Weight Training in Youth–Growth, Maturation, and Safety: An Evidence-Based Review

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Objective: To review the effects of resistance training programs on pre- and early-pubertal youth in the context of response, potential influence on growth and maturation, and occurrence of injury.

Design: Evidence-based review.

Methods: Twenty-two reports dealing with experimental resistance training protocols, excluding isometric programs, in pre- and early-pubertal youth, were reviewed in the context of subject characteristics, training protocol, responses, and occurrence of injury.

Results: Experimental programs most often used isotonic machines and free weights, 2- and 3-day protocols, and 8- and 12-week durations, with significant improvements in muscular strength during childhood and early adolescence. Strength gains were lost during detraining. Experimental resistance training programs did not influence growth in height and weight of pre- and early-adolescent youth, and changes in estimates of body composition were variable and quite small. Only 10 studies systematically monitored injuries, and only three injuries were reported. Estimated injury rates were 0.176, 0.053, and 0.055 per 100 participant-hours in the respective programs.

Conclusion: Experimental training protocols with weights and resistance machines and with supervision and low instructor/participant ratios are relatively safe and do not negatively impact growth and maturation of pre- and early-pubertal youth.

Key Words: resistance training, injuries, childhood, early adolescence, growth

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BACKGROUND

"Weight training" is a generic term that relates to a variety of dynamic resistance training programs based on progressive overload and designed to improve muscular strength and endurance. Historically, resistance training was not recommended for prepubertal children. It was generally believed that a lack of sufficient quantities of circulating androgenic hormones in prepubertal boys precluded strength improvement with resistance training. Secondary factors included risk of injury, potential for damage to growth plates, and premature closure of epiphyses because of excessive loads. Although there are some risks, resistance training is now recommended as a safe and effective means of developing strength in children and early adolescents, as long as the activities are performed in a supervised setting, with proper techniques and safety precautions.[1,2] In addition, resistance training has potentially beneficial effects on motor and sports performances, bone mineral content, and body composition, and in reducing sport injuries. In contrast, the value of resistance training has not been questioned for adolescent boys. Favorable responses to isometric and isotonic resistance training programs have been reported in boys described as pubertal and postpubertal or at ages commonly associated with later adolescence.[3]

Systematic surveillance information on injuries associated with resistance training programs in youth is not available. Catastrophic injuries and case reports and series associated with weight lifting, power lifting, and resistance training equipment receive more attention.[4–7]

OBJECTIVE

The present paper considers the effects of resistance training programs on pre- and early-pubertal youth in the context of growth, maturation, and safety. It specifically considers (1) responses to training programs, (2) the potential influence on indicators of growth and maturation, and (3) occurrence of injury. The paper builds, in part, on earlier reviews[8,9] and two meta-analyses.[10,11]

Data Sources and Synthesis

Reports dealing with experimental resistance training protocols in pre- and early-pubertal youth were identified (n = 22), reviewed, and evaluated. Studies based on young athletes and isometric protocols were not included. Subject characteristics (age, sex, maturity status), training protocol, outcome measures, analytical methods, main findings, conclusions, and observations on safety and injury were abstracted in a standardized, tabular format. Data for youth advanced in puberty were included when they were an integral component of the reviewed study.

Results and Discussion

Details of specific studies are summarized in Table 1.

Training Protocols

The majority of studies used 3 (12) and 2 days (8) of training, with rest days between. Most programs used isotonic

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TABLE 1. Experimental Studies of Resistance Training in Youth, Arranged Chronologically

Reference	Characteristics of Participants	Training Program	Statistical Analysis	Outcome Measure(s)	Main Findings	Conclusion
Vrijens[12]	Boys, n = 16, 10.5 yrs n = 12, 16.7 yrs, pre- & post-pubescent ages though pubertal status not apparently assessed	Concentric isotonic circuit, 8 exercises (arm, leg, back, abdomen), 8–12 reps, 75% 1RM, 3 times/wk, 8 wks	Pre/post, t tests	6 muscle groups, isometric tests: arm & leg flexors & extensors, back & abdominal muscles; soft tissue x-rays of arm & thigh	Negligible changes in young boys except abdominal and back strength; significant gains in older boys	Gains more apparent in older boys; significant gains in arm & thigh muscle areas of older boys; small changes in younger boys; **injuries not reported**
Pfeiffer and Francis[13]	Boys, 8-21 yrs E = experimental (trained), C = control Prepubertal: 15 E, 10.3 yrs 15 C. 9.7 yrs Pubertal: 15 E, 13.1 yrs 15 C, 12.5 yrs Postpubertal: 10 E, 19.7 yrs 10 C, 19.6 yrs; G/PH assessed, random assignment to E and C groups	Isotonic machine and free weights; 4 primary exercises, 5 ancillary; 3 sets of 10 reps for primary exercises; 3 times/wk, 9 wks	ANOVA; 33 E & 31 C completed the program; only relative gains considered	Strength of elbow & knee flexors & extensors	Significant gains in E compared to C; inconsistent relative gains across maturity groups; greater relative gains in elbow vs knee muscle groups: Elbow flexion, right (120°/sec) – Pre, +28.7 Pub, +13.9% Post, +10.5%; Knee extension, right (120°/sec) – Pre, +16.7% Pub, +13.2% Post, −1.0%	Gains in strength in E across maturity groups compared to C; variable relative gains by maturity groups; **injuries not reported**
Sewall and Micheli[14]	Boys & girls, 10–11 yrs, E = 10 (8b, 2g), C = 8 (7b, 1g); stages 1–2 secondary sex characteristics (specific criteria not indicated); method of group assignment not indicated	Nautilus thigh press and CAM II chest press & back row machines; 3 sets of 10 reps; ~25–30 min/session 3 times/wk, 9 wks	Repeated measures ANOVA & ANCOVA	Knee flexion & extension, shoulder flexion & extension strength; hip, knee & shoulder flexibility	Mean relative gains in strength: E 43%, C 9%; greater relative gains in E in each strength test, considerable variation among measures; similar gains in flexibility in E & C (4%), considerable variation among measures	Considerable variation in strength & flexibility gains between E & C; **no injuries associated with the training program were noted**
Weltman et al,[15] Rains et al[16]	Boys, 6–11 yrs, all prepubertal (PH, testicular volume); E = 18 & C = 10; volunteers, 1st 18 assigned to E; all but 3 involved in organized sports	Hydraulic machine circuit, 10 sec at each of 10 stations (8 hydraulic, sit-ups + stationary cycle), 30 sec rest between stations; ~45 min/session 3 times/wk, 14 wks	ANOVA; 16 E completed program	Strength of elbow and knee flexors and extensors; standing long jump (SLJ), vertical jump (VJ), flexibility (sit & reach); VO_{2max}	% change in E: Elbow +19% to 37%; Knee +19% to +24% % change in C: Elbow −1% to +15%; Knee −5% to +5%; SLJ, no change in E and C; VJ, greater gain in E (+10%) than C (−3%); Flex, greater gain in E (+8%) than C (−1%); VO_{2max}, greater gain/kg in E (+14%) than C (−5%)	Significant gains in strength, power (VJ), flexibility and VO_{2max}; **one injury during strength training; no evidence of damage to muscle and skeletal tissues in E; 6 E boys experienced injuries outside of the training program**
Sailors and Berg[17]	11 boys 12.6 ± 0.7 yrs all pubertal (PH, axillary hair), E = 5, C = 6; 9 men 24.0 ± 0.5 yrs, E & C; voluntary assignment	Weights: squats, bench press, arm curl; 3–10 reps at 65–100% 5 RM, 3 times/wk, 8 wks	Repeated measures ANCOVA	5 RM for squat, bench press, arm curl	Similar increases by boys & men: squat: 52% & 35%, press: 20% & 20%, curl: 26% & 28%	Similar strength – endurance gains in pubertal boys and young adult men; **injuries not reported**
Blimkie et al[18]	Boys, 9–11 yrs, all prepubertal (PH 1, serum free T); volunteers, E = 14 & C = 13; method of assignment not indicated; all involved in organized sports	Global Gym apparatus, circuit of 6 exercises; 5 sets primary & 3 sets secondary exercises per session, 75% 1 RM; 3 times/wk, 10 wks	Repeated measures ANOVA	1 RM bench press & double arm curl, isometric elbow flexion & extension strength	Significant gains by E in 1 RM bench press & double arm curl; no change in C for bench press; significant gains by E in absolute (16 to 38%) & relative (14 to 25%) isometric strength compared to C, absolute (−6 to 6%) & relative (−6 to −1%)	Significant gains in voluntary isometric strength independent of changes in estimated muscle cross-sectional area; **injuries not reported**

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TABLE 1. (*continued*) Experimental Studies of Resistance Training in Youth, Arranged Chronologically

Reference	Characteristics of Participants	Training Program	Statistical Analysis	Outcome Measure(s)	Main Findings	Conclusion
Siegel et al[19]	School-based, third grade, boys & girls: E = 26b, 24g ~8.5 ± 0.4 yrs; C = 30b, 16g ~8.5 ± 0.4 yrs; method of assignment not indicated; described as prepubertal but no indication that pubertal status was assessed	E: 30 min upper body resistance exercises, combination self-supported & weight activities, continuous, 30 sec work, 30 sec rest, progressing to 45 sec work, 45 sec rest; 3 X/wk, 12 wks C: 30 min free play	ANCOVA, pre-test as covariate	Strength & endurance: sit-ups, chin-ups, flexed arm hang, grip & elbow flexion & extension strength; flexibility: sit & reach; hours in sport-related activity per week-parental report	Significant gains in E compared to C: R grip +1.5 vs +0.3 kg; chin-ups +1.0 vs −0.2; flexed arm hang +6.8 vs −3.2 sec; sit & reach +2.5 vs −0.1 cm; others not significant; time in sport-related activity not related to strength & endurance	School-based resistance exercise program may improve strength, endurance & flexibility; **injuries not reported**
Ramsay et al[20]	Boys, 9–11 yrs, all prepubertal (PH 1, serum free T); E = 13 & C = 13; method of assignment not indicated; all involved in organized sports	Weights, circuit of 6 exercises; 5 sets primary & 3 sets secondary exercises per session; phase 1, 75% 1 RM; phase 2, 85% 1 RM; all except first set done to volitional failure; 3 X/wk, 20 wks	Repeated measures ANOVA	1 RM bench press & double leg press; maximal isokinetic & peak isometric strength of elbow flexors & knee extensors; muscular endurance: n reps of bench & leg press with pre-training 1 RM	Significant gains in E compared to C; performance strength gains E: bench press +35%, leg press +22%; similar gains in endurance; isokinetic gains E: elbow +26%, knee +21%; isometric gains E: elbow +37%, knee, sig only +25% at 90° & +13% at 120°	Significant gains in performance, isokinetic & isometric strength independent of changes in muscle cross-sectional area; **injuries not reported**
Faigenbaum et al[21]	Boys & girls, 8–12 yrs, E = 15, 11b & 4g; C = 10, 6b & 4g; stages 1 & 2 SSC (specific criteria not indicated); random assignment	Weight machines, 3 sets 5 primary exercises: leg curl, leg extension, chest press, overhead press, biceps curl + abdominal curls & leg raises; 10–15 reps, 50%, 75% & 100% of 10 RM; 2 X/wk, 8 wks	Repeated measures ANOVA	Strength: 10 RM leg extension, leg curl, bench press, overhead press, biceps curl; power: vertical jump, seated two hand medicine ball put (1.4 kg); flexibility: sit & reach; resting blood pressure	Significant gains in strength, E: leg extension (65%) leg curl (78%) chest press (64%) overhead press (87%), biceps curl (78%); C: mean gains (12–14%); small differences in power, E: jump (14%), put (4%); C: jump (8%), put (4%); no effects on blood pressure	Significant gains in strength; **no injuries occurred with the strength training program**
Isaacs et al,[22] Isaacs[23]	Girls, 7–11 yrs, matched for age & pubertal status (B or PH, estradiol): E = 9. C = 7, method of assignment not indicated	Free weights, knee extension, knee flexion, bench press, elbow flexion; 5 sets (15 reps/set or voluntary failure), loads set at 50%, 60%, 70% I RM; 3X/wk, 12 wks; follow-up after 8 wks no training; activity of control group not indicated	Pre-post comparison	1 RM for each of the 4 exercises	Significant gains in E compared to C in the four exercises, differences apparent by 6 wks; significant decrease in elbow flexor strength after 8 wks detraining in E; apparently not significant in other tests	Significant gains in strength in prepubertal-early pubertal girls; loss of strength with detraining more evident in non-weight-bearing muscles; **no injuries associated with the weight training program were noted**
Ozmun et al[24]	Boys & girls, 9–12 yrs, prepubertal (PH 1, B 1); E = 8, 3b & 5g; C = 8, 5b & 3g; randomly assigned to E & C	Dumbbell, right elbow flexors, 3 sets of 7–10 reps, 3 times/wk, 8 wks, gradual weight increment	ANOVA	Isokinetic & isotonic elbow flexion strength	Greater gains in isokinetic in E (+28%) than C (+15%), and in isotonic in E (+23%) than C (+4%)	Significant gains in strength without change in arm circumference; **injuries not reported**
Stahle et al[25]	Boys, 7–16 yrs, randomly assigned, 3 groups: 1: 2 days lift, n = 18; 2: 3 days lift, n = 18; 3: control, n = 19; equally distributed by age; pubertal status apparently not evaluated	Weights: 10 stations, load based on initial 1 RM, "perform as many repetitions as possible on each exercise using 75% of their 1 RM," resistance adjusted for next session based on number of reps; 2 or 3 X/week, 9 mo	Pairwise comparisons	Sum of 1 RM scores for each exercise	Significant gains in strength in groups 1 and 2, but no difference between groups	Weight training 2 and 3 times per week give similar results in boys 7–16 yrs; **no injuries associated with the weight training program were noted**

TABLE 1. (*continued*) Experimental Studies of Resistance Training in Youth, Arranged Chronologically

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Faigenbaum et al[26]	Boys & girls, 7–12 yrs; SSC: stages 1–2, specific criteria not indicated; E = 15, 11b & 4g, volunteers; C = 9, 3b & 6g, matched to E	Isotonic machine weights, 2–3 sets of 6 reps, 5 exercises, 2 X/wk, 8 wks; in 4th wk, 2–3 sets of 10–20 reps of abdominal curls and bent knee leg raises; follow-up after 8 wks of no training	Repeated measures ANOVA, paired t tests	6 RM chest press & leg extension; vertical jump-VJ; sit and reach-S&R	Greater gains in leg extension in E (+53%) than C (+6%), and in chest press in E (+41%) than C (+9%); no changes in VJ & S&R; after 8 wks of no strength training in E, decrease in leg ext (−28%) & chest press (−19%); no change in C	Significant gains in strength, but loss of strength after detraining; **injuries not reported**
Falk and Mor[27]	Boys 6–8 yrs, E n = 14 C n = 15; all prepubertal (PH,G)-assessed by parents; method of group assignment not indicated	E: upper body (variations of push-ups) & abdominal (variations of sit-ups) strength exercises, 3 sets of each, no external resistance; martial arts skills focus on lower body strength, 40 min, 2 X/wk, 12 wks; C: no formal program but some did after school activities	Repeated measures ANOVA	Sit-ups-abdominal strength & endurance; seated 2 hand medicine ball (1 kg) put-upper body power; standing long jump-lower body power; sit & reach-flexibility; shuttle run-agility; arm circles & vertical movements-arm coordination	E: significantly greater gains than C in sit-ups (+26 vs −10%), long jump (+14 vs −10%), arm coordination (+68 vs +22%); no differences in other measures	Program of strength + martial arts exercises can improve muscular strength & endurance, power, coordination; **injuries not reported**
Lillegard et al[28]	Boys & girls, volunteers; self-assessment: stages 1, 2-pre-early, stages 3, 4, 5-pubertal/post-pubertal; specific criteria not indicated; pre/early: E = 20 b 11.2 yrs, 8 g 9.5 yrs; C = 18 b 10.0 yrs, 6 g 9.6 yrs; pubertal/post: E = 16 b 14.0 yrs, 8 g 13.8 yrs; C = 10 b 13.1 yrs, 5 g 12.5 yrs; method of group assignment not indicated	Progressive resistance weights, 3 sets of 10 reps at 10 RM of 6 exercises, 1 hr per session, 3 X/wk 12 wks	ANOVA by sex, treatment, pubertal group	Six strength tests: barbell curl, triceps extension, bench press, lat pull, leg curl, leg extension; sit & reach (flex); 30 yd dash, jump & reach, standing long jump, shuttle run, flexed arm hang	Variable results; 10 RM gains greater in males for lat pull & leg extension; 10 RM gains greater in E for triceps extension, bench press, lat pull, leg extension; no differences in 10 RM strength gains by pubertal group; significant gains in E for shuttle run, 30 yd dash, long jump & sit & reach	Inconsistent results, suggest greater gains with training; **one injury recorded in E (boy, shoulder muscle strain)**
Faigenbaum et al[29]	Boys & girls 5–11 yrs, randomly assigned: E1 - low rep, heavy load (5g, 11b) or E2 - high rep, moderate load (4g, 12b); C, 3g, 9b; pubertal status not assessed	Isotonic machine, 9 exercises - E1: 1 set 6–8 reps, heavy load; E2: 1 set 13–15 reps, moderate load; + 1 set 15 reps of abdominal curl & lower back extension for both groups; 2 X/wk, 8 wks	Repeated measures ANOVA	1 RM strength: vertical chest press & leg extension; local muscular endurance: number of reps of chest press & leg extension to volitional fatigue with 1 RM pre-training weight	E1 low rep: +5% chest press, +31% leg extension; E2 high rep: +16% chest press, +41% leg extension; C: +4% chest press, +14% leg extension; E2 high rep sig greater endurance than E1 & C	Muscular strength & endurance improved with training; upper-lower body differences in response to high & low rep protocols; **no injuries occurred with either protocol**
Faigenbaum et al[30]	Boys & girls 5–12 yrs, randomly assigned, 4 groups: E1-low rep, heavy load (5g, 10b), E2-high rep, moderate load (4g, 12b); C, 3g, 9b – note, E1, E2 & C already reported in Faigenbaum et al.[29]; E3-low rep, heavy load + medicine ball exercises (5g, 7b); E4-medicine ball exercises (5g, 6b); subjects labeled prepubescent but no indication is pubertal status was assessed	E1 & E2: same protocol as Faigenbaum et al.[29]; E3: 13–15 reps of 8 exercises (except vertical chest press) + 6–8 reps vertical chest press + 6–8 medicine ball chest passes; E4: 13–15 reps of all exercises +13–15 medicine ball chest passes (ball 1 kg, gradually increased to 2.5 kg)	Repeated measures ANOVA	1 RM strength: vertical chest press; local muscular endurance: number of reps of vertical chest press to volitional fatigue with 1 RM pre-training weight	Relative gains in vertical chest press: E1 +5% E2 +16% E3 +17% E4 +7% C +4%; E2 & E3 significantly different from others; E2 & E3 significantly higher number of 1RM chest presses	Improved upper body strength & endurance with high rep protocols of strength or strength + plyometric (med ball) exercises; **injuries not reported**

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TABLE 1. (*continued*) Experimental Studies of Resistance Training in Youth, Arranged Chronologically

Reference	Characteristics of Participants	Training Program	Statistical Analysis	Outcome Measure(s)	Main Findings	Conclusion
Sadres et al[31]	Boys 9–10 yrs; E = 30, C = 30, all boys from selected classes; all pre/early pubertal PH 1, 2, except 1 (PH3); E-resistance exercises 2X/wk, C-physical education	Weights, 8 exercises: clean pulls, jerk, clean, front & back squats, dead lift, snatch, snatch pulls;150 reps & 3–6 exercises per session; mean load: yr 1, 50% 1 RM (range 30–70%); yr 2, 60% 1RM (range 50–70%); % 1 RM increased while number of repetitions decreased; 2X/wk, 2 school years (9 mo/yr), total 21 mo	Unpaired t tests two way ANOVA	1 RM strength of knee flexors and extensors	Significantly greater strength gains in E compared to C: Knee extension: E yr 1: 4.8 kg, 0.10 kg/kg); yr 2: 8.5 kg (0.17 kg/kg) C yr 1: 2.9 kg (0.08 kg/kg); yr 2: 5.0 kg (0.11 kg/kg) Knee flexion: E yr 1: 2.4 kg (0.04 kg/kg); yr 2: 5.4 kg (0.10 kg/kg) C yr 1: 1.8 kg (0.04 kg/kg); yr 2: 3.6 kg (0.07 kg/kg)	Improved knee strength (absolue and relative) with the low-moderate intensity program, **one injury reported (0.055/100 participant hours)**
Faigenbaum et al[32]	Boys & girls 7–12 yrs; volunteers: E1: 1 day/wk = 7g, 15b or E2: 2 day/wk = 9g, 11b; C = 5g, 8b; no indication if pubertal status was assessed	Isotonic machine, 10 exercises: 1 set 10–15 reps + 1 set 15 reps lower back extension & abdominal curl; ~50 min/session; E1: 1 X/wk, E2: 2 X/wk, 8 wks	ANOVA	1 RM seated chest press & leg press, grip strength, sit & reach, vertical jump, standing long jump	E2-2 day/wk: +11% chest press, +25% leg press; E1-1 day/wk: +9% chest press, +14% leg press; C: +4% chest press, +2% leg press; no sig changes in grip, S & R, VJ, SLJ	Within each training protocol, greater relative gains in lower than upper body strength; suggests greater gains with 2 day/wk compared to 1 day/wk; **injuries not reported**
Flanagan et al[33]	Boys & girls ~8–9 yrs, 3 groups- not random: machine trained = 8, body weight exercise trained = 22, control = 20; growth and pubertal status not indicated	Machine-Future Force 8 exercises: squat, bench press, pull-down, biceps curl, triceps press-down, military press, hamstring curls, curl-ups; 10–15 reps, 1 set, wks 1–3; 2 sets, wks 4–7; 8–12 reps, 3 sets, wks 8–10; body weight as resistance using same body parts as machine exercises; 2X/wk, 10 wks; control: physical education	ANOVA	Medicine ball put (1 kg), standing long jump, shuttle run (9.1 m)	Relative gains (%): Machine / Body Weight / Control Put 4 / 12* / 4 Jump 9 / 4 / 2 Run 4 / 2 / 3 *only significant difference	Relatively small gains in motor performances with each strength training mode; **no injuries occurred with either program**
Pikosky et al[34]	11 boys & girls, volunteers; pubertal status not indicated; no control group	Dynamic constant external resistance (DCER) machine, 7 exercises: leg extension, leg curl, pullover, vertical chest press, seated row, abdominal flexion, front pull down; 2 body weight exercises: abdominal curl, lower back extension; 2X/wk, 6 wks	Pre-post t tests	1 RM vertical chest press & leg extension	Significant gains: chest press, 10%; leg extension 73%	Significant strength gains, more so in lower extremities; **injuries not reported**
Tsolakis et al[35]	Boys 11–13 yrs, G, PH stages 1 & 2, serum T; E = 9, C = 10; volunteers, method of assignment not indicated	Variable resistance machine, 3 sets 10 RM, 6 upper body exercises: supine bench press, pull downs, biceps curl, triceps extensions, seated row, overhead press, 3X/wk, 2 mo; follow-up after 2 mo no training except physical education	Repeated measures ANOVA	Isokinetic-elbow flexion; Isotonic-10 RM elbow flexion	E: significant gain in isometric strength (17%), non-significant gain in isotomic strength (24%); C: non-significant gains in isometric (1%) and isotonic (7%) strength; E: significant decline in isometric (−9%) and non-significant decline in isotonic (−5%) with 2 mo detraining	Significant gains in isometric but smaller gains in isotonic upper body strength; decline in strength gains with detraining; **no injuries associated with training sessions; complaints of muscle pain and limited range of motion during early training sessions**

machines (12) and free weights (8). Duration of programs ranged from 6 weeks to 21 months; 8- and 12-week protocols were the most common.

Muscular Strength

Overall, resistance training two or three times per week resulted in significant improvements in muscular strength during childhood and early adolescence, although one study indicated negligible gains in prepubertal boys.[12] Interindividual differences in responses to the training programs were not considered or reported. Two meta-analyses indicated mean effect sizes of 0.57[10] and 0.75.[11] It is difficult, however, to compare results of different studies because of the qualitative and quantitative variation in training and testing modalities, subject characteristics, analytical protocols, and frequency, intensity, and duration of training.

Three studies included an 8-week period of no resistance training after experimental programs of 8 and 12 weeks; all showed a decline in strength.[22,26,35] A follow-up of six boys (9 to 11 years old) who completed a 20-week training program,[20] compared maintenance training (1 d/wk, three to five reps of six exercises, 75% to 85% 1RM) versus no training for 8 weeks.[36] Strength gains associated with resistance training were lost during detraining, and a maintenance program of 1 d/wk was not sufficient to retain prior strength gains.

Growth and Maturity Status

The lower age limits of subjects were 5 and 6 years,[15,27,29,30] but samples typically spanned several years. Samples included only males (10) and combined samples of males and females (10); two studies included separate samples of both sexes.

Pubertal status was indicated in 19 studies, although it was assessed in only 14. It was apparently assumed based on subject ages in the others. A limitation of the pubertal assessments is use of the generic term "Tanner stage" without specification of the specific indicator(s). Stages of pubertal development are specific to genitals (G) in boys, breasts (B) in girls, and pubic hair (PH) in both sexes. Stages are not equivalent between indicators and sexes.[37] The focus of studies was generally pre- (stage 1 of G, B, PH) or early-pubertal (stage 2 of G, B, PH) subjects.

Mean heights and weights of experimental subjects 6 to 14 years old at the beginning of the respective training programs are plotted by mean ages in Figure 1 relative to U.S. reference data.[38] Mean heights generally fell between the medians and 75th percentiles (Figure 1A), whereas mean weights were more variable (Fig. 1B). Of interest, 11 mean weights were equal to or greater than the age-specific 75th percentiles (six were combined samples of boys and girls), suggesting greater weight-for-height ratios. Experimental subjects were, on average, taller and heavier than control subjects at the start of several training programs, but both groups made similar gains,[15,17,21,26,28,31] which may have relevance for analysis and interpretation of the results.

Mean body mass indexes (BMIs) were reported in only two studies; mean heights and weights were used to estimate BMIs for the others. Estimated BMIs of experimental subjects

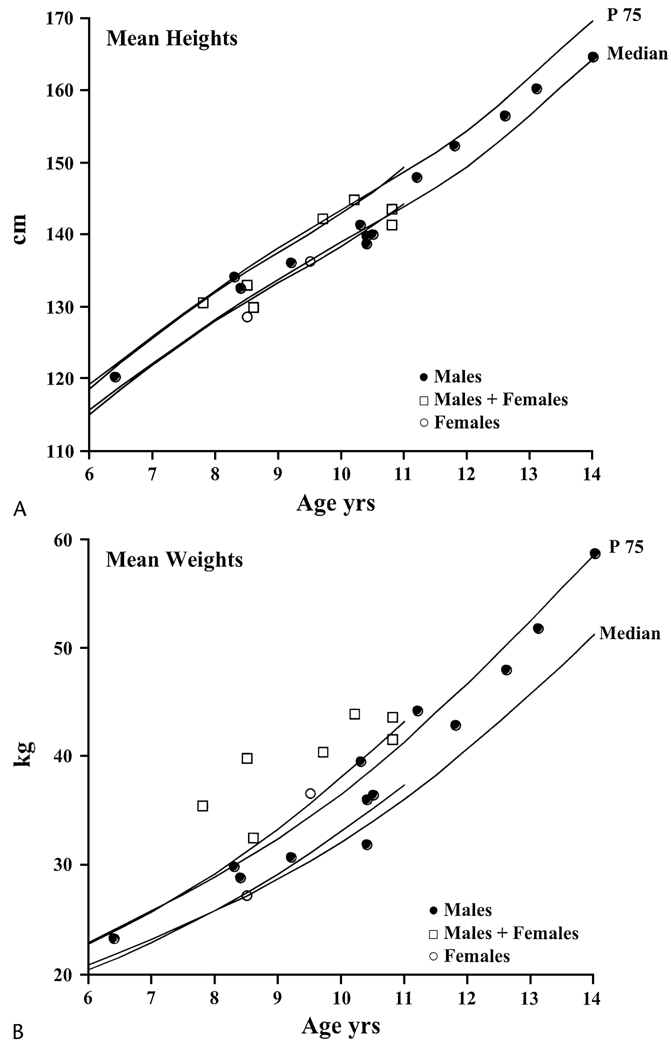
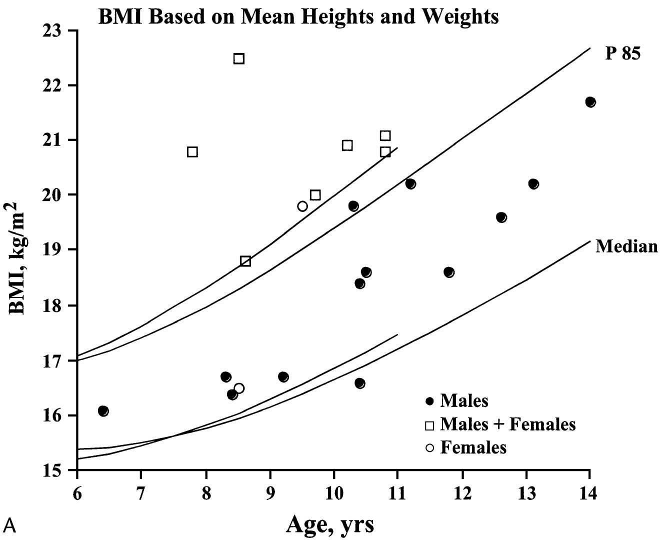


FIGURE 1. Mean heights (A) and weights (B) of experimental subjects in the resistance training programs plotted by mean ages relative to U.S. reference medians and 75th percentiles for boys 6 to 14 years and corresponding percentiles for girls 6 to 11 years. Sex differences in medians prior to the adolescent spurt are negligible and there was only one female sample >11 years.

at the start of the respective training programs are shown in Figure 2 relative to medians and 85th percentiles for U.S. reference data.[38] With few exceptions, estimated BMIs were above the age-specific reference medians, and nine were equal to or greater than the 85th percentiles (Fig. 2A), suggesting that experimental subjects as a group were overweight and, perhaps, obese. The nine samples with estimated BMIs equal to or greater than the 85th percentiles were reported in the 1990s and 2000, and six of these were combined samples of boys and girls (Fig. 2B). Do strength training programs attract overweight/obese youth? Some evidence suggests that resistance training loads appropriate for normal-weight boys may not be sufficient to produce similar strength gains in overweight boys.[39]



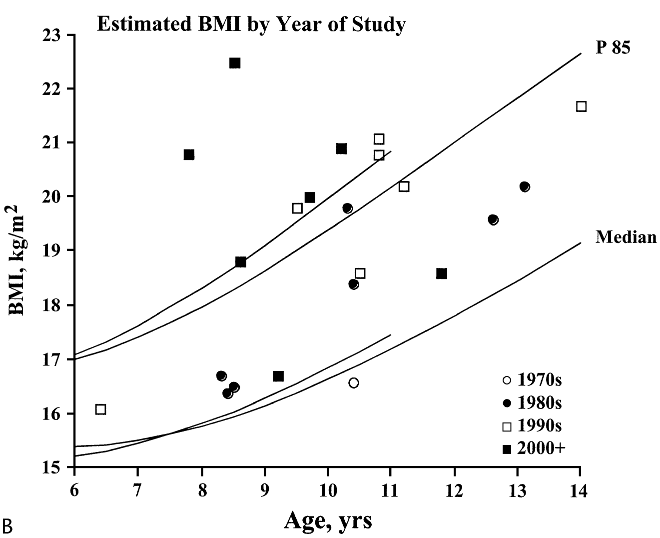


FIGURE 2. Estimated BMIs of experimental subjects in the resistance training programs plotted by mean ages (A) and year of publication of the respective studies (B) relative to U.S. reference medians and 85th percentiles for boys 6 to 14 years and corresponding percentiles for girls 6 to 11 years. Sex differences in medians prior to the adolescent spurt are relatively small and there was only one female sample >11 years.

Changes in Height, Weight, and Estimated Body Composition

Nine studies reported mean heights and weights at the start of and after the programs. Differences between means are summarized in Table 2. Gains in height and weight overlapped between experimental and control groups, suggesting that the respective training protocols did not influence linear growth. The rather large height gains in a 21-month program[31] suggest that the subjects may have been entering and/or already have begun the adolescent growth spurt.

All gains in weight were positive, which would suggest that the resistance training programs were not associated with weight loss. The values are differences between group means and not individual change scores; it is likely that some subjects lost weight. Several studies included skinfold-thickness estimates of limb musculature. Skinfolds were, on average, generally thinner after training, but differences were small, variable among skinfolds,[12,15,17–21,28] and well within the range of measurement error. Changes in limb girths were also small.[12,15,17,21,28] Estimated arm- and thigh-muscle areas (radiography) increased in boys after 8 weeks of strength training,[12] whereas estimated lean arm area (anthropometry)[18] and estimated lean arm and thigh cross-sectional areas (computed axial tomography)[20] increased by the same magnitudes in trained and control boys after 10 and 20 weeks, respectively. A small decline in mean body density in experimental boys and no change in mean density of control boys were noted after a 14-week training program,[15] while negligible changes in anthropometric estimates of FFM, FM, and % fat were reported in a combined sample of trained boys and girls after 6 weeks.[34]

Resistance training is frequently included in treatment programs for obese youth to maintain FFM with weight loss.[40–43] A school based low volume resistance training (3×/wk, 5 mo) in prepubertal girls 7 to 10 years increased strength but did not influence FFM, FM, and subcutaneous abdominal fat, whereas intra-abdominal adipose tissue remained unchanged.[41,42]

Estimated changes in body size and composition in experimental and control subjects are based on differences between group means at the initiation and completion of the respective programs. Individual change scores were not considered, and no analyses controlled for initial status (age, height, weight, strength) in evaluating changes with training. None of the studies reported measurement variability for weight, height, skinfolds and girths (two sources of measurement variability are involved). Allowing for these limitations, resistance training programs do not influence growth in height and weight and estimates of body composition of pre- and early-adolescent youth.

Strength Gains and Associated Changes in Size and Composition

Strength is related to the cross-sectional area of a muscle. The lack of or minimal changes in estimates of limb musculature suggest that pre- and early-pubertal youth show no or minimal muscular hypertrophy in association with strength gains. The training programs may not have been sufficiently long or intense. Anthropometric estimates of limb muscle size are indirect indicators. Ages of subjects in many studies spanned several years, while studies based on more narrowly defined age groups[18,20] showed small gains in estimated arm muscle area in trained and control subjects, but gains in arm and leg strength were independent of changes in muscle cross-sectional areas of the arm and thigh (computed axial tomography).[20]

Potentially confounding factors in explaining strength gains with resistance training in youth are variations in age, sex, and maturity status. As noted, many studies combine samples across a broad age range, and the analyses do not control for the age variation, per se. Some data suggest smaller absolute gains in younger children when an isometric protocol

TABLE 2. Differences Between Mean Heights and Weights at the Start and Completion of Resistance Training Programs

			Experimental (E) Group			Control (C) Group			
Reference	Duration	Sex	Age (yrs)	Height (cm)	Weight (kg)	Age (yrs)	Height (cm)	Weight (kg)	Growth Status at Stall of Program
Vrijens et al[12]	8 wks	♂	10.5	+1.3	+0.6				—
Weltman et al[15]	14 wks	♂	8.2*	+2.0	+1.6		+0.9	+0.6	E taller and heavier than C; >body density
Sailors and Berg[17]	8 wks	♂	12.6*	+1.6	+0.5		+1.8	+2.0	E taller and heavier than C; > mesomorphy
Siegel et al[19]	12 wks	♂	8.4	+1.5	+0.3	8.6	+0.5	+0.8	—
		♂	8.5	+1.4	+0.7	8.4	+1.0	+0.2	—
Ramsay et al[20]	20 wks	♂	10.5	+0.7	+1.6	10.8	+0.2	+1.4	—
Faigenbaum et al[21]	8 wks	♂♀	10.8	+2.2	+0.6	9.9	+2.0	+0.8	E taller, heavier, and older than C
Faigcnbaum et al[26]	8 wks	♂♀	10.8	+1.1	+0.9	10.0	+1.1	+0.1	E taller, heavier, and older than C
Sadres et al[31]	21 mos	♂	9.1**	+3.6	+3.4	9.4	+4.1	+2.0	E taller and heavier than C
			2	+6.1	+3.6		+5.2	+3.3	—
Pikosky et al[34]	6 wks	♂♀	8.6	+1.0	+1.1				

*Mean age for experimental and control groups combined.
**The first line refers to the first year of the study and the second line refers to the second year of the study.

is used.[44] Nevertheless, the relatively small increases in muscle size compared with gains in strength suggest that responses to resistance training stimuli in pre- and early-pubertal youth are largely neural and may include a learning component.

Enhanced motor unit recruitment and/or frequency of motor unit firing, alterations in pattern of motor unit recruitment, and changes in muscle activation and contractile characteristics with strength training are possible contributing factors.[20,24] Among those in advanced puberty (boys more so than girls), neuromotor changes are likely complemented by increased circulating levels of growth and gonadal hormones, which influence muscular hypertrophy and strength.[37]

Measures of strength are positively related with indicators of maturity status.[37] Interindividual variations in maturity status and/or changes in maturity status during the course of the study were not controlled in analyses. Youth were generally classified as pre- or early-pubertal and pubertal. “Prepubertal” indicates the absence of overt signs of puberty and does not indicate an identical level of biological maturity. Skeletal age can vary by as much as 5 years in samples of 6-, 7-, and 8-year-old children[37] and was significantly related to gains in estimated muscle area associated with isometric training (r = 0.36) in children 7 to 11 years old.[44] Prepubertal boys (10.3 ± 1.2 years) made larger relative strength gains, specifically in the upper extremity, than pubertal boys (13.1 ± 1.0 years) after a 9-week resistance program.[13] The focus was on relative gains. Absolute strength is probably less trainable in prepubertal than in pubertal and/or postpubertal youth.[3,9] Further, grouping by stage of G, B, or PH to the exclusion of chronological age overlooks variations in size and body composition independently associated with age.[37] There are apparently no or only small sex differences in responses to resistance training among pre- and early-pubertal children,[3,9] but data for girls are limited.[22,28] Sex differences in estimated strength gains associated with a 12-week weight training program[28] were, with few exceptions, generally small, varying among measures in both pre- and early-pubertal and late-pubertal males and females, respectively (Table 3). The small samples and the age difference in the younger subjects should be noted.

Injuries

Only 10 studies (Table 1) systematically monitored injuries during the training programs; only three injuries (requiring cessation of training or absence from a session) were reported in boys. The reported injuries included two shoulder strains[16,28] and nonspecific thigh pains associated with the bar falling after a lift.[31] Estimated injury rates were 0.176, 0.053, and 0.055 per 100 participant-hours in the respective programs. No injuries were reported in girls. Thus, experimental training protocols with weights and resistance machines are relatively safe. It should be noted that all programs were supervised and generally had a low instructor-to-participant ratio. In a study of obese youth 7 to 12 years old, no injuries were reported during a 10-week, home-based, low-volume resistance training program.[44]

Two reports considered potential subclinical manifestations of musculoskeletal injury associated with resistance training in pre- and early-pubertal boys. Scintigraphy of bone, epiphyses, and muscle indicated no evidence of damage in 17 boys aged 6 to 11 years who were involved in a 14-week

TABLE 3. Differences in Estimated Strength Gains (post- minus pretraining mean 10RM strength measures) in Pre-, Early-, and Late-pubertal Males and Females*

	Pre-/early Pubertal		Late Pubertal	
Strength Measure	Males	Females	Males	Females
Barbell curl	2.4	0.3	3.1	4.2
Triceps extension	5.3	6.2	7.1	6.2
Bench press	7.4	5.3	7.5	9.0
Lateral pull	8.6	5.0	12.8	10.2
Leg extension	11.9	9.4	16.2	9.6
Leg curl	7.3	2.2	2.2	4.2

*Calculated from means reported by Lillegard et al.[28] Pre- and early-pubertal subjects were in stages 1 and 2 of secondary sex characteristics; late-pubertal subjects were in stages 3 through 5 (specific criteria were not indicated; ie, breasts, genitals, pubic hair). Mean ages at the beginning of the 12-week progressive weight training program were as follows: boys 11.2 ± 1.1 years; girls 9.5 ± 1.4 years; boys 14.0 ± 1.0 years; girls 13.8 ± 2.9 years.

program and no elevation of creatine phosphokinase.[16] Six boys incurred injuries outside of the training program, and two showed abnormal scans. The second report considered indicators of trauma to muscle, articular cartilage, and collagen after training sessions in early (second week) and late (19th week) stages of a 20-week resistance program in boys 9 to 11 years old.[45] Changes in serum creatine kinase (muscle), serum keratin sulfate (articular cartilage), and urinary hydroxyproline (collagen) were relatively small and not significant after training sessions early and late in the program. However, resting creatine kinase levels late in training were significantly elevated, suggesting chronic damage to muscle but not to connective tissues in this sample of young boys.[45]

Although weight training is an important component of training programs for many sports, information on injuries is very limited. A retrospective survey of weight training injuries in interscholastic junior and senior high school football players (n = 354) indicated 27 injuries (more than 7 days of missed participation), giving an estimated rate of 0.082 injuries per person-year.[46] Estimated rates decreased from junior high (0.110 per person-year) to high school freshman/junior varsity (0.091 per person-year) to high school varsity football players (0.051 per person-year), although the differences were not significant. Of potential relevance, weight training was more commonly supervised in high school (88% freshman/junior varsity; 97% varsity) compared with junior high school (36%) athletes. High school athletes more often trained at school (69% and 94%) and were instructed by a coach (62% and 73%); corresponding percentages for junior high athletes were 14% and 25%, respectively.

Strains were the most commonly reported injury (20/27), and the back was the most frequently injured area (16/27).[46] The lower back (13) was injured more often than the upper back (3). Back injuries were more common in high school athletes. The bench press, overhead press, and squat lift were most frequently reported among junior high athletes, whereas the bench press, incline press, power clean, squat lift, and overhead press were reported among high school athletes.

Discussions of weight training occasionally consider weight lifting. In a survey of sport-related injuries (based on accident reports) in school-age children in a single community during 1 year, 11 of 1576 (0.7%) injuries were attributed to weight lifting.[47] The injuries occurred in nonorganized sports (seven) and physical education (four). A retrospective survey of 71 competitive teenage (14 to 19 years old) power lifters indicated 89 injuries associated with lifting.[48] Using group statistics for duration of training, workouts per week, and length of workouts, the estimated injury rate was 0.29/100 participant-hours. Back injuries were most common (lower 50%, upper 4%), and the majority of injuries were muscle pulls (61%).

The information from retrospective surveys thus suggests a more frequent occurrence of weight training/weight lifting injuries. Two of the surveys were based on junior and senior high school athletes and competitive lifters, and the results may reflect, in part, more aggressive use of free weights by adolescent males. In contrast, evidence from resistance training studies in younger samples (above) indicates low injury rates. Injuries to growth plates, which may have the potential to alter linear growth, are of particular relevance to young participants in weight training. Although growth-plate injuries incurred during weight training or lifting have been reported in the clinical literature, they are rare and are generally associated with improper technique and unsupervised activity.[49,50] None have been reported in prospective resistance training studies.

CONCLUSIONS

Resistance training two or three times per week results in significant improvements in muscular strength during childhood and early adolescence; strength gains are lost during detraining. Resistance training programs do not influence growth in height and weight of pre- and early-adolescent youth. Changes in estimates of body composition are variable and, in most cases, minimal. Gains in strength associated with resistance training seem to be independent of changes in body composition and estimated muscularity. Estimated BMIs suggest that recent experimental resistance training studies may have attracted overweight/obese youth. Supervised experimental training protocols with weights and resistance machines and low instructor-to-participant ratios are relatively safe. There is a need for expanded surveillance of injuries associated with resistance training programs.

Interindividual differences in responses to training programs are not ordinarily considered. The potential role of genetic factors in responses to resistance training among youth has not been investigated. Limited results for young adult male twins suggest that responses to resistance training are independent of genotype.[51,52]

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