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The effects of hydraulic resistance strength training in pre-pubertal males

ARTHUR WELTMAN, CAROL JANNEY, CLARK B. RIANS,
KEN STRAND, BEN BERG, STEVE TIPPITT, JOYCE WISE,
BERNARD R. CAHILL, and FRANK I. KATCH

Center for Sports Medicine and Health Fitness,
Saint Francis Medical Center,
Peoria, IL 61614

ABSTRACT

WELTMAN, A., C. JANNEY, C. B. RIANS, K. STRAND, B. BERG, S. TIPPITT, J. WISE, B. R. CAHILL, and F. I. KATCH. The effects of hydraulic strength training in pre-pubertal males. *Med. Sci. Sports Exerc.*, Vol. 18, No. 6, 629–638. 1986. In order to examine the effectiveness and safety of hydraulic resistance strength training in young males, 26 pre-pubertal males ($\bar{X}$ age = 8.2 ± 1.3 yr) completed a 14-wk strength training study. Subjects were evaluated before and after the 14-wk experimental period for pubertal state (Tanner's sexual maturity rating, serum testosterone, and serum dihydroepiandrosterone sulfate). Effectiveness of the strength training program was determined by measuring pre-post differences in: isokinetic strength for flexion and extension at the knee and elbow joints at two speeds ($30° $ and $90°\cdot s^{-1}$) (KIN COM, Chattecx, Inc., Chattanooga, TN), flexibility, standing long jump, vertical jump, body composition parameters, maximal oxygen consumption, and creatinine phosphokinase. Safety of strength training was assessed by biphasic musculoskeletal scintigraphy before and after the program and by physician evaluation of complaints by subjects. Strength training subjects (N = 16) participated in a 45 min/session, 3 session/wk, 14-wk supervised strength training program with an attendance rate of 91.5%. Participants performed concentric work using hydraulic resistance equipment (Hydra-Fitness Industries, Belton, TX). Eccentric work was not performed. Control subjects (N = 10) did not strength train but did participate in sport activities and activities of daily living. Results indicated that strength training subjects increased isokinetic strength as a result of strength training (average concentric work/repetition ↑ by 18.5 to 36.6% for the eight motions tested; torque scores over the first 90% of the range of motion ↑ by 13.1 to 45.1% for the eight motions tested). These changes were significantly greater than changes seen in the control group ($P < 0.05$). Strength training subjects also demonstrated significant improvements (as compared to control subjects) in vertical jump (+10.4%), flexibility (+8.4%), and maximal oxygen consumption [+19.4% ($l\cdot min^{-1}$), +13.8% ($ml\cdot kg\cdot min^{-1}$)] after the experimental period. Musculoskeletal scintigraphy revealed no evidence of damage to epiphyses, bone, or muscle as a result of strength training. Only one strength training-related injury was reported (left shoulder pain, 3 strength training sessions missed). In contrast, six strength training subjects sustained injuries during activities of daily living, resulting in 47 missed strength training sessions. It was concluded that, in the short term, supervised concentric strength training using hydraulic resistance equipment is safe and effective in pre-pubertal boys.

ISOKINETIC STRENGTH, CIRCUIT TRAINING, $\dot{V}O_{2max}$, MUSCULOSKELETAL SCINTIGRAPHY, SERUM LIPIDS

Increasing muscular strength as a result of a strength training program has been well documented in adults [for a review see Atha (3)]. Currently, there is controversy as to the safety and effectiveness of strength training in children. The American Academy of Pediatrics has suggested that "maximal benefits are obtained from appropriate weight training in the post-pubertal athlete, and minimal benefits are obtained from weight training in the prepubertal athlete" (1): Insufficient quantities circulating androgens have been suggested as a rationale for limiting strength training in pre-pubertal males (1). In contrast, it has been suggested by Micheli et al. [unpublished findings; (6)] and Sewell and Micheli (24) that pre-adolescent boys show large isometric strength gains as a result of a 12-wk isotonic strength training program.

To our knowledge, the issue of effectiveness and safety of strength training in pre-pubertal children has not been examined in a controlled setting. Because training improvement in neuromuscular power may be related to enhanced recruitment of motor units (9) as well as hypertrophy of individual muscle fibers, one can speculate that the pre-pubertal child may increase strength in the absence of sufficient concentrations of circulating androgens. In the present study, we have examined this hypothesis.

METHODS

Subjects. Thirty-two boys between the ages of 6 to 11 volunteered as subjects, and parental written consent was obtained.

Medical evaluation. All subjects were medically evaluated before and after the 14-wk experimental period by the same physician (C.B.R.). The evaluation was performed to: i) rule out medical conditions contraindicating strength training; ii) insure all boys were prepubertal; and iii) evaluate the safety of this particular strength training program.

A comprehensive history and physical examination, including a detailed musculoskeletal examination, was conducted to document pre-existing orthopedic injuries

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and conditions. This included an evaluation of flexibility, joint range of motion, and joint integrity. No volunteer was eliminated because of orthopedic injury or abnormality or because of another medical contraindication.

Pubertal status. A pre-adolescent examination by the method of Tanner was performed (15). This included separate ratings for pubic and axillary hair of the genitalia as well as gonadometry to estimate testicular volume. A testicular volume of less than 4 ml is considered pre-pubertal. In addition, serum concentrations of testosterone and dihydroepiandrosterone-sulfate (DHEA-S) were measured. A testosterone level less than 20 $ng \cdot dl^{-1}$ is considered pre-pubertal. DHEA-S is an adrenal androgen that is, in part, responsible for the growth of pubic hair. Levels less than 600 $ng \cdot ml^{-1}$ are considered pre-adrenarchal (15). Three of the original 32 volunteers were rejected because of advanced pubertal status (pubic hair, Tanner stage 2, and/or enlarged testicular volume, 6 ml or greater). Bone age estimation was not performed because the above indices were collectively considered adequate to establish prepubertal status.

The remaining 29 subjects were assigned to a strength training (N = 19) or control group (N = 10). All but three subjects (1 strength training, 2 control) were actively participating in one or more organized sport activities (ice hockey, swimming, football, basketball, soccer, and tennis) at the time of the study. The mean age of these 29 subjects was 8.2 ± 1.3 yr.

Strength training. Strength training subjects participated in a closely supervised, 3 $d \cdot wk^{-1}$, 14-wk strength training program. Each session was 45 min in duration and consisted of 5 to 7 min of warm-up exercises that included stretching, 30 min of strength training, and 5 to 7 minutes of cool-down exercises that also included stretching. Strength training was performed in a circuit fashion which consisted of eight hydraulic resistive machines (Hydra-Fitness Industries, Belton, TX). Two additional stations that consisted of sit-ups and stationary cycling were included in the circuit. The hydraulic resistance devices allowed for concentric reciprocal movement and included the following: biceps/triceps, bench press, quadriceps/hamstring, shoulder press, abduction/adduction hip, butterfly, forearm conditioner, and jump squat.

One circuit consisted of exercise for 30 s at each of the 10 stations, with 30 s rest between stations. On the hydraulic resistance devices, the subject attempted as many repetitions as possible in 30 s. All subjects began training at the lowest of six resistance settings. When a subject could perform 30 or more repetitions at a given resistance setting, he was allowed to advance the resistance by one setting on that particular machine. Each subject completed 3 circuits during a single training session. No strength training activities were allowed outside of the supervised setting.

Control subjects continued to participate in their organized sport activities and activities of daily living (ADL) during the 14 wk. No control subject strength trained during the experimental period. In addition to the organized strength training program, strength training subjects participated in their organized sport activities and ADL during the study.

The following parameters were measured and/or monitored before and after the training period.

Strength. Strength was measured using an isokinetic dynamometer (KIN COM, Chattecx, Inc., Chattanooga, TN). Subjects were evaluated for concentric strength (eccentric work was performed by the investigator) at the knee and elbow joints for both flexion and extension at speeds of 30° and 90°$\cdot s^{-1}$. Average concentric work (Joules) and average torque (N-m) at each 10% of the range of motion (ROM) were also measured.

Performance measures. After three to five practice trials, each subject completed three trials of the standing long jump and vertical jump. The average of the three trials was used as the criterion score.

Flexibility. Flexibility of the lower back and hamstrings was measured using the sit and reach test suggested by the American Alliance of Health, Physical Education, Recreation, and Dance (2).

Anthropometric and body composition parameters. Body circumferences and skinfold measurements were taken following guidelines outlined by Behnke and Wilmore (4). Circumferential measurements were taken at the following sites: head, neck, shoulders, chest, waist, umbilicus, buttocks, thighs, knees, calves, ankles, deltoids, biceps flexed, biceps extended, forearms, and wrists. Skinfolds were taken in triplicate at the following sites: chin, chest, scapula, triceps, mid-axillary, waist, supra-iliac, abdominal, thigh, knee, and calf.

Body density was assessed by hydrostatic weighing. Each subject was weighed in air on an Accu Weigh beam scale accurate to 0.1 kg and weighed underwater with a Chatillon autopsy scale accurate to 10 g. Underwater weight was assessed at residual volume for at least 10 trials (17). The average of the last three trials was used as an estimate of the true underwater weight score for body density determination (16). Residual volume was determined using a nitrogen washout technique. The formula of Lohman et al. (20), for pre-pubertal children, was used to calculate percent body fat from body density.

Maximal oxygen consumption. $\dot{V}O_{2max}$ was measured using a walking treadmill protocol. The initial stage was at 0% grade, and the subjects walked at a self-selected speed between 3 to 3.5 mph. Speed remained constant, and the elevation of the treadmill was increased by 2½% every 2 min until voluntary exhaustion. Subjects were verbally encouraged throughout the duration of the test. The identical speed was used within each subject pre- and post-training.

Metabolic parameters were measured using standard open circuit spirometery. Inspired ventilation was measured using a Rayfield Spirometer fitted with a potentiometer. Output from the spirometer was continuously integrated into an Apple IIe microcomputer (Rayfield Ltd., Chicago, IL). Expired ventilation was channeled from a Hans Rudolph high velocity valve through low resistance plastic tubing into a 5-l mixing chamber. The concentration of oxygen and carbon dioxide in the mixing chamber was continuously sampled using Applied Electrochemistry oxygen and carbon dioxide analyzers. Output from the gas analyzers was integrated into the microcomputer. The analyzers were calibrated using commercial gases of known concentration (micro-Scholander technique). Heart rate was determined electrocardiographically.

Blood analysis. Pre- and post-fasting blood samples were drawn for the measurement of serum testosterone, DHEA-S, and creatine phosphokinase (CPK).

Testosterone was determined using a solid-phase ^{125}I-radioimmunoassay designed for the quantitative measurement of testosterone in unextracted serum or plasma (Diagnostic Products Corporation, Los Angeles, CA). DHEA-S was measured using an adaptation of the direct radioimmunoassay method of Buster and Abraham (7) (Pantex, Santa Monica, CA). CPK was determined in accordance with procedures outlined by Rosalki (23). All subjects, with the exception of two control subjects, consented to the blood work procedures. For the experimental group, the post-training sample was drawn within 24 to 48 h of the final strength training session.

Safety. Safety of the strength training program was assessed by: i) biphasic musculoskeletal scintigraphy before and after the program (21, 25), and ii) physician evluation of complaints by the subjects. A description of the safety assessment is described in greater detail elsewhere (22).

RESULTS

Subjects. Sixteen of the 19 strength training subjects completed the study. One subject moved outside the study area, and two subjects sustained injuries during sport activities and ADL which prohibited post-testing. All 10 control subjects completed the study. The attendance rate for the 16 strength training subjects was 91.5%.

Pubertal status. All subjects were pre-pubertal. One subject had two pigmented pubic hairs (early SMR2) and an elevated DHEA-S concentration, but a testicular volume of 2 ml, and a testosterone level of <20 ng·dl^{-1}. All but one subject had testicular volumes of 4 ml or less. He had a testicular volume of 6 ml, but no pubic hair (SMR1). All but one subject had serum testerone levels of <20 ng·dl^{-1} both before and after training. The subject (strength training group) who had a testicular volume of 6 ml had a pre-training testosterone level of 72 ng·dl^{-1} and a post-training testosterone level of 172 ng·dl^{-1}. However, his testicular volume and his SMR remained unchanged. Three subjects in the strength training group and three control subjects had DHEA-S levels >600 ng·ml^{-1} pre-training. Their scores remained unchanged at post-testing.

Strength. Table 1 shows average concentric work/repetition for the two experimental groups, at each motion and speed before and after training. A 2 × 2 ANOVA with repeated measures was used to analyze each individual movement. Since the present study is concerned with magnitude of strength change (Δ) pre- to post-, the statistic of relevance is the two-way interaction. Table 1 shows that the strength training group gained in strength in all eight motions (% change ranged from +18.5 to +36.6%). For all but three motions, a significant two-way interaction was present, indicating that the change in $\bar{X}$ work for the strength training group was greater than the change in $\bar{X}$ work for the control group, $P < 0.05$. A similar trend was observed

TABLE 1. Changes in average isokinetic concentric work/repetition (Joules) as a result of strength training.

		Average Concentric Work/Repetition (Joules) $\bar{X}$ (SD)					
		Strength Training Group (N = 16)			Control Group (N = 10)		
Movement	ROM	Pre	Post	% Change	Pre	Post	% Change
Knee flexion: 30°·s^{-1}	110°	19.5 (5.4)	24.1 (7.5)	+23.6	21.1 (5.9)	20.9 (5.9)	−1.0*†
Knee flexion: 90°·s^{-1}	110°	16.2 (3.8)	19.6 (6.3)	+21.0	18.1 (6.4)	17.1 (4.9)	−5.5*†
Knee extension: 30°·s^{-1}	90°	26.9 (10.3)	33.5 (12.2)	+24.5	38.5 (15.6)	38.4 (18.3)	−0.3*†
Knee extension: 90°·s^{-1}	90°	23.6 (9.1)	28.0 (13.1)	+18.6	31.0 (14.8)	32.5 (17.6)	+4.8*
Elbow flexion: 30°·s^{-1}	90°	11.3 (3.7)	14.6 (5.5)	+29.2	9.6 (4.0)	9.5 (4.1)	−1.0*†
Elbow flexion: 90°·s^{-1}	90°	10.1 (4.0)	13.8 (5.7)	+36.6	8.5 (4.1)	9.0 (3.6)	+5.9*†
Elbow extension: 30°·s^{-1}	90°	11.5 (3.3)	15.2 (3.6)	+32.1	11.7 (3.7)	13.4 (5.3)	+14.5*
Elbow extension: 90°·s^{-1}	90°	11.2 (3.2)	13.3 (3.3)	+18.5	9.6 (3.9)	11.0 (4.8)	+14.6*

* Main effect, post > pre, $P < 0.05$.

† Significant two-way interaction, $P < 0.05$.

for the three motions where significant two-way interaction was not present.

Comparison of torque scores before and after training, over the first 90% of the ROM, for each individual movement is shown in Figures 1 to 8. For each movement, a 2 × 2 × 9 ANOVA with repeated measures was used (pre- vs post- × experimental vs control × ROM over 9 levels). When significant two-way interactions were observed (there were no significant three-way interactions), subsequent ANOVA analyses were performed.

For knee flexion: 30°$\cdot s^{-1}$, a significant two-way interaction was present over the entire ROM (Δ strength training > Δ control, $P < 0.05$). The improvement in torque for the strength training group ranged from +15.6% (80% ROM) to +43.3% (20% ROM). The control group showed changes in torque ranging from −11.5% (50% ROM) to +17.9% (10% ROM) (Fig. 1). Similar results were found for knee flexion: 90°$\cdot s^{-1}$ and for both speeds of knee extension (Figs. 2 to 4). For each of these movements, a significant two-way interaction was present over the entire ROM. For knee flexion: 90°$\cdot s^{-1}$, the strength training group showed increased torque that ranged from +14.4% (70% ROM) to +25.8% (40% ROM), while the change in torque for the control group ranged from −12.3% (50% ROM) to −1.7% (20% ROM) (Fig. 2). For knee extension: 30°$\cdot$ s^{-1}, the strength training group showed increased torque ranging from +16.9% (40± ROM) to +42.2% (90% ROM), while the change in torque in the control group

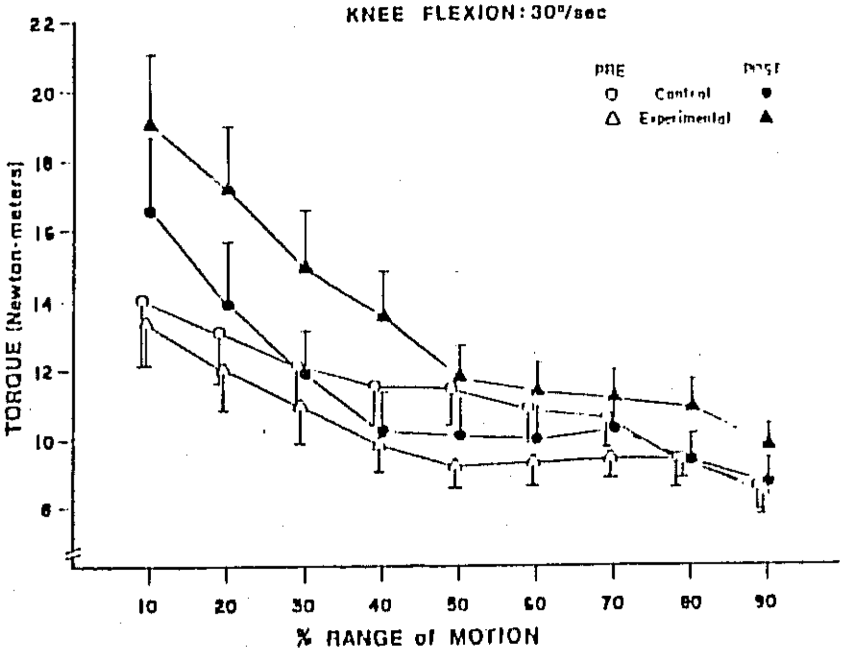

Figure 1—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for knee flexion: 30°$\cdot s^{-1}$. Control (N = 10) and strength training (experimental, N = 16) groups.

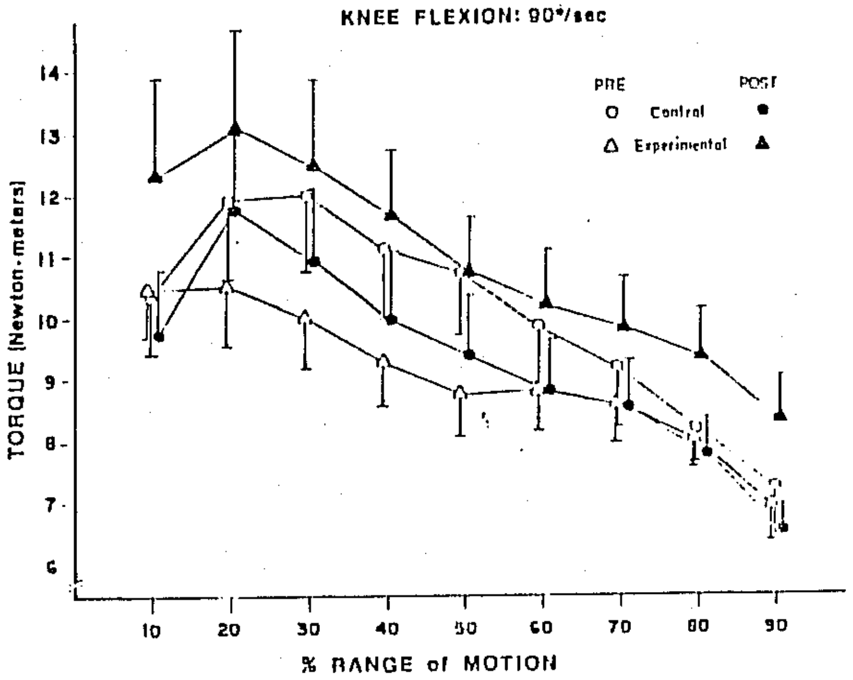

Figure 2—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for knee flexion: 90°$\cdot s^{-1}$. Control (N = 10) and strength training (experimental, N = 16) groups.

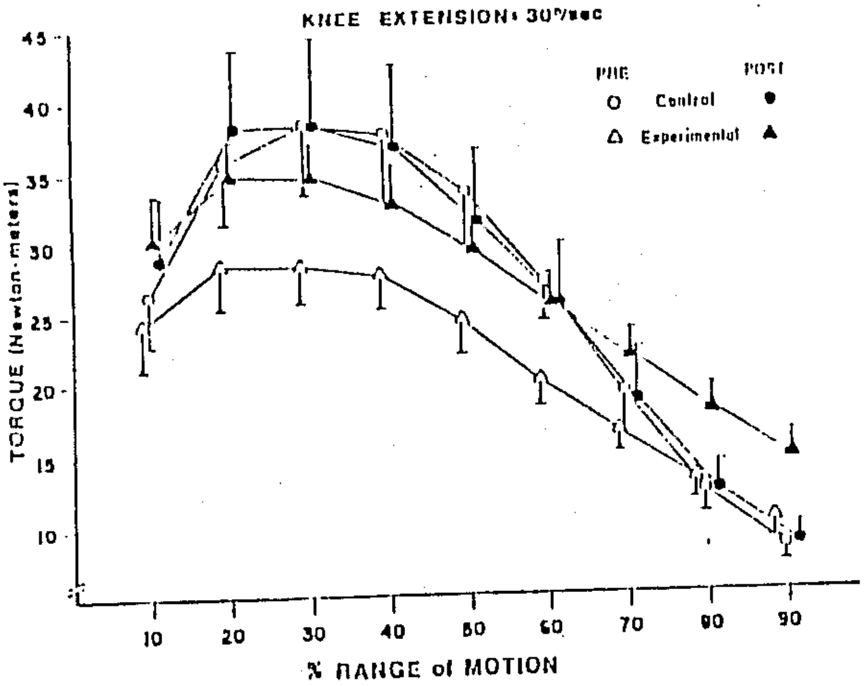

Figure 3—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for knee extension: 30°·s⁻¹. Control (N = 10) and strength training (experimental, N = 16) groups.

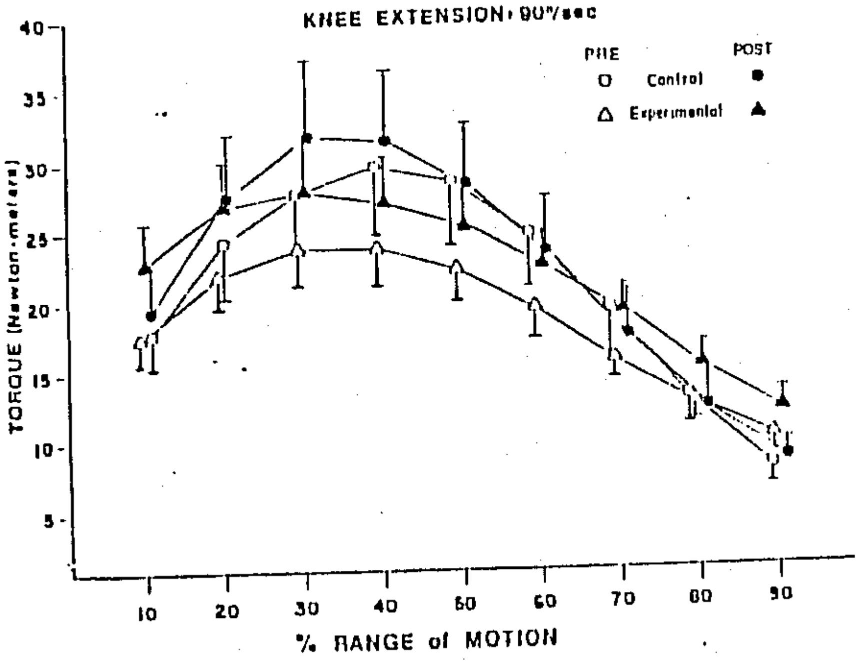

Figure 4—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for knee extension: 90°·s⁻¹. Control (N = 10) and strength training (experimental, N = 16) groups.

ranged from −8.1% (60% ROM) to +9.9% (10% ROM) (Fig. 3). For knee extension: 90°·s^{-1}, the strength training group showed increases in torque ranging from +13.1% (40% ROM) to +30.1% (10% ROM), while the change in torque in the control group ranged from −9.4% (70% ROM) to +14.6% (30% ROM) (Fig. 4).

Similar results were observed when the four elbow movements were examined. For both speeds of elbow flexion, significant two-way interactions existed over the entire ROM (Figs. 5 and 6). For elbow flexion: 30°·s^{-1}, the strength training subjects showed increases in torque ranging from +19.4% (40% ROM) to +38.8% (90% ROM), while the change in torque in the control group ranged from −16.4% (20% ROM) to +19.1% (90% ROM) (Fig. 5). For elbow flexion: 90°·s^{-1}, the strength training group showed increases in torque ranging from +30.5% (30% ROM) to +45.1% (90% ROM), while the control group showed changes in torque ranging from −7.7% (10% ROM) to +25.0 (90% ROM) (Fig. 6). When the two elbow extension movements were analyzed, it was revealed that the post-torque scores were significantly greater than the pre-torque scores. While a trend was present which suggested that the change in strength training group torque scores was greater than the change in control group torque scores, a significant two-way interaction was not present. However, when the average of the nine torque scores were compared (t-tests, dependent measures), the following results were observed: i) for elbow extension: 30°·s^{-1}, the mean change in the torque score of

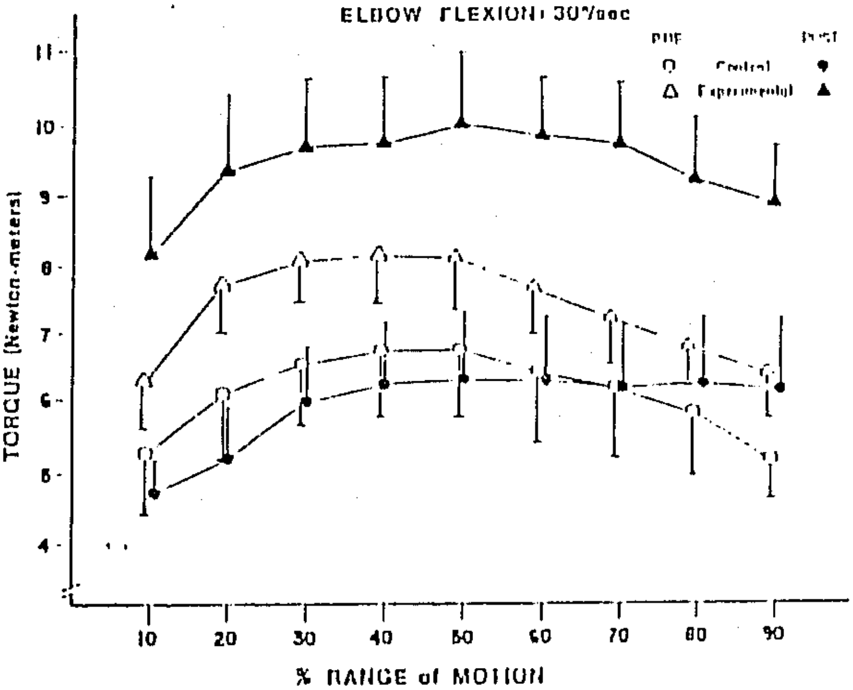

Figure 5—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for elbow flexion: 30°·s⁻¹. Control (N = 10) and strength training (experimental, N = 16) groups.

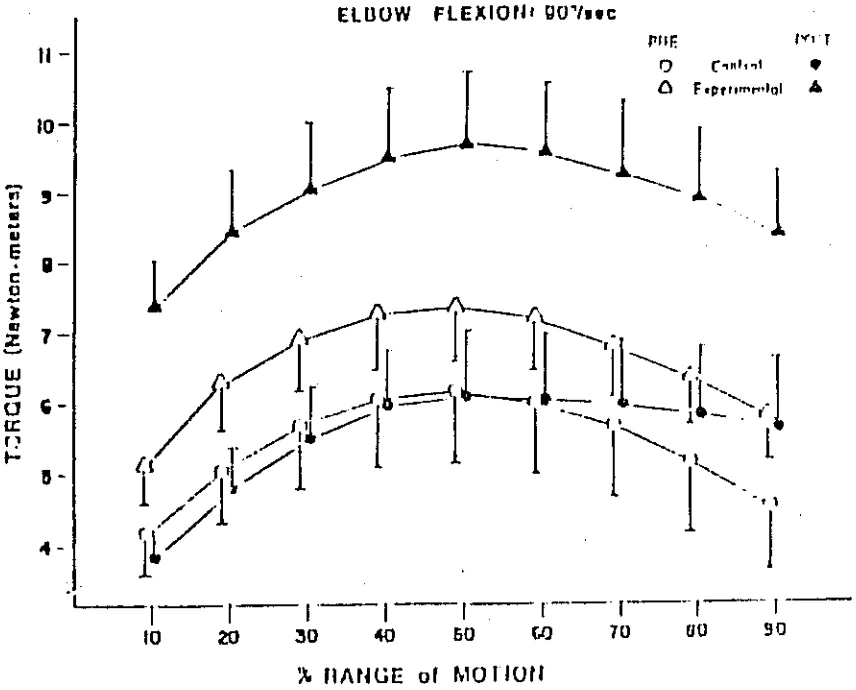

Figure 6—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for elbow flexion: 90°·s⁻¹. Control (N = 10) and strength training (experimental, N = 16) groups.

the strength training group was greater than the mean change in the torque score of the control group (1.97 N-m vs 1.42 N-m $P < 0.05$); ii) for elbow extension: 90°·s⁻¹, the mean change in the torque score of the strength training group = 1.47 N-m, while the mean change in the torque score of the control group = 0.89 N-m, $P < 0.05$.

Performance measures. Changes in the standing long jump and vertical jump with that of training are presented in Table 2. A 2 × 2 ANOVA with repeated measures was used to analyze each of these parameters. While no difference was seen between groups or before and after training for the standing long jump, the change in vertical jump performance in the strength training group (+10.4%) was greater than the change in vertical jump performance in the control group (−3.0%) ($P < 0.05$).

Flexibility. A 2 × 2 ANOVA with repeated measures revealed that the increase in the sit and reach score of +8.4% in the strength training group was significantly greater than the change in the sit and reach score of the control group (−1.2%) ($P < 0.05$, Table 2).

Anthropometric and body composition parameters. Changes in anthropometric and body composition parameters were measured using 2 × 2 ANOVA techniques with repeated measures. Both groups increased in height and weight during the 14 wk (Table 2, $P < 0.05$). Although a trend for greater growth rate was

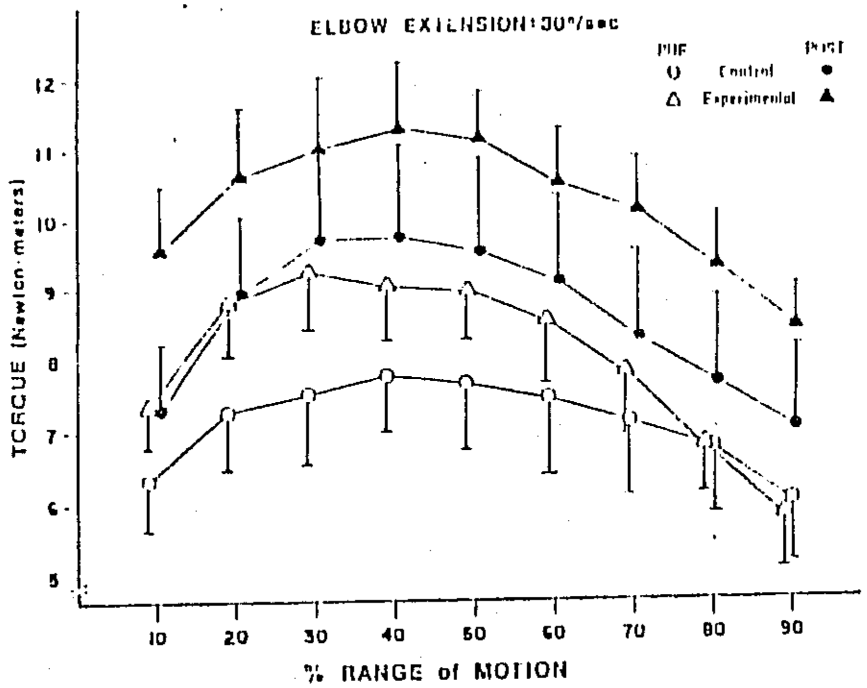

Figure 7—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for elbow extension: 30°·s^{-1}. Control (N = 10) and strength training (experimental, N = 16) groups.

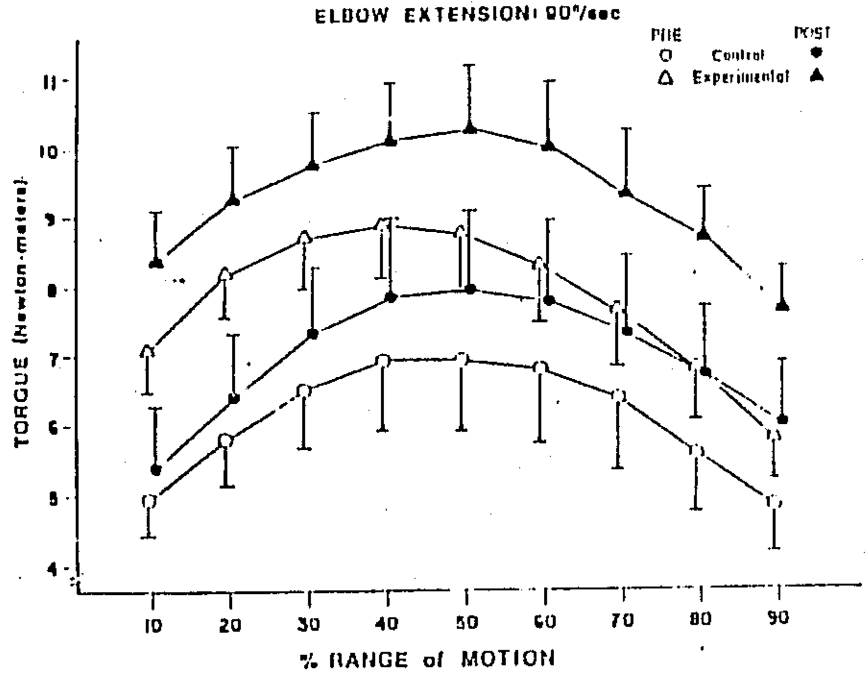

Figure 8—Comparison of torque scores, before and after training, over the first 90% of the range of motion, for elbow extension: 90°·s^{-1}. Control (N = 10) and strength training (experimental, N = 16) groups.

observed in the strength training group, a significant two-way interaction was not observed for height. A significant two-way interaction was observed for weight with the change in weight in the strength training group being significantly greater than the change in weight in the control group.

No significant main effects or interactions were observed for any of the skinfold sites measured. For circumferences, the only sites where significant two-way interactions were observed occurred at the shoulder, chest, and average abdomen (increased circumference scores in the strength training group). Body density did not change significantly during the study (Table 2).

Maximal oxygen consumption. $\dot{V}O_{2max}$ and other parameters measured during the $\dot{V}O_{2max}$ test are presented in Table 3. Each variable was analyzed using a 2 × 2 ANOVA with repeated measures. $\dot{V}O_{2max}$ increased in the strength training group (+19.4% and +13.8% when expressed in l·min^{-1} and ml·kg·min^{-1}, respectively). The control group showed decreases in $\dot{V}O_{2max}$ of −2.7% (l·min^{-1}) and −5.4% (ml·kg·min^{-1}). A significant two-way interaction was observed for $\dot{V}O_{2max}$ ($P < 0.05$). Similar results were observed for treadmill time (Table 3). No significant differences were observed between groups or before or after training for respiratory exchange ratio and maximal (peak) heart rates (Table 3).

Blood analyses. CPK changes were analyzed using

TABLE 2. Changes in performance measures, flexibility, and body composition parameters as a result of strength training.

	Strength Training Group (N = 16)			Control Group (N = 10)		
Variable	Pre $\bar{X}$ (SD)	Post $\bar{X}$ (SD)	% Change	Pre $\bar{X}$ (SD)	Post $\bar{X}$ (SD)	% Change
Standing long jump (cm)	124.0 (14.3)	128.6 (19.2)	+3.0	126.1 (12.5)	129.3 (15.9)	+1.7
Vertical jump (cm)	21.1 (4.8)	23.3 (3.4)	+10.4	22.7 (3.9)	22.0 (2.5)	−3.0*†
Sit and reach (cm)	39.2 (6.4)	42.5 (6.2)	+8.4	38.5 (3.0)	38.0 (3.8)	−1.2*†
Height (cm)	134.0 (7.0)	136.0 (7.1)	+1.5	132.5 (9.3)	133.4 (9.0)	+0.7*
Weight (kg)	29.87 (6.84)	31.50 (7.59)	+5.5	27.32 (6.12)	27.91 (5.54)	+2.2*†
Body density ($g \cdot cm^{-3}$)	1.060 (0.018)	1.056 (0.018)	−0.4	1.052 (0.013)	1.056 (0.009)	+0.4
Skinfolds (mm)						
Chin	3.71 (1.15)	4.06 (1.14)	+9.4	3.71 (0.79)	3.72 (0.83)	+0.2
Chest	7.64 (4.86)	7.98 (5.29)	+4.4	6.45 (2.93)	5.49 (2.12)	−14.9
Scapula	7.23 (3.08)	7.21 (3.04)	−0.3	6.18 (1.99)	6.19 (1.41)	+0.2
Triceps	10.47 (3.75)	10.69 (4.15)	+2.1	8.96 (2.25)	9.51 (1.83)	+6.1
Mid axillary	6.89 (4.63)	6.61 (1.23)	−3.8	5.07 (1.83)	5.01 (1.62)	−1.2
Waist	8.44 (4.95)	7.81 (4.80)	−7.5	7.16 (3.33)	6.44 (1.25)	−10.0
Iliac crest	6.63 (6.24)	6.50 (5.55)	−1.9	4.96 (2.10)	3.90 (1.36)	−21.3
Abdomen	9.85 (7.18)	10.65 (7.44)	+8.1	8.69 (5.46)	8.17 (4.17)	−6.0
Thigh	13.31 (3.84)	14.98 (3.99)	+12.5	11.80 (3.78)	11.53 (3.02)	−2.3
Knee	6.10 (2.02)	6.90 (3.00)	+13.1	5.65 (0.99)	5.78 (1.00)	−2.3
Calf	10.99 (3.67)	12.00 (4.01)	+9.2	10.57 (3.13)	9.90 (2.07)	−6.3
Circumferences (cm)						
Head	53.16 (1.86)	53.39 (1.81)	+0.4	52.10 (1.39)	52.17 (1.75)	+0.1
Neck	27.53 (1.85)	27.98 (2.52)	+1.6	27.29 (1.77)	26.96 (1.43)	−1.2
Shoulder	77.87 (6.00)	79.28 (6.21)	+1.8	76.99 (5.44)	74.33 (7.61)	−3.5†
Chest	64.62 (5.36)	66.23 (5.70)	+2.5	63.24 (4.49)	62.96 (4.83)	−0.4†
Average abdomen	57.81 (6.30)	60.17 (6.70)	+4.1	57.60 (5.95)	57.63 (4.93)	+0.1*†
Buttocks	68.43 (7.00)	67.86 (10.53)	−0.8	65.67 (5.86)	65.57 (5.01)	−0.2
Thigh (right)	38.07 (6.14)	37.84 (5.39)	−0.6	35.74 (5.17)	35.65 (4.00)	−0.3
Knee (right)	28.01 (2.22)	28.36 (2.51)	+1.2	27.33 (2.56)	26.89 (2.29)	−1.6
Calf (right)	26.32 (2.92)	27.10 (3.00)	+2.9	25.21 (2.02)	25.38 (2.45)	+0.7
Ankle (right)	18.47 (1.94)	18.41 (1.72)	−0.3	17.33 (1.40)	17.44 (1.48)	+0.6
Deltoid (right)	21.69 (2.80)	21.95 (2.96)	+1.2	19.99 (2.56)	21.42 (3.02)	+7.1
Biceps extended (right)	19.22 (2.54)	20.56 (2.42)	+7.0	18.20 (2.24)	18.44 (2.02)	+1.3
Biceps flexed (right)	20.98 (2.65)	21.79 (2.89)	+3.9	19.68 (2.00)	20.17 (2.00)	+2.5
Forearm (right)	18.98 (2.10)	19.58 (2.12)	+3.2	17.61 (1.74)	18.72 (1.07)	+6.3
Wrist (right)	13.19 (0.88)	13.41 (1.07)	+1.7	12.61 (0.97)	12.91 (1.01)	+2.3

* Main effect post > pre, $P < 0.05$.

† Significant two-way interaction, $P < 0.05$.

TABLE 3. Changes in $\dot{V}O_{2max}$ and other parameters measured during the $\dot{V}O_{2max}$ test as a result of strength training.

	Strength Training Group (N = 16)			Control Group (N = 10)		
Variable	Pre $\bar{X}$ (SD)	Post $\bar{X}$ (SD)	% Change	Pre $\bar{X}$ (SD)	Post $\bar{X}$ (SD)	% Change
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	1.39 (0.26)	1.66 (0.32)	+19.4	1.48 (0.31)	1.44 (0.26)	−2.7*†
$\dot{V}O_{2max}$ ($ml \cdot kg \cdot min^{-1}$)	46.79 (3.48)	53.23 (4.61)	+13.8	54.62 (3.12)	51.69 (2.59)	−5.4*†
Treadmill time (min)	15.0 (1.9)	17.1 (1.9)	+14.0	17.0 (1.5)	16.9 (1.7)	−0.5*†
Respiratory exchange ratio	1.00 (0.05)	1.03 (0.05)	+3.0	1.01 (0.05)	1.02 (0.04)	+1.0
Maximal heart rate	197.8 (5.2)	199.9 (5.7)	+1.1	200.5 (9.0)	196.9 (7.2)	−1.8

* Main effect post > pre, $P < 0.05$.

† Significant two-way interaction, $P < 0.05$.

a 2 × 2 ANOVA with repeated measures with no significant changes observed.

Safety. The safety aspects of hydraulic resistance strength training in these children has been presented in greater detail elsewhere (22). Briefly, the musculoskeletal phase of scintigraphy showed no evidence of damage to muscules in either group. There was no evidence of damage to muscle tissue or bone attributable to strength training.

Injuries. Injury data have also been presented in greater detail elsewhere (22). Briefly, six strength training subjects sustained injuries outside of the strength training program (ADL and sport activities). These injuries accounted for 47 subjects/sessions missed of a total 756 subject/sessions. In contrast, only one subject missed 3 sessions due to a complaint arising during strength training (22).

DISCUSSION

Strength. The major finding of the present study was that a short term, closely supervised resistance strength training program that utilizes hydraulic exercise devices significantly increased concentric isokinetic strength in pre-pubertal boys. The observed increases in average isokinetic concentric work of +18.5 to +36.6% (Table 1), as well as the increases observed in torque over the full range of motion (Figs. 1 to 8), compare favorably with previously reported strength gains in adult males (9, 14, 19). The present data also support the observation of Clarke et al. (8) that a competitive season of a strength-related sport (wrestling) significantly improved leg strength and arm endurance in young boys. In further support of the above observation, the only movement that resulted in a significant improvement in the control group was elbow extension. Since the majority of subjects (both strength training and control) were involved in a competitive ice hockey season during the time of the study, this may help to explain the improvement observed in this motion. It should be noted, however, that the strength training group improved to a greater degree than might be attributable to competing in a strength-related sport (Figs. 7 and 8).

The present data do not support the contention of the American Academy of Pediatrics that weight training should not be attempted by pre-pubertal boys because they do not have sufficient levels of circulating androgens to improve strength (1). It has been shown that women (with low levels of circulating androgens) can significantly improve strength without appreciable muscular hypertrophy (26). It has recently been suggested that muscular hypertrophy is only one of the physiological adaptions that may be responsible for training-induced improvements in neuromuscular power (9). Several factors, such as the number of motor units recruited as well as their synchronization, may also control the development of neuromuscular power (9). Indeed, Hakkinen and Komi (13) have reported that initial increases in strength, as a result of strength training, can be accounted for by neural factors rather than by hypertrophic factors. Since the boys in the present study increased muscular strength in the absence of increased circumference scores (Table 2, presumably no muscular hypertrophy occurred), the increases in strength were probably the result of neural adaptations.

Performance and flexibility measures. One may speculate that motor performance that involves neuromuscular power should be enhanced after strength training. The present study weakly supports this suggestion, in that vertical jump was significantly improved in the strength-trained group when compared to the control group (Table 2). An interesting anecdotal finding was the fact that parents consistently reported improved performance of the strength-trained subjects in their organized sports activities. Furthermore, parents also reported that, in the hours that immediately followed strength training, the children appeared to be more attentive to homework and other activities than they were on days when weight training was not performed.

With respect to flexibility changes, it should be noted that stretching exercises were performed during the warm-up and cool-down phases of the strength training sessions. While a more specific test of joint flexibility was not available in the present study, the fact that low back and hamstring flexibility improved (sit and reach, Table 2) in the strength training group is supportive of the suggestion that a proper strength training program, which also includes a specific flexibility routine, does not cause a loss of flexibility (1).

Anthropometric and body composition parameters. There was little change in body composition and anthropometric parameters (Table 2). This differs from previous findings in adults which indicate that both men and women reduce percent body fat and skinfold thickness consequent to short-term strength training (26).

It should be realized, that the boys in the present study were growing (Table 2). It is, however, interesting to note that the strength-trained group gained a significantly greater amount of weight and showed a trend for greater height gain as compared to the control group (Table 2). These data support the suggestion of Ekblom (10) that physical training in adolescent boys may result in an accelerated rate of increase in stature with age.

Maximal oxygen consumption. The increases observed in $\dot{V}O_{2max}$ of +19.4% ($l \cdot min^{-1}$) and +13.8 ($ml \cdot kg \cdot min^{-1}$) in the strength training group (the control group did not change, Table 3) differ from recent data in adults. Hurley et al. (14) reported that, while 16 wk of high-intensity, variable resistance Nautilus strength training (using the manufacturer's recommendation) increased strength in adult males, maximal oxygen consumption was not affected by Nautilus training. Perhaps the increase in $\dot{V}O_{2max}$ observed in the present study may be related to the reciprocal concentric nature of the hydraulic resistance training devices and the volume of exercise performed in a given training session. In support of the above, Katch et al. (18) reported the MET level and caloric expenditure of hydraulic resistance exercise were considerably higher than values compared for exercise using free weights, Nautilus, or Universal Gym equipment. This increased energy expenditure may help explain the increase observed in $\dot{V}O_{2max}$ in the present study. In addition, as Gettman and Pollock (11) pointed out, improvements in $\dot{V}O_{2max}$ as a result of circuit weight training depends on the amount of work performed. The fact that three sets of up to 30 repetitions per set was performed may also have contributed to the increase observed in $\dot{V}O_{2max}$. Therefore, the changes in $\dot{V}O_{2max}$ observed in the present study need to be confirmed in future work.

Safety. The importance of adequate supervision in preventing strength training-related injuries has been emphasized (1, 5, 12). Documentation of injuries during the experimental period revealed that this supervised, concentric hydraulic resistance strength training program was safe (22). In addition, bone scintigraphy showed no evidence of injury, at least in the short-term follow-up, as a result of strength training. In the few subjects who showed abnormal bone scans (both strength training and control), it was concluded that the observed abnormalities were related to ADL and/or sports activities rather than to strength training (22).

It appears that the risk of short-term musculoskeletal damage is minimal from this type of supervised strength training in pre-pubertal males. The fact that the program was closely supervised and almost no eccentric work was performed may, in part, account for these findings (22). It should be noted that we have reached no conclusion regarding the effects of this program on articular cartilage. None of the study methods used could address that issue.

CONCLUSIONS

We conclude that, in the short term, supervised concentric strength training using hydraulic resistance equipment is both effective and safe for pre-pubertal males. No conclusions can be stated, nor should any be inferred, regarding the effectiveness or safety of strength training which involves eccentric work, such as occurs in the use of free weights or commonly available isotonic-type machines.

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Present address for A. Weltman: Exercise Physiology Laboratory, Curry School of Education, Memorial Gymnasium, University of Virginia, Charlottesville, VA 22903.

Present address for C. Janney and F. I. Katch: Department of Exercise Science, University of Massachusetts, Amherst, MA 01003.

Present address for K. Strand: Department of Educational Administration, Illinois State University, Bloomington, IL 61701.

Address for correspondence: Arthur Weltman, Exercise Physiology Laboratory, Curry School of Education, Memorial Gymnasium, University of Virginia, Charlottesville, VA 22903.