Resistance Training in Children and Youth: A Meta-Analysis

V. Gregory Payne, James R. Morrow, Jr., Lynne Johnson, and Steven N. Dalton

This research used meta-analysis to examine the effect of resistance training on children and youth. Studies investigating the effects of various forms of resistance training in participants of ages less than 18 years were analyzed. Effects sizes (ES) were calculated by gender, age group (boys ages ≥ 16 years and girls ages ≥ 14 years were defined as older), training (isokinetic, isometric, isotonic), and design type (pretest-posttest or experimental-control). Similar ESs were obtained for older and younger children; isometric methods demonstrated larger ESs than isometric or isokinetic. Larger ESs were obtained in studies with cross-sectional (experimental-control) than pre-post designs. Resistance training appears to enhance muscular endurance and strength in children and youth. The magnitude of the effect appears to be a function of gender, training method, and experimental design.

Key words: children, muscular strength, meta-analysis, resistance, training

Katch (1983) proposed a “trigger hypothesis,” stating that phenomena such as increased body dimensions, maturation of the central nervous system, increased practice, and, for males, increased levels of certain hormones at the end of childhood through early adolescence contribute to a “triggering effect.” This triggering phenomenon is thought to be the result of “modulating effects of hormones that initiate puberty and influence functional development and subsequent organic adaptations” (p. 241). Katch’s hypothesis further maintained that prior to this “critical period” the effects of physical conditioning would be minimal to nonexistent. However, after the “trigger” and the establishment of necessary physiological precursors, such as neuromuscular maturity, sufficient endocrine levels, and an increase in lean-to-fat tissue ratio, the individual theoretically would become increasingly predisposed to improvements from physical training.

In support of the trigger hypothesis, several qualitative reviews of literature have suggested that trainability for maximal aerobic power is less in prepubescents than in older individuals (Bar-Or, 1989; Borms, 1986; Vaccaro & Mahon, 1987). A recent meta-analysis (Payne & Morrow, 1993) lent further support to Katch’s hypothesis by examining the effect of children’s training on VO_{max}. Exercise programs from the most carefully controlled studies elicited only “small-to-moderate” improvements in the aerobic fitness of children compared to adolescents or adults. The authors concluded that their findings “lead to questions concerning traditional practices when dealing with children and their fitness” (p. 311).

Like the research examining the effects of training on children’s aerobic power, studies have sought also to determine if children are similarly less trainable in muscular endurance and strength than adolescents and adults. For the purposes of this study, muscular endurance was considered to be the “...ability of a muscle or muscle group to perform repeated contractions against a light load for an extended period of time.” (Fox, Bowers, & Foss, 1993, p. 686). Muscular strength was considered to be the “...force or tension that a muscle or group of muscles can exert against a resistance on one maximal effort” (Fox et al., 1993. p. 686) or very few repetitions.

Studies generally have supported the role of training in improving muscular endurance and strength in children, although the methods of testing and training have varied (Docherty, Wenger, Collis, & Quinney, 1987; McGovern, 1984; Ramsay et al., 1990; Servedio et al., 1985; Sewall & Micheli, 1986; Siegel, Camaione, & Manfredi, 1989; Weltman et al., 1986). Research also has supported the notion that gains in prepubescents are similar to those seen in pubescents and postpubescents (Nielsen, Nielsen, Hansen, & Asmussen, 1980; Pfeiffer & Francis, 1986; Sailors & Berg, 1987). The National
Strength and Conditioning Association (1985) agrees that prepubescent strength can be improved with training and claims that this improvement can lead to enhanced sports performance, decreased severity and rate of injury, and improved self-image.

A 1985 conference conducted by the American Orthopedic Society for Sports Medicine focused specifically on resistance training for prepubescents. Attendees included representatives from the American Academy of Pediatrics, American College of Sports Medicine, National Athletic Trainers Association, National Strength and Conditioning Association, President's Council on Physical Fitness and Sports, US Olympic Committee, and the Society of Pediatric Orthopedics. Participants unanimously agreed that resistance training could be safe and beneficial for youngsters. They further concluded that increased muscular strength and endurance, improved motor skill development, and injury prevention were among the benefits of resistance training in prepubescents (Cahill, 1990).

Numerous qualitative reviews of literature also have been written on this topic (Blimkie, 1993; Cahill, 1990; Jacobson & Kulling, 1989; Kraemer, Fry, Frykman, Conroy, & Hoffman, 1989; Siegel, 1988; Webb, 1990; Weltman, 1989) often leading to the conclusion that resistance training can improve muscular strength in children (Bar-Or, 1989; Micheli, 1988; Sale, 1989). Despite the generally positive findings of these reviews, Sale (1989) stated, "...the practice of resistance strength training by children (particularly prepubertal children) is controversial" (p. 166). Sale further stated, "There is less controversy over whether pubescent children can make significant increases in strength with resistance strength training" (p. 168).

Recent positive conclusions regarding the effect of training on children's muscular endurance and strength led the American Academy of Pediatrics (AAP, 1990) to modify their 1983 position which stated, "prepubertal boys...do not significantly improve strength or increase muscle mass in a weight training program because of insufficient circulating androgens" (p. 158). In 1983, the AAP cited a lack of sufficient evidence of strength gains and safety issues as reasons to avoid weight training in children. By 1990, the AAP stated that "short-term programs in which prepubescent athletes are trained and supervised by knowledgeable adults can increase strength without significant injury risk" (AAP, 1990, p. 801).

Nevertheless, Vrijens (1978) found that resistance training had little effect on prepubescents following an 8-week program of resistance training. While prepubescent showed no consistent pattern of strength gain, postpubescents improved strength in leg flexors and extensors, arm flexors and extensors, abdominal muscles, and the lower back. General opposition to prepubescent resistance training programs has been based primarily on three areas of concern: (1) children lack sufficient circulating androgens to make significant improvements in muscular endurance or strength, (2) even if improvements do occur, they may not improve sport performance, (3) prepubertal resistance training may induce an unacceptably high injury rate (Sale, 1989; Sewall & Micheli, 1986; Weltman, 1989).

In short, based on Katch's hypothesis and research examining children's aerobic power, physical training would not be expected to enhance significantly prepubertal muscular endurance or strength. Nevertheless, many individual studies have noted improvements. Qualitative reviews on this topic generally have supported the findings of these individual studies. Unfortunately, reviews have been qualitative and incomplete. Therefore, the present research was conducted using the meta-analysis technique to examine quantitatively the effectiveness of resistance training on muscular endurance and strength of children and youth.

**Method**

Meta-analysis is a statistical method that enables the simultaneous and quantitative evaluation of multiple research studies. The dependent variable in this process is known as the effect size (ES), an indicator of the magnitude of the treatment effect in standard deviation units. ES is calculated by using the formula:

\[
ES = \frac{(Me - Mc)}{Sc}
\]

where the Me is the mean of the experimental group, Mc is the mean of the control group, and Sc is the control group standard deviation. The algebraic sign in ES is important, as it indicates which group performed better on the dependent measure (Thomas & French, 1986). Effectively, the ES is interpreted as the difference between contrasted means in standard deviation units. For example, an ES of .50 indicates that the treated group mean is one-half of standard deviation higher than the untreated group.

To locate research examining the effects of resistance training on children and adolescents, five separate on-line computer searches (i.e., ERIC, Medline, SPORT Database, SPORT Discus, and University Microfilms International [UMI]) were conducted. ERIC accesses 750 education-related journals and serial publications with sources available since 1966. Sources back to 1975 were reviewed using Medline, which searches over 3,600 biomedically oriented journals. SPORT Database and SPORT Discus resources include journals, magazines, books, theses, conference papers, and related published research since 1975 and 1977, respectively. UMI accesses abstracts published in Dissertation Abstracts since 1981.
Potential sources identified in the computer search were reviewed and reference lists crosschecked for additional citations. Over 500 papers, including non-data-based articles as well as published manuscripts and unpublished theses and dissertations were crosschecked and screened while finalizing the criteria for inclusion for the meta-analysis. Criteria for inclusion were:

1. Studies must have examined the effects of resistance training on muscular strength or muscular endurance of participants.
2. Studies must have been conducted on "healthy-normal" participants (e.g., studies using participants with asthma, various heart conditions, etc. were excluded).
3. Measurements of muscular strength or muscular endurance must have been reported. Measures of power (e.g., vertical jump, Wingate test) and physical fitness indexes were excluded.
4. Means, standard deviations, and sample sizes must have been reported for the control and experimental groups.
5. Research must have included participants who were 18 years of age or less.
6. Controls must have been reported from an untreated group in an experimental-control design or as a pretest in a pretest-posttest control group design (pre-post).

Table 1 illustrates the categories developed. For the purposes of determining the effects of age (and potentially puberty), boys and girls were categorized into "younger" or "older" groups. For girls, younger was less than 11 years, and older was more than 14 years. For boys, younger was less than 13 years and older was more than 16 years. These categories were determined based on the average age of peak height velocity (PHV). According to Malina and Bouchard (1991), considerable individual variation exists for this characteristic. However, the average age for PHV is 11.4 and 13.4 years for girls and boys, respectively.

Statistical analyses were conducted with META-STAT (version 1.3, LMP Associates, Chevy Chase, MD). Results are presented with descriptive statistics, diagrams, and correlation coefficients.

### Results

Only 28 of the reviewed studies met the criteria for inclusion in this meta-analysis. This resulted in 263 ESs. Eleven ESs were eliminated as outliers, because they were >2.8 SD above the mean ES, resulting in 252 ESs for analy-

<table>
<thead>
<tr>
<th>Table 1. Variable Definitions for Meta Analysis</th>
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<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Younger &lt; 13</td>
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<tr>
<td>Older 16+</td>
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<tr>
<td>Training-measurement type</td>
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<tr>
<td>Isokinetic</td>
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<tr>
<td>Isometric</td>
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<tr>
<td>Isotonic</td>
</tr>
<tr>
<td>Body segment</td>
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<tr>
<td>Arm</td>
</tr>
<tr>
<td>Back</td>
</tr>
<tr>
<td>Leg</td>
</tr>
<tr>
<td>Duration</td>
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<tr>
<td>Number of weeks duration for the study</td>
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<tr>
<td>Frequency</td>
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<tr>
<td>Number of times per week the training was conducted</td>
</tr>
<tr>
<td>Design type</td>
</tr>
<tr>
<td>Experiment versus control</td>
</tr>
<tr>
<td>Pre- and posttesting</td>
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<tr>
<td>Study status</td>
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<tr>
<td>Journals</td>
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<td>Theses-dissertations</td>
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<th>Table 2. Mean effect sizes for resistance training in children and youth</th>
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<tr>
<td>Effect size group</td>
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<tr>
<td>Overall (N=252)</td>
</tr>
<tr>
<td>Younger (n=91)</td>
</tr>
<tr>
<td>Older (n=11)</td>
</tr>
<tr>
<td>Boys (n=156)</td>
</tr>
<tr>
<td>Girls (n=23)</td>
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<tr>
<td>Isokinetic (n=18)</td>
</tr>
<tr>
<td>Isometric (n=88)</td>
</tr>
<tr>
<td>Isotonic (n=139)</td>
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<tr>
<td>Arm (n=141)</td>
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<tr>
<td>Back (n=12)</td>
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<tr>
<td>Leg (n=82)</td>
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<tr>
<td>Pre-post design (n=115)</td>
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<tr>
<td>Experimental-control design (n=137)</td>
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<tr>
<td>Journals (n=114)</td>
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<tr>
<td>Theses-dissertations (n=110)</td>
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Note. r² represents the strength of association between the effect size and training group status (i.e., trained and untrained).
* p < .05 when tested against a mean effect size of .00; df = N - 1 for each test.
Additionally, many studies grouped participants across age categories or gender, and identifying specific effects for such studies was impossible. Summary statistics are presented in Table 2. Figure 1 illustrates the considerable variability in the ESs.

Each mean ES was significantly different ($p < .05$) from zero. These results indicate that resistance training was generally effective, regardless of participant or study characteristics.

Many ($n = 73$) of the studies grouped boys and girls together for the original analyses, thus, differentiating a gender effect in these studies was impossible. No studies were included in the analyses that consisted of young (i.e., $< 11$ years) females alone; clearly additional work is needed in this area.

Duration of training (i.e., number of weeks) was not related to ES for all observations, $r(220) = .09, p < .17$, nor for males, $r(148) = .08, p < .65$, or females, $r(19) = .11, p < .63$. Duration of training was related to ES in the pre-post design studies, $r(90) = .22; p < .04$, but not in the experimental-control studies, $r(118) = .00; p < .97$.

![Figure 1. Box and whiskers of mean effect size by study characteristics. (The top of the whisker is the maximum value, the bottom of the whisker is the minimum value, the top of the box is the 75th percentile, the bottom of the box is the 25th percentile, and the line inside the box is the 50th percentile.)](image)
Discussion

As reported by Payne and Morrow (1993) and suggested by Thomas, Salazar, and Landers (1991), many authors do not report sufficient statistics (i.e., means, standard deviations, and number of observations) to permit use of study results in secondary analyses. Others do not report them in sufficient detail to permit reanalysis by subgroups (e.g., boys and girls are grouped together) or provide insufficient detail to permit clear identification of the correct classification of the study (e.g., type of training completed, number of weeks duration, number of sessions per week). As a minimum, authors should present descriptive statistics (i.e., mean, standard deviation, sample size) and ESs for important outcome measures. Additionally, these should be presented for important subgroups of the sample (e.g., gender, training level).

The overall average ES (.75) in this research was comparable to that reported by Payne and Morrow (1993) for children's aerobic capacity (.65). However, Payne and Morrow noted that aerobic trainability as indicated by ES appeared to be strongly related to the type of experimental design employed, because participants in the most carefully designed studies (pretest-posttest) improved their aerobic capacity only about 4% despite a relatively high overall ES. This finding supported Katch's trigger hypothesis in aerobic training with children.

ESs ranged from .65 ≤ ES ≤ .83 with a few notable exceptions. Regardless of age, children generally appeared to be capable of eliciting an improvement in muscular strength and muscular endurance. The mean ES for younger participants (.75) varied only slightly from that of older participants (.69). Therefore, unlike the previous research on children's aerobic trainability (Payne & Morrow, 1993), these findings do not support Katch's trigger hypothesis as it relates to muscular endurance and strength. Therefore, Katch's hypothesis (1983) appears to be supported for aerobic capacity though not for measures involving muscular endurance and strength. This could be the result of greater impact of learning or neuromuscular adaptation in the movements used to measure muscular endurance and strength. In addition, children may be generally closer to their potential for aerobic capacity, reducing the intended impact of training regimens designed to enhance VO2max. Conversely, children typically may not be involved in daily activities that require high levels of strength. Thus, specific resistance training activities may have a greater effect than aerobic training because of the relative "untrained" state associated with resistance activities. Significant ESs for each age group and that reported for adults of varying ages suggest that resistance training has a significant effect, not only on young children and youth but throughout the age range (i.e., well into adulthood and aging populations).

The mean ES for the girls (.81) was greater than that for boys (.72). In apparent contradiction to the comments above, this would appear to lend support to Katch's (1983) trigger hypothesis. Boys may not have reached the trigger point, while the girls, because of an earlier trigger point (closer to sexual maturity), may demonstrate a greater effect. However, this finding may have resulted because the girls were further from their potential in muscular endurance and strength measures due to less involvement in physical activities which would enhance muscular endurance and strength. In addition, the generalizability of the girls' result is limited given the small number of ESs (n = 23). Note, however, that the strength of association is large for the girls (r² = .91), indicating that the true training effect could be quite large.

Most studies reported using isotonic training programs. The number of isokinetic training programs was smallest, perhaps a function of the newness of the apparatus involved or the degree of sophistication and cost associated with purchasing such equipment. The mean ES (.20) for isokinetic training is the smallest obtained in this analysis. This may be a function of our current lack of knowledge concerning isokinetic training and optimal protocols, the increased complexity of the machines, or an attenuation in children's learning or neuromuscular adaptation with isotonic equipment. This notion is supported by Sale (1989) in a previous qualitative review where he stated that in children strength changes are more a result of neural factors than muscular hypertrophy. The present conclusion should, however, be interpreted with some caution as it was a result of a relatively small number of ESs (n = 18). The isotonic training programs had the largest ES (.90), which, in contrast to isokinetic programs, may be a function of learning, neuromuscular, or other physiological adaptations.

As indicated in Table 2, training was effective regardless of the body segment under investigation. Most studies used the arms for training (probably a function of equipment availability) and few studies obtained back measurements.

Similar to the research of Payne and Morrow (1993), the mean experimental-control design ES was greater than the pretest-posttest design ES. This may be related to selection bias in placing participants into training groups. Determining if true random assignment occurred for treatment condition is difficult. The pretest-posttest change ES is less than the experimental-control design ES, suggesting that the difference in pre- to posttest measurements for a single group of participants is less than the effect demonstrated between two differently trained groups.

The final variable examined—publication status—indicated that unpublished studies (theses and disser-
lations) tended to generate a larger training effect than those studies which had been published in journals. This suggests that peer-reviewed publications, which may be more rigorously reviewed, have a smaller ES.

In general, the results of this research suggest that children and youth can demonstrate considerable increases in muscular endurance and strength as a result of training. This finding generally supports positions taken by the National Strength and Conditioning Association (1985), the American Academy of Pediatrics (1990), and the 1985 conference conducted by the American Orthopedic Society for Sports Medicine (Cahill, 1990) stating that resistance training for prepubescents can be beneficial. It also supports a number of previous qualitative reviews conducted on this topic (Blimkie, 1993; Jacobson & Kulling, 1989; Siegel, 1988; Webb, 1990; and Welman, 1989). This includes the work of Kraemer et al. (1989) where the authors concluded that benefits like “increased muscular strength and local muscular endurance” (p. 336) appear to improve as a result of resistance training in youth.

Despite yielding considerable evidence that training can improve muscular endurance and strength in children and youth, many related issues remain to be clarified or resolved. Studies have yet to resolve the effects of intensity of exercise on children and youth, and none have researched the effects of resistance training on physical performance in sports or games. Even if children and youth can improve muscular endurance and strength, can this contribute to improved movement skill, athletic performance, or reduced risk of injury? In addition, what are the psychological and physical ramifications of resistance training programs of various intensities at a young age? Perhaps most importantly, what are the underlying physiological mechanisms affecting youth who have been involved in a resistance training program? Research on this topic could lead to answers concerning the differences between isotonic and isokinetic training programs and the apparent difference between aerobic and resistance training programs. It could also lead to explanations concerning how and why children improve (i.e., physiological training effects, increases in lean body mass, learning, or neuromuscular adaptation). Lastly, of the 179 ESs which could be subdivided by gender, only 23 were from female participants. Much more work needs to be conducted on all these issues as they pertain to girls.


Appendix. Studies Used in the Meta-Analysis


Authors' Note

Please address all correspondence concerning this article to V. Gregory Payne, Department of Human Performance, San Jose State University, San Jose, CA 95192

E-mail: vgpayne@sjsvm1.sjsu.edu