STATE OF THE ART
REVIEWS

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# Resistance Training for Children and Adolescents: Are There Health Outcomes?

Abstract *Although much of what we understand about the stimulus of resistance exercise has been gained by exploring the responses of adults to various training protocols, research into the effects of resistance exercise on children and adolescents has increased over the past decade. Despite outdated concerns that resistance training was ineffective or unsafe for youth, research increasingly suggests that resistance training can be a safe and effective method of exercise for children and adolescents provided that appropriate training guidelines are followed. In addition to enhancing motor skills and sports performance, regular participation in a youth resistance training program has the potential to positively influence several measurable indices of health. It helps strengthen bone, facilitate weight control, enhance psychosocial well-being, and improve one's cardiovascular risk profile. Furthermore, a stronger musculoskeletal system will enable boys and girls to perform life's daily activities with more energy and vigor and may increase a young athlete's resistance to sports-related injuries. Along with other types of physical activity, a properly designed youth resistance training program can offer observable health value to children and adolescents when appropriately prescribed and supervised.*

Keywords: youth; physical activity; muscular fitness; strength training; exercise program

Children and adolescents need to participate regularly in 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate, enjoyable, and involves a variety of activities.[1,2] Not only is regular physical activity essential for normal growth and development, but physical activity habits established early in life tend to carryover into adulthood.[3,4] Although activities that enhance cardiorespiratory fitness are generally recommended for youth, research increasingly suggests that resistance training can offer unique benefits for children and adolescents when appropriately prescribed and supervised.[5-8] As previously observed in adults,[9] youth resistance training can have favorable effects on musculoskeletal strength, body composition, cardiovascular risk factors, and psychosocial well-being.[1,6] Furthermore, a stronger musculoskeletal system will enable children and adolescents to perform life's daily activities with more energy and vigor and may increase a young athlete's resistance to sports-related injuries.[10,11]

> "…youth resistance training can have favorable effects on musculoskeletal strength, body composition, cardiovascular risk factors, and psychosocial well-being."

This review examines the potential health-related benefits associated with youth resistance training. A discussion of these benefits is particularly relevant because of the increasing number of children and adolescents who engage in various forms of resistance exercise and the current emphasis on promoting participation in health-enhancing physical activities during childhood and adolescence.[12-14] Since the act of resistance training itself does not result in health-promoting benefits unless the training stimulus exceeds an individual's strength threshold, specific recommendations for designing health-enhancing resistance training programs for children and adolescents are also reviewed.

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For the purposes of this review, the term *children* refers to boys and girls who have not yet developed secondary sex characteristics (approximately up to age 11 in girls and 13 in boys; Tanner stages 1 and 2 of sexual maturation). This period of development is often referred to as *preadolescence*. The term *adolescence* refers to the period of time between childhood and adulthood and includes girls aged 12 to 18 years and boys aged 14 to 18 years (Tanner stages 3 and 4 of sexual maturation). For ease of discussion, the term *youth* is broadly defined in this article to include the years of childhood and adolescence.

Resistance training is defined as a specialized method of conditioning that involves the progressive use of a wide range of resistive loads and a variety of training modalities (eg, free weights [barbells and dumbbells], weight machines, elastic cords, medicine balls [weighted balls filled with sand or cloth], and body weight) designed to enhance health, fitness, and sports performance. While the terms *resistance training*, *strength training*, and *weight training* are sometimes used synonymously, the term *resistance training* encompasses a broader range of training modalities (eg, weight machines and plyometic exercises) and a wider variety of training goals (eg, enhancing physical appearance and improving athletic performance). Although there is no real consensus on the behaviors required to achieve optimal health in children and adolescents, for the purposes of this review, behaviors and exposures that increase the acquisition of health-associated characteristics are deemed desirable for children and adolescents.

## Resistance Training for Youth

Health-minded organizations such as the American Academy of Pediatrics,[15] the American College of Sports Medicine,[16] the National Strength and Conditioning Association,[6] the British Association for Sports and Exercise,[17] and the Presidents Council on Physical Fitness and Sports[18] now recognize the importance of enhancing muscular strength during childhood and adolescence. Despite outdated concerns associated with youth resistance training, scientific evidence and clinical impressions indicate that resistance exercise can be safe and effective for children and adolescents provided that age-appropriate training guidelines are followed.[6-8,19] Currently, comprehensive school-based programs such as Physical Best are specifically designed to enhance health-related fitness components including muscular strength and endurance along with cardiorespiratory endurance, flexibility, and body composition.[13]

Investigations performed over the past 15 years provide compelling evidence that well-designed resistance training programs can enhance the strength of children and adolescents beyond what is normally expected from growth and maturation (see reviews by Blimkie,[5] Faigenbaum et al,[6] and Falk and Tenenbaum[7]). Children as young as 6 years have benefited from resistance training, and various combinations of sets and repetitions have proven to be effective provided the training stimulus was adequate.[20-24] Strength gains of roughly 30% to 50% are typically observed in untrained youth following short-term (8-12 weeks) training programs. In general, it appears that percentage-based gains made by children and adolescents who resistance train are similar to gains made by resistance-trained adults.[25] However, training-induced strength gains during childhood are primarily due to neural adaptations as opposed to hypertrophic factors.[26]

## Health-Related Benefits of Resistance Training

Participation in a youth resistance training program provides children and adolescents with yet another opportunity to improve their health and quality of life. Although research on the health-related benefits of youth resistance exercise continue to be elucidated, the available evidence suggests that if appropriate training guidelines are followed, the health of children and adolescents is more likely to improve rather than be adversely affected by participation in a resistance training program. The safe and proper prescription of resistance exercise has been shown to favorably influence bone mineral density, body composition, cardiovascular risk, resistance to sports-related injuries, and psychosocial well-being.[1,6,8] These health-related benefits, along with performance-related benefits, such as improvements in motor performance skills (eg, sprinting and jumping), will likely enhance the quality of life for children and adolescents by enabling them to perform life's daily activities with more energy and vigor. A summary of the potential benefits associated with youth resistance training is presented in Table 1.

### Bone Health

From a public health perspective, it is interesting to note that traditional fears that resistance training would be harmful to the immature skeleton of young

**Table 1.**

Potential Benefits of Youth Resistance Training

| |
|---|
| Increase muscle strength and power |
| Increase local muscular endurance |
| Increase bone mass |
| Increase cardiorespiratory fitness |
| Improve blood lipid profile |
| Improve body composition |
| Improve motor performance skills |
| Enhance sports performance |
| Increase resistance to injury |
| Enhance mental health and well-being |
| Stimulate a more positive attitude toward lifetime physical activity |

weight trainers have been replaced by current findings that suggest that childhood and adolescence may be the opportune time for the bone-modeling and -remodeling process to respond to the tensile and compressive forces associated with weight-bearing activities.[27-29] For example, concerns that resistance exercise would cause harm to the growth plates of youth weight trainers have been replaced by observations that indicate that the mechanical stress placed on developing growth plates from weight-bearing exercise or high-strain-eliciting sports (eg, gymnastics) are actually essential for bone formation and growth.[30]

Weight-bearing sports and exercise can be beneficial for individuals of any age; however, it appears that this type of physical activity during periods of growth and development may be most beneficial because the mechanical stress from weight-bearing activities may act synergistically with growth-related increases in bone mass, resulting in a higher bone mass later in life.[28,29,31] While peak bone mass is strongly influenced by genetics,[32] regular participation in high-strain-eliciting sports and specialized exercise such as resistance training appears to maximize bone mineral density during childhood and adolescence.[28,29] Moreover, scientific evidence indicates that there is no detriment of youth resistance training on linear growth in children and adolescents.[26]

Interestingly, the increase in lean mass is the most important predictor for bone mineral mass accrual during childhood and adolescence.[33,34] It seems that the increase in muscle strength associated with muscle development allows for greater forces to be placed on bones where the strengthened muscles attach.[35] Hence, in addition to the direct effect of physical activity on bone, resistance training can increase bone acquisition indirectly by increasing muscle mass and muscle strength, which in turn could increase the tensions placed on bones. In support of these observations, it has been reported that elite adolescent Olympic weightlifters who regularly train with heavy weights while performing multijoint exercises (eg, snatch and clean and jerk) display levels of bone mineral density[36] and bone mineral content[37] well above values of age-matched controls. It appears that muscular forces that must act on bone to perform a desired movement with a heavy load may be a potent osteogenic stimulus for new bone formation in certain individuals.

Others have reported that participation in school-based exercise interventions can have a favorable impact on bone health.[38-42] In one study that provides direct evidence that high-impact exercise enhances bone accrual in preadolescent girls, participation in a 10-month physical activity program (which included resistance training and aerobic exercise 3 times per week) resulted in a significant improvement in bone mineral density (BMD) in the exercise group as compared to the age-matched control group.[41] Likewise, preadolescent boys who performed a high-impact circuit exercise program for 20 months had greater bone expansion on both the periosteal and endosteal surfaces.[39] Others reported that a physical activity intervention that consisted of 10 plyometric jumps performed 3 times per day for 8 months enhanced bone mass at the weight-bearing proximal femur in children.[40] It is noteworthy that this exercise intervention was inexpensive, easily implemented by elementary school teachers, and short in duration (requiring about 3 minutes per day).

In addition to regular participation in weight-bearing physical activity, bone health is influenced by lifestyle factors such as proper nutrition. In a study designed to examine the effects of increasing milk on bone responses to 12 weeks of resistance training in adolescent males, subjects who added to their diet 3 additional servings of milk per day increased whole-body BMD to a greater extent than subjects who consumed juice.[43] Although the potential importance of calcium and perhaps other nutrients in milk in optimizing bone development in youth should not be underemphasized, it appears that increased consumption of calcium boosts bone development only when combined with progressive weight-bearing physical activity.[44] Furthermore, the desired changes in bone mineral content and BMD may be lost over time if the sport or exercise program is not continued.[45]

While the human skeleton is sensitive to the mechanical stimulation elicited by weight-bearing physical activity and resistance exercise, the exercise intensity rather than the exercise duration seems to be the primary determinant for maximizing peak bone mass in youth. For example, limited data suggest that eccentric training may be more osteogenic than concentric training.[46] Since eccentric muscle actions produce about 25% greater force than concentric muscle actions, eccentric loading should generate greater forces on bone than concentric loading. The importance of eccentric loading was evident in a study that examined the effects of 26 weeks of resistance training on adolescent females.[47] Despite significant gains in muscle strength, there were no significant changes in bone mineral content. Since the subjects performed all exercises reciprocally and concentrically on hydraulic resistance training machines, eccentric loading did not occur, and hence, the training intensity may have been suboptimal to elicit favorable changes in bone mineral content.[47]

While additional clinical trials are needed to more precisely define the optimal exercise prescription for optimizing bone development in children and adolescents, it appears that high loads involving concentric and eccentric muscle actions play a critical role in bone mass acquisition during childhood and adolescence. Moreover, since bone tissue rapidly becomes desensitized during a prolonged exercise session,[48] it is important to design a resistance training program whereby short intense loading sessions are followed by brief periods of rest. Consequently, it seems that the osteogenic response to exercise in youth can be enhanced by sensibly prescribing multijoint, moderate- to high-intensity resistance training exercises (eg, bench press and squat) with high-impact, unaccustomed, strain-producing plyometric exercises (eg, jumping and hopping).

## Body Composition

Over the past 3 decades, the prevalence of childhood obesity has more than doubled for adolescents, and it has more than tripled for children.[49] Among American youth aged 2 through 19 years, data from a national survey using body mass index (BMI) as a main outcome measure indicate that 33.6% are at risk for becoming obese (≥85% but <95% of the sex-specific BMI for age) and 17.1% are obese (≥95% of the sex-specific BMI for age).[49] Based on current trends, it is estimated that 20% of overweight 4-year-olds and as many as 80% of overweight adolescents will become obese adults (BMI ≥30 kg/m$^2$).[50,51] These trends have led some observers to predict that the overall adult life expectancy will decrease because of the increased prevalence of obesity-related comorbidities such as type 2 diabetes, cardiovascular disease, and cancer.[52]

It is becoming more apparent that the increasing prevalence of obesity in children and adolescents is primarily due to a reduction in total daily energy expenditure. Even though the energy cost of any given movement increases as a child becomes obese, societal changes during the past several decades have reduced the need to be physically active. Since obese youth may lack the motor skills and confidence to be physically active, they may actually perceive physical activity to be discomforting and embarrassing. In a recent study, total body fat expressed as a percentage of body mass was inversely related to minutes of vigorous physical activity per day in both boys and girls.[53] Sadly, this decline in physical activity may start early in life in obese youth.[54]

Along with parent training/modeling, behavioral counseling, and nutrition education, regular physical activity is a cornerstone of multicomponent treatment programs for obese youth.[55] Although both normal weight and obese boys and girls have traditionally been encouraged to participate in aerobic activities, excess body weight hinders the performance of weight-bearing physical activities such as jogging and increases the risk of musculoskeletal overuse injuries. More recently, it has been reported that regular participation in a resistance training program resulted in a decrease in fatness among normal-weight youth[21,22,56] as well as obese children and adolescents.[57-59] Even though resistance training is not typically characterized by high caloric expenditure, a growing body of evidence suggests that exercise programs that include resistance training can improve the health and body composition of both normal-weight and obese youth.[60]

Sothern et al[58] studied the safety, feasibility, and level of compliance of a progressive, moderate-intensity resistance training program in a group of obese children during a multidisciplinary outpatient treatment program. During the intervention period, subjects reported no injuries or accidents, and 79% of the subjects completed the 10-week program. Body weight, BMI, and percentage body fat were reduced significantly at 10 weeks and did not increase significantly at 1-year follow-up. Treuth et al[61] tested the hypothesis that resistance training would benefit obese children with respect to body composition and energy expenditure. These researchers reported gains in fat-free mass in obese children who participated in a 5-month resistance training program. Compliance with the resistance training program was 83%. While total body weight and percentage body fat also increased during the intervention period, intra-abdominal adipose tissue (measured by computed tomography) remained stable. Since central obesity is associated with cardiovascular risk in children, this finding has important health implications. In a separate analysis of these data, Treuth et al[62] examined the effects of resistance training on energy expenditure in obese girls. Despite significant increases in muscle strength, resting metabolic rate did not change. It is possible, however, that a higher volume, more intense resistance training program might have more favorable effects on energy expenditure in obese youth.

Watts et al[59] found that circuit training (both cycle ergometry and resistance training) not only improved the body composition of obese adolescents but also normalized vascular dysfunction (assessed using high-resolution ultrasound and flow-mediated dilation of the brachial artery) in obese subjects. Since endothelial dysfunction is an early manifestation of atherosclerotic disease,[63] this important finding highlights the potential clinical relevance of circuit training in obese adolescents. More recently, Shabi et al[64] reported that a progressive 16-week resistance training program significantly improved insulin sensitivity (directly measured via a frequently sampled intravenous glucose tolerance test) in overweight (≥85% of the sex-specific BMI) adolescent men independent of changes in body composition. These findings coupled with a very high 96% attendance rate suggest that resistance training may be a viable and efficacious modality for improving metabolic health in overweight youth.

Of note, Falk et al[65] observed that the level of adiposity was a strong negative predictor of the resistance training effect of the lower limbs following 3 school years of resistance training. It was reported that the individually prescribed training program resulted in greater strength gains in normal-weight children (14.5% to 16.7% body fat) compared with the so-called nonresponders (23.5% to 32.8% body fat). Thus, it was suggested that a training intensity that may be appropriate to increase strength in normal-weight children may be insufficient in children who have excess body fat. These findings suggest that obese youth may need a higher relative training intensity to produce the desired result.

Although the treatment of childhood obesity is complex, scientific evidence and clinical observations suggest that obese youth enjoy resistance training because it is not aerobically taxing and provides an opportunity for all participants to experience success and feel good about their performance. Thus, the first step in encouraging obese children and adolescents to exercise may be to increase their confidence in their ability to be physically active, which in turn may lead to an increase in regular physical activity, a noticeable improvement in muscle strength, and exposure to a form of exercise that can be carried over into adulthood. Although further study is warranted, youth resistance training with moderate loads and a high number of repetitions may be part of the solution for long-term fat loss and weight management in obese children and adolescents.

## Sports-Related Injuries

The number of children and adolescents involved in school-sponsored and community-based sports programs continues to increase. While this is a favorable trend, sports-related injuries can have a significant impact on young athletes, their parents, and the health care system. Sports-related injuries are a significant cause of hospitalization and health care costs during childhood and adolescence,[66] and it is possible that certain youth sport injuries can increase the risk of osteoarthritis later in life.[67] It is also estimated that about 8% of adolescents drop out of sports annually because of injury occurrence.[68]

While the total elimination of sports-related injuries is an unrealistic goal, the incidence of sports-related injuries in youth sports can be reduced by identifying contributory risk factors. Intrinsic risk factors such as previous injury, poor conditioning, muscle imbalances, and growth are noteworthy; however, extrinsic risk factors such as errors in training (ie, too much too soon) seem to be a major factor in a growing number of sports-related injuries in young athletes.[10,69] In a growing number of cases, it appears that young athletes are ill-prepared for the demands of both sports practice and competition.[70,71] More than a third of young people in grades 9 to 12 do not regularly engage in vigorous physical activity,[12] and the percentage of children and adolescents aged 6 to 19 years who are obese continues to increase.[49] While all aspiring young athletes will likely benefit from preparatory resistance training, it seems that those who might benefit the most are those who are less fit to begin with.

By addressing risk factors associated with youth sports injuries, it has been suggested that both acute and overuse injuries could be reduced by 15% to 50%.[10] Although there are many mechanisms to potentially reduce sports-related injuries in young athletes (eg, coaching education and proper equipment), enhancing musculoskeletal strength as a preventative health measure should not be overlooked.[10,11,69] Because many of the injuries that occur in sports involve connective tissues, it is reasonable to believe that by changing the size, density, or mechanical properties of the connective tissue framework, the risk of injury will be reduced.[72,73] These changes in tissue makeup form the foundation on which the rehabilitation of musculoskeletal injuries is based and hence may also play a role in injury reduction. Several studies have demonstrated a decreased injury rate in adolescent athletes who have participated in a multicomponent conditioning program that included resistance training,[74-80] and it seems likely that children would experience similar benefit if appropriate training guidelines are followed.

Clearly, a youngster's participation in sport should not start with competition but should evolve out of preparatory conditioning and instructional practice sessions that are gradually progressed over time. Even though youth who participate in recreational sports seem to have higher levels of muscular strength and anaerobic power than less active youth,[81] it is unlikely that a child will gain the specific benefits of resistance training without actually participating in a progressive resistance training program. Thus, it seems prudent for aspiring youth athletes to participate in several weeks (at least 6 to 8 weeks) of preparatory conditioning (which includes resistance training) prior to sports participation. During this time, correctable risk factors (eg, poor physical condition) could be identified and treated by qualified teachers and coaches. This type of preseason conditioning could decrease the likelihood that young athletes drop out of sport because of frustration, embarrassment, failure, or injury. Preseason conditioning that includes resistance training has proven to be particularly beneficial for young female athletes, who appear to be more susceptible to knee injuries than young male athletes are.[76,78,82]

It is noteworthy that most prospective resistance training trials that significantly reduced injuries had a training frequency of 2 or 3 days per week. A downfall of some youth programs is not allowing for adequate recovery between training sessions. A reduction in performance and an increased risk if injury can result by frequent training sessions without adequate rest and recovery in between.[83] Because children and adolescents are still growing and developing, it is likely that they may need even more time for rest and recovery between exercise sessions than adults. Professionals who work with youth need to pay special attention to the intensity and volume of the exercise program as well as the amount of rest and recovery between exercise sessions if injury reduction is a primary training objective. It is important to realize that what is done between training sessions can have a significant impact on what is done during each training session. In short, resistance training should not be simply added onto a young athlete's training program but rather sensibly incorporated into a multifactorial conditioning program that varied throughout the year. In some cases, young athletes may need to reduce the amount of time they spend practicing sport-specific skills to allow time for preparatory conditioning.

## Cardiovascular Risk Factors

Primary hypertension in children has become more common in association with obesity and other risk factors including a positive family history of hypertension.[84] Although there is no clear association between regular physical activity and reducing blood pressure in normotensive youth, limited data suggest that resistance training may be an effective nonpharmacologic intervention that may prevent the return of blood pressure to preintervention levels in hypertensive adolescents provided that submaximal loads are used and proper exercise procedures are followed.[85] Although decreasing resting blood pressure following exercise training in hypertensive youth may be due to favorable changes in body composition and nutritional intake, it is possible that a comprehensive health-enhancing physical activity plan that includes both aerobic exercise and resistance training may offer the most benefit for hypertensive youth.[85,86]

The effects of resistance training on blood lipoproteins in youth are not well-documented. Limited data suggest that when compared to an inactive control group, resistance-trained youth demonstrate favorable changes in their blood lipid profiles.[87,88] While nutrition and genetics may account for much of the variability in serum lipids, it does appear that resistance training programs characterized by a relatively high volume may have a desirable influence on lipoprotein concentrations.

### Psychosocial Health

Perhaps the most overlooked benefit of youth resistance training is its potential impact on psychosocial health (ie, both psychological and social-psychological outcomes). It has been observed that the socialization and mental discipline exhibited by youth participating in a resistance training program are similar to the experiences of children and adolescents participating in team sports.[89] If the resistance training program is well designed and competently supervised by professionals who appreciate the uniqueness of children and adolescents, resistance training may positively influence children's' attitudes toward physical education, physical fitness, and lifelong exercise.[90]

Favorable changes in selected psychometric measures (eg, self-concept, self-esteem, and body cathexis) have been observed in adults who resistance train,[91,92] and it seems that similar benefits could occur in children and adolescents. Holloway et al[93] reported significant improvements in self-efficacy and general self-esteem in untrained adolescent girls who participated in a 12-week resistance training program. More recently, Annesi et al[94] observed significant improvements in self-efficacy scores in girls who completed a 12-week after-school physical activity program that consisted of resistance training, cardiovascular exercises, and behavioral skills training.

However, others reported no change in psychological measures in children following a resistance training program despite significant gains in muscle strength.[95,96] It is conceivable that relatively high pretraining self-concept scores in the aforementioned reports precluded significant gains following the training period. This contention is consistent with data from Tucker,[91] who reported an inverse association between pretest measures of self-concept in adult men who participated in a resistance training program. It seems that the potential impact of resistance exercise on selected psychosocial measures in youth will depend on the design of the exercise program as well as the initial levels of muscular strength and psychological well-being. While no data suggest that an age-appropriate resistance training program will have adverse psychosocial consequences on youth, it is possible that excessive pressure from parents, coaches, and teachers to perform at a level beyond one's capabilities can negatively influence the youth resistance training experience.

## Recommendations for Youth Resistance Training

Because of interindividual differences in stress tolerance, resistance training needs to be carefully prescribed and progressed. Overprescription of resistance training may result in overtraining, whereas underprescription of resistance training will result in suboptimal adaptations. For that reason, the magnitude of individual effort along with the systematic structuring of the resistance training program needs to be carefully monitored. In addition, cautionary measures (eg, qualified supervision, safe environment, health screening) need to be considered when children and adolescents want to participate in a resistance training program.

It is likely that the type, intensity, and volume of resistance training necessary to elicit a desired health outcome will depend on the health outcome in question. For example, a resistance training program necessary to improve body composition in obese adolescents may differ from a program designed to reduce the likelihood of sports-related injuries in young athletes. Therefore, once a child is deemed healthy enough to participate in a resistance training program, goal-oriented issues that may affect the design of a resistance training program should be identified and addressed.

Although most youth resistance training programs aim to collectively improve several of these goals, a key factor in the design of any resistance training program is appropriate program design, which includes proper exercise instruction and supervision, the correct prescription of the program variables, and the inclusion of specific methods of progression that will keep the training stimulus fresh and effective. Moreover, since enjoyment has been shown to mediate the effects of youth physical activity programs,[97] the importance of creating an enjoyable exercise experience for all young participants should not be overlooked.

The program variables that should be considered when designing a youth resistance training program include (1) warm-up, (2) choice and order of exercise, (3) training intensity, (4) training volume, (5) rest intervals between sets and exercises, (6) repetition velocity, (7) training frequency, (8) cooldown, and (9) program variation. Table 2 summarizes resistance training guidelines for children and adolescents. A more detailed description of youth resistance program variables is available elsewhere.[98-100]

### Warm-up

Although warm-up protocols that include low-intensity aerobic exercise and static stretching have become standard practice, over the past few years, long-held beliefs regarding the routine practice of preevent static stretching have been questioned.[101,102] Recently, there has been rising interest in warm-up procedures that involve the performance of dynamic movements (eg, hops, skips, jumps, and movement-based exercises for the upper and lower body) designed to elevate core body temperature, enhance motor unit excitability, improve kinesthetic awareness, and maximize active ranges of motion.[103] During a dynamic exercise, the muscles are stretched to a new range of motion and then forced to contract to perform the desired action. Since muscles are actually used in a new range of motion, it is logical to assume that they will be better prepared for resistance training. It is important to understand that a dynamic stretch does not involve a bouncing-type movement, which is characteristic of a ballistic stretch, but rather a controlled elongation of specific muscle groups.

Warm-up dynamic exercise may create an optimal environment for resistance training by enhancing neuromuscular function. This phenomenon has been referred to as postactivation potentiation and is believed to improve power performance.[104] Recently, it has been reported that exercise protocols that include pre-event moderate- to high-intensity dynamic movements can enhance power performance in youth[105-107] and reduce the likelihood of lower limb injuries.[108] This is not to say that static stretching should be eliminated from a youngster's resistance training program but rather that the potential impact of pre-event dynamic exercise on performance should be considered. A reasonable suggestion is to perform 5 to 10 minutes of dynamic activities during the warm-up and static stretching during the cooldown. A description of warm-up dynamic exercises for youth is available elsewhere.[109]

## Choice and Order of Exercise

Although a limitless number of exercises can be used to enhance muscular fitness, it is important to select exercises that are appropriate for a child's body size, fitness level, and exercise technique experience. Also, the choice of exercises should promote muscle balance across joints and between opposing muscle groups (eg, quadriceps and hamstrings). Weight machines (both child sized and adult sized) as well as free weights, elastic bands, and medicine balls have been used by children and adolescents in clinical and school-based exercise programs. In most cases, it may be reasonable to start resistance training on weight machines and gradually progress to free weight and medicine ball exercises, which generally require more coordination and skill to perform correctly. Regardless of the mode of exercise, the concentric and eccentric phases of each lift should be performed in a controlled manner with proper exercise technique.

There are many ways to arrange the sequence of exercises in a resistance training session. Most youth will perform total body workouts several times per week, which involve multiple exercises stressing all major muscle groups each session. In this type of workout, large muscle group exercises should be performed before smaller muscle group exercises, and multiple-joint exercises should be performed before single-joint exercises. Following this exercise order will allow heavier weights to be used on the multiple-joint exercises because fatigue will be less of a factor. It is also helpful to perform more challenging exercises earlier in the workout when the neuromuscular system is less fatigued. Thus, if a child is learning how to perform a barbell squat exercise, this exercise should be performed early in the training session so that the child can practice the exercise without undue fatigue.

## Training Intensity

The most important variable in the design of a resistance training program is the training intensity. To maximize gains in muscular fitness, youth should first learn how to perform each exercise correctly and then learn how to perform each set to volitional fatigue (defined as the inability to complete a repetition because of temporary fatigue) using the appropriate resistance. Individual effort combined with a well-designed training program will ultimately determine the adaptations that take place.

The use of repetition maximum (RM) loads is a relatively simple method to prescribe resistance training intensity. Research studies involving adults suggest that RM loads of 6 or less have the greatest effect on developing muscle strength, whereas RM loads of 20 or more have the greatest impact on developing local muscular endurance.[110] However, most studies involving youth suggest that lighter loads and higher repetitions (eg, 10 to 15 RM) are most beneficial for enhancing muscular strength during the initial adaptation period (8 weeks).[20,21,111] Since different combinations of sets and/or repetitions may be needed to promote long-term gains in muscular fitness, the best approach for a child or adolescent may be to start resistance training with 1 set of 10 to 15 repetitions with a moderate load and then gradually progress the training program depending on goals, objectives, and time available for training.

When prescribing an appropriate training intensity for youth, it seems reasonable to first establish a repetition range (eg, 10 to 15) and then titrate the training load to maintain the desired training intensity. In an attempt to aid in the exercise prescription, a child-specific perceived exertion rating scale has been used to assess the exertional perceptions of children during strength exercise.[112] The Perceived Exertion for Children Scale contains verbal expressions along a numerical

**Table 2.**

General Youth Resistance Training Guidelines

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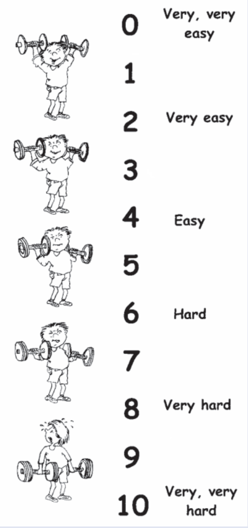
|---|
| Provide qualified instruction and supervision |
| Ensure the exercise environment is safe and free of hazards |
| Begin each session with a 5- to 10-minute dynamic warm-up period |
| Start with 1 set of 10 to 15 repetitions with a moderate load on a variety of exercises |
| Progress to 2 or 3 sets of 6 to 15 repetitions depending on needs and goals |
| Increase the resistance gradually (5% to 10%) as strength improves |
| Focus on the correct exercise technique instead of the amount of weight lifted |
| Resistance train 2 to 3 times per week on nonconsecutive days |
| Use individualized workout logs to monitor progress |
| Keep the program fresh and challenging by systematically varying the training program |

**Figure 1.**

Perceived Exertion for Children Scale (from Faigenbaum et al[112]).




response range of 0 to 10 and 5 pictorial descriptors that represent a child varying the levels of exertion while strength training (Figure 1). Subjective information from this scale combined with information on training experience and training goals can be used to assist in the prescription of safe and effective youth strength training programs. For example, findings suggest that an effort rating of 6 or 7 on the Perceived Exertion for Children Scale is consistent with a training intensity of approximately 75% of the 1 repetition maximum, which is a desirable training intensity for most youth.[112]

### Training Volume

The number of exercises performed per session, the repetitions performed per set, and the number of sets performed per exercise all influence the training volume. For example, if a child performs 2 sets of 10 repetitions with 100 lb on the leg press exercise, the training volume for this exercise would be 2000 lb ($2 \times 10 \times 100 = 2000$). Although there is some debate regarding training volume, it is important to remember that every training session does not need to be characterized by the same number of sets, repetitions, and exercises. The National Strength and Conditioning Association recommends that children and adolescents perform 1 to 3 sets on each exercise to achieve muscular fitness goals.[6].

In general, it is reasonable to begin resistance training with 1 set on a variety of exercises and then gradually progress to 2-, or 3-set protocols following the first few weeks of resistance training. Although long-term training studies (>6 months) are needed to explore the effects of different resistance training programs on youth, multiple-set training protocols have proven to be more effective than single-set protocols in adults,[113] and it is likely that similar findings would occur in children and adolescents over the long term. With a careful prescription of sets, repetitions, and exercises, the training stimulus will remain effective, and therefore the effort-to-benefit ratio will be maximized.

### Rest Intervals Between Sets and Exercises

The rest interval between sets and exercises is an important but often overlooked training variable. In general, the length of the rest period will influence energy recovery and the training adaptations that take place. For example, if the goal is to promote energy expenditure, lighter weights and shorter rest periods (eg, <1 min) are required. Obviously, training intensity, training goals, and fitness level will influence the length of the rest interval. In general, a rest period of 1 to 2 minutes between sets is appropriate for most beginners. Short rest periods (<30 seconds between sets and exercises) need to be carefully prescribed because of the muscular discomfort associated with this type of training. However, over time, the rest periods can be reduced gradually to provide ample opportunity for the body to tolerate this type of resistance training (eg, circuit training).

### Repetition Velocity

The velocity or cadence at which a strength exercise is performed can affect the adaptations to a training program.[114] Since beginners need to learn how to perform each exercise correctly with a light resistance, it is recommended that untrained youth perform resistance exercises with added weight in a controlled manner at a moderate velocity. As youth gain experience with resistance training, different training velocities may be used depending on the choice of exercise (eg, weight machine exercise or Olympic-style lift) and program goals. Although additional research is needed, it is likely that the performance of different training velocities within a training program may provide the most effective resistance training stimulus.

### Training Frequency

A resistance training frequency of 2 to 3 times per week on nonconsecutive days is recommended for children and adolescents. Limited evidence indicates that 1 day per week of resistance training may be suboptimal for enhancing muscular strength in youth.[115] It was reported that following 8 weeks of progressive strength training (1 set of 10-15 repetitions on 12 exercises), children who strength trained once per week achieved 67% of the 1 RM strength of children who strength trained twice per week.[115] A training frequency of twice or thrice weekly on nonconsecutive days will allow for adequate recovery between sessions (48 to 72 hours between sessions) and will be effective for enhancing musculoskeletal strength and performance. Factors such as the training volume, training intensity, exercise selection, nutritional intake, and sleep habits should also be considered when prescribing a training frequency as these factors may influence one's ability to recover from and adapt to the training program.

### Proper Cooldown

A 5- to 10-minute cooldown period consisting of general calisthenics and static stretching can help to relax the body and improve flexibility. Posttraining static stretching can facilitate range-of-motion improvements because of the increase in muscle temperature. During the cooldown period, it is often worthwhile to reflect on what each participant learned and review training objectives for the next session.

### Program Variation

By periodically varying program variables, long-term performance gains will be optimized and the risk of overuse injuries may be reduced.[114] The concept whereby a training program is systematically varied over time is known as periodization.[114] It is also reasonable to suggest that children and adolescents who participate in well-designed, progressive resistance training programs and continue to improve their health and fitness may be more likely to adhere to their exercise program. Furthermore, by systematically changing the exercises, the number of sets and/or repetitions and the rest interval between sets and exercises can help to prevent training plateaus, which are not uncommon after the first 8 to 12 weeks of resistance training. In the long term, periodized resistance training programs (with adequate recovery between training sessions) will allow participants to make even greater gains because the body will be challenged to adapt to even greater demands.

## Conclusion

Youth resistance training has the potential to offer observable health value to children and adolescents provided that appropriate training guidelines are followed. Despite traditional concerns regarding the safety and efficacy of resistance training for boys and girls, scientific evidence and clinical impressions indicate that resistance training should be part of a comprehensive health maintenance strategy for young populations. In addition to performance-related benefits, the effects of resistance training on selected health-related measures including bone health, body composition, cardiovascular risk factors, and sports injury reduction should be recognized by teachers, coaches, parents, and health care providers.

These health benefits can be safely obtained by most children and adolescents when prescribed appropriate resistance training guidelines. Unlike some other types of physical activity, resistance training programs can be developed to meet the needs of all boys and girls, especially those who need physical activity the most. Important future research goals should be to elucidate the mechanisms responsible for the health-related benefits associated with youth resistance exercise and to establish the combination of program variables that may optimize training adaptations in children and adolescents. We now have the information to justify the incorporation of resistance training activities into a health-oriented approach to lifelong physical activity.

## References

1. Strong W, Malina R, Blimkie C, et al. Evidence based physical activity for school-age youth. *J Pediatr.* 2005;46:732-737.
2. US Department of Health and Human Services, US Department of Agriculture. Dietary guidelines for Americans. Available at: http://www.healthierus.gov/dietaryguidelines. Accessed June 1, 2005.
3. Raitakari O, Porkka K, Taimela S, et al. Effects of persistent physical activity and inactivity on coronary risk factors in children and young adults: the Cardiovascular Risk in Young Finns Study. *Am J Epidemiol.* 1994;40:195-205.
4. Telama R, Yang X, Viikari, J, et al. Physical activity from childhood to adulthood: a 21 year tracking study. *Am J Prev Med.* 2005;28:267-273.
5. Blimkie C. Resistance training during pre-adolescence: issues and controversies. *Sports Med.* 1993;15:389-407.
6. Faigenbaum A, Kraemer W, Cahill B, et al. Youth resistance training: position statement paper and literature review. *Strength Cond J.* 1996;18:62-75.
7. Falk B, Tenenbaum G. The effectiveness of resistance training in children: a meta-analysis. *Sports Med.* 1996;22:176-186.
8. Guy J, Micheli L. Strength training for children and adolescents. *J Am Acad Orthop Surg.* 2001;9:29-36.
9. Graves J, Franklin B, eds. *Resistance Training for Health and Rehabilitation.* Champaign, Ill: Human Kinetics; 2001.
10. Micheli L. Preventing injuries in sports: what the team physician needs to know. In: Chan K, Micheli L, Smith A, Rolf C, Bachl N, Frontera W, Alenabi T, eds. *F.I.M.S. Team Physician Manual.* 2nd ed. Hong Kong: CD Concept; 2006:555-572.
11. Parkkari J, Kujala U, Kannus P. Is it possible to prevent sports injuries? *Sports Med.* 2001;31:985-995.
12. Grunbaum J, Kann L, Kinchen S, et al. Youth risk behavior surveillance—United States 2003. *MMWR Morb Mortal Wkly Rep.* 2004;53(SS-2):1-95.
13. National Association for Sport and Physical Education. *Physical Education for Lifelong Fitness.* 2nd ed. Champaign, Ill: Human Kinetics; 2005.
14. US Department of Health and Human Services. *The Surgeon General's Call to Action to Prevent and Decrease Overweight and Obesity 2001.* Washington, DC: US Department of Health and Human Services, Public Health Service, Office of the Surgeon General; 2001.
15. American Academy of Pediatrics. Strength training by children and adolescents. *Pediatrics.* 2001;107:1470-1472.
16. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription.* 7th ed. Philadelphia, Pa: Lippincott Williams & Wilkins; 2006:237-251.
17. British Association of Exercise and Sport Sciences. BASES position statement on guidelines for resistance exercise in young people. *J Sports Sci.* 2004;22:383-390.
18. Faigenbaum A. Youth resistance training. *President's Council on Physical Fitness and Sports Research Digest.* 2003;4:1-8.
19. Hamill B. Relative safety of weight lifting and weight training. *J Strength Cond Res.* 1994;8:53-57.
20. Faigenbaum A, Westcott W, Loud R, Long C. The effects of different resistance training protocols on muscular strength and endurance development in children. *Pediatrics.* 1999;104:e5.
21. Faigenbaum A, Zaichkowsky L, Westcott W, et al. The effects of a twice per week strength training program on children. *Pediatr Exerc Sci.* 1993;5:339-346.
22. Lillegard W, Brown E, Wilson D, et al. Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity. *Pediatr Rehabil.* 1997;1:147-157.
23. Ramsay J, Blimkie C, Smith K, et al. Strength training effects in prepubescent boys. *Med Sci Sports Exerc.* 1990;22:605-614.
24. Weltman A, Janney C, Rians K, et al. The effects of hydraulic resistance strength training in pre-pubertal males. *Med Sci Sports Exerc.* 1986;18:629-638.
25. Pfeiffer R, Francis R. Effects of strength training on muscle development in prepubescent, pubescent and postpubescent males. *Phys Sports Med.* 1986;14:134-143.

26. Falk, B, Eliakim A. Resistance training, skeletal muscle and growth. *Pediatr Endocrinol Rev.* 2003;1:120-127.
27. Bass S. The prepubertal years: a uniquely opportune stage of growth when the skeleton is most responsive to exercise? *Sports Med.* 2000;39:73-78.
28. Turner C, Robling A. Designing exercise regimens to increase bone strength. *Exerc Sport Sci Rev.* 2003;31:45-50.
29. Vicente-Rodriguez G. How does exercise affect bone development during growth? *Sports Med.* 2006;36:561-569.
30. Malina R, Bouchard C, Bar-Or O. *Growth, Maturation and Physical Activity.* Champaign, Ill: Human Kinetics; 2004.
31. Heinonen A, Sievanen H, Kannus P, et al. High-impact exercise and bones of growing girls: a 9-month controlled trial. *Osteoporos Int.* 2000;11:1010-1017.
32. Seeman E, Hopper J, Bach L, et al. Reduced bone mass in daughters of women with osteoporosis. *N Engl J Med.* 1989;320:554-558.
33. Pietrobelli A, Faith MS, Wang J, Brambilla P, Chiumello G, Heymsfield SB. Association of lean tissue and fat mass with bone mineral content in children and adolescents. *Obes Res.* 2002;10:56-60.
34. Witzke K, Snow C. Lean body mass and leg power best predict bone mineral density in adolescent girls. *Med Sci Sports Exerc.* 1999;1:1558-1563.
35. Rauch F, Bailey D, Baxter-Jones A, et al. The "muscle-bone" unit during the pubertal growth spurt. *Bone.* 2004;34:771-775.
36. Conroy B, Kraemer W, Maresh C, et al. Bone mineral density in elite junior Olympic weightlifters. *Med Sci Sports Exerc.* 1993;5:1103-1109.
37. Virvidakis K, Georgiou E, Korkotsidis A, et al. Bone mineral content of junior competitive weightlifters. *Int J Sports Med.* 1990;11:244-246.
38. Linden C, Ahlborg H, Besjakov J, et al. A school curriculum-based exercise program increases bone mineral accrual and bone size in prepubertal girls: two-year data from the pediatric osteoporosis prevention (POP) study. *J Bone Miner Res.* 2006;21:829-835.
39. MacKelvie K, Petit M, Khan K, et al. Bone mass and structure and enhanced following a 2-year randomized controlled trial of exercise in prepubertal boys. *Bone.* 2004;34:755-764.
40. McKay H, Maclean L, Petit M, et al. 2005. "Bounce at the Bell": a novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *Br J Sports Med.* 2005;39:521-526.
41. Morris F, Naughton G, Gibbs J, et al. Prospective ten-month exercise intervention in premenarcheal girls: positive effects on bone and lean mass. *J Bone Miner Res.* 1997;12:1453-1462.
42. Valdimarsson O, Linden C, Johnell O, et al. Daily physical education in the school curriculum in prepubertal girls during 1 year is followed by an increase in bone mineral accrual and bone width: data from the prospective controlled Malmo Pediatric Osteoporosis Prevention Study. *Calcif Tissue Int.* 2006;78:65-71.
43. Volek J, Gomez A, Scheett T, et al. Increasing fluid milk intake favorably affects bone mineral density responses to resistance training in adolescent boys. *J Am Diet Assoc.* 2003;103:1353-1356.
44. Specker B. Evidence of an interaction between calcium intake and physical activity on changes in bone mineral density. *J Bone Miner Res.* 1996;11:1539-1544.
45. Gustavsson A, Olsson T, Nordstrom P. Rapid loss of bone mineral density of the femoral neck after cessation of ice hockey training: a 6 year longitudinal study in males. *J Bone Miner Res.* 2003;18:1964-1969.
46. Hawkins S, Schroeder E, Wiswell R, et al. Eccentric muscle action increases site-specific osteogenic response. *Med Sci Sports Exerc.* 1999;31:1287-1292.
47. Blimkie C, Rice S, Webber C, et al. Effects of resistance training on bone mineral content and density in adolescent females. *Can J Physiol Pharmacol.* 1996;74:1025-1033.
48. Burr D, Robling A, Turner C. Effects of biomechanical stress on bones in animals. *Bone.* 2002;30:781-786.
49. Ogden C, Carrol L, McDowell M, et al. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA.* 2006;295:1549-1555.
50. Dietz W. Overweight in childhood and adolescence. *N Engl J Med.* 2004;350;855-857.
51. Guo S, Chumlea W. Tracking of body mass index in children in relation to overweight in adulthood. *Am J Clin Nutr.* 1999;70(suppl):145S-148S.
52. Narayan K, Boyle J, Thompson T, et al. Lifetime risk for diabetes mellitus in the United States. *J Am Med Assoc.* 2003;290:1884-1890.
53. Dencker M, Thorsson O, Karlsson M, et al. Daily physical activity related to body fat in children aged 8-11 years. *J Pediatr.* 2006;149:38-42.
54. Gillis L, Kennedy L, Bar-Or O. Overweight children reduce their activity levels earlier in life than healthy weight children. *Clin J Sport Med.* 2006;16:51-55.
55. American Dietetic Association. Position of the American Dietetic Association: individual-, family-, school-, and community-based interventions for pediatric overweight. *J Am Diet Assoc.* 2006;106:925-945.
56. Siegal J, Camaione D, Manfredi T. The effects of upper body resistance training in prepubescent children. *Pediatr Exerc Sci.* 1989;1:145-154.
57. Sothern M. Exercise as a modality in the treatment of childhood obesity. *Pediatr Clin North Am.* 2001;48:995-1015.
58. Sothern M, Loftin J, Udall R, et al. Safety, feasibility and efficacy of a resistance training program in preadolescent obese youth. *Am J Med Sci.* 2000;319:370-375.
59. Watts K, Beye P, Siafarikas A, et al. Exercise training normalizes vascular dysfunction and improves central adiposity in obese adolescents. *J Am Coll Cardiol.* 2004;43:1823-1827.
60. Watts K, Jones T, Davis E, et al. Exercise training in obese children and adolescents. *Sports Med.* 2005;35:375-392.
61. Treuth M, Hunter G, Figueroa-Colon R, et al. Effects of strength training on intra-abdominal adipose tissue in obese prepubertal girls. *Med Sci Sports Exerc.* 1998;30:1738-1743.
62. Treuth M, Hunter G, Pichon C, et al. Fitness and energy expenditure after strength training in obese prepubertal girls. *Med Sci Sports Exerc.* 1998;30:1130-1136.
63. Celermajer D, Sorensen K, Gooch V, et al. Non-invasive detection of endothelial dysfunction in children and adults at risk of atherosclerosis. *Lancet.* 1992;340:1111-1115.
64. Shabi G, Cruz M, Ball G, et al. Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. *Med Sci Sports Exerc.* 2006;38:1208-1215.
65. Falk B, Sadres E, Constantini N, et al. The association between adiposity and the response to resistance training among pre- and early-pubertal boys. *J Pediatr Endocrinol Metab.* 2002;15:597-606.
66. Micheli L, Glassman R, Klein M. The prevention of sports injuries in youth. *Clin Sports Med.* 2000;19:821-834.
67. Drawer F, Fuller C. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *Br J Sports Med.* 2001;35:402-408.

68. Grimmer K, Jones D, Williams J. Prevalence of adolescence injury from recreational exercise: an Australian perspective. *J Adolesc Health*. 2000;27:266-272.
69. Smith A, Andrish J, Micheli L. The prevention of sports injuries of children and adolescents. *Med Sci Sports Exerc*. 1993;25(suppl):1-7.
70. Emery C, Meeuwisse W, McAllister J. Survey of sport participation and sport injury risk in Calgary and area high schools. *Clin J Sport Med*. 2006;16:20-26.
71. Malina R, Morano P, Barron M, et al. Incidence and player risk factors for injury in youth football. *Clin J Sports Med*. 2006;16:214-222.
72. Stone M. Implications for connective tissue and bone remodeling alterations resulting from resistance training. *Med Sci Sports Exerc*. 1988;20:S162-S168.
73. Stone M. Muscle conditioning and muscle injuries. *Med Sci Sports Exerc*. 1990;22:457-462.
74. Cahill B, Griffith E. Effect of preseason conditioning on the incidence and severity of high school football knee injuries. *Am J Sports Med*. 1978;6:180-184.
75. Dominguez R. Shoulder pain in age group swimmers. In: Erikkson B, Furberg B, eds. *Swimming Medicine IV*. Baltimore, Md: University Park Press; 1978:105-109.
76. Heidt R, Swetterman L, Carlonas R, et al. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med*. 2000;28:659-662.
77. Hejna W, Rosenberg A, Buturusis D, et al. The prevention of sports injuries in high school students through strength training. *National Strength and Conditioning Association Journal*. 1982;4:28-31.
78. Hewett T, Linderfeld T, Riccobene J, Noyes F. The effect of neuromuscular training on the incidence of knee injury in female athletes. *Am J Sports Med*. 1999;27:699-705.
79. Mandelbaum B, Silvers H, Watanabe D, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes. *Am J Sports Med*. 2005;33:1003-1010.
80. Wedderkopp N, Kaltoft B, Lundgaard M, et al. Prevention of injuries in young female players in European team handball: a prospective intervention study. *Scand J Med Sci Sports*. 1999;9:41-47.
81. Hoffman J, Kang J, Faigenbaum A, et al. Recreational sports participation is associated with enhanced physical fitness in children. *Res Sports Med*. 2005;13:149-161.
82. De Loes M, Dahlstedt J, Thomee R. A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports*. 2000;10:90-97.
83. Fry A, Kraemer W. Resistance exercise overtraining and overreaching. *Sports Med*. 1997;23:106-129.
84. Sorof J, Daniels S. Obesity hypertension in children: a problem of epidemic proportions. *Hypertension*. 2002;40:441-447.
85. Hagberg J, Ehsani A, Goldring D, et al. Effect of weight training on blood pressure and hemodynamics in hypertensive adolescents. *J Pediatr*. 1984;104:147-151.
86. Ewart C, Young D, Hagberg J. Effects of school-based aerobic exercise on blood pressure in adolescent girls at risk for hypertension. *Am J Public Health*. 1998;88:949-951.
87. Fripp R, Hodgson J. Effect of resistive training on plasma lipid and lipoprotein levels in male adolescents. *J Pediatr*. 1987;111:926-931.
88. Weltman A, Janney C, Rians C, et al. Effects of hydraulic-resistance strength training on serum lipid levels in prepubertal boys. *Am J Dis Child*. 1987;141:777-780.
89. Rians C, Weltman A, Cahill, B, et al. Strength training for prepubescent males: is it safe? *Am J Sports Med*. 1987;15:483-489.
90. Westcott W. A new look at youth fitness. *Am Fitness Q*. 1992;11:16-19.
91. Tucker L. Effect of weight training on self-concept: a profile of those influenced most. *Res Q Exer Sport*. 1983;54:389-397.
92. Tucker L. Effect of weight training on body attitudes: who benefits most? *J Sports Med*. 1987;27:70-78.
93. Holloway J, Beuter A, Duda J. Self-efficacy and training in adolescent girls. *J Appl Soc Psychol*. 1988;18 :699-719.
94. Annesi J, Westcott W, Faigenbaum A, et al. Effects of a 12-week physical activity protocol delivered by YMCA after-school counselors (Youth Fit for Life) on fitness and self-efficacy changes in 5-12 year old boys and girls. *Res Q Exerc Sport*. 2005;76 :468-476.
95. Faigenbaum A, Zaichkowsky L,Westcott W, et al. Psychological effects of strength training on children. *J Sport Behav*. 1997;20:164-175.
96. Sadres E, Eliakim A, Constantini N, Lidor R, Falk B. The effect of long-term resistance training on anthropometric measures, muscle strength, and self-concept in pre-pubertal boys. *Pediatr Exerc Sci*. 2001;13:357-372.
97. Dishman R, Motl R, Saunders R, et al. Enjoyment mediates effects of a school-based physical-activity intervention. *Med Sci Sports Exerc*. 2005;37:478-487.
98. Chu D, Faigenbaum A, Falkel J. *Progressive Plyometrics for Kids*. Monterey, Calif: Healthy Learning; 2006.
99. Faigenbaum A, Westcott W. *Strength and Power for Young Athletes*. Champaign, Ill: Human Kinetics; 2000.
100. Kraemer W, Fleck S. *Strength Training for Young Athletes*. 2nd ed. Champaign, Ill: Human Kinetics; 2005.
101. Knudson D, Magnusson P, McHugh M. Current issues in flexibility fitness. *President's Council on Physical Fitness and Sports Research Digest*. 2000;3:1-8.
102. Thacker S, Gilchrist J, Stroup D, Kimsey C. The impact of stretching on sports injury risk: a systematic review of the literature. *Med Sci Sports Exerc*. 2004;36:371-378.
103. Rutledge I, Faccioni A. Dynamic warm-ups. *Sports Coach*. 2001;24:20-22.
104. Robbins D. Postactivation potentiation and its practical application: a brief review. *J Strength Cond Res*. 2005;19:453-458.
105. Faigenbaum A, Bellucci M, Bernieri A, Bakker B, Hoorens K. Acute effects of different warm-up protocols on fitness performance in children. *J Strength Cond Res*. 2005;19:376-381.
106. Faigenbaum AD, Kang J, McFarland J, et al. Acute effects of different warm-up protocols on anaerobic performance in teenage athletes. *Pediatr Exerc Sci*. 2006;17:64-75.
107. Siatras T, Papadopoulos G, Mameletzi D, Gerodimos V, Kellis S. Static and dynamic acute stretching effect on gymnasts' speed in vaulting. *Pediatr Exerc Sci*. 2003;15:383-391.
108. Olsen O, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomized controlled trial. *Br Med J*. 2005;330:449.
109. Faigenbaum A, McFarland J. Guidelines for implementing a dynamic warm-up for physical education. *J Phys Ed Rec Dance*. In press.
110. Campos G, Luecke T, Wendeln H, et al. Muscular adaptations in response to three different resistance training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol*. 2002;88:50-60.
111. Faigenbaum A, Milliken L, Moulton L, Westcott W. Early muscular fitness adaptations in children in response to two different resistance training regimens. *Pediatr Exerc Sci*. 2005;17:237-248.

112. Faigenbaum A, Milliken L, Cloutier G, et al. Perceived exertion during resistance exercise in children. *Percept Mot Skills*. 2004;98:627-637.

113. Rhea M, Alvar B, Burkett L, et al. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc*. 2003;35:456-464.

114. Kraemer W, Adams K, Cafarelli E, et al. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2002;34:364-380.

115. Faigenbaum A, Milliken L, LaRosa Loud R, et al. Comparison of 1 and 2 days per week of strength training in children. *Res Q Exerc Sport*. 2002;73:416-424.