POSITION STATEMENT

Youth Resistance Training: Updated Position Statement Paper From the National Strength and Conditioning Association

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Abstract

Faigenbaum, AD, Kraemer, WJ, Blimkie, CJR, Jeffreys, I, Micheli, LJ, Nitka, M, and Rowland, TW. Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association. *J Strength Cond Res* 23(5): S60–S79, 2009—Current recommendations suggest that school-aged youth should participate daily in 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate and enjoyable and involves a variety of activities (219). Not only is regular physical activity essential for normal growth and development, but also a physically active lifestyle during the pediatric years may help to reduce the risk of developing some chronic diseases later in life (196). In addition to aerobic activities such as swimming and bicycling, research increasingly indicates that resistance training can offer unique benefits for children and adolescents when appropriately prescribed and supervised (28,66,111,139,147,234). The qualified acceptance of youth resistance training by medical, fitness, and sport organizations is becoming universal (5,6,8,12,18,33,104,167,192,215).

Nowadays, comprehensive school-based programs are specifically designed to enhance health-related components of physical fitness, which include muscular strength (169). In addition, the health club and sport conditioning industry is getting more involved in the youth fitness market. In the U.S.A., the number of health club members between the ages of 6 and 17 years continues to increase (127,252) and a growing number of private sport conditioning centers now cater to young athletes. Thus, as more children and adolescents resistance train in schools, health clubs, and sport training centers, it is imperative to determine safe, effective, and enjoyable practices by which resistance training can improve the health, fitness, and sports performance of younger populations.

The National Strength and Conditioning Association (NSCA) recognizes and supports the premise that many of the benefits associated with adult resistance training programs are attainable by children and adolescents who follow age-specific resistance training guidelines. The NSCA published the first position statement paper on youth resistance training in 1985 (170) and revised this statement in 1996 (72). The purpose of the present report is to update and clarify the 1996 recommendations on 4 major areas of importance. These topics include (a) the potential risks and concerns associated with youth resistance training, (b) the potential health and fitness benefits of youth resistance training, (c) the types and amount of resistance training needed by healthy children and adolescents, and (d) program design considerations for optimizing long-term training adaptations. The NSCA based this position statement paper on a comprehensive analysis of the pertinent scientific evidence regarding the anatomical, physiological, and psychosocial effects of youth resistance training. An expert panel of exercise scientists, physicians, and health/physical education teachers with clinical, practical, and research expertise regarding issues related to pediatric exercise science, sports medicine, and resistance training contributed to this statement. The NSCA Research Committee reviewed this report before the formal endorsement by the NSCA.

For the purpose of this article, the term children refers to boys and girls who have not yet developed secondary sex characteristics (approximately up to the age of 11 years in girls and 13 years in boys; Tanner stages 1 and 2 of sexual maturation). This period of development is referred to as preadolescence. The term adolescence refers to a period between childhood and

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adulthood and includes girls aged 12–18 years and boys aged 14–18 years (Tanner stages 3 and 4 of sexual maturation). The terms youth and young athletes are broadly defined in this report to include both children and adolescents.

By definition, the term resistance training refers to a specialized method of conditioning, which involves the progressive use of a wide range of resistive loads and a variety of training modalities designed to enhance health, fitness, and sports performance. Although the term resistance training, strength training, and weight training are sometimes used synonymously, the term resistance training encompasses a broader range of training modalities and a wider variety of training goals. The term weightlifting refers to a competitive sport that involves the performance of the snatch and clean and jerk lifts.

This article builds on previous recommendations from the NSCA and should serve as the prevailing statement regarding youth resistance training. It is the current position of the NSCA that:

1. A properly designed and supervised resistance training program is relatively safe for youth.
2. A properly designed and supervised resistance training program can enhance the muscular strength and power of youth.
3. A properly designed and supervised resistance training program can improve the cardiovascular risk profile of youth.
4. A properly designed and supervised resistance training program can improve motor skill performance and may contribute to enhanced sports performance of youth.
5. A properly designed and supervised resistance training program can increase a young athlete's resistance to sports-related injuries.
6. A properly designed and supervised resistance training program can help improve the psychosocial well-being of youth.
7. A properly designed and supervised resistance training program can help promote and develop exercise habits during childhood and adolescence.

Key Words strength training, weight training, weightlifting, children, adolescents

Literature Review

Risks and Concerns Related to Youth Resistance Training

During the 1970s and 1980s, one of the reasons that resistance training was not often recommended for children and adolescents was the presumed high risk of injury associated with this type of exercise. In part, the widespread fear of injury associated with youth resistance training during this era stemmed from data gathered by the National Electronic Injury Surveillance System (NEISS) of the U.S. Consumer Product Safety Commission. NEISS uses data from various emergency room departments to make nationwide projections of the total number of injuries related to exercises and equipment (231,232). However, NEISS data are based on injuries that patients state are related to resistance exercise and equipment, and therefore, it is incorrect to conclude that the injuries were caused by such activities and devices. In fact, many of the reported injuries were actually caused by inappropriate training techniques, excessive loading, poorly designed equipment, ready access to the equipment, or lack of qualified adult supervision. Although these findings indicate that the unsupervised and improper use of resistance training equipment may be injurious, it is misleading to generalize these findings to properly designed and supervised youth resistance training programs.

Current findings from prospective resistance training studies indicate a low risk of injury in children and adolescents who follow age-appropriate training guidelines. In the vast majority of published reports, no overt clinical injuries have been reported during resistance training. Although various resistance training modalities and a variety of training regimens have been used, all the training programs were supervised and appropriately prescribed to ensure that the training program was matched to the initial capacity of the participant. Only 3 published studies have reported resistance training–related injuries in children (a shoulder strain that resolved within 1 week of rest (187), a shoulder strain that resulted in 1 missed training session (144), and a nonspecific anterior thigh pain that resolved with 5 minutes of rest (198)). In a report (187), there was no evidence of either musculoskeletal injury (measured by biphasic scintigraphy) or muscle necrosis (determined by serum creatine phosphokinase levels) after 14 weeks of progressive resistance training.

Youth resistance training, as with most physical activities, does carry with it some degree of inherent risk of musculoskeletal injury, yet this risk is no greater than many other sports and recreational activities in which children and adolescents regularly participate. In a prospective study that evaluated the incidence of sports-related injuries in school-aged youth over a 1-year period (258), resistance training resulted in 0.7% of 1576 injuries whereas football, basketball, and soccer resulted in approximately 19, 15, and 2%, respectively, of all injuries. When the data were evaluated in terms of injury to participant ratio in school team sports, football (28%), wrestling (16.4%), and gymnastics (13%) were at the top of the list. In general, injuries related to resistance training in high school athletes appear to involve the aggressive progression of training loads or improper exercise technique (31,35,108,197).

Findings from the 2005–2006 High School Sports-Related Injury Surveillance Study revealed that participation in team sports resulted in an estimated 1.4 million injuries at a rate of 2.4 injuries per 1,000 athlete exposures (i.e., practices and competition) (45). Of the 9 sports studied, football had the highest injury rate (4.36 injuries per 1,000 athlete exposures), whereas boys' baseball (1.19) and girls' softball (1.13) had the lowest injury rates (45). Although data comparing the relative safety of resistance training, weightlifting, and other sports are limited, in a retrospective evaluation of injury rates in adolescents it was revealed that resistance training and weightlifting were markedly safer than many other sports and activities (114). In the aforementioned report (114), the overall injury rate per 100 participant hours was 0.8000 for rugby and 0.0120 and 0.0013 for resistance training and weightlifting, respectively. This later finding may be explained, at least in part, by the fact that the sport of weightlifting is typically characterized by well-informed coaches and a gradual progression of training loads, which are required to effectively learn the technique of advanced multi-joint lifts. With qualified instruction and a stepwise progression of the training program, researchers have reported significant gains in muscular strength without any report of injury when weightlifting movements (snatch; clean and jerk; and modified cleans, pulls, and presses) were incorporated into a youth resistance training program (74,105,198,204).

In support of these observations, others have evaluated the incidence of injury in young weightlifters and concluded that competitive weightlifting can be a relatively safe sport for children and adolescents provided that age-appropriate training guidelines are followed and qualified coaching is available (38,182). Because weightlifting movements involve more complex neural activation patterns than other resistance exercises, childhood may be the ideal time to develop the coordination and skill technique to perform these lifts correctly (57). To date, no scientific evidence indicates that properly performed and sensibly progressed weightlifting movements performed during practice or competition are riskier than other sports and activities in which youth regularly participate. Nevertheless, due to the potential for injury during the performance of multi-joint free weight exercises (190), youth coaches should be aware of the considerable amount of time it takes to teach these lifts and should be knowledgeable of the progression from basic exercises (e.g., front squat) to skill transfer exercises (e.g., overhead squat) and finally to the competitive lifts (snatch and clean and jerk).

Another concern related to youth resistance training regards the safety and suitability of plyometric training (also called stretch-shortening cycle exercise) for children and adolescents. Unlike traditional strength-building exercises, plyometric training conditions the body through dynamic movements, which involve a rapid eccentric muscle action that is immediately followed by a rapid concentric muscle action (47,97). When the stretching and shortening of a muscle are performed quickly, the force generated during the muscle action is greater than the force that would be generated if the muscle were not stretched immediately before the muscle action (97). The contention that age-appropriate plyometric training is unsafe for youth or that a predetermined baseline level of strength (e.g., 1 repetition maximum [1RM] squat should be 1.5 times body weight) should be a prerequisite for lower-body plyometric training is not supported by current research and clinical observations. Indeed, comprehensive resistance training programs that include plyometric exercises have been found to enhance movement biomechanics, improve functional abilities, and decrease the number of sports-related injuries in young athletes (115,120,143,149,168).

Research studies indicate that plyometric training can be a safe and worthwhile method of conditioning for youth if appropriately prescribed and implemented (56,69,75,125,134,143,150,151,202). Although plyometric exercises typically include hops and jumps that exploit the muscles' cycle of lengthening and shortening to increase muscle power, watching children on a playground supports the premise that the movement pattern of boys and girls as they skip and jump can be considered plyometric. For example, when a child plays hopscotch and jumps from square to square, the quadriceps stretch eccentrically when the child lands and then they shorten concentrically when the child jumps. This type of exercise, although game like in nature, actually conditions the body to increase speed of movement and improve power production (47). Nonetheless, there is the potential for injury or illness to occur if the intensity, volume, or frequency of plyometric training exceed the abilities of the participants. In a case report, a 12-year-old boy developed exertional rhabdomyolysis after he was instructed to perform excessive (>250) repetitive squat jumps in a physical education class (48).

A traditional area of concern related to youth resistance training is the potential for training-induced damage to the growth cartilage, which is found at 3 main sites in a growing child's body: the growth plates near the ends of the long bones, the cartilage lining the joint surfaces (articular cartilage), and the points at which the major tendons attach to the bones (apophysis) (161). Because growth cartilage is "pre-bone," it is weaker than adjacent connective tissue and therefore more easily damaged by repetitive microtrauma (161). In some cases, damage to this area of the bone could result in time lost from training, significant discomfort, and growth disturbances (41). A few retrospective case reports published in the 1970s and 1980s noted injury to the growth cartilage during preadolescence (108) and adolescence (25,31,108,128,194,197). However, most of these injuries were due to improper lifting techniques, maximal lifts, or lack of qualified adult supervision.

Although children and adolescents are susceptible to injury to the growth cartilage, the potential for this type of injury may be less in a preadolescent child than in an adolescent because the growth cartilage may actually be stronger and more resistant to sheering type forces in younger children (160). To date, injury to the growth cartilage has not been reported in any prospective youth resistance training research study. Furthermore, there is no evidence to suggest that resistance training will negatively impact growth and maturation during childhood and adolescence (91,147).

The potential for repetitive-use soft-tissue injuries is another concern related to youth resistance training. This type of injury often does not always cause children or adolescents to go to the emergency room or even to see a physician, so the incidence of these injuries is more difficult to determine. Nevertheless, lower back pain among youth has become a significant public health issue with prevalence rates in adolescents approaching those in adults (9,131). In several reports, lower back pain was the most frequent injury in high school athletes who participated in resistance training programs (31,35,190). In a study that involved adolescent powerlifters who presumably trained with maximal or near-maximal resistances, it was revealed that 50% of reported injuries were to the lower back (35). Although many factors need to be considered when evaluating these data (e.g., exercise technique and progression of training loads), the importance of general physical fitness and lower back health should not be overlooked. Because insufficient strength, muscular endurance, and stability in the lower back have been associated with current and future lower back pain in adolescents (9,211), there is a role for preventive interventions that include resistance exercise to possibly reduce the prevalence or severity of lower back pain in youth.

Of note, there is an increased risk of injury to children and adolescents who use exercise equipment at home (107,132). It has been reported that young children are more likely to be injured from home exercise equipment than older age groups due, in part, to unsafe behavior, equipment malfunction, and lack of supervision (132). There is also the potential for a catastrophic injury if safety standards for youth resistance training are not followed. In a case study report, a 9-year-old boy died when a barbell rolled off a bench press support and fell on his chest (102). These findings underscore the importance of providing close supervision and safe training equipment for all youth resistance training programs.

Any exercise or activity recommendation for children and adolescents has risks as well as benefits. The risk of injury while resistance training or weightlifting can be minimized by qualified supervision, appropriate program design, sensible progression, and careful selection of training equipment. In addition, the risk of injury can be minimized by limiting the number of heavy lifts during a workout, allowing for adequate recovery between training sessions, and listening to each child's questions and concerns. In general, the risk of injury associated with resistance training is similar for youth and adults. There are no justifiable safety reasons that preclude children or adolescents from participating in such a resistance training program.

Effectiveness of Youth Resistance Training

During childhood and adolescence, physiologic factors related to growth and development are in a constant state of evolution. Due to the progression of growth, it can be expected that healthy children will show noticeable gains in height, weight, maximal oxygen uptake, anaerobic capacity, and muscle strength during the developmental years (195). Although different children do not follow the same rates of change, performance variables such as grip strength normally increase from childhood through the early teenage years (148). Consequently, strength changes from low-volume (sets × repetitions × load), short-duration resistance training programs may not be distinguishable from gains due to normal growth and development (59,117). To differentiate training adaptations from those of normal growth and development, it is apparent that an adequate training stimulus and a prolonged training period are required.

A compelling body of scientific evidence indicates that children and adolescents can significantly increase their strength–above and beyond growth and maturation–providing that the resistance training program is of sufficient intensity, volume, and duration (30,55,70,74,77,79,80,86–88, 92,144,180,183,186,199,205,210,221,227,238,246,248,250). In addition, 2 meta-analyses on youth resistance training indicated mean effect sizes of 0.57 and 0.75 (94,179). Collectively, these findings along with clinical observations and evidence-based reviews (28,66,111,139,147,200,234) indicate that well-designed resistance training programs can enhance the muscular strength of children and adolescents beyond that which is normally due to growth and development.

Children as young as 5 and 6 years have benefited from regular participation in a resistance training program (11,86, 246), although most samples typically spanned several years (e.g., 7 to 12 years of age). While a majority of training studies had a duration of 8–20 weeks (79,80,92,118,144,186,205, 210,246), studies lasting 2–3 school years have been reported (93,198). A wide variety of resistance training programs from single set sessions on weight machines (249) to progressive, multi-set training protocols on different types of equipment (22,74,105,186,198,238) have proven to be efficacious. Training modalities have included weight machines (both adult (55,180,238,239) and child size (79,80,86,183,249)), free weights (22,55,74,94,105,198,199), hydraulic machines (30,246), pneumatic machines (205), medicine balls (77,221); elastic bands (11), isometric contractions (101,117,174), and body weight exercises (17,92,210,236). As previously observed in adult populations, training adaptations that occur in youth are specific to the muscle action or muscle groups that are trained (97,174).

Strength gains up to 74% (88) have been reported after 8 weeks of progressive resistance training, although gains of roughly 30% are typically observed after short-term (8–20 weeks) youth resistance training programs. Reported relative (% change above initial levels) strength gains achieved during preadolescence are equal to if not greater than the relative gains observed during adolescence (144,174,180,248). Adult athletes tend to be stronger than adolescent athletes (14), and there is no clear evidence of any major difference in strength between preadolescent boys and girls (27,81,200). In terms of absolute strength gains, it appears that adolescents make greater gains than children (144,200,239) and adults make greater gains than young adolescents (199), although some findings are at variance with this suggestion (248).

Persistence of Training-Induced Strength Gains

The evaluation of strength changes in youth after the temporary or permanent reduction or withdrawal of a training stimulus (referred to as detraining) is complicated by the concomitant growth-related strength increases during the same period. Although relative information regarding the effects of detraining on younger populations is not extensive, the available data suggest that training-induced gains in strength and power in children are impermanent and tend to regress toward untrained control group values during the detraining period (29,87,125,205,227). The precise nature of the detraining response and the physiological adaptations that occur during this period remain uncertain, although changes in neuromuscular functioning and the hormonal responses to resistance training and detraining should be considered. Of interest, researchers found that training-induced increases in the levels of testosterone and free androgen index in children were maintained during an 8-week detraining period despite the regression of strength toward untrained control group values during this phase of the study (226,227).

Only a limited number of studies have evaluated the effects of training frequency on the maintenance of strength and power in children and adolescents. After 20 weeks of progressive resistance training, a once-weekly maintenance training program was not adequate to maintain the training-induced strength gains in preadolescent males (29). Conversely, a once-weekly maintenance program was just as sufficient as a twice-weekly maintenance program in retaining the strength gains made after 12 weeks of resistance training in a group of adolescent male athletes (55). Others observed that children who participated in a 10-week plyometric training program were able to maintain training-induced gains in power after 8 weeks of reduced training, which included soccer practice (56). Clearly, more research is needed before specific maintenance training recommendations can be made.

Program Evaluation and Testing

Factors such as previous exercise experience, program design, specificity of testing and training, choice of equipment, quality of instruction, and whether or not the learning effect was controlled for in the study can directly influence the degree of measured strength change. In addition, the methods of evaluating changes in muscular strength consequent to training are noteworthy considerations. In some studies, the subjects were trained and tested using different modalities (180,205,246), and in other published reports, strength changes were evaluated by relatively high RM values (e.g., 10RM) (74,88,144,248). Strength changes have also been evaluated by maximal load lifting (e.g., 1RM) on the equipment used in training (22,55,79,80,118,178,183,186,198,238).

Some clinicians and researchers have not used 1RM testing to evaluate training-induced changes in muscular strength because of the presumption that high-intensity loading may cause structural damage in children. Thus, the maximal force production capabilities of children have not been directly evaluated in some studies. Yet no injuries have been reported in prospective studies that utilized adequate warm-up periods, appropriate progression of loads, close and qualified supervision, and critically chosen maximal strength tests (1RM performance lifts, maximal isometric tests, and maximal isokinetic tests) to evaluate resistance training–induced changes in children. In a study, 96 children performed a 1RM strength test on 1 upper-body and 1 lower-body weight machine exercise (81). No abnormal responses or injuries occurred during the study period, and the testing protocol was reportedly well tolerated by the subjects. In other reports, children and adolescents safely performed 1RM strength tests using free weight exercises (14,22,118,124,142,152,153,178,198,238).

Paradoxically, most of the forces that youth are exposed to in various sports and recreational activities are likely to be greater in both exposure time and magnitude than competently supervised and properly performed maximal strength tests. These observations along with current research findings indicate that the maximal force–producing capabilities of healthy children and adolescents can be safely evaluated by 1RM testing procedures, provided that youth participate in an habituation period before testing to learn proper exercise technique and qualified professionals closely supervise and administer each test. Detailed procedures for evaluating 1RM strength are available elsewhere (81,140).

Although maximal strength testing can be used to evaluate training-induced changes in muscular strength in children and adolescents in clinical and recreational settings, when properly administered 1RM tests are labor intensive and time consuming. Thus, in some instances (e.g., physical education class) the use of field-based measures may be more appropriate and time efficient. Researchers have documented significant correlations between 1RM strength and common field measures (e.g., handgrip strength and long jump) in children (164). In any case, unsupervised and improper 1RM testing (e.g., inadequate progression of loading and poor lifting technique) should not be performed by children or adolescents under any circumstances due to the real risk of injury (189,190).

Physiological Mechanisms for Strength Development

In children it appears that training-induced strength gains are more related to neural mechanisms than to hypertrophic factors (139,147,178,186,200). Without adequate levels of circulating testosterone to stimulate increases in muscle size, children appear to experience more difficulty increasing their muscle mass consequent to a resistance training program (up to 20 weeks) as compared with older populations (178,186,239). However, because some findings are at variance with this suggestion (100,158), it cannot be stated a priori that resistance training will not increase the muscle mass of prepubescent youth. It is possible that more intensive training programs, longer training durations, and more sensitive measuring techniques that are ethically appropriate for this population may be needed to partition the effects of training on fat free mass from expected gains due to growth and maturation.

Without corresponding increases in fat-free mass, it appears that neural adaptations (i.e., a trend toward increased motor unit activation and changes in motor unit coordination, recruitment, and firing) (178,186) and possibly intrinsic muscle adaptations (as evidenced by increases in twitch torque) (186) are primarily responsible for training-induced strength gains during preadolescence. Improvements in motor skill performance and the coordination of the involved muscle groups may also play a significant role because measured increases in training-induced strength are typically greater than changes in neuromuscular activation (178,186). Although speculative, developmental alterations in muscle fiber architecture (e.g., pennation angle) and changes in central inhibitory influences on maximal muscle strength should also be considered (195). In support of these observations, several training studies have reported significant improvements in strength during preadolescence without corresponding increases in gross limb morphology, as compared with a similar control group (88,144,178,186,199,246).

During puberty, testicular testosterone secretion in males is associated with considerable increases in fat-free mass and linear growth (139,195). Training-induced strength gains during and after puberty in males may therefore be associated with changes in hypertrophic factors because testosterone and other hormonal influences on muscle hypertrophy would be operant (139). Smaller amounts of testosterone in females (resulting from enzymatic conversion of androgenic precursors in the adrenal gland) limit the magnitude of training-induced increases in muscle hypertrophy (195,200). Other hormone and growth factors (e.g., growth hormone and insulin-like growth factors) may be at least partly responsible for muscle development in females (135).

Potential Health and Fitness Benefits

There are many health and fitness benefits associated with regular physical activity in children and adolescents. Not only is habitual physical activity essential for normal growth and development, but also participation in age-appropriate fitness programs can enhance the physical and psychosocial well-being of youth. Although a majority of the pediatric research has focused on activities that enhance cardiorespiratory fitness (195), recent findings indicate that resistance training can offer unique benefits for children and adolescents when appropriately prescribed and supervised. As previously observed in adults (97), regular participation in a resistance training program has the potential to positively influence several measurable indices of health and fitness. Youth resistance training can improve one's cardiovascular risk profile, facilitate weight control, strengthen bone, enhance psychosocial well-being, improve motor performance skills, and increase a young athletes' resistance to sports-related injuries.

Research that supports the utility of youth resistance training in the acquisition of favorable degrees of health-associated characteristics is expanding (67,147,219). Moreover, the contention that the overall health of children and adolescents is likely to improve rather than be adversely affected by regular participation in a resistance training program is supported by statements from professional organizations (8,18,33,167,192). Although good health habits established during childhood do not always carry over into adulthood, the potential positive influence of these habits on the adult lifestyle should be recognized (146,196,222,225). Hence, a compelling reason to encourage children and adolescents to participate regularly in physical activity is to reduce their risk of developing adult diseases later in life.

Cardiovascular Risk Profile. The potential influence of resistance training on body composition (the percentage of total body weight that is fat compared with the percentage that is fat free) has become an important topic of investigation, given that the prevalence of obesity among children and adolescents continues to increase worldwide (175,240). Today, childhood obesity, with its associated comorbidities such as type 2 diabetes and likelihood of persistence into adulthood, is a critical public health threat (126). Although genetic, psychosocial, economic, and environmental factors likely play a role in the development of obesity during childhood and adolescence (4,62), it is becoming more apparent that the increasing prevalence of obesity among school-aged youth may be due, at least in part, to a sedentary lifestyle (62,106).

Although obese youth 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. Furthermore, obese youth often lack the motor skills and confidence to be physically active, and they may actually perceive prolonged periods of aerobic exercise to be boring or discomforting. In support of these observations, it has been reported that total body fat was inversely related to minutes of vigorous physical activity per day in youth (54). Others observed that this decline in physical activity may start early in life in obese youth (103).

Recently, it has been suggested that resistance training may offer observable health value to obese children and adolescents (23,83,243). Obese youth tend to enjoy resistance training because it is typically characterized by short periods of physical activity interspersed with brief rest periods between sets and exercises, which is more consistent with how youth move and play (13,106). Several studies have reported favorable changes in body composition in children and adolescents who were obese or at risk for obesity after participation in a resistance training program or a circuit weight training (i.e., combined resistance and aerobic training) program (24,203,206,214,220,224,242,254). In a report, the level of adiposity in school-aged youth was a strong negative predictor of the resistance training effect in the lower limbs (93). Thus, obese youth may need a higher relative training intensity to produce the desired effect.

Of interest, researchers found that participation in a 16-week resistance training program significantly decreased body fat and significantly increased insulin sensitivity in adolescent males who were at risk for obesity (206). Because the increase in insulin sensitively remained significant after adjustment for changes in total fat mass and total lean mass, it appeared that regular resistance training may have resulted in qualitative changes in skeletal muscle that contributed to enhanced insulin action. Compliance to this program was impressive with 96% of the participants completing the program. Other researchers identified muscular strength as an independent and powerful predictor of better insulin sensitivity in youth aged 10–15 years (21). Because resistance training may provide a more enjoyable and sustainable approach to health-related physical activity promotion in children and adolescents who are obese or at risk for obesity, additional randomized controlled trials are needed to further examine the effects of resistance training on metabolic health outcomes in youth.

At present, there is no clear association between regular physical activity and reducing blood pressure in normotensive youth, although limited data suggest that resistance training may be an effective nonpharmacologic intervention in hypertensive adolescents, provided that submaximal loads are used and proper exercise procedures are followed (112). Others have recommended low-intensity, high-repetition resistance training for hypertensive adolescents who want to experience this type of training (256). Although the acute blood pressure response to resistance exercise is reportedly similar between children and adults (172), blackouts (loss of consciousness) and chronic hypertension, which have been reported in adult competitive weightlifters (49), have not been reported in children (88,187) or adolescents (112) after resistance training.

The effects of resistance training on blood lipoproteins in youth are not well documented. Limited data suggest that when compared with an inactive control group, resistance training characterized by moderate loads and a high number of repetitions can have a positive influence on the blood lipid profile of children (220,247), and similar trends have been observed in adolescents (98). Because changes in body composition and nutritional intake may influence lipoprotein concentrations in youth, a comprehensive health-enhancing program that includes regular physical activity, behavioral counseling, and nutrition education may be most effective for improving the blood lipid profile in youth with dyslipidemia (7).

Bone Health. Despite traditional fears that resistance training would be harmful to the immature skeletal of youth, current observations 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 (15,121,230,235). Indeed, weight-bearing physical activity is essential for normal bone formation and growth (148). If age-specific resistance training guidelines are followed and if nutritional recommendations (e.g., adequate calcium) are adhered to, regular participation in a resistance training program can maximize bone mineral density during childhood and adolescence (230,235,238). Moreover, there is no detrimental effect of resistance training on linear growth in children and adolescents (91,147)

Results from several research studies indicate that regular participation in sports and specialized fitness programs that include resistance training can be a potent osteogenic stimulus in youth (16,20,50,145,154,166,173,237,241). It has been reported that adolescent weightlifters displayed levels of bone mineral density (50) and bone mineral content (237) well above values of age-matched controls. Other researchers found that weightlifting can impart some benefit on bone development in youth but not as much as year-round soccer (20). The repetitive exposure to physical loading in sports such as gymnastics has also resulted in significantly higher bone mineral density in young athletes as compared with age-matched controls (16,241).

In a study that provides direct evidence that high-impact exercise enhances bone accrual in preadolescent girls, participation in a 10-month physical activity program (combined resistance training and aerobic exercise) resulted in significant improvements in bone mineral density in the exercise group as compared with the control group (166). 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 (145). Others noted that a school-based physical activity intervention that included plyometric training enhanced bone mass at the weight-bearing proximal femur in children (154).

Although peak bone mass is influenced by genetics (43), regular participation in high-strain-eliciting sports and specialized exercise such as resistance training may have a desirable influence on bone health in children and adolescents. It appears that the osteogenic response to exercise in youth can be enhanced by sensibly prescribing multi-joint, moderate to high intensity resistance training exercises (e.g., bench press, squat, and weightlifting movements) and unaccustomed plyometric exercises (e.g., jumping and hopping). Although additional clinical trials are needed to more precisely define the exercise prescription, the importance of maintaining participation in sports and specialized activities throughout life must not be overlooked because training-induced improvements in bone health may be lost over time if the program is not continued (110).

Psychosocial Health and Well-being. Data from adult studies suggest that the effects of resistance training extend beyond physical measures and include improvements in mental health and well-being (157,228,229). Although it is reasonable to assume that similar findings would be observed in children and adolescents who participate in a resistance training program, caution is needed in extending observations to younger populations because of the psychological immaturity of youth as compared with adults. Limited evidence suggests that resistance training may positively influence the psychological well-being of children (123,253). Others noted significant improvements in mood and self-appraisal factors in children who participated in a physical activity program that included resistance training and aerobic games (10). Conversely, no significant changes in self-concept were found in children after resistance training in other studies (89,198), although initial scores in psychological measures were relatively high in these reports. Although speculative, the psychological benefits of resistance training may be most apparent in youth who begin training with below average measures of strength and psychosocial well-being.

Of interest, clinicians have noted that the socialization and mental discipline exhibited by children who resistance trained were similar to those exhibited by team sport participants (187), and children's attitudes toward physical education, physical fitness, and lifelong exercise reportedly improved after a conditioning program that included resistance training (249,250). If appropriate resistance training guidelines are followed and if children and adolescents are encouraged to embrace self-improvement and feel good about their performances, the positive psychosocial effects of resistance training programs may indeed be comparable with other sports and recreational activities. Conversely, intensive training, overzealous coaching, and excessive pressure to perform at a level beyond one's capabilities can have a negative effect on some youth who are emotionally and psychologically vulnerable (3,42). In some cases, inappropriate coaching methods, unethical training practices, or an emphasis on leanness may lead to the abuse of performance-enhancing drugs (122), restrictive eating behaviors (171), or burnout (overtraining syndrome) (32).

Motor Performance Skills and Sports Performance. Improvements in selected motor performance skills (e.g., long jump, vertical jump, sprint speed, and medicine ball toss) have been observed in children and adolescents after resistance training with weight machines, free weights, body weight strength exercises, and medicine balls (77,92,96,118,144,221,246). Gains in motor performance skills in youth have also been noted after regular participation in plyometric training programs (36,134,151,216). More recently, researchers have reported that the combination of resistance training and plyometric training may offer the most benefit for adolescent athletes (75,143,168,202). As previously observed in adults (2,95), the effects of resistance training and plyometric training may actually be synergistic, with their combined effects being greater than each program performed alone.

In contrast, other studies (80,88,96) reported significant gains in strength without concomitant improvements in selected motor performance skills after several weeks of resistance training. Because the effects of resistance training on motor performance are dependent on the design of the training program, the principle of training specificity should be considered when evaluating these data. As previously observed in adult populations (97), training adaptations in children and adolescents are rather specific to the movement pattern, velocity of movement, contraction type, and contraction force (113,174). Thus, irrespective of age, resistance training programs that include specific exercises (e.g., weightlifting movements and plyometrics) and types of muscle actions in a manner that is specific for which training is being performed are more likely to result in the greatest improvements in motor skill performance.

Although the potential for resistance training to enhance the sports performance of young athletes seems reasonable, scientific evaluations of this observation are difficult because athletic performance is such a multivariate outcome. Two studies (26,37) reported favorable changes in swim performance in age group swimmers, although one study found no significant difference in freestyle turning performance in adolescent swimmers who performed 15 minutes of plyometric training for 20 weeks (51). In another report, researchers found significant correlations between balance and skating speed in junior ice hockey players younger than 19 years (19). Other studies involving young basketball and soccer players have noted the importance of incorporating some type of resistance training into sports training sessions to maximize gains in strength and power in young athletes (46,233). Although most published reports and anecdotal comments from youth coaches suggest that regular participation in a well-designed resistance training program will result in some degree of improvement in athletic performance (84,137,163), further research is still required in this important field of study.

To date, there have not been any long-term investigations studying the effects of a comprehensive youth resistance training program on sports performance during the adult years, although theoretical models highlighting the potential benefits have been proposed (130). Nevertheless, based on the available evidence, curtailment of sports practice and competitions during the developmental years to allow time for fitness conditioning that includes resistance training seems reasonable, providing that the training program is competently supervised, is progressive, and is of sufficient duration and intensity. Because aspiring young athletes cannot play themselves into shape, one of the greatest benefits of youth resistance training may be its ability to better prepare children and adolescents for successful and enjoyable participation in athletic activities.

Sports-Related Injuries. The number of children and adolescents in school-sponsored and community-based sports programs continues to increase. However, along with this increase in sports participation has come numerous reports of injuries to the ill-prepared or improperly trained young athlete (3,40,64,162). Sports-related injuries have become a significant cause of hospitalization and health care costs during childhood and adolescence (162), and it is possible that certain youth sport injuries can increase the risk of osteoarthritis later in life (61). Sports-related injuries are also one reason why some young athletes drop out of sports (109).

Although the total elimination of sports-related injuries is an unrealistic goal, appropriately designed and sensibly progressed fitness conditioning programs that include resistance training may help reduce the likelihood of sports-related injuries in young athletes (1,119,161,212). In a growing number of cases, it seems that aspiring young athletes are ill prepared for the demands of sports practice and competition (64,162). By addressing the risk factors associated with youth sport injuries (e.g., previous injury, poor conditioning, muscle imbalances, and errors in training), it has been suggested that both acute and overuse injuries could be reduced by 15–50% (161). Although there are many mechanisms to potentially reduce sports-related injuries in young athletes (e.g., coaching education, safe equipment, proper nutrition), enhancing physical fitness as a preventative health measure should be considered a cornerstone of multicomponent treatment programs.

Comprehensive conditioning programs that included resistance training, plyometric training, or both have proven to be an effective strategy for reducing sports-related injuries in adolescent athletes (39,60,115,116,120,149,176), and it is possible that similar effects would be observed in children, although additional research is needed to support this contention. Preseason conditioning programs that included resistance training decreased the number and severity of injuries in high school football players (39) and, similarly, decreased the incidence of injury in adolescent soccer players (115). Others observed that balance training (63,65) or balance training and strengthening exercises (244,245) were effective in reducing sports-related injuries in adolescent athletes.

Because of the relatively high incidence of knee injuries in young female athletes as compared with males (185), researchers have investigated the effects of various training programs on injury rates in young female subjects. Of note, preseason conditioning programs that included plyometric exercises, resistance training, and education on jumping mechanics significantly reduced the number of serious knee injuries in adolescent female athletes (120,149). Conversely, no significant differences in injury rates were observed in adolescent female athletes who participated in an in-season plyometric training program (181) or structured warm-up activities that included strength, balance, and agility exercises (217). Differences in the design of the training programs and time of implementation (i.e., preseason vs. in-season) could explain, at least in part, these conflicting results.

Collectively, a majority of the evidence suggests that regular participation in a preseason conditioning program that includes plyometric exercises, resistance training, balance skills, and education may reduce the likelihood of sports-related injuries in young athletes. Yet some data suggest that only a minority of young athletes participate in comprehensive conditioning programs before sports participation (34). Clearly, there is an ongoing need for school- or coach-sponsored involvement to ensure that all young athletes participate in multi-component conditioning programs before sports training and competition.

However, the addition of preseason conditioning to the total exercise dose, which includes free play as well as organized sports, should be carefully considered because this type of training adds to the chronic, repetitive stress placed on the developing musculoskeletal system. Some young athletes with relatively immature musculoskeletal systems may be intolerant of the same exercise dose that the majority of the athletes in the same program can tolerate. This biologic uniqueness in growing athletes can result in stress fracture syndromes manifested by a variety of conditions such as traction apophysitis, injuries to the developing joint surfaces, or injuries to the immature spine (3,159,177).

Because of the interindividual variability of stress tolerance, each child must be treated as an individual and observed for signs of incipient stress failure syndromes, which would require a modification of the frequency, volume, intensity, and progression of training. With the awareness of this variability in children and adolescents of the same age to accept and tolerate stress, many of these stress failure syndromes can be prevented. In some instances, it may be necessary for young athletes to reduce their sport involvement to allow time for preparatory strength and conditioning with adequate rest and recovery between training sessions. A reduction in performance and an increased risk of injury can result by frequent training sessions without adequate rest and recovery in-between (99).

There is insufficient evidence to decide for or against improvements in subjective “energy” level, sleep patterns, emotional maturity, immune function, nutritional status, cognitive performance, or health care utilization. It is probable that either these characteristics would be favorably altered or at least not unfavorably influenced by resistance training, providing that the program is properly designed, pleasurable, and rewarding.

Youth Resistance Training Guidelines

A prerequisite for the development and administration of safe, effective, and enjoyable youth resistance training programs is an understanding of established training principles and an appreciation for the physical and psychosocial uniqueness of children and adolescents. Although there is no minimum age requirement at which children can begin resistance training, all participants must be mentally and physically ready to comply with coaching instructions and undergo the stress of a training program. In general, if a child is ready for participation in sport activities (generally age 7 or 8 years), then he or she is ready for some type of resistance training. Although a medical examination before participation in a youth resistance training program is not mandatory for apparently healthy children, a medical examination is recommended for youth with signs or symptoms suggestive of disease and for youth with known disease.

Instruction and supervision should be provided by qualified adults who have an understanding of youth resistance training guidelines and who are knowledgeable of the physical and psychosocial uniqueness of children and adolescents. Moreover, teachers, personal fitness trainers, and youth coaches should develop an appropriate philosophy about training youth that is consistent with the needs, goals, and interests of children and adolescents. Ideally, adults who teach and coach youth resistance training should have practical experience working with children and adolescents, a recognized professional certification (e.g., National Strength and Conditioning Association [NSCA] Certified Strength and Conditioning Specialist or NSCA Certified Personal Trainer), and a level of knowledge commensurate with a college degree in physical education, exercise science, or a related field. For youths participating in advanced training programs, coaches should have additional knowledge and practical experience to properly instruct and sensibly prescribe or advance this type of training. Although less experienced supervisors may assist in the organization and implementation of youth resistance training programs, it is unlikely they will be able to provide the quality of care and instruction needed for more advanced training. If qualified supervision, age-appropriate exercise equipment, and a safe training environment are not available, youth should not perform resistance exercise due to the increased risk of injury (107,132).

Basic education on weight room etiquette, proper exercise technique, individual goals, and realistic outcomes should be part of youth resistance training programs. All participants should receive instruction on safety concerns including the correct use of collars; appropriate spotting procedures; the proper storage of exercise equipment; the appropriate handling of barbells, dumbbells, and plates; and sensible starting weights. This is particularly important for untrained children who often overestimate their physical abilities (184) and who may not be aware of the inherent risks associated with resistance training exercise equipment. Instead of competing against each other, youth should be encouraged to embrace self-improvement and feel good about their performances (e.g., the ability to correctly perform a multijoint lift). The importance of creating an enjoyable exercise experience for all participants should not be overlooked because enjoyment has been shown to mediate the effects of youth physical activity programs (58). Adults should teach youth about their bodies as well as the potential benefits of a healthy lifestyle (e.g., proper nutrition, adequate sleep, stress management, and regular physical activity) (129).

Qualified and enthusiastic instruction not only enhance participant safety and enjoyment but also direct supervision of youth resistance training programs can improve program adherence and optimize strength gains (53). Although all training sessions should be supervised by a qualified adult (or several adults depending on class size), additional supervision may be needed during the first few weeks of the resistance training program when participants are learning proper exercise technique and training procedures. Adults should present information to children and adolescents in a style and language that is appropriate for their level of understanding, and positive, encouraging feedback should be used to foster feelings of competence and reduce anxiety (188). All participants should be encouraged to ask questions and freely state their concerns about the program. Charts, posters, and workout cards that promote proper exercise technique and realistic expectations are helpful.

Various combinations of resistance training program variables have proven to be safe and effective for children, providing that program developers used scientific information, established training principles, and common sense. All youth resistance training programs should include instruction on proper lifting techniques, safety procedures, and specific methods of progression. Because the act of resistance training itself does not ensure that optimal gains in strength and power will be realized, the ideal approach is to incorporate resistance training into a progressive conditioning program in which the volume and intensity of training change throughout the year (141). It is the systematic structuring of program variables along with individual effort and qualified instruction that will determine the outcomes associated with resistance training. Finally, children and adolescents must not be treated as miniature adults, nor should adult exercise guidelines and training philosophies be imposed on youth.

The program variables that should be considered when designing a youth resistance training program include (a) warm-up and cool-down, (b) choice and order of exercise, (c) training intensity and volume, (d) rest intervals between sets and exercises, (e) repetition velocity, (f) training frequency, and (g) program variation. Table 1 summarizes youth resistance training guidelines. A more detailed description of youth resistance program variables and training considerations is available elsewhere (47,84,130,137,156,192).

Warm-up and Cool-down. Over the past few years, long-held beliefs regarding the routine practice of warm-up static stretching have been questioned (133,208,223). An acute bout of static stretching has been found to have a negative impact on strength and power performance in adults (208), and similar findings have been reported in adolescents (155,257). In recent times, there has been rising interest in warm-up procedures that involve the performance of dynamic movements (e.g., 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 (73,191). This type of dynamic warm-up may

Table 1. General youth resistance training guidelines.

- Provide qualified instruction and supervision
- Ensure the exercise environment is safe and free of hazards
- Start each training session with a 5- to 10-minute dynamic warm-up period
- Begin with relatively light loads and always focus on the correct exercise technique
- Perform 1–3 sets of 6–15 repetitions on a variety of upper- and lower-body strength exercises
- Include specific exercises that strengthen the abdominal and lower back region
- Focus on symmetrical muscular development and appropriate muscle balance around joints
- Perform 1–3 sets of 3–6 repetitions on a variety of upper- and lower-body power exercises
- Sensibly progress the training program depending on needs, goals, and abilities
- Increase the resistance gradually (5–10%) as strength improves
- Cool-down with less intense calisthenics and static stretching
- Listen to individual needs and concerns throughout each session
- Begin resistance training 2–3 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
- Optimize performance and recovery with healthy nutrition, proper hydration, and adequate sleep
- Support and encouragement from instructors and parents will help maintain interest

create an optimal environment for resistance training by enhancing neuromuscular function (191,201). It has been reported that warm-up protocols that include moderate to high intensity dynamic movements can enhance power performance in youth (68,71,76,209).

In the absence of sufficient evidence to endorse pre-event static stretching with respect to performance enhancement, the potential impact of pre-event dynamic exercise on anaerobic fitness performance should be considered. In addition to potential physiological benefits, a well-designed dynamic warm-up can also set the tone for the training session and establish a desired tempo for the upcoming activities. A reasonable suggestion is to perform 5–10 minutes of dynamic activities during the warm-up period and less intense calisthenics and static stretching at the end of the workout. A cool-down period consisting of general calisthenics and static stretching can help relax the body and improve flexibility. Moreover, regular long-term stretching (not performed during the warm-up) may improve performance and may reduce the risk of injury (208,218). During the cool-down period, it is often worthwhile to reflect on what each participant learned and review training objectives for the next session.

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 (e.g., quadriceps and hamstrings). Weight machines (both child sized and adult sized) as well as free weights, elastic bands, medicine balls, and body weight exercises have been used by children and adolescents in clinical- and school-based exercise programs. It is reasonable to start with relatively simple exercises and gradually progress to more advanced multi-joint movements as confidence and competence improve. However, in some cases (e.g., weightlifting class), it may be appropriate to start with multi-joint movements, provided that light loads are used and the focus is on enhancing fundamental movement patterns. 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 multi-joint exercises should be performed before single-joint exercises. 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 weightlifting movement or a plyometric exercise, this type of exercise should be performed early in the training session so that the child can practice the exercise without undue fatigue.

Training Intensity and Volume. Training intensity typically refers to the amount of resistance used for a specific exercise, whereas training volume generally refers to the total amount of work performed in a training session. Although both of these program variables are significant, training intensity is one of the more important factors in the design of a resistance training program. However, to maximize gains in muscular fitness and reduce the risk of injury, youth must first learn how to perform each exercise correctly with a light load (e.g., unloaded barbell) and then gradually progress the training intensity, or volume, or both, without compromising exercise technique to lift heavier loads.

If 1RM tests are not performed, a simple approach may be to first establish the repetition range and then by trial and error determine the maximum load that can be handled for the prescribed range. For example, a child or adolescent may begin resistance training with 1 or 2 sets of 10–15 repetitions with a relatively light or moderate load to develop proper exercise technique. Depending on individuals' needs, goals, and abilities, over time the program can be progressed to include additional sets with heavier loads (e.g., 6 to 10RM) on large muscle group exercises to maximize gains in muscle strength and power. Although additional training studies 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 (136), and it is likely that similar findings would occur in children and adolescents over the long-term.

With a careful prescription of sets and repetitions, the training stimulus will remain effective and therefore the effort to benefit ratio will be maximized. However, it is important to realize that not all exercises need to be performed for the same number of sets and repetitions. For example, an adolescent with resistance training experience may perform 3 sets of 6–8 repetitions on multi-joint exercises (e.g., back squat and bench press) with a relatively heavy weight and 2 sets of 10–12 repetitions on single-joint exercises (e.g., biceps curl and triceps extension) with a relatively moderate weight. Of interest, findings from adult studies indicate that the number of repetitions that can be performed at a given percentage of the 1RM is influenced by the amount of muscle mass used during an exercise (207), and similar observations have been reported in children (85).

Due to the relatively intense nature of power exercises (e.g., plyometric or weightlifting movements), fewer than 6–8 repetitions per set are typically recommended for youth. Unlike traditional strength-building exercises, power exercises are explosive but highly controlled movements that require a high degree of technical skill. Because fatigue can influence the performance of power exercises, it is recommended that youth perform fewer quality repetitions to maintain movement speed and efficiency for all repetitions within a set.

In an attempt to aid in the exercise prescription, researchers have developed prediction equations based on repetitions performed to fatigue with a submaximal load (124,142,152). In general, it was found that 1RM strength on selected exercises may be predicted with reasonable accuracy in young male and female athletes. Others have developed child-specific perceived exertion rating scales to assess the exertional perceptions of children during resistance exercise (78,193). Subjective information from these scales can be used to assist in the prescription of effective youth resistance training programs.

Rest Intervals Between Sets and Exercises. The length of the rest interval between sets and exercises is a program variable of primary importance to coaches, teachers, athletes, and researchers (251). Because acute force and power production may be compromised if the rest interval is too short, longer rest intervals of at least 2–3 minutes for primary, multiple-joint exercises are typically recommended during adult resistance training programs (136). However, rest interval recommendations for adults may not be consistent with the needs and abilities of younger populations due to growth- and maturation-related differences in response to physical exertion. Studies have shown that children are able to recover from high-intensity, short-term, intermittent exercise faster than adults (82,90,255).

Although few data examining the effects of rest interval length on strength performance in younger populations are available, it appears that children and adolescents can resist fatigue to a greater extent than adults during several repeated sets of resistance exercise (82,213,255). Thus, a shorter rest interval (about 1 minute) may suffice in children and adolescents when performing a moderate-intensity resistance exercise protocol, although the likelihood that adolescents may fatigue more rapidly than children should be considered. Obviously, training intensity, training volume, exercise choice, and fitness level will influence the length of the rest interval. Some young athletes (e.g., adolescent weightlifters) who perform exercises that require higher levels of power or skill may require longer rest intervals (e.g., 2–3 minutes) between sets and trials during practice and competition to maintain muscle performance.

Repetition Velocity. The velocity or cadence at which a strength exercise is performed can affect the adaptations to a training program (136). Because youth need to learn how to perform each exercise correctly with a relatively light load, it is generally recommended that youth resistance train in a controlled manner at a moderate velocity. However, different training velocities may be used depending on the choice of exercise. For example, plyometric exercises and weightlifting movements are explosive but highly controlled movements that should be performed at a high velocity. 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 2–3 times per week on nonconsecutive days is recommended for children and adolescents. Limited evidence indicates that 1 $d\cdot wk^{-1}$ of resistance training may be suboptimal for enhancing muscular strength in youth (29,79), although once per week training maybe effective in retaining the strength gains made after resistance training (55). In general, a training frequency of 2 or 3 times per week on nonconsecutive days will allow for adequate recovery between sessions

(48–72 hours between sessions) and will be effective for enhancing strength and power in children and adolescents. Although some young athletes may participate in strength and conditioning activities more than 3 d·wk^{-1}, factors such as the training volume, training intensity, exercise selection, nutritional intake, and sleep habits need to be considered as these factors may influence one's ability to recover from and adapt to the training program. As training programs become more advanced (and potentially more frequent), the importance of reinforcing proper exercise technique and training habits with less intense workouts during the week should not be overlooked.

Program Variation. By periodically varying program variables, long-term performance gains will be optimized, boredom will be reduced, and the risk of overuse injuries will likely decrease (136,138). The concept whereby a training program is systematically varied over time is known as periodization. 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. Although additional research involving younger populations is needed, it is reasonable to suggest that children and adolescents who participate in well-designed, periodized resistance training programs and continue to improve their health and fitness may be more likely to adhere to their exercise programs. Furthermore, planned changes in the program variables can help prevent training plateaus, which are not uncommon after the first 8–12 weeks of resistance training.

Program variables for progression during youth resistance training for strength and power are outlined in Table 2 and Table 3, respectively. Regardless of the training goal, all youth should begin with a light load and progress gradually to learn proper exercise technique and become skilled in various exercise procedures. Because both force and velocity components are important for power training, 2 loading strategies are required, namely, moderate to heavy loads for strength and light to moderate loads performed at an explosive lifting velocity. Although multi-joint exercises such as power cleans and push presses have been used extensively for power training, proper technique must be stressed because the quality of effort per repetition (maximal velocity) is critical to the performance of these lifts. A power component for novice and intermediate lifters consisting of 1–3 sets of 3–6 repetitions performed not to failure should be integrated into the resistance training program. Although traditional repetition systems normally involve the performance of successive repetitions with minimal pause in between each repetition, the performance of explosive movements does not always need to conform to this pattern. Given the importance of learning proper exercise technique, every repetition should be initiated from the proper starting position. Hence, it may be advantageous for young weightlifters to pause briefly between each repetition to reset their starting position to ensure that optimal technique is achieved on every repetition.

For the purpose of this review, a "novice" refers to an individual who has no or limited resistance training experience (≤2 to 3 months) or an individual who has not trained for several months. "Intermediate" refers to an individual who has approximately 3–12 months of consistent resistance training experience. "Advanced" refers to those individuals with at least 12 months of resistance training experience who also attained significant improvements in muscular strength and power.

Although there is not one model of periodization, the general concept is to prioritize training goals and then develop a long-term plan that changes throughout the year. By periodically varying the training intensity, training volume, rest interval length, and exercise choice, the risk of overtraining may be minimized and potential for maintaining training-induced gains could be maximized (99). It is worth noting that periodized training programs should include periods of active rest (e.g., 1–3 weeks recovery between sport seasons) to allow for physical and psychological recovery from the training sessions. This is particularly important for youth who represent different sports teams, specialize in 1

TABLE 2. Recommendations for progression during resistance training for strength.*

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exercise choice	SJ and MJ	SJ and MJ	SJ and MJ
Intensity	50–70% 1RM	60–80% 1RM	70–85% 1RM
Volume	1–2 sets × 10–15 reps	2–3 sets × 8–12 reps	≥3 sets × 6–10 reps
Rest intervals (min)	1	1–2	2–3
Velocity	Moderate	Moderate	Moderate
Frequency (d·wk^{-1})	2–3	2–3	3–4

*ECC = eccentric; CON = concentric; SJ = single joint; MJ = multi-joint; 1RM = 1 repetition maximum; rep = repetition.

Table 3. Recommendations for progression during resistance training for power.*

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exercise choice	MJ	MJ	MJ
Intensity	30–60% 1RM VEL	30–60% 1RM VEL 60–70% 1RM STR	30–60% 1RM VEL 70 to ≥80% 1RM STR
Volume	1–2 sets × 3–6 reps	2–3 sets × 3–6 reps	≥3 sets × 1–6 reps
Rest intervals (min)	1	1–2	2–3
Velocity	Moderate/fast	Fast	Fast
Frequency ($d \cdot wk^{-1}$)	2	2–3	2–3

*ECC = eccentric; CON = concentric; MJ = multi-joint; 1RM = 1 repetition maximum; VEL = velocity; STR = strength; rep = repetition.

sport year-round, or participate in extracurricular conditioning activities at private training centers. In addition, to promote long-term gains in strength and performance in children and adolescents, training programs should include educational sessions on lifestyle factors and behaviors that are conductive to high performance (129). Of note, the importance of proper nutrition (52), sufficient hydration (44), and adequate sleep (165) should not be overlooked. A detailed review of periodization and lifestyle factors that may influence athletic performance are beyond the scope of this review, but they are available elsewhere (129,136,138).

Conclusions

Despite outdated concerns regarding the safety or effectiveness of youth resistance training, scientific evidence and clinical impressions indicate that youth resistance training has the potential to offer observable health and fitness value to children and adolescents, provided that appropriate training guidelines are followed and qualified instruction is available. In addition to performance-related benefits, the effects of resistance training on selected health-related measures including bone health, body composition, 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 age-appropriate resistance training guidelines.

We now have the information to support the consideration of incorporating resistance training into a health-oriented approach to lifelong physical activity. Important future research goals should be to elucidate the mechanisms responsible for the health-related benefits associated with youth resistance exercise, to establish the combination of program variables that may optimize long-term training adaptations and exercise adherence in children and adolescents, and to explore the potential benefits of resistance training on youth with various medical conditions including obesity, diabetes, cancer, severe burns, and physical limitations, and intellectual disabilities.

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