes between tests may have represented an additional source of variability. Häkkinen and Komi (4) used the technique of marking the skin of adult subjects with a small tattoo. While this procedure is inappropriate with prepubescent subjects, great care was taken to record accurate electrode placement locations using anthropometric measurements. However, the potential for greater measurement error exists with anthropometric measurements when compared to the permanent marking of skin.

The results from this investigation provide evidence that in prepubescent children, neurological adaptations play a role in the development of muscular strength following participation in a weight training program. These results reflect similar neurological adaptation patterns described in adult subjects.

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