

# The Effects of Different Resistance Training Protocols on Muscular Strength and Endurance Development in Children

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**ABSTRACT.** *Background.* Previous research has shown that children can increase their muscular strength and muscular endurance as a result of regular participation in a progressive resistance training program. However, the most effective exercise prescription regarding the number of repetitions remains questionable.

*Objective.* To compare the effects of a low repetition-heavy load resistance training program and a high repetition-moderate load resistance training program on the development of muscular strength and muscular endurance in children.

*Design.* Prospective, controlled trial.

*Setting.* Community-based youth fitness center.

*Subjects.* Eleven girls and 32 boys between the ages of 5.2 and 11.8 years.

*Intervention.* In twice-weekly sessions of resistance training for 8 weeks, children performed 1 set of 6 to 8 repetitions with a heavy load ( $n = 15$ ) or 1 set of 13 to 15 repetitions with a moderate load ( $n = 16$ ) on child-size exercise machines. Children in the control group ( $n = 12$ ) did not resistance train. One repetition maximum (RM) strength and muscular endurance (repetitions performed posttraining with the pretraining 1-RM load) were determined on the leg extension and chest press exercises.

*Results.* One RM leg extension strength significantly increased in both exercise groups compared with that in the control subjects. Increases of 31.0% and 40.9%, respectively, for the low repetition-heavy load and high repetition-moderate load groups were observed. Leg extension muscular endurance significantly increased in both exercise groups compared with that in the control subjects, although gains resulting from high repetition-moderate load training ( $13.1 \pm 6.2$  repetitions) were significantly greater than those resulting from low repetition-heavy load training ( $8.7 \pm 2.9$  repetitions). On the chest press exercise, only the high repetition-moderate load exercise group made gains in 1-RM strength (16.3%) and muscular endurance ( $5.2 \pm 3.6$  repetitions) that were significantly greater than gains in the control subjects.

*Conclusion.* These findings support the concept that muscular strength and muscular endurance can be improved during the childhood years and favor the prescription of higher repetition-moderate load resistance training programs during the initial adaptation period. *Pediatrics* 1999;104(1). URL: <http://www.pediatrics.org/cgi/content/full/104/1/e5>; strength training, weight training, exercise, youth, preadolescent.

ABBREVIATIONS. RM, repetition maximum; DCER, dynamic constant external resistance.

In the past several years, resistance training has proven to be a safe and effective method of conditioning for children, provided that appropriate exercise guidelines are followed.<sup>1-3</sup> Although the capability of children to increase their muscular strength was questioned in the past,<sup>4</sup> current findings suggest that children may benefit from regular participation in resistance training activities. Reports indicate that youth resistance training may improve motor performance skills,<sup>5</sup> may reduce injuries in sports and recreational activities,<sup>6,7</sup> and may favorably alter selected anatomic<sup>8</sup> and psychosocial parameters.<sup>9,10</sup> The American Academy of Pediatrics,<sup>11</sup> the American College of Sports Medicine,<sup>12</sup> and the National Strength and Conditioning Association<sup>1</sup> support children's participation in appropriately designed and competently supervised resistance training programs. In addition, public health objectives discussed in the recent Surgeon General's report *Physical Activity and Health* aim to increase the number of children who participate regularly in physical activities that enhance and maintain muscular strength and muscular endurance.<sup>13</sup>

To evaluate the trainability of children, researchers have used different combinations of the acute program variables (ie, choice of exercise, order of exercise, resistance used, number of sets, and rest period between sets) to study the effects of resistance training on boys and girls. In general, it appears that a variety of training protocols and modalities can be effective, although the amount of resistance used seems to be one of the more important variables. The training resistance influences the number of repetitions that can be performed, which, in turn, provides the stimulus related to changes in muscular strength and muscular endurance. The classic work on adults done by DeLorme<sup>14</sup> and Berger<sup>15,16</sup> suggests that heavy resistance-low repetition protocols build muscular strength, whereas low resistance-high repetition protocols build muscular endurance. More recent findings support the contention that the use of heavy resistances (eg, repetition maximum [RM] resistances of six or less) would have the greatest effect on muscular strength, whereas lighter resistances (eg, RM resistances of 20 or more) would have the greatest effect on muscular endurance.<sup>17</sup>

Although generally it is believed that there is a direct linear relationship between the training inten-

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sity and the magnitude of strength change,<sup>18</sup> limited data suggest that children and older populations may respond differently to resistance training protocols. For example, Hunter and Treuth<sup>19</sup> reported a negative relationship between training intensity and increase in 1-RM strength in women older than 60, and similar observations have been noted in children younger than 12.<sup>20,21</sup> However, no controlled, prospective trial comparing different resistance training protocols on muscular strength and endurance development in children has been reported, nor has the minimal training intensity for children been established. Although it has been recommended that children should perform at least 1 set of 6 to 15 repetitions on a variety of upper and lower body exercises 2 to 3 days per week,<sup>1</sup> more specific information regarding the most effective resistance training protocol for children would be useful to physical educators, physical therapists, and pediatricians. Therefore, the purpose of this study was to compare and evaluate the responses of a low repetition–heavy load training program versus a high repetition–moderate load training program on children.

## METHODS

### Subjects

Eleven girls and 33 boys between 5.2 and 11.8 years of age volunteered to participate in this study. All subjects were healthy children who had no previous resistance training experience. Both the children and their parents were informed about the nature of this project and completed a health history questionnaire. The following exclusionary criteria were used: 1) children with a chronic pediatric disease, 2) children with an orthopedic limitation, and 3) children older than 12 years of age at the beginning of the study. All volunteers were accepted for participation, and informed consent was obtained from the parents and their children.

Subjects were randomly assigned to a low repetition–heavy load (girls,  $n = 5$ ; boys,  $n = 11$ ) or a high repetition–moderate load (girls,  $n = 4$ ; boys,  $n = 12$ ) resistance training program. Twelve children (girls,  $n = 3$ ; boys,  $n = 9$ ) who enrolled in this study after the recruitment of the experimental groups acted as nontraining control subjects. Because boys and girls demonstrate fairly similar rates of strength gain during preadolescence, they were combined in this study.<sup>22</sup> The methods and procedures used in this study were approved by the Institutional Review Board of the University of Massachusetts–Boston before data collection. Descriptive characteristics of the subjects are presented by group in Table 1.

### Testing Procedures

All subjects participated in one introductory training session before testing procedures. During this time, they were taught the proper technique (ie, controlled movements and proper breathing) on each testing exercise, and any questions they had were answered. A warm-up session consisting of at least 10 minutes of low-intensity aerobic exercise and stretching preceded all tests. Measurements were made with identical equipment positioning

using child-size dynamic constant external resistance (DCER) equipment (Schnell Equipment, Peutenhausen, Germany).

### Performance Strength

Each subject's 1-RM strength was determined only on the vertical chest press and leg extension exercises at baseline, 4 weeks, and 8 weeks. For the vertical chest press exercise, children were standing erect with their back against the support pad and both hands in a neutral grip position grasping the handles located at chest level. Children were instructed to extend their arms in front of them until their elbows were  $\sim 5^\circ$  short of full extension (to prevent locking at the elbow joint), then return to the starting position. For the leg extension exercise, children were seated upright with both ankles behind an ankle pad. Children were instructed to extend their knees as fully as possible, from  $90^\circ$  of flexion to full extension, then return to the starting position. The 1 RM was taken as the maximum resistance that could be lifted throughout the full range of motion (determined in the unweighted position) using good form one time only.

Before attempting a 1 RM, subjects performed 6 repetitions with a relatively light load, then 3 repetitions with a heavier load, and finally a single repetition with 95% of their predicted 1 RM. Subjects then attempted a single repetition with the perceived 1-RM load. If this weight was lifted with the proper form, the weight was increased by  $\sim 1$  kg to 2.5 kg, and the subject attempted another repetition. The increments in weight were dependent on the effort required for the lift and became progressively smaller as the subject reached the 1 RM. Failure was defined as a lift falling short of the full range of motion on at least two attempts spaced at least 2 minutes apart. The 1 RM was typically determined within four trials. Throughout all testing procedures, an instructor to subject ratio of 1:1 was maintained, and uniform verbal encouragement was offered to all subjects. Test–retest reliabilities in our laboratory for 1-RM testing in children varies from 0.93 to 0.98 depending on the type of exercise.<sup>23</sup>

### Local Muscular Endurance

At the end of the training period, each subject performed a test of local muscular endurance on the chest press and leg extension exercises. After a warm-up set of 6 repetitions with a relatively light load (and a 2-minute rest period), subjects attempted to perform as many repetitions as possible with their pretraining 1-RM weight. During each lift, subjects were verbally encouraged to perform as many repetitions as possible. The number of repetitions performed to volitional fatigue using the correct form were counted and recorded as criterion values of local muscular endurance.

### Resistance Training Program

The exercise groups trained twice per week on nonconsecutive days for 8 weeks. Before each resistance training session, all subjects performed 10 minutes of low intensity aerobic exercise and stretching (focusing on the muscle groups that were about to be trained), and instructors discussed and demonstrated proper resistance training procedures. Instructional sessions gave children an opportunity to understand the importance of proper form as well as to appreciate the potential benefits and risks associated with resistance training. Children were taught how to record their data on workout logs and did so throughout the training period. The instructors reviewed the workout logs daily and made appropriate adjustments in training resistance and repetitions. The resistance training segment of each session lasted  $\sim 30$  to 40 minutes. Throughout the training period, children typically exercised in groups of 6 to 10, and an instructor to subject ratio of at least 1:3 was maintained. All training sessions took place after school in a YMCA youth fitness center.

The resistance training program consisted of 1 set of 11 exercises on child-size exercise equipment. Right and left limbs were trained simultaneously. Two body weight exercises that used each child's own body weight as resistance (abdominal curl and lower back extension) and 9 DCER exercises (leg extension, leg press, leg curl, hip abduction, pullover, vertical chest press, seated row, abdominal flexion, and front pull down) were performed. On the DCER exercises, subjects in the low repetition–heavy load group performed 6 to 8 repetitions, whereas subjects in the high repetition–moderate load group performed 13 to 15 repetitions. The last

TABLE 1. Baseline Characteristics

	Control ( $n = 12$ )	LoRep ( $n = 15$ )	HiRep ( $n = 16$ )	<i>P</i>
Age (y)	8.6 $\pm$ 2.2	7.8 $\pm$ 1.4	8.5 $\pm$ 1.6	.43
Weight (kg)	27.7 $\pm$ 6.0	35.4 $\pm$ 8.4	39.8 $\pm$ 11.9	.01
Height (cm)	127.4 $\pm$ 10.6	130.6 $\pm$ 8.5	133.0 $\pm$ 9.6	.31

LoRep indicates low repetition–heavy load exercise group; HiRep, high repetition–moderate load exercise group. Data are presented as the mean  $\pm$  SD. *P* values based on comparisons of groups using ANOVA.

repetition of each set represented momentary muscular fatigue. During the first week of training the exercise loads were titrated on all DCER exercises to elicit volitional fatigue within the prescribed repetition range. When the subjects in the low repetition–heavy load and high repetition–moderate load training groups were able to perform either 8 or 15 repetitions, respectively, on a DCER exercise, the weight was increased by 5% to 10% and the repetitions were decreased to the low end of the prescribed repetition range. If a subject missed a session, the training load was not increased at the returning session.

On the body weight exercises, subjects in both exercise groups performed up to 1 set of 15 repetitions to provide a general conditioning effect. The order of exercises changed every session to maximize enjoyment for the subjects, and no form of resistance training outside of the research setting was allowed. All children were permitted to participate in school-based physical education classes and recreational activities throughout the study period. Attendance was taken at every training session (total number of sessions = 16). Subjects in the control group were specifically asked not to participate in any resistance training program. The influence of the resistance training programs on laboratory indices of muscular strength and local muscular endurance was assessed by comparing changes between exercise and control groups.

### Statistical Analysis

Descriptive statistics (mean  $\pm$  SD) for age, height, and weight were calculated. An ANOVA was used to compare the study groups at baseline. This provided data that examined whether the subjects in the three groups differed before training. After the training period, the results of the 1-RM tests were analyzed using repeated-measures ANOVA, with the testing occasion as a within-subject factor. When significant differences were found, a series of Scheffe post hoc comparisons were used to identify in which groups and at what testing occasions the differences occurred. One-way ANOVA was performed to determine any differences among groups for tests of muscular endurance. The  $\alpha$  level was set at  $P \leq .05$ , and the analyses were conducted using the SPSS statistical package (SPSS, Inc, Chicago, IL).

## RESULTS

Of the 44 subjects, 43 completed the study according to the aforementioned methodology. One subject in the low repetition–heavy load training group was unable to complete the study because of a scheduling conflict. There were no differences in baseline strength, height, or age among the three groups, but the weight of the control group was significantly less than that of the exercise groups (Table 1). Average attendance at the training sessions over the 8 weeks for the low- and high-repetition training groups was 93.5% and 92.0%, respectively. Post hoc averaging of training loads indicated that the training stimulus on the chest press and leg extension exercises for the low repetition–heavy load group had been 78.9% and 80.6%, respectively, of their initial 1 RM, whereas the high repetition–moderate load group trained at an intensity of 67.5% and 69.3%, respec-

tively, of their initial 1 RM. Throughout the study period, 6 children (40%) in the low repetition–heavy load group, 5 children (31%) in the high repetition–moderate load group, and 5 children (42%) in the control group participated regularly (at least twice per week) in organized community sports programs (principally soccer and swimming). No injuries occurred throughout the study period.

### Upper Body Strength and Endurance

High repetition–moderate load training resulted in significantly greater gains in 1-RM chest press strength compared with gains in the control subjects ( $P < .01$ ) (Table 2; Fig 1). For the high repetition–moderate load training group, significant gains in chest press strength occurred during the first 4 weeks (5.1%;  $P < .01$ ) and latter 4 weeks (10.7%;  $P < .01$ ) of training. Gains in chest press strength resulting from low repetition–heavy load training were not significantly different from results for the control subjects ( $P = .13$ ). Gains in chest press strength observed during the first 4 weeks of low repetition–heavy load training were not significant (2.0%;  $P = .56$ ), whereas gains during the latter 4 weeks of training were significant (3.2%;  $P < .01$ ). For both training groups, the greatest gains in upper body strength were observed during the latter 4 weeks of the study. A significant increase in 1-RM chest press strength, indicative of growth and maturation, also was observed for the control group at the end of the study period (4.2%;  $P = .03$ ). High repetition–moderate load training resulted in significantly greater gains in chest press muscular endurance ( $5.2 \pm 3.6$  repetitions) compared with results in the control group ( $1.7 \pm 1.1$  repetitions;  $P < .01$ ), whereas gains made by the low repetition–heavy load group ( $3.1 \pm 2.5$  repetitions) were not significantly different from gains by the other groups ( $P = .39-.11$ ) (Table 3).

### Lower Body Strength and Endurance

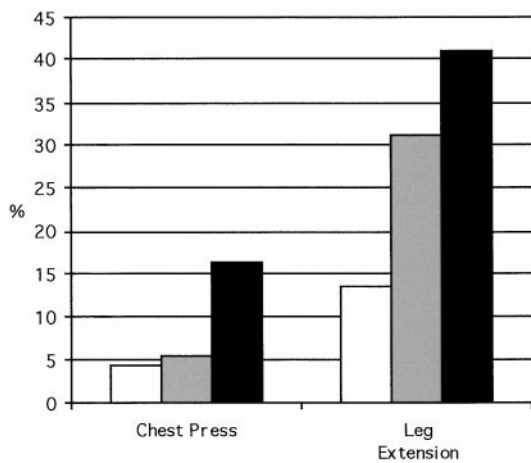
Training resulted in significantly greater gains in 1-RM leg extension strength for the low repetition–heavy load and high repetition–moderate load training groups compared with the control group ( $P = .02- < .01$ ) (Table 2; Fig 1). There was no significant difference in 1-RM leg extension strength gains between training groups ( $P = .55$ ). For the low repetition–heavy load and high repetition–moderate load training groups, significant gains in leg extension strength occurred during the first 4 weeks (17.9%

**TABLE 2.** Results for the 1 Repetition Maximum (RM) Leg Extension and Chest Press Tests at Pretraining, Midtraining, and Posttraining

Variable	Group	Pretraining	Midtraining	Posttraining
Chest press (kg)	Control	21.2 $\pm$ 5.1	22.0 $\pm$ 5.1*	22.1 $\pm$ 5.3‡
	LoRep	24.5 $\pm$ 5.9	25.0 $\pm$ 6.0	25.8 $\pm$ 6.4‡
	HiRep	25.7 $\pm$ 9.1	27.0 $\pm$ 9.5*	29.9 $\pm$ 9.7†,‡,§
Leg extension (kg)	Control	14.7 $\pm$ 6.7	16.2 $\pm$ 7.3*	16.7 $\pm$ 6.9‡
	LoRep	18.4 $\pm$ 7.0	21.7 $\pm$ 7.1*	24.1 $\pm$ 7.6†,‡,§
	HiRep	19.3 $\pm$ 9.0	23.5 $\pm$ 10.4*	27.2 $\pm$ 10.9†,‡,§

Data are presented as the mean  $\pm$  SD; \*,†,‡ indicates significant difference ( $P < .05$ ) within a group between pretraining and midtraining, midtraining and posttraining, and pretraining and posttraining, respectively. § Significantly different from control. LoRep indicates low repetition–heavy load exercise group; HiRep, high repetition–moderate load exercise group.





**Fig 1.** Percent change in chest press and leg extension 1-RM strength (pre- to posttraining). Open, gray, and black bars represent the control, low repetition-heavy load, and high repetition-moderate load groups, respectively.

and 21.7%, respectively;  $P < .01$ ) and latter four weeks (11.1% and 15.7%, respectively;  $P < .01$ ) of training. For both training groups, the greatest gains in lower body strength were noted during the initial phase of the study, but strength did continue to improve over the 8-week training period. A significant increase in 1-RM leg extension strength, indicative of growth and maturation, also was observed for the control group at the end of the study period (13.6%;  $P < .01$ ). Gains in leg extension muscular endurance made by the low repetition-heavy load ( $8.7 \pm 2.9$  repetitions) and the high repetition-moderate load ( $13.1 \pm 6.2$  repetitions) training groups were significantly greater than gains observed in the controls ( $3.7 \pm 1.6$  repetitions;  $P = .02$ – $<.01$ ), although gains in muscular endurance attributable to high repetition-moderate load training were significantly greater than those resulting from low repetition-heavy load training ( $P = .03$ ) (Table 3).

### DISCUSSION

The present investigation differed from previous resistance training studies on children by comparing and evaluating the effects of different resistance training protocols on the development of muscular strength and endurance. In addition, by the inclusion of 1-RM strength testing at midtraining, it was possible to explore the time course of strength adaptations to different resistance training protocols. To our knowledge, no other study has compared the dynamics of muscular strength and endurance changes in children in response to 1 set of low repetition-heavy load and high repetition-moderate load resistance training. It should be noted that the purpose of this study was to determine for practical purposes the most effective 1-set repetition range for eliciting gains in muscular strength and endurance in untrained children who volunteered to participate in a youth fitness program; this is not to say that higher volumes of training might not provide a better training stimulus. The primary outcome measures in this investigation were muscular strength and muscular endurance.

**TABLE 3.** Results for the Chest Press and Leg Extension Muscular Endurance Tests Posttraining

Variable	Group	Repetitions With Pretraining 1 RM
Chest press	Control	$1.7 \pm 1.1$
	LoRep	$3.1 \pm 2.5$
	HiRep	$5.2 \pm 3.6^*$
Leg extension	Control	$3.7 \pm 1.6$
	LoRep	$8.7 \pm 2.9^*$
	HiRep	$13.1 \pm 6.2^{*,\dagger}$

Data are presented as the mean  $\pm$  SD; \*, $\dagger$  indicates significantly different ( $P < .05$ ) from control or LoRep only, respectively. LoRep indicates low repetition-heavy load exercise group; HiRep, high repetition-moderate load exercise group.

### Muscular Strength

Previous reports indicate that children can increase their muscular strength above and beyond normal growth and maturation by participating in a progressive resistance training program.<sup>5,21,24–28</sup> In the present study, only high repetition-moderate load training resulted in chest press strength gains that were significantly greater than gains for the control subjects. The observed gains in chest press strength after this short-term resistance training program were lower than those reported in previous studies involving adults<sup>16,29</sup> and children.<sup>20,21,26,27</sup> Upper body strength gains of 19.6%<sup>26</sup> to 64.1%<sup>21</sup> have been observed on similar exercises in children after the first 8 weeks of a resistance training program. The absolute increases in chest press strength made by the low repetition-heavy load and high repetition-moderate load groups (0.9 kg and 4.2 kg, respectively) also were lower than results reported previously in short-term investigations involving children.<sup>20,21,26</sup>

It is reasonable to conclude that the greater gains in upper body strength in previous investigations compared with those in the present study may be attributable to differences in training volume (ie, the total amount of work performed per training session and per week). It seems that high-volume training programs (eg, 3 sets of 10 to 15 repetitions per exercise with a moderate load) result in greater gains in upper body strength than low-volume training programs.<sup>20,21</sup> In the present investigation, both training groups performed only 1 set per exercise, yet the lower-than-expected gains resulting from 6 to 8 repetitions with a heavy load may have been caused, at least partly, by a lower training volume compared with volume for the high repetition-moderate load exercise group. It should be noted that in our study, muscular strength was evaluated using 1-RM testing procedures on the same equipment used for training. Thus issues related to testing-training specificity cannot explain the relatively small gains in upper body strength. In fact, because training loads for the low repetition-heavy load group were closer to loads used for the 1-RM strength test, one could speculate that factors needed to exert maximal strength would be better trained by this protocol. The results from this study do not support this contention, however.

Although speculative, it may be that there is a

threshold level of strength exercise (ie, training volume, training intensity, or both) necessary to stimulate upper body strength development in children, and that in the short-term, 1 set of 6 to 8 repetitions with a heavy load may be suboptimal for increasing the upper body strength of children above and beyond growth and maturation. In our study, training was done under close supervision with frequent adjustments in training intensity to maintain the desired training stimulus. When appropriate, attempts were made to increase the training load using judgment of the child's exercise technique and perceived exertion during a lift. Nevertheless, upper body strength gains made by the low repetition-heavy load group were not significantly different from those for the control group. Although additional study is warranted, it is possible that the low repetition-heavy load training protocol may have delayed the time course of upper body strength change.

The training-induced gains in muscular strength during childhood have been attributed primarily to neuromuscular adaptations as opposed to hypertrophic factors.<sup>30</sup> Although not assessed in this study, increases in motor unit activation, improvements in motor skill coordination, and perhaps some qualitative changes in the muscle have been suggested as possible mechanisms by which children increase their muscular strength in response to resistance training.<sup>25,31</sup> In our study, both training groups performed each set to concentric contraction failure, which is recognized as an important training stimulus for gains in adults.<sup>32</sup> Yet high-repetition training with a moderate load resulted in more favorable changes in upper body strength compared with low-repetition training with a heavy load. It is reasonable to conclude, although not with complete confidence, that high-repetition training during the initial adaptation period may have provided a better opportunity for improved coordination or learning and increased activation of the prime movers (ie, increased number of motor units recruited and increased discharge frequency). Because it has been suggested that children cannot activate their muscles as well as adults in the untrained state,<sup>30</sup> low repetition-heavy load training programs that typically are used to enhance the upper body strength of adults may not be ideal for younger populations. The validity of this contention is clouded by our limited understanding of the precise physiologic determinants of training-induced strength gains in children, however.

In the present investigation, leg extension strength gains made by both training groups were significantly greater than control group. These results are consistent with gains observed in adults<sup>26,32</sup> and in similar age groups.<sup>20,26,27,33</sup> The absolute increase in leg extension strength attributable to low- and high-repetition training (5.7 kg and 7.9 kg, respectively) was less than the increase for same lift in other reports involving children.<sup>20,21,26</sup> Differences in training volume may explain these findings.

Our data suggest that the lower body of children was more trainable than the upper body, whereas Pfeiffer and Francis<sup>24</sup> reported that the upper extremities of children were more responsive to the training

stimulus than the lower extremities. Although it is possible that the upper body muscles of children in our study may have been at a higher level of conditioning than were the knee extensors, this seems unlikely because no child had any previous experience with resistance training, and the active role of the quadriceps during activities of daily living would suggest that they would be at a higher initial level of conditioning at the start of the study period. Thus, it may be reasonable to conclude that the greater gains in lower body strength compared with gains in upper body strength may be simply attributable to the fact that the resistance-training program included only one exercise for the upper body (vertical chest press) and two exercises for the quadriceps (leg press and leg extension).

The measurement of 1-RM strength at pre-, mid-, and posttraining intervals provided additional insight into the time course of training-induced adaptations in children. Significant upper body strength gains resulting from high repetition-moderate load training were evident during both phases of the study (ie, weeks 1 to 4 and weeks 5 to 8), whereas significant gains in upper body strength resulting from low repetition-heavy load training occurred only during the latter phase. Interestingly, the magnitude of upper body strength gain for both training groups was greater during the latter 4 weeks of training compared with the initial 4 weeks of training. Conversely, both training groups made significant gains in leg extension strength during both phases of training, but the magnitude of strength gain during the first 4 weeks of training was greater than during the latter 4 weeks of training.

Although the tendency for children to improve their strength more rapidly during the early phase of training is consistent with results from other studies involving adults<sup>34</sup> and children,<sup>20,25</sup> it is noteworthy that gains in upper body strength did not follow a similar pattern. It is possible that the time course of training-induced strength gains in children may vary by muscle group and, perhaps, training protocol (ie, session training volume and number of sessions per unit time). Although more data are needed on the dynamics of strength changes in children, it is possible that training-induced gains in upper body strength during childhood may be relatively slow to develop and if a 1-set low repetition-heavy load protocol is followed, gains may not become apparent until later in a training program.

#### *Muscular Endurance*

One could speculate that muscular endurance should be enhanced after several weeks of progressive resistance training. In the present study, gains in leg extension muscular endurance were significantly greater for both training groups compared with control group gains. Furthermore, leg extension endurance gains resulting from high repetition-moderate load training were significantly greater than those resulting from low repetition-heavy load training. The improvements in chest press muscular endurance also were significantly greater for the high-

repetition group training compared with the control group.

The improvements in muscular endurance in the present study support the observations of Ramsay and colleagues,<sup>25</sup> who reported increases in muscular endurance in children who participated in a 20-week progressive resistance training program. Our finding that higher repetition–moderate load training enhanced lower body muscular endurance more so than low repetition–heavy load training is consistent with findings from previous studies on adults<sup>34</sup> and children.<sup>25</sup> In adult populations, however, resistance training programs that are designed to increase strength are not typically as effective in increasing muscular endurance.<sup>17</sup> The present data demonstrate that in the short term, one form of training (eg, high repetition–moderate load) may be equally effective in enhancing the muscular strength and muscular endurance of untrained children. Thus, it appears that the relationship between training stimulus and response may vary in children versus and older populations.

This study attempted to provide more specific answers to questions regarding the development of resistance training programs for children. Conducting the training program at a YMCA and allowing parents to exercise in the adult fitness center during the study period contributed to the high compliance in this study. In the past, it has been difficult to compare the relative effectiveness of resistance training on children because of differences in program design, study duration, and training methodologies (namely, the quality of instruction and type of equipment). Although our findings confirm the results of earlier studies that noted significant gains in muscular strength in children after resistance training, the dynamics and magnitude of muscular strength and endurance development in the present study resulting from high repetition–moderate load training versus low repetition–heavy load training are novel. Although both training protocols can be considered safe (ie, no injuries resulted from either program), the results from this investigation suggest that if untrained children begin training with 1 set per exercise, a relatively high number of repetitions (eg, 13 to 15) with a moderate load should be prescribed for upper and lower body exercises (assuming that repetitions are performed to the point of temporary fatigue). Additional youth resistance training guidelines that include qualified supervision and an appropriate progression of training loads are available elsewhere.<sup>35–37</sup> An interesting anecdotal observation from this study is that children seemed to enjoy high repetition–moderate load training more so than low repetition–heavy load training.

A potential limitation of the present study relates to our assumption that all the subjects were preadolescents. Because we did not assess biologic maturation before the start of this study, it is possible that older subjects may have entered their pubertal years, or adolescence. In this study, 1 girl and 4 boys were between the 11.0 and 11.8 years of age. Although most boys under younger than 12 are likely to be preadolescent, girls tend to begin puberty earlier,

although there is a high degree of interindividual variability. Admittedly, some of the subjects in this study may not have been preadolescents. But for the purpose of this study, we contend that this limitation is not serious because relative (percent improvement) strength gains achieved during preadolescence are comparable with relative gains observed during adolescence.<sup>24</sup> However, we recognize that the lower body weight of the control group compared with the exercise groups may complicate the interpretation of our findings, because a given absolute increase in strength may represent a smaller relative increase in a heavier child who is likely to begin training with a greater initial level of absolute strength. Finally, our results should not be applied to highly trained young athletes, in whom the relationship between training intensity and the magnitude of strength gain may be different.

## CONCLUSION

In summary, this study demonstrates that different training protocols can enhance the muscular strength and muscular endurance of children, and that 1 set of high repetition–moderate load training may be more beneficial than 1 set of low repetition–heavy load training for children participating in an introductory program. Although it is likely that a greater training stimulus would be required to elicit additional adaptations in trained children, beginning a resistance training program for children with a single set of 13 to 15 repetitions per exercise not only allows for positive changes in muscular performance, but provides an opportunity for each child to experience success and feel good about his/her performance. Because of the growing popularity of youth resistance training, future long-term studies should evaluate the effects of varying the combination of sets and repetitions on selected health and fitness parameters in children.

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