5.2 Strength Training for Children and Adolescents

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5.2.1 INTRODUCTION

Physical activity is essential for normal growth and development during childhood and adolescence. It is generally agreed that school-age youth should participate regularly in at least 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate and enjoyable (Department of Health, 2004; Department of Health and Human Services, 2008). While a variety of activities should be recommended, research increasingly indicates that strength training can offer unique benefits for children and adolescents when appropriately prescribed and supervised (Faigenbaum and Myer, 2010; Ortega *et al.*, 2008; Strong *et al.*, 2005; Vaughn and Micheli, 2008). Despite outdated concerns regarding the safety and effectiveness of strength training for children and adolescents, the qualified acceptance of youth strength training by medical and fitness organizations is becoming universal (American College of Sports Medicine, 2010; Australian Strength and Conditioning Association, 2009; Behm *et al.*, 2008; British Association of Sport and Exercise Sciences, 2004; Faigenbaum *et al.*, 2010; Mountjoy *et al.*, 2008).

Nowadays, public health guidelines aim to increase the number of boys and girls who regularly engage in muscle-strengthening physical activities (Department of Health, 2004; Department of Health and Human Services, 2008). Many school-based physical education programmes are specifically designed to enhance health-related components of physical fitness, including muscular strength, and a growing number of young athletes now strength-train to enhance their sports performance (Lee *et al.*, 2007; National Association for Sport and Physical Education, 2005; Vaughn and Micheli, 2008). As more children and adolescents strength-train in schools, fitness centres, and sport-training facilities, it is important to understand safe and effective practices by which strength training can improve the health, fitness, and sports performance of younger populations. Therefore, the main focus of this chapter is to review the risks and concerns associated with youth strength training, examine the trainability of muscular strength in younger populations, and highlight programme design considerations for healthy children and adolescents.

For the purpose of this chapter, the term 'children' refers to boys and girls who have not yet developed secondary sex characteristics such as changes in voice pitch, facial hair, and body configuration. This period of development is referred to as 'pre-adolescence' and generally includes girls and boys up to the age of roughly 12 years. The term 'adolescence' refers to a period of time between childhood and adulthood (typically ages 13–18 years). The terms 'youths' and 'young athletes' are broadly defined in this chapter to include both children and adolescents. By definition, the term 'strength training' (also called 'resistance training') refers to a specialized method of conditioning which involves the progressive use of a wide range of resistive loads (including body mass) and a variety of training modalities designed to enhance health, fitness, and sports performance. Strength training should be distinguished from weightlifting, which is a competitive sport in which athletes attempt to lift maximal amounts of weight in the clean-and-jerk and snatch exercises.

5.2.2 RISKS AND CONCERNS ASSOCIATED WITH YOUTH STRENGTH TRAINING

The traditional concerns associated with youth strength training stemmed from three general misconceptions about strength exercise. First, that any type of exercise that involved moderate to heavy lifting would be unsafe and inappropriate for children and adolescents. Second, that strength training would damage developing growth plates and possibly stunt the linear growth of children and adolescents. Third, that children would not benefit from strength training because youths lacked adequate amounts of circulating androgens. Categorically, all of these misperceptions have been disproved by research evidence, which clearly indicates that regular participation in a well-designed and competently supervised strength-training programme can be safe, effective and worthwhile for healthy children and adolescents (Faigenbaum and Myer, 2010; Falk and Eliakim, 2003; Malina, 2006; Pierce *et al.*, 2008).

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A careful evaluation of research findings indicates a relatively low risk of injury in children and adolescents who follow age-appropriate strength-training guidelines (Faigenbaum *et al.*, 2010; Malina, 2006; Pierce *et al.*, 2008). Based on an analysis of strength training-related injuries that resulted in visits to US emergency rooms, Myer *et al.* (2010) noted that children had a lower risk of strength training-related joint sprains and muscle strains than adults. In support of these observations, others reported no evidence of either musculoskeletal injury (measured by biphasic scintigraphy) or muscle necrosis (determined by serum creatine phosphokinase levels) in children following 14 weeks of strength training (Rians, Weltman and Cahill, 1987).

Only three published studies have reported strength training-related injuries in children (a shoulder strain which resolved within one week of rest (Rians, Weltman and Cahill, 1987); a shoulder strain which resulted in one missed training session (Lillegard *et al.*, 1997); and nonspecific anterior thigh pain which resolved with five minutes of rest (Sadres *et al.*, 2001)). In the vast majority of prospective published reports, no serious injuries are reported in young lifters who participated in supervised strength-training programmes that were appropriately prescribed to ensure they were matched to each participant's initial capabilities. Although strength training, like most physical activities, does have an inherent risk of musculoskeletal injury, the available data suggest that this risk is no greater than that in other sports and recreational activities in which youths regularly participate.

Despite these noteworthy findings, a recurring concern among some youth coaches and health-care providers centres around the safety and appropriateness of weightlifting and plyometric exercises for youths. Unlike traditional strength-building exercises such as the chest press or biceps curl, which are relatively easy to learn and perform, weightlifting movements and plyometrics are explosive but highly controlled movements that require a relatively high degree of technical skill. For example, to accomplish the clean and jerk, the barbell must be lifted from the platform to the shoulders and then to the overhead position to complete the two-part lift. While this movement involves more complex neural activation patterns than most strength exercises, the belief that weightlifting movements are riskier than other sports and activities is not supported by research finding (Byrd *et al.*, 2003; Hamill, 1994; Pierce, Byrd and Stone, 1999).

In one retrospective evaluation of injury rates in adolescents, it was revealed that strength training and weightlifting were markedly safer than many other sports and activities in which youths regularly participate (Hamill, 1994). In this report the overall injury rate per 100 participant hours was 0.8000 for rugby and 0.0120 and 0.0013 for strength training and weightlifting, respectively. This latter finding may be explained, at least in part, by the observation that weightlifting is typically characterized by well-informed coaches and a gradual progression from basic exercises (e.g. front squat) to skill-transfer exercises (e.g. overhead squat) and finally to competitive lifts (snatch and clean and jerk). Others have reported significant gains in muscular strength without any report of injury when weightlifting movements such as the snatch, clean and jerk, and modified cleans, pulls, and presses are incorporated into youth strength-training programmes (Faigenbaum *et al.*, 2007a; Gonzales-Badillo *et al.*, 2005; Sadres *et al.*, 2001).

A related concern associated with youth strength training regards the safety of plyometric exercises for children and adolescents. Although plyometric training typically includes 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 patterns of boys and girls as they skip and jump can be considered plyometric (Chu, Faigenbaum and Falkel, 2006). The belief that age-appropriate plyometric training is unsafe for youths, or that a pre-determined baseline level of strength (e.g. one-repetition maximum (1 RM) 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, well-designed strength-training programmes 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 (Hewett *et al.*, 1999; Mandelbaum *et al.*, 2005; Myer *et al.*, 2005; Thomas, French and Hayes, 2009).

Perhaps the most enduring concern related to youth strength training regards the potential for training-induced damage to the growth cartilage. Since growth cartilage is 'pre-bone', it is weaker than adjacent connective tissue and therefore more easily damaged by repetitive microtrauma (Micheli, 2006). A few retrospective case reports published in the 1970s and 1980s noted injury to the growth cartilage in young lifters (Gumbs *et al.*, 1982; Jenkins and Mintowt-Czyz, 1986; Rowe, 1979; Ryan and Salciccioli, 1976). However, most of these injuries were due to improper lifting techniques, maximal lifts, or lack of qualified adult supervision. To date, injury to the growth cartilage has not been reported in any prospective youth strength-training research study. Furthermore, there is no evidence to suggest that strength training will negatively impact growth and maturation during childhood and adolescence (Falk and Eliakim, 2003; Malina, 2006). If age-specific training guidelines are followed and if nutritional recommendations (e.g. adequate calcium) are adhered to, weight-bearing physical activity (including strength training) will likely have a favourable influence on growth during childhood and adolescence, but will not affect the genotypic maximum.

It is worth noting that there is an increased risk of injury to children and adolescents who use exercise equipment at home without supervision (Gould and DeJong, 1994; Jones, Christensen and Young, 2000). However, the risk of injury while strength training can be minimized by qualified supervision, appropriate programme design, careful selection of training equipment, and a safe training environment. In addition, the risk of injury can be reduced by systematically varying the training programme, limiting the number of heavy lifts during a workout, and allowing for adequate recovery between training sessions.

5.2.3 THE EFFECTIVENESS OF YOUTH RESISTANCE TRAINING

A compelling body of scientific evidence indicates that children and adolescents can significantly increase their muscular strength given a training programme of sufficient intensity, volume, and duration (Behm *et al.*, 2008; Blimkie and Bar-Or, 2008; Faigenbaum and Myer, 2010; Myer and Wall, 2006; Pierce *et al.*, 2008; Vaughn and Micheli, 2008). In addition, two meta-analyses on youth strength training (Falk and Tenenbaum, 1996; Payne *et al.*, 1997), along with clinical observations, indicate that well-designed strength-training programmes can enhance the muscular strength of children and adolescents beyond that produced by normal growth and development.

A majority of youth strength-training studies lasted 8–20 weeks and most subjects were between 7 and 15 years of age. A wide variety of strength-training programmes, from single-set sessions on weight machines to progressive, multi-set training protocols on different types of equipment, have proven to be effective (Annesi *et al.*, 2005; Faigenbaum *et al.*, 2007a; Gonzales-Badillo *et al.*, 2005; Ramsay *et al.*, 1990; Sadres *et al.*, 2001; Westcott, 1992). Training modalities have included weight machines (both adult- and child-size), free weights (i.e. barbells and dumbbells), medicine balls, elastic bands, and body-weight exercises.

Strength gains of roughly 30% are common following short-term (8–20 weeks) youth strength-training programmes. Figure 5.2.1 illustrates training-induced lower-body-strength gains in children following an eight-week strength-training programme. While it is evident that all children responded favourably to the training stimulus (1–2 sets of 10–15 repetitions at 60–70% 1 RM), the individual response was variable. Subject 1 demonstrated relatively small gains in muscle strength, while subject 20 experienced the largest gains. Although the group mean strength gain was significant, the variation in the individual response to the training programme suggests that other factors (e.g. genetics, training experience, motivation) need to be considered when evaluating such data. From a practical standpoint, coaches and teachers should be aware of the individual responses to strength exercise and may need to identify participants who might warrant more attention and/or a modification of their strength-training programme.

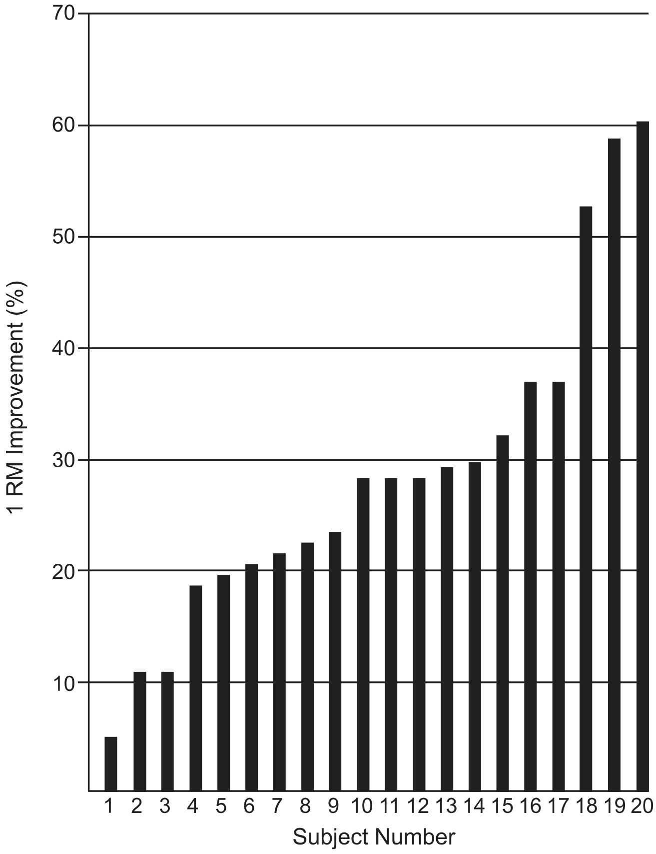

Figure 5.2.1 Individual changes in muscle strength in 20 children in response to eight weeks of strength training. Unpublished data from Avery Faigenbaum, The College of New Jersey, USA

5.2.3.1 Persistence of training-induced strength gains

The temporary or permanent reduction or withdrawal of a training stimulus is referred to as 'de-training'. The evaluation of strength changes in youths following a de-training period is complicated by the concomitant growth-related strength increases in the same time period. The available data suggest that training-induced gains in strength in youths are impermanent and tend to regress towards untrained control-group values during the de-training period (Faigenbaum *et al.*, 1996; Ingle *et al.*, 2006; Tsolakis, Vagenas and Dessypris, 2004). Although the precise nature of the de-training response and the physiological adaptations that occur during this period remain uncertain, it seems that changes in neuromuscular functioning and the hormonal responses to de-training should be considered.

The effects of training frequency on the maintenance of training-induced strength gains in children and adolescents are also worthy of further study. Following 20 weeks of strength training, Blimkie *et al.* (1989) found that a once-weekly maintenance training programme was not adequate to maintain the training-induced strength gains in pre-adolescent males. Conversely, a once-weekly maintenance programme was just as sufficient as a twice-weekly maintenance programme in retaining the strength gains made after 12 weeks of strength training in a group of adolescent male athletes (DeRenne *et al.*, 1996).

5.2.3.2 Programme evaluation and testing

The degree of measured strength change following a training programme can be influenced by many factors, including training experience, programme design, and specificity of testing and training. In addition, the methods for evaluating training-induced changes in muscle strength need to be considered. In some studies subjects were trained and tested using different modalities (Pfeiffer and Francis, 1986; Sewall and Micheli, 1986; Weltman *et al.*, 1986), and in other published reports strength changes were evaluated by relatively high RM values (e.g. 10 RM) (Faigenbaum *et al.*, 1993; Lillegard *et al.*, 1997).

Strength changes have also been evaluated by maximal load lifting (e.g. 1 RM) on the equipment used in training (DeRenne *et al.*, 1996; Faigenbaum *et al.*, 2002; Pikosky *et al.*, 2002; Ramsay *et al.*, 1990; Volek *et al.*, 2003). However, some practitioners and researchers have not used 1 RM testing to evaluate training-induced changes in muscular strength because of the presumption that high-intensity loading may cause structural damage in children. 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 to evaluate training-induced changes in young lifters.

In one report, 96 children performed a 1 RM strength test on upper-body and lower-body weight-machine exercises (Faigenbaum, Milliken and Westcott, 2003). 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 1 RM strength tests using free-weight exercises (Baker, 2002; Hetzler *et al.*, 1997; Sadres *et al.*, 2001; Volek *et al.*, 2003). These observations suggest that the maximal force-producing capabilities of healthy children and adolescents can be safely evaluated by 1 RM testing procedures provided that youths participate in a habituation period prior to testing and that qualifed professionals closely supervise and administer each test. Since most of the forces that youths are exposed to in sports and recreational activities are likely to be greater in both duration and magnitude than carefully performed 1 RM testing, the careful evaluation of maximal muscle strength in children and adolescents should be supported by qualified professionals.

However, when properly administered, 1 RM tests are time-consuming and labour-intensive; in some instances, such as physical-education classes, field-based measures may be more appropriate and time-efficient. Milliken *et al.* (2008) and Holm *et al.* (2008) have documented significant correlations between 1 RM strength and common field measures such as handgrip strength and long jump in children. In any case, unsupervised and improper strength testing characterized by inadequate progression of loading and poor exercise technique should not be performed by children or adolescents under any circumstances due to the real risk of injury (Risser, 1991).

5.2.4 PHYSIOLOGICAL MECHANISMS FOR STRENGTH DEVELOPMENT

Training-induced strength gains in children are more related to neurological mechanisms than to morphological changes in muscle size (Malina, 2006; Sale, 1989). Without adequate levels of circulating testosterone to stimulate increases in muscle size, children experience greater difficulty increasing their muscle mass consequent to a strength-training programme as compared to older populations (Ozmun, Mikesky and Surburg, 1994; Ramsay *et al.*, 1990). However, since some findings are at variance with this suggestion (Fukunga, Funato and Ikegawa, 1992; Mersch and Stoboy, 1989), it is possible that more intensive training programmes, 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, neuromuscular adaptations (i.e. a trend towards increased motor-unit activation and changes in motor-unit coordination, recruitment, and firing) and possibly intrinsic muscle adaptations appear to be primarily responsible for training-induced strength gains during pre-adolescence (Ozmun, Mikesky and Surburg, 1994; Ramsay *et al.*, 1990). Using the interpolated twitch technique, Ramsay *et al.* (1990) found an increase of 12 and 14% in motor-unit activation of the elbow flexors and knee extensors, respectively, in pre-adolescent boys following 20 weeks of strength training. Likewise, Ozmun, Mikesky and Surburg (1994) used integrated electromyography amplitude to demonstrate an increase in neuromuscular activation in agonist muscles following eight weeks of strength training in children.

In both of the aforementioned studies (Ozmun, Mikesky and Surburg, 1994; Ramsay *et al.*, 1990), measured increases in training-induced strength were greater than changes in neuromuscular activation. Thus, it is likely that improvements in motor-skill performance and the coordination of the involved muscle groups also play a significant role. In support of these observations, several training studies have reported significant improvements in strength during pre-adolescence without corresponding increases in gross limb morphology, as compared to a similar control group (Faigenbaum *et al.*, 1993; Lillegard *et al.*, 1997; Ramsay *et al.*, 1990). Since most children have limited experience of strength training, it is reasonable to suggest that the first few weeks of training involve neuromuscular learning or optimization of inter-muscular coordination (agonists, synergists, stabilizers) (Behm *et al.*, 2008). During and after puberty, training-induced gains in muscle strength may be associated with changes in hypertrophic factors in males, since testosterone and other hormonal influences on muscle hypertrophy will be operant (Kraemer *et al.*, 1989).

5.2.5 POTENTIAL HEALTH AND FITNESS BENEFITS

While a majority of the paediatric research has focused on activities that enhance cardiorespiratory fitness (Rowland, 2005), recent findings indicate that strength training can offer unique benefits to children and adolescents. In addition to

Table 5.2.1 Potential benefits of youth strength training

- Increased muscle strength.
- Increased muscle power.
- Increased local muscular endurance.
- Improved bone health.
- Improved body composition.
- Improved motor performance skills.
- Enhanced sports performance.
- Increased resistance to sports-related injuries.
- A more positive attitude towards lifetime physical activity.

enhancing musculoskeletal strength, regular participation in youth strength training can improve cardiovascular risk profile, facilitate weight control, improve motor performance skills, and increase resistance to sports-related injuries. Moreover, since good health habits established during childhood may carry over into adulthood, the potential positive influence on the adult lifestyle should be recognized (Telama *et al.*, 2005; Trudeau, Laurencelle and Shephard, 2004). A summary of the potential benefits of regular participation in a youth strength-training programme is given in Table 5.2.1.

5.2.5.1 Cardiovascular risk profile

The potential influence of strength training on body composition (the percentage of total body weight that is fat verus fat-free) has become an important topic of investigation given that the prevalence of obesity among children and adolescents continues to increase worldwide (Wang and Lobstein, 2006). Although regular physical activity is the cornerstone of treatment, obese youths 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. Excess body weight also hinders the performance of weight-bearing physical activities such as jogging and increases the risk of musculoskeletal injuries.

Recently, it has been suggested that strength training may offer observable health value to obese children and adolescents (Benson, Torade and Fiatarone Singh, 2008a; Faigenbaum and Westcott, 2007). Several studies have reported favourable changes in body composition following participation in a strength-training programme or a circuit weight-training (i.e. combined strength and aerobic training) programme in children and adolescents who were obese or at risk for obesity (Benson, Torade and Fiatarone Singh, 2008b; McGuigan *et al.*, 2009; Shaibi *et al.*, 2006; Sothern *et al.*, 2000). Of note, Shaibi *et al.* (2006) found that participation in a 16-week strength-training programme significantly decreased body fat and significantly increased insulin sensitivity in adolescent males who were at risk for obesity. Since the increase in insulin sensitively remained significant after adjustment for changes in total fat mass and total lean mass, it appeared that regular strength training may have resulted in qualitative changes in skeletal muscle that contributed to enhanced insulin action. In support of these observations, Benson, Torade and Singh (2006) found that muscular strength was an independent and powerful predictor of better insulin sensitivity in youth.

There is no clear association between strength training and reductions in blood pressure or improvements in the blood lipid profile in healthy youths. Limited data suggest that strength training may be an effective nonpharmacologic intervention in hypertensive adolescents (Hagberg *et al.*, 1984), and others have suggested that strength training characterized by moderate loads and a high number of repetitions can have a positive influence on the blood lipid profile of children and adolescents (Fripp and Hodgson, 1987; Sung *et al.*, 2002; Weltman *et al.*, 1987). Although further research is warranted, a comprehensive health-enhancing programme that includes regular physical activity (both aerobic and strength exercise), behavioural counselling, and nutrition education may be most effective for improving the blood pressure in hypertensive youths and the blood lipid profile in children and adolescents with dyslipidemia.

5.2.5.2 Bone health

Current observations suggest that childhood and adolescence may be the most opportune time for the bone-modelling and remodelling process to respond to the tensile and compressive forces associated with weight-bearing activities (Bass, 2000; Hind and Borrows, 2007). Since 50% of adult peak bone mass is acquired before puberty (Magarey *et al.*, 1999; Sabatier *et al.*, 1996), it is critical to maximize bone formation during this developmental period. If age-specific strength-training guidelines are followed and if nutritional recommendations are adhered to, regular participation in a strength-training programme can be a potent osteogenic stimulus during childhood and adolescence.

Results from several research studies indicate that regular participation in sports and specialized fitness activities that include strength training can enhance bone health in youth (MacKelvie *et al.*, 2004; Morris *et al.*, 1997; Ward *et al.*, 2005). Moreover, it has been observed that adolescent weightlifters displayed levels of bone-mineral density (Conroy *et al.*, 1993) and bone-mineral content (Virvidakis *et al.*, 1990) well above the values of age-matched controls. Others reported that pre-adolescent gymnasts whose training involved high-impact loading had significantly thicker cortical bone at the tibia and radius than the control group (Ward *et al.*, 2005). McKay *et al.* (2005) found that a school-based physical activity intervention which included body-weight jump training enhanced bone mass at the weight-bearing proximal femur in children.

Strength training at a young age has also been associated with a decreased risk of osteoporotic fractures later in life (Bass *et al.*, 1998; Heinonen *et al.*, 2000). However, the importance of maintaining participation in weight-bearing physical activities as an ongoing lifestyle choice must not be overlooked as training-induced improvements in bone health may be lost over time if the programme is not continued (Gustavsson, Olsson and Nordstrom, 2003).

5.2.5.3 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 following strength training (Faigenbaum and Mediate, 2006; Falk and Mor, 1996; Flanagan *et al.*, 2002; Hetzler *et al.*, 1997). As previously observed in adults, researchers have reported that the combination of strength training and plyometric training may offer the most benefit for children and adolescents (Faigenbaum *et al.*, 2007b; Lephart *et al.*, 2005; Myer *et al.*, 2005). The available data indicate that the effects of strength training and plyometric training may actually be synergistic, with their combined effect being greater than that of each programme performed alone.

Although the potential for strength training to enhance the sports performance of young athletes seems reasonable, scientific evaluations of this observation are difficult. Two studies (Blanksby and Gregor, 1981; Bulgakova, Vorontsov and Fomichenko, 1990) reported favourable 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 (Cossor *et al.*, 1999). Other researchers who studied young basketball, rugby, and soccer players noted the importance of incorporating strength training into sports practice sessions in order to maximize gains in muscular strength and power (Christou *et al.*, 2006; Gabbett, Johns and Riemann, 2008; Vamvakoudis *et al.*, 2007). Although most published reports and anecdotal comments from youth coaches suggest that regular participation in a well-designed strength-training programme will enhance athletic performance, further research is still required in this important field of study.

5.2.5.4 Sports-related injuries

Appropriately designed and sensibly progressed conditioning programmes that include strength training may help to reduce the likelihood of sports-related injuries in young athletes (Abernethy and Bleakley, 2007; Hewett, Myer and Ford, 2005; Renstrom *et al.*, 2008). By addressing the risk factors associated with youth sport injuries (e.g. low fitness level, muscle imbalances, errors in training), it has been suggested that both acute and overuse injuries could be reduced by 15% to 50% (Micheli, 2006). While 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 multi-component treatment programmes.

Comprehensive conditioning programmes that include strength training have proven to be an effective strategy for reducing sports-related injuries in adolescent athletes (Heidt *et al.*, 2000; Hewett *et al.*, 1999; Mandelbaum *et al.*, 2005) and it is possible that similar effects would be observed in children, although additional research is needed to support this contention. Pre-season conditioning programmes that included strength training decreased the number and severity of injuries in adolescent American football players (Cahill and Griffith, 1978) and, similarly, decreased the incidence of injury in adolescent soccer players (Heidt *et al.*, 2000). Others observed that balance training and strengthening exercises were effective in reducing sports-related injuries in adolescent athletes (Wedderkopp *et al.*, 1999, 2003).

In addition, pre-season conditioning programmes that included strength training and education on jumping mechanics significantly reduced the number of serious knee injuries in adolescent female athletes (Hewett *et al.*, 1999; Mandelbaum *et al.*, 2005). Due to the sedentary lifestyle of a growing number of children and adolescents (Hill, King and Armstrong, 2007), there is a distinct need to ensure that all aspiring young athletes participate in some type of pre-season conditioning programme prior to sports practice and competition.

5.2.6 YOUTH STRENGTH-TRAINING GUIDELINES

Although there is no minimum age at which children can begin strength training, all participants must be mentally and physically ready to comply with coaching instructions and undergo the stress of a training programme. In general, if a child is ready for participation in sports activities (generally age seven or eight), then they may be ready for some type of strength training. A medical examination prior to participation in a youth strength-training programme is not mandatory for apparently healthy children, but a medical examination is recommended for youths with known medical conditions, including diabetes, obesity and orthopedic ailments (Behm *et al.*, 2008; Faigenbaum *et al.*, 2009).

Instruction and supervision should be provided by qualified adults who have an understanding of youth strength-training guidelines and knowledge of the physical and psychosocial uniqueness of children and adolescents. Qualified and enthusiastic instruction not only enhances participant safety and enjoyment, but can improve programme adherence and optimize strength gains (Coutts, Murphy and Dascombe, 2004). Instructors should provide basic education on weight-room etiquette, spotting procedures, and exercise technique. Since visual feedback can help young lifters learn proper form and become cognizant of poor lifting biomechanics, exercise demonstrations, mirrors, or video equipment can be used to make youths aware of training errors.

It is important that youth coaches teaching advanced training programmes have the appropriate practical experience and training (e.g. Certified Strength and Conditioning Specialist or Accredited Strength and Conditioning Coach). While less experienced coaches and volunteers can assist in the implementation and supervision of an advanced strength-training workout, it is unlikely that they will be able to provide the level of technical expertise and instruction that is needed to safely and effectively learn advanced training procedures. If qualified supervision and a safe training environment are not available, youths should not perform strength exercise, due to the increased risk of injury.

Prior to every strength-training session, youths should participate in warm-up activities. Since long-held beliefs regarding the routine practise of warm-up static stretching have recently been questioned (Shrier, 2004; Thacker *et al.*, 2004), there has been rising interest in dynamic warm-up procedures. Dynamic warm-up involves the performance of various hops, skips, jumps, and movement-based exercises for the upper and lower body, designed to elevate core body temperature, enhance motor-unit excitability, improve kinaesthetic awareness, and maximize active ranges of motion (Faigenbaum and McFarland, 2007; Robbins, 2005). A dynamic warm-up that includes moderate- and high-intensity movements has been shown to enhance power performance in youths (Faigenbaum *et al.*, 2005, 2006a, 2006b; Siatras *et al.*, 2003). Without evidence to endorse pre-event static stretching, a reasonable suggestion is to perform five to ten minutes of dynamic activities during the warm-up period, and less-intense callisthenics and static stretching at the end of the workout.

Other programme variables that should be considered when designing a youth strength-training programme include: (1) choice and order of exercise, (2) training intensity and volume, (3) rest intervals between sets and exercises, (4) repetition velocity, (5) training frequency, and (6) programme variation. Table 5.2.2 summarizes youth strength-training guidelines.

5.2.6.1 Choice and order of exercise

Although a limitless number of exercises can be used to enhance muscular strength, it is important to select exercises that are appropriate for a child's body size, fitness level, and exercise technique experience. 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 (barbells and dumbbells), elastic bands, medicine balls, and body-weight exercises, have been used by children and adolescents in clinical and school-based fitness programmes. While weight-machine and body-weight exercises help to facilitate a safe environment when supervision is limited, training with free weights and medicine balls may offer the best opportunity to enhance motor performance skills and athletic performance.

Regardless of the mode of training, it is reasonable to start with relatively simple exercises and gradually progress to more advanced multi-joint movements as confidence and competence improve. With qualified supervision and instruction, youths can learn how to perform plyometric exercises as well as weightlifting movements such as the snatch and clean and jerk. As shown in Figure 5.2.2, young weightlifters should learn how to perform advanced exercises with a light load.

An important issue concerning the choice of exercise is the inclusion of exercises for the *core* of a young lifter's body (i.e. abdomen, gluteals, and lower back) (Hibbs *et al.*, 2008). In several reports, lower-back pain was the most frequent injury in adolescent athletes who participated in a strength-training programme (Brady, Cahill and Bodnar, 1982; Brown and Kimball, 1983). Although many factors need to be considered when evaluating these data (e.g. exercise technique

Table 5.2.2 General youth strength-training guidelines

- Provide qualified instruction and supervision.
- Ensure the exercise environment is safe and free of hazards.
- Start each training session with a 5–10 minute dynamic warm-up.
- Begin with relatively light loads and focus on learning the correct exercise technique.
- Perform one to three sets of 6–15 repetitions on a variety of strength exercises.
- Include specific exercises that strengthen the core muscles.
- Gradually progress the intensity and volume of training, depending on goals and abilities.
- Increase the resistance gradually (5–10%) as strength improves.
- Cool-down with less-intense callisthenics and static stretching.
- Strength-train two to three times per week on non-consecutive days.
- Systematically vary the training programme over time.

Figure 5.2.2 A 12-year-old child completing the clean-and-jerk exercise

and progression of training loads), the importance of general physical fitness and lower-back health should not be overlooked (Andersen, Wedderkopp and Leboeuf-Yde, 2006). Because of the potential for lower-back injuries, there is a need for pre-habilitation interventions for the core musculature in order to attempt to reduce the prevalence and/or severity of lower-back pain in youth. That is, exercises that can be prescribed for the rehabilitation of an injury should be prescribed beforehand as part of a preventative health measure. Since there is no one single exercise that activates all of the core muscles, a combination of different exercises will likely offer the most benefit.

In regards to the order of exercises, most youths will perform total-body workouts involving multiple exercises several times per week, 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. It is also helpful to perform more challenging exercises earlier in the workout, when the neuromuscular system is less fatigued. Thus, if weightlifting or plyometric exercises are part of a child's workout programme, these should be performed early in the training session so that the child can perform them properly without undue fatigue.

5.2.6.2 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. While both of these programme variables are significant, training intensity is one of the more important factors in the design of a strength-training programme. Nonetheless, in order to maximize gains in muscular fitness and minimize the risk of injury, youths must first learn how to perform each exercise correctly with a light load (e.g. unloaded barbell) and then gradually progress the training intensity and/or volume to the desired level without compromising exercise technique.

A simple approach is 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 might begin strength training with one set of 10–15 repetitions with a relatively light load in order to develop proper exercise technique (Faigenbaum *et al.*, 1999). Depending on individuals needs, goals, and abilities, over time the programme can be progressed to two to three sets with heavier loads (e.g. 6–10 RM) to maximize gains in muscular strength and power (Faigenbaum *et al.*, 2010). While all exercises do not need to be performed for the same number of sets, multiple-set training protocols have proven to be more effective than single-set protocols in adults, and it appears that similar findings occur in children and adolescents (Ratamess *et al.*, 2009). Note that due to the relatively intense nature of weightlifting and plyometric movements, fewer than six to eight repetitions per set are typically recommended in order to maintain movement speed and efficiency for all repetitions within a set.

5.2.6.3 Rest intervals between sets and exercises

The length of the rest interval between sets and exercises is of primary importance. While a rest interval of at least two to three minutes for primary exercises is typically recommended during adult strength-training programmes (Ratamess *et al.*, 2009), this may not be consistent with the needs and abilities of children and adolescents due to growth- and maturation-related differences in response to physical exertion (Falk and Dotan, 2006). For example, it has been reported that children have a higher oxidative capacity than adults and a tendency towards faster phosphocreatine resynthesis following high-intensity exercise (Kuno *et al.*, 1995; Taylor *et al.*, 1997).

The available data suggest that strength-training recommendations for rest interval length may need to be age-specific (Faigenbaum *et al.*, 2008; Zafeiridis *et al.*, 2005). For example, Faigenbaum *et al.* (2008) reported significant differences in lifting performance between boys, teenagers, and men in response to various rest-interval lengths on the bench-press exercise. In this study, pre-adolescent boys (age 11.3 ± 0.8 years), adolescent boys (age 13.6 ± 0.6 years), and men (age 21.4 ± 2.1 years) performed three sets with a 10 RM load and a one-, two-, and three-minute rest interval between sets. As shown in Figure 5.2.3, boys and adolescents performed significantly more total repetitions than adults following protocols with a one-, two-, and three-minute rest interval. While adults

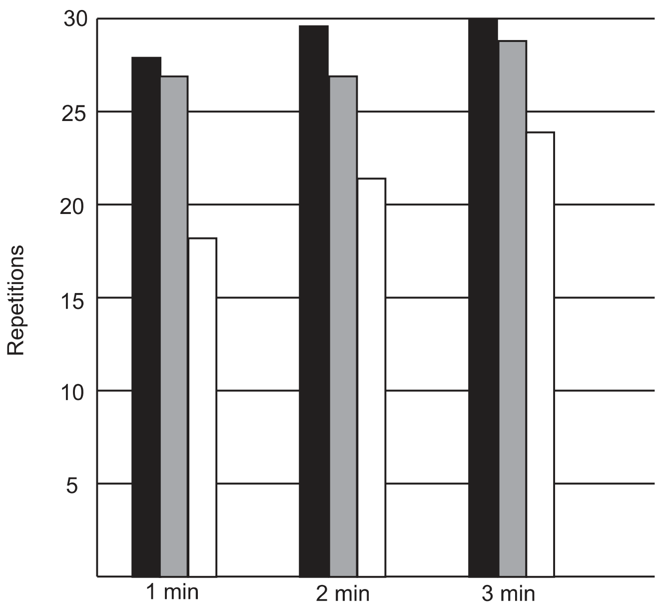

Figure 5.2.3 Effect of rest-interval length on bench-press lifting performance in boys (black bar), teenagers (hatched bar), and men (white bar). Subjects performed three sets with a 10 RM load and a one-, two-, and three-minute rest interval between sets. Total repetitions completed for three sets at each rest interval are shown. Based on data from Faigenbaum *et al.* (2008)

may require up to three minutes of recovery between sets if strength training is the primary goal, these findings suggest that a rest interval of only one to two minutes is needed to minimize loading reductions while maintaining a high lifting volume in youths.

5.2.6.4 Repetition velocity

Since youths need to learn how to perform each exercise correctly with a relatively light load, it is generally recommended that they strength-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 and weightlifting movements are explosive but highly controlled and 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 programme may provide the most effective strength-training stimulus.

5.2.6.5 Training frequency

A strength-training frequency of two to three times per week on non-consecutive days will allow for adequate recovery between sessions (48–72 hours) and will be effective for enhancing muscular fitness in children and adolescents. Although once-per-week training may be effective in retaining the strength gains made after strength training (DeRenne *et al.*, 1996), it may be suboptimal for enhancing muscular strength in youth (Blimkie *et al.*, 1989; Faigenbaum *et al.*, 2002). While some young athletes may participate in strength and conditioning activities more than three days per week, factors such as the training volume, training intensity, exercise selection, nutritional intake, and sleep habits need to be considered as they may influence the athlete's ability to recover from and adapt to the training programme.

5.2.6.6 Programme variation

Systematic variance of a training programme over time is known as periodization. In the long term, periodized training programmes (with adequate recovery between training sessions) will reduce the risk of overtraining and allow participants to make even greater gains as the body will be challenged to adapt to even greater demands (Ratamess *et al.*, 2009). While additional research involving younger populations is needed, it is reasonable to suggest that children and adolescents who participate in periodized strength-training programmes and continue to improve their health and fitness may be more likely to adhere to their exercise programmes. Furthermore, planned changes in the programme variables can help to prevent training plateaus, which are not uncommon after the first weeks of strength training.

In order to maximize long-term gains in physical fitness, youth conditioning-training programmes should also include educational sessions on lifestyle factors and behaviours that are conducive to high performance. For example the importance of proper nutrition, sufficient hydration, and adequate sleep should not be overlooked. Detailed information on designing youth strength-training programmes is beyond the scope of this chapter; see Faigenbaum and Westcott (2009), Jeffreys (2008), Kraemer and Fleck (2005), or Mediate and Faigenbaum (2007) for further information.

5.2.7 CONCLUSION

Despite outdated concerns regarding the safety and effectiveness of youth strength training, a compelling body of scientific evidence now indicates that strength 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 fitness-related benefits, the effects of strength training on selected health-related measures, including bone health, body composition, and sports-injury reduction, should be recognized by teachers, coaches, and health-care providers. If youth strength-training programmes are well designed and sensibly progressed over time, children and adolescents can gain the knowledge, skills, and self-motivation to regularly strength-train as a lifestyle choice. An important future research goal should be to establish the combination of programme variables that enhance long-term training adaptations in young athletes and youths with various medical conditions.

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