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Position statement on youth resistance training: the 2014 International Consensus

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Adapted from the position statement of the UK Strength and Conditioning Association on youth resistance training

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ABSTRACT

The current manuscript has been adapted from the official position statement of the UK Strength and Conditioning Association on youth resistance training. It has subsequently been reviewed and endorsed by leading professional organisations within the fields of sports medicine, exercise science and paediatrics. The authorship team for this article was selected from the fields of paediatric exercise science, paediatric medicine, physical education, strength and conditioning and sports medicine.

OPERATIONAL DEFINITIONS

Prior to discussing the literature surrounding youth resistance training, it is pertinent to define key terminologies used throughout the manuscript.

- *Childhood* represents the developmental period of life from the end of infancy to the beginning of adolescence. The term *children* refers to girls and boys (generally up to the age of 11 and 13 years, respectively) who have not developed secondary sex characteristics.[1]
- The term *adolescence* refers to a period of life between childhood and adulthood. Although adolescence is a more difficult period to define in terms of chronological age due to differential maturation rates,[2] girls 12–18 years and boys 14–18 years are generally considered adolescents.
- The terms *youth* and *young athletes* represent global terms which include both children and adolescents.[1]
- *Growth* is typically viewed as a quantifiable change in body composition, the size of the body as a whole or the size of specific regions of the body.[3]
- *Maturation* refers to the highly variable timing and tempo of progressive change within the human body from childhood to adulthood, and which, in addition to growth, influences overall physical performance capabilities.[3]
- *Training age* refers to the number of years an individual has been involved in a structured and appropriately supervised training programme.[4]
- *Resistance training* refers to a specialised method of conditioning whereby an individual is working against a wide range of resistive loads to enhance health, fitness and performance.[5] Forms of resistance training include the use of body weight, weight machines, free weights (barbells and dumbbells), elastic bands and medicine balls.
- *Weightlifting* is a sport that involves the performance of the snatch and clean and jerk lifts in competition.[6] Weightlifting training refers to a variety of multijoint exercises including the snatch, clean and jerk and modified variations of these lifts, that are explosive but highly controlled movements that require a high degree of technical skill.
- *Qualified professional* is a term used to represent those individuals who are trained and aware of the unique physiological, physical and psychosocial needs of children and adolescents, and possess a relevant and recognised strength and conditioning qualification (eg, the UK Strength and Conditioning Association (UKSCA) Accredited Strength and Conditioning Coach or National Strength and Conditioning Association (NSCA) Certified Strength and Conditioning Specialist). Importantly, such individuals should have a strong pedagogical background to ensure that they are knowledgeable of the different styles of communication and interaction that will be needed to effectively teach or coach children and adolescents.[4 5] Qualified professionals should possess the knowledge and expertise to plan, teach and progress age-related resistance training programmes to youth of all ages and abilities using various forms of resistance exercises, and should be able to identify and modify technical deficiencies when necessary. Qualified professionals would also be expected to work effectively and respectively with other healthcare practitioners (eg, physicians, physical therapists, certified athletic trainers, registered dieticians, physical education teachers, youth coaches, paediatric exercise specialists and researchers) to enhance the health and well-being of all youth.

INTRODUCTION

Since seminal attempts to address concerns surrounding prepubescent strength training,[7] the concept of children and adolescents participating in various forms of resistance training has been of growing interest among researchers, clinicians and practitioners. There is now a compelling body of scientific evidence that supports regular participation in youth resistance training to reinforce positive health and fitness adaptations and sports performance enhancement. There is even stronger support for the use of resistance training in youth provided that these programmes are supervised by qualified professionals and consistent with the needs, goals and abilities of children and adolescents.[5 8–13] Research has indicated that various forms of resistance training can elicit significant performance improvements in muscular strength,[14] power production,[5 15] running velocity,[16] change-of-direction speed[17] and general motor performance[12] in youth. From a health perspective, evidence indicates that resistance training can make positive alterations in overall body composition,[18] reduce body fat,[19 20] improve insulin-sensitivity in adolescents who are overweight[21] and enhance cardiac function in children who are obese.[22] Importantly, it has also been demonstrated that regular participation in an appropriately designed exercise programme inclusive of resistance training, can enhance bone-mineral density and improve skeletal health[23 24] and likely reduce sports-related injury risk in young athletes.[25 26] This would appear to be an important consideration given that approximately 3.5 million sports-related injuries in youth require a medical visit each year in the USA.[27] Comparable relative data from Europe found that nearly 1.3 million cases of sports-related injuries reported in 2009 required hospitalisation for children under the age of 15 years.[28] Additionally, muscular strength and resistance training have been associated with positive psychological health and well-being in children and adolescents.[29–33]

The World Health Organization (WHO) and other public health agencies now include resistance training as part of their physical activity guidelines for children and adolescents.[34–36] However, recent evidence indicates that the muscular strength levels of school-age youth are decreasing.[37–39] Progressive resistance training under the supervision of qualified professionals can offer a safe, effective and worthwhile method for reversing this undesirable trend, while encouraging participation in resistance training as an ongoing lifestyle choice. The importance of effective education by qualified professionals is essential,[4 5 40 41] as positive early experiences in physical education have been associated with lifelong physical activity.[42]

EFFECTS OF GROWTH AND MATURATION ON THE DEVELOPMENT OF MUSCULAR STRENGTH DURING CHILDHOOD AND ADOLESCENCE

It has been established previously that muscular strength development is a multidimensional fitness component that is influenced by a combination of muscular, neural and biomechanical factors.[43] Due to the non-linear development of physiological processes such as stature and body mass during childhood and adolescence, the assessment and monitoring of muscular strength can be a challenging task during the growing years.[44] Similarly, a non-linear pattern emerges when examining the development of physical performance qualities in younger populations.[3] Assessments of muscular strength in children and adolescents indicate that strength increases in a relatively linear fashion throughout childhood for both boys and girls.[45] As children reach the onset of puberty, they experience rapid growth along with observable non-linear gains in muscular strength.[46] During this period, sex differences in muscular strength begin to emerge, with boys demonstrating accelerated gains as a result of the adolescent spurt, and girls appearing to continue to develop in a more linear fashion.[3] Potential factors inherently responsible for increases in strength during childhood appear to be related to the maturation of the central nervous system,[47] for example, improvements in motor unit recruitment, firing frequency, synchronisation and neural myelination.[48 49] Strength gains during adolescence are typically driven by further neural development, but structural and architectural changes resulting largely from increased hormonal concentrations, including testosterone, growth hormone and insulin-like growth factor play a significant role, especially in males.[2] Further increases in muscle cross-sectional area, muscle pennation angle and continued motor unit differentiation will typically enable adolescents to express greater levels of force, and partly explain the age-related differences in strength between children, adolescents and adults.[50] The number of muscle fibres that an individual will possess is determined as a result of prenatal myogenesis,[51] and therefore it should be noted that postnatal increases in muscle cross-sectional area will be largely governed by increases in muscle fibre size, not an increase in the number of muscle fibres.[51 52]

Sex-related differences in muscular strength are more evident as children enter adolescence, with males consistently outperforming females.[53] Research has indicated that muscle growth will largely explain the disparity between sexes, especially for absolute measures of muscular strength and power.[54 55] It is essential that those responsible for teaching and training children and adolescents are aware of these paediatric scientific principles to ensure that an exercise prescription is planned according to the unique demands of the individual inclusive of baseline fitness levels, motor skill development, movement competencies and health or medical issues. Owing to the highly individualised nature of growth and maturation, children and adolescents of the same chronological age will vary markedly in biological status (up to 4–5 years), and consequently, chronological age is deemed a weak indicator of maturational status.[56] Awareness of the potential variation in biological age among children of the same chronological age group is a central tenet of most long-term physical development programmes in order to ensure that youth are trained according to their biological status, as opposed to age-group classifications.[4 57–62] In addition to chronological and biological age, those responsible for the design and implementation of youth resistance training programmes must take into consideration the training age of the individual.[4] From a developmental perspective, this becomes critically important when training an adolescent who is approaching adulthood, but has no experience of participating in a structured resistance training programme. Conversely, a technically proficient 10-year-old child should not be restricted to introductory training methods, provided they have the interest and desire to participate in more advanced training programmes.[4 63]

HEALTH BENEFITS OF RESISTANCE TRAINING FOR YOUTH

The WHO now recognises physical inactivity as the fourth leading risk factor for global mortality for non-communicable diseases, and supports participation in a variety of physical activities including those that strengthen muscle and bone.[35] Since contemporary youth are not as active as they should be,[64–67] children and adolescents should be encouraged to participate regularly in play, games, sports and planned exercise in the context of school and community activities. Not only is physical activity essential for normal growth and development, but also youth programmes that enhance muscular strength and fundamental movement skill performance early in life appear to build the foundation for an active lifestyle later in life.[68–71] Since muscular strength is an essential component of motor skill performance,[2 12 72] developing competence and confidence to perform resistance exercise during the growing years may have important long-term implications for health, fitness and sports performance.[73]

Resistance training as part of a well-rounded fitness training programme can offer unique health benefits to children and adolescents when appropriately prescribed and supervised. Regular participation in youth resistance training programme has been shown to elicit favourable short-term influences on musculoskeletal health, body composition and cardiovascular risk factors.[11 74–77] However, following a period of detraining (8–12 weeks) various measures of muscular fitness appear to regress towards baseline values,[78–80] suggesting that engagement in resistance training should be viewed as a long-term, year-round commitment to a well-constructed and varied periodised programme.

Given the growing prevalence of youth who are overweight and obese and the associated health-related concerns, the influence of resistance training on the metabolic health, body composition and injury risk profile of children and adolescents with excess body fat has received increased attention.[21 81–86] Although low intensity, long-duration aerobic exercise is typically prescribed for youth who are overweight or obese, excess body fat and weight may hinder the performance of physical activities such as jogging. Additionally, adolescents who are overweight and obese are more than twice as likely to be injured in sports and other physical activities compared with their peers who are not overweight or obese, typically due to a reduced ability to demonstrate and maintain postural stability.[84] Furthermore, youth deemed to be overweight and obese seem to demonstrate significantly lower motor coordination than normal weight youth,[87–89] which is of concern due to the established relationship between motor coordination and levels of physical activity.[70 90–92] While the treatment of youth who are overweight and obese is complex, participation in a formalised training programme that is inclusive of resistance training may provide an opportunity to improve their muscle strength, enhance motor coordination and gain confidence in their perceived abilities to be physically active.[93 94]

The available evidence indicates that resistance training has the potential to offer observable health value to sedentary youth and young athletes, and such training should always be designed by qualified professionals to meet the needs of all children and adolescents, regardless of body size or physical ability.

Resistance training and the growing skeleton

From a public health perspective, it is noteworthy that traditional fears and misinformed concerns that resistance training would be harmful to the developing skeleton have been replaced by reports indicating that childhood may be the opportune time to build bone mass and enhance bone structure by participating in weight-bearing physical activities.[95–97] Fears that resistance training would injure the growth plates of youths are not supported by scientific reports or clinical observations, which indicate that the mechanical stress placed on the developing growth plates from resistance exercise, or high strain eliciting sports such as gymnastics or weightlifting, may be beneficial for bone formation and growth.[29 98–102] While children have a lower risk of resistance training-related injury to joint sprains and muscle strains than adults,[103] attention to initial postural alignment and technical competency during all exercises throughout the training programme is essential to ensure safe and effective practice irrespective of resistance training mode. While numerous factors, including genetics and nutritional status influence skeletal health, regular participation in sports and fitness programmes, which include multijoint, moderate-to-high intensity resistance exercise, can help to optimise bone-mineral accrual during childhood and adolescence.[23 24 97 104–110] In fact, the literature suggests that childhood and adolescence are indeed key developmental periods for increasing bone-mineral density, and that failure to participate in moderate-to-vigorous weight-bearing physical activity during these stages of growth may predispose individuals to long-term bone-health implications.[24 95 111] Furthermore, no scientific evidence indicates that resistance training will have an adverse effect on linear growth during childhood or adolescence[99 112] or reduce eventual height in adulthood.[98–100]

INJURY PREVENTION BENEFITS OF RESISTANCE TRAINING FOR YOUTH

Although the total elimination of sport-related and physical activity-related injuries is an unrealistic goal, multifaceted training programmes that include general and specific strength and conditioning activities may help to reduce the likelihood of injuries in youth. Cahill and Griffith[113] incorporated resistance training into their preseason conditioning for adolescent American football players and reported a reduction in non-serious knee injuries, as well as knee injuries requiring surgery, over four competitive seasons. Hejna *et al*[114] reported that adolescent athletes who incorporated resistance training in their physical development programme suffered fewer injuries and recovered from injuries with less time spent in rehabilitation as compared with team-mates who did not participate in a similar resistance training programme. Similarly, Soligard *et al*[115] successfully reduced the risk of severe and overuse injuries in female adolescent soccer players, following the implementation of a comprehensive warm-up programme that incorporated resistance-based exercises. Likewise, Emery and Meeuwisse[116] reported a reduction in overall injuries and acute injury incidence in adolescent soccer players with the use of an integrative training programme that included resistance training. Of note, recent evidence suggests that adherence of adolescent female soccer players to injury prevention programmes is greater when facilitated by appropriately skilled coaches.[117] This underscores the importance of regular coach education to ensure that qualified professionals understand the mechanical requirements of correct exercise techniques, fundamental principles of paediatric exercise science and the pedagogical aspects of coaching youth training programmes.

Despite specific case study reports highlighting acute resistance training-related injuries,[112 118 119] such injuries have generally occurred when youth are unsupervised or supervised by individuals with unqualified instruction and/or inappropriate training loads.[29] Recent data examining acute resistance training-related injuries in youth and adults reveal that approximately 77.2% of all injuries are accidental[103] and that most injuries are potentially avoidable with appropriate supervision, sensible training progression based on technical competency and a safe training environment.[29] With respect to overuse injuries, literature indicates that appropriately prescribed and well-supervised training programmes will reduce the likelihood of overuse injuries occurring in youth populations[120–122] and that resistance training focused on addressing the risk factors associated with youth-sport injuries (eg, low-fitness level, muscle imbalances and errors in training) has the potential to reduce overuse injuries by approximately 50% in children and adolescents.[26 123] For example, training protocols incorporated into preseason and in-season conditioning programmes reduced overuse injury risks, and decreased anterior cruciate ligament (ACL) injuries in adolescent athletes.[124–128]

It appears that multifaceted programmes that increase muscle strength, enhance movement mechanics and improve functional abilities may be the most effective strategy for reducing sports-related injuries in young athletes.[116 124 129 130] Additionally, the effectiveness of these injury prevention programmes is greater if implemented in younger age groups prior to the onset of neuromuscular deficits and biomechanical alterations.[130 131] Clearly, participation in physical activity should not begin with competitive sport but should evolve out of preparatory fitness conditioning that is sensibly progressed over time. This notion is supported by the fact that basic jumping and landing activities commonly encountered within both competitive sports and free-play activities can expose individuals to ground reaction forces of approximately 5–7 times body weight,[132 133] which are in excess of the forces experienced during resistance training activities.

Since physical inactivity is a risk factor for activity-related injuries in children,[134] youth who participate regularly in age-appropriate fitness programmes, which include resistance exercise, may be less likely to suffer an injury owing to the apparent decline in free-time physical activity among children and adolescents.[34 67 135–137] As such, it seems that the musculoskeletal system of some aspiring young athletes may be ill-prepared for the demands of sports practice and competition.[25 29 138 139] Recent position statements have recognised the importance of physical activity and sport for youth, and promote the early identification of fitness deficits in aspiring young athletes and the proper prescription of training programmes to address individual limitations.[140 141] Consequently, aspiring young athletes should be encouraged to participate in, and appreciate the value of, multifaceted preparatory conditioning programmes that include resistance training to address deficits in muscular fitness and skill development, and enhance symmetry in strength development around joints. Importantly, for youth who participate in multiple sports or multiple leagues within the same sport, resistance training sessions should not be simply viewed as an addition to the overall sporting schedule, but should form a compulsory component in lieu of additional competitive events or sport-specific training sessions.

Resistance training considerations for young females

Musculoskeletal growth during puberty, in the absence of corresponding neuromuscular adaptation, may facilitate the development of abnormal joint mechanics and injury risk factors in young adolescent girls.[142 143] If not addressed, these intrinsic risk factors may continue to develop throughout adolescence, thus predisposing female athletes to increased risk of injuries.[144 145] In a recent longitudinal study, Ford *et al*[146] noted that young females who did not participate in resistance training programmes as they matured developed injury risk factors (eg, increased knee valgus moment when landing). Conversely, those maturing athletes who did report participation in resistance training activities were found to have safer movement mechanics and increased posterior chain strength.[146]

Well-supervised, multifaceted resistance training programmes have been shown to reduce abnormal biomechanics (eg, increased knee valgus landing) that manifest during adolescence[127 128 147 148] and appear to decrease injury rates in female athletes.[127] The findings of a recent meta-analysis revealed that within existing literature, an age-related association between resistance training and reduction of ACL incidence only occurred in the youngest female athletes (14–18 years), indicating that the earlier youth can engage with a well-rounded training programme inclusive of resistance training, the lower the likelihood of ACL injury.[130] Resistance training utilised to enrich the motor learning environment in early youth may initiate adaptation and help low-motor competence children 'catch-up' with their peers in neuromuscular control.[149–153] In addition to reduced knee injuries in adolescent[154] and mature[155] female athletes, regular participation in a multifaceted resistance training programme may also induce measures of the 'neuromuscular spurt', defined as the natural increases in muscle power, strength and coordination that occurs with increasing age in adolescent boys,[139] which are not typically seen in females.[128 153] Of potential interest to sports medicine professionals, resistance training timed with growth and development may induce the desired neuromuscular spurt, which may improve sports performance and improve biomechanics related to injury risk in young females.[128 144] Observed relative gains in females can be greater than in males, perhaps because baseline neuromuscular performance levels are lower on average in females.[128 156–159]

PSYCHOSOCIAL BENEFITS OF RESISTANCE TRAINING FOR YOUTH

At present, research examining the psychological benefits of resistance training for youth is limited, and the literature that is available has thus far produced equivocal findings. While a small number of studies have previously failed to demonstrate significant resistance training-induced psychological benefits for healthy youth,[112 160] other research indicates that physical activity interventions inclusive of resistance training can lead to improvements in psychological well-being,[30 33] mood and self-appraisal.[161] Of note, youth who possess relatively low levels of self-concept at the start of an exercise programme may be more likely to show significant improvement in comparison with those who begin training with a relatively high self-concept.[160]

Research indicates that self-concept and self-perception are related to an individual's level of engagement in physical activity.[162–166] It has been reported that adolescent girls improved their physical self-perceptions in response to an 8-week resistance training programme.[167] Similarly, various measures of self-concept have been shown to improve in adolescent males and females after a 12-week resistance training programme.[32] Collectively, these findings indicate that age-related resistance training can have a favourable influence on the psychological well-being of school-age youth provided that self-improvement and enjoyment remain central to the training programme.

It should be noted that excessive volumes of physical training (inclusive of resistance training) could lead to negative psychosocial effects, especially for those youth who are emotionally and psychologically vulnerable.[168] Excessive training with inadequate recovery may lead to a child or adolescent experiencing overtraining syndrome, which is identified by prolonged maladaptation of biological, neurochemical and hormonal systems. In addition to physiological concerns, overtraining can have serious psychosocial consequences[169] and may require substantial time for a young athlete to make a full recovery.[170] This highlights the need for appropriate prescription and supervision by qualified professionals who listen to individual concerns and understand the physical and psychological uniqueness of younger populations.

EFFECTIVENESS OF YOUTH RESISTANCE TRAINING FOR THE DEVELOPMENT OF MUSCLE STRENGTH, MOTOR SKILL AND PHYSICAL PERFORMANCE

The term 'trainability' describes the sensitivity of developing athletes to a given training stimulus.[2] As previously documented, children and adolescents will increase muscular strength levels as a result of growth and maturation.[2 3 56 171 172] Growth and maturation can obscure the effects of training, as they can quite often mask potential training effects if the intensity and volume of the conditioning programme are suboptimal.[169 173 174] The appropriate development of muscular strength can have important implications for sport and daily life. To induce adaptations in muscular strength above and beyond those of growth and maturation alone, the volume and intensity of training stimulus must be sufficient.[2 5 12 175 176] Research clearly indicates that appropriately designed resistance training programmes can benefit youth of all ages, with children as young as 5–6 years of age making noticeable improvements in muscular fitness following exposure to basic resistance training exercises using free weights, elastic resistance bands and machine weights.[161 177–179] Irrespective of chronological age, it is recommended that any child engaging in a form of resistance training is emotionally mature enough to accept and follow directions, and possesses competent levels of balance and postural control.[5 9] While reports indicate that the magnitude of absolute strength gains is greater in adolescents (effect size=1.91) in comparison to children (effect size=0.81),[14] relative increases in strength appear to be similar during the developmental periods of childhood and adolescence.[119 180 181]

It is acknowledged that muscular strength is important for effective motor skill performance.[2 72] Findings from a recent meta-analysis showed that resistance training is effective in enhancing motor skill performance (jumping, running and throwing tasks), and that children showed greater gains in performance than adolescents.[12] These findings, in addition to several reviews[4 13 14 25 29 74 100 180 182] highlight the effectiveness of resistance training for enhancing motor skill performance in school-age youth, and underscore the importance of implementing progressive interventions early in life when children possess higher levels of neural plasticity.

Despite the growing body of evidence demonstrating that resistance training can lead to established improvements in motor performance through increases in qualities such as strength, speed, power and other related characteristics,[12] an aspect of discussion among some observers relates to the degree of training-induced muscle hypertrophy that is possible in children prior to puberty.[169 183–185] Existing research suggests that increases in muscular strength are a result of muscle cross-sectional area, architectural (muscle size, moment arm length) and neural (voluntary activation level) adaptations.[53 186] However, the mechanisms appear to differ according to the stage of development and are tissue dependent (ie, muscle vs tendon). The primary mechanism underlying resistance training-induced gains in muscular strength and related characteristics before puberty depend primarily on neural adaptations.[2 49 187 188] However, among early and particularly late adolescents, the effects of resistance training appear to be a result of additional gains in lean body mass and muscle cross-sectional area (especially in males); with further alterations in neural mechanisms appearing to be the same as those adaptations experienced by adults.[14 189] Therefore, the focus of resistance training for children should be based on goals related to enhancement of muscle strength, function and control, as opposed to trying to make substantial increases in muscle size. Indeed, when training children and adolescents the adoption of a long-term approach to physical development should be implemented with a clear understanding of the primary mechanisms responsible for training-induced adaptations during different stages of development.[4 41]

Collectively, the existing literature highlights several important concepts. First, appropriate resistance training can result in an increased level of strength during childhood and adolescence.[12 14 182 190–195] Gains in maximum strength have ranged from approximately 10% to 90%,[14] depending on several factors including the volume, intensity, frequency, duration and design of the training programme, as well as the quality of supervision.[196] However, in general, expected strength gains of 30–40% are typically observed in untrained youth following participation in an introductory (8–20 weeks) resistance training programme.[5] Second, resistance training results in only a minor sex-associated effect on both absolute and relative strength gains among prepubertal children, however, the magnitude of effect does appear to be a function of sex in older groups.[119] Third, evidence indicates that the most effective programmes last more than 8 weeks and involve multiple sets, and that generally strength gains increase with the frequency of training sessions per week.[12] Finally, following a short training programme, detraining will be quite rapid.[78–80] Consequently, youth should be encouraged to participate in year-round resistance training in order to maintain training-induced gains in muscular strength. It should be noted that resistance training programmes for youth should follow a training model with a progressive and systematic variation in exercise selection, intensity, volume, frequency and repetition velocity to enhance training adaptations, reduce boredom and decrease the risk of overuse injuries.[197–199] Qualified professionals should regularly assess the readiness of youth to participate in resistance training sessions, and should manipulate daily training sessions when appropriate.

Weightlifting for youth

The available literature indicates that participation in the sport of weightlifting and the performance of weightlifting movements as part of a strength and conditioning programme can be safe, effective and enjoyable for children and adolescents provided qualified supervision and instruction are available and progression is based on the technical performance of each lift.[41 103 200–202] However, it must be emphasised that regardless of the exercise choice, all youth resistance training programmes should be consistent with a participant's training age, technical competency and maturational status. Additionally, qualified professionals who are knowledgeable of youth resistance training protocols and are able to teach and progress a variety of exercises including weightlifting movements should instruct such programmes.

Weightlifting exercises have previously been used by paediatric researchers to examine the potential effects of strength-power training on a number of performance and physiological variables.[200 203 204] The data gleaned from these studies indicate that the incorporation of weightlifting exercises into a training programme can produce positive alterations in body composition, cardiorespiratory variables, various motor fitness parameters (eg, jumping and sprinting) and overall weightlifting performance among youth.[200 203 204] Additionally, weightlifting injury rate is reportedly lower than other forms of resistance training and sports in general.[200 201] If training and competition are properly supervised and sensibly progressed, then the performance of weightlifting exercises may provide a safe and effective stimulus for enhancing strength and power performance in school-age youth. Owing to the skill level required to perform weightlifting movements correctly, it is important that individuals responsible for teaching complex movements to youth hold the requisite coaching qualifications, and have experience teaching weightlifting to children and adolescents to ensure their continued safety and well-being.

RESISTANCE TRAINING GUIDELINES FOR CHILDREN AND ADOLESCENTS

Training variable considerations

Exercise selection

While a range of exercises performed using a variety of equipment can be prescribed to both children and adolescents, it is vital that the fundamentals of technical competency are prioritised at all times. The principles of equipment suitability and familiarity for paediatric testing, also apply for youth participating in a resistance training programme. The use of child-size equipment (light barbells, small dumbbells or fixed machine weights) is important for children or adolescents to properly and safely execute a movement with correct technique.[205] Some of the resistance modes available to those prescribing youth resistance training programmes include bodyweight, weight machines, free weights (ie, barbells and dumbbells), elastic resistance bands and medicine balls; all of which have been proven to elicit physiological adaptation and/or performance enhancement when used in youth resistance training programmes.[17 21 79 80 112 128 153 177 190 206–217]

The selection of the resistance modality will largely depend on the technical ability and baseline fitness levels of the individual, the level of coaching expertise, the overall goal of the training programme and the availability of equipment. However, when basic bodyweight exercise technique (eg, bodyweight squatting, lunging, pressing and pulling movements) is sufficiently developed in the individual, exercises with free weights should be incorporated into the training programme since alternative forms of resistance such as machine-based resistance have been reported to stimulate less muscle activation in lower body,[218] upper body[219] and whole-body[220] exercises compared with free-weight resistance, albeit in adult populations. For technically competent youth, dynamic qualities can be enhanced with multijoint, velocity-specific training in the form of free-weight resistance training (eg, weightlifting and plyometrics).[202 210 212]

For youths with a minimal training experience and associated poor technical competency (ie, low-training age), qualified professionals should employ a range of exercises which are designed to promote the development of muscular strength and enhance overall fundamental motor skill competency. Childhood is deemed to be a crucial time in which to develop motor skill competency, as it is during these formative years that neuromuscular coordination is most susceptible to change.[221] During this stage of development, children will experience rapid brain maturation,[222] and exposing children to key athletic movement patterns at a time where natural strengthening of existing synaptic pathways[223] and synaptic pruning[224] takes place, is considered crucial for long-term athletic development[4] and lifelong physical activity.[225] Once the child can demonstrate appropriate technical competency, they can be introduced to more advanced exercises that challenge the child in terms of coordination and require greater levels and rates of force production. In the case of weightlifting exercises, which by their nature are more complex movements, researchers have previously suggested that early exposure should focus on technical development using modified equipment and light external loads.[5 41]

Training volume and intensity

Volume and intensity are key resistance training variables that are routinely manipulated within a training session, or overall phase of training, depending on the primary training goal of the individual. *Volume* refers to the total number of times an exercise is performed within a training session multiplied by the resistance used (kg).[197 226] *Intensity* most commonly refers to the resistance that is required to overcome during a repetition.[226] The relationship between volume and intensity is inverse in nature; the greater the load (intensity), the lower the number of repetitions that can be completed (volume) by the individual.[226] Both variables must be considered synergistically when prescribing resistance training to maximise physiological adaptation and minimise injury risk. Exposing a child or adolescent to excessive intensity (external loading) at the expense of correct technique may lead to acute injury, while prescribing excessive volume of training over a training block may induce a state of overtraining. This highlights the need for qualified professionals to not only understand resistance training prescription theory but also the unique intricacies associated with youth of different ages and maturity levels.

To prescribe appropriate training intensity, teachers and coaches typically stipulate a percentage of an individuals' one repetition-maximum (1 RM). Research indicates that maximal strength and power testing of children[227] and adolescents[228] is safe and reliable when standardised protocols are implemented and monitored by qualified professionals. While 1 RM measurements are routinely used within paediatric research settings and youth sport training facilities, owing to time and class size, physical education teachers and youth fitness professionals may benefit from the use of alternative means of assessing strength. Predictive equations that estimate 1 RM values from submaximal loads have been used in adult populations,[229–231] however, methods of predicting 1 RM values from higher repetition ranges possess less accuracy, in particular when repetition ranges exceed more than 10.[227] Additionally, the fatiguing effects of higher RM testing schemes (eg, 5 RM or 10 RM) are noteworthy since the cumulative effects of fatigue will influence the ability of a child or adolescent to maintain proper exercise technique throughout the testing set. If an overarching demonstration of muscular strength is the desired outcome, simple field-based measures such as vertical jump, long jump and handgrip strength assessment have been significantly correlated to 1 RM strength values in youth and may serve as an appropriate surrogate measure of muscular strength, especially in schools and recreational settings.[232 233] Crucially, it should be noted that a child or adolescent must be able to demonstrate sound technical competency irrespective of the RM load or test selected.

Progression of volume and intensity

When untrained or sedentary youth with a low-training age and poor technical competency first begin to participate in formalised resistance training programmes, the use of 1RM measurements (actual or predicted) to determine training intensities will typically be unnecessary. Consequently, an appropriate repetition range should be prescribed to develop technical competency and acquire a base level of adaptation, and over time the external load can be increased provided exercise technique has sufficiently improved. For individuals without prior experience of resistance training, initial prescription should use low volume (1–2 sets) and low-moderate training intensities (≤60% 1 RM) for a range of exercises and movement patterns.[197] It should be noted that when children are initially exposed to multijoint resistance training exercises (eg, squatting), then multiple repetitions might be counterproductive for motor control development. Instead, it is recommended that children perform fewer repetitions (1–3) and are provided with real-time feedback after each repetition to ensure safe and correct movement development. This is especially true for weightlifting exercises, which will naturally require more frequent feedback owing to the increased technical demands, associated with the movements. Once basic exercise technique is competent, then prescription should be progressed; for example, 2–4 sets of 6–12 repetitions with a low-moderate training intensity (≤80% 1 RM). Such progression should provide the child with sufficient exposure in order to aid motor control development, while serving as a suitable volume for physical conditioning. As training age and athletic competency increases, youth can be introduced to periodic phases of lower repetition ranges (≤6) and higher external loads (>85% 1 RM) in training, on the proviso that technical competency remains.[15 77 200 234 235]

However, it is important to note that not all exercises need to be performed for the same number of sets and repetitions within a training session. For example, an experienced adolescent lifter may perform three sets of three repetitions of a power-oriented exercise (eg, clean and jerk, snatch and derivatives of these lifts); then complete three sets of 3–5 repetitions of a large compound, multijoint movement (eg, back squat); and then finish with two sets of 6–8 repetitions of a unilateral exercise (eg, dumbbell lunge). Irrespective of the specific prescription, qualified professionals must observe and monitor for the effects of accumulated fatigue during the training session to minimise the risks of fatigue-induced technique decrements, which may predispose youth to training-related injury.

Depending on the learning environment, qualified professionals will need to provide feedback to ensure that technical competency is maintained throughout each set of the training programme. The frequency and mode of feedback will depend to a large degree on the number of individuals training, type of exercise being performed and the stage of learning and personality traits of the youth involved. For example, when coaching a novice, constructive feedback may be most helpful if it is provided after each repetition.[41] In physical education classes in which the focus of the lesson is aimed at enhancing muscle strength and fundamental motor skill development, constructive feedback is most important since students are typically learning the correct movement patterns for the first time.

Rest intervals during training sessions

Available research indicates that children can recover more quickly from fatigue-inducing resistance training,[236 237] and are less likely to suffer muscle damage following this form of exercise, owing to the increased pliability of their muscle tissue.[238] Therefore, rest periods of approximately 1 min should suffice for most children. However, this may need to be increased (eg, 2–3 min) as the intensity of training increases, especially if the exercises require high levels of skill, force or power production (eg, weightlifting or plyometric exercises). While children can recover more quickly from short, intermittent high-intensity exercise bouts than adults,[236 237 239] within-session resistance training performance should always be monitored to ensure correct resistance exercise technique is maintained throughout the training session. As such, commercial metabolic high-intensity resistance training programmes characterised by insufficient recovery between sets and exercises may result in the performance of potentially injurious exercise movements.

Training frequency

Training *frequency* typically refers to the number of sessions performed within a week. Previous research has indicated that 2–3 sessions per week on non-consecutive days is most appropriate in order to develop muscular strength levels in children and adolescents.[5 240] Behringer *et al*[14] recently substantiated these recommendations, indicating that across 42 studies (where mean training frequency was 2.7±0.8 sessions/week), training frequency was significantly correlated with increased resistance training effect. Since youth are still growing and developing, resistance training programmes should provide adequate time for rest and recovery. Youth who participate in resistance training programmes with a high training frequency should be monitored closely. Training frequency may increase as children go through adolescence and approach adulthood, especially for youth in competitive sport. While sampling and exposure to a variety of physical activity experiences should be recommended to help promote long-term physical development,[4 225] parents, coaches and fitness professionals should be cognisant of the potential difficulties when youth participate in numerous activities resulting in the accumulation of high exercise volumes. For youth participating in competitive sports, in-season resistance training is needed to maintain gains in muscular fitness and reduce injury-risk. However, to reduce the chances of non-functional overreaching or overtraining, and to allow natural growth processes to occur, resistance training should not simply be viewed as an additional training session within the overall youth training programme, but as an alternative commitment in place of sport-specific training sessions and/or competitive fixtures. Depending on the competitive demands of the sport, anywhere between one and three resistance training sessions should be completed in-season to enable the development (or at least the maintenance) of previously acquired strength gains, and to allow adequate time for rest and recovery. Increased lesson time in physical education, taught by well-trained specialists may hold a realistic and evidenced-based opportunity to increase muscle strength and motor skill competency, which would facilitate an overall improvement in general physical fitness.[2 72 137] Research demonstrates that exposure to resistance training with qualified supervision during exercise lessons or physical education classes does not have an adverse effect on after-school performance in adolescent athletes.[241]

Repetition velocity

While moderate movement velocities may typically be recommended for youth when learning new movements or exercises, there is also a need to promote the intention to move quickly to develop motor unit recruitment patterns and firing frequencies within the neuromuscular system.[242] A child with limited training experience may need to perform resistance exercises with a moderate speed to maximise control and ensure correct technical development (eg, limb alignment, maintenance of correct posture); however, a participant with a training history of several months should be exposed to much greater movement velocities. Repetition velocities may also fluctuate within a session; for example, the movement preparation phase (including low load technical warm-up exercises) may consist of slower, controlled movements, however, the main strength and power exercises (inclusive of weightlifting and plyometric exercises) will involve rapid movement speeds. For resistance training exercises, the mass of the resistance will govern the velocity at which the movement is performed. Although heavy strength development exercises such as squatting, deadlifting, pressing and pulling will typically involve slower movement velocities, there should always be an intention to move as explosively as possible to promote appropriate neuromuscular adaptations and to maximise the transfer of training effect,[243] providing the individual can demonstrate appropriate technique. The development of high velocity movement may be especially important during the growing years when neural plasticity and motor coordination are most sensitive to change.[224]

SUMMARY

A compelling body of scientific evidence supports participation in appropriately designed youth resistance training programmes that are supervised and instructed by qualified professionals. The current article has added to previous position statements from medical and fitness organisations, and has outlined the health, fitness and performance benefits associated with this training for children and adolescents. In summarising this manuscript, it is proposed that

1. The use of resistance training by children and adolescents is supported on the proviso that qualified professionals design and supervise training programmes that are consistent with the needs, goals and abilities of younger populations.
2. Parents, teachers, coaches and healthcare providers should recognise the potential health and fitness-related benefits of resistance exercise for all children and adolescents. Youth who do not participate in activities that enhance muscle strength and motor skills early in life may be at increased risk for negative health outcomes later in life.
3. Appropriately designed resistance training programmes may reduce sports-related injuries, and should be viewed as an essential component of preparatory training programmes for aspiring young athletes.
4. Regular participation in a variety of physical activities that include resistance training during childhood and adolescence can support and encourage participation in physical activity as an ongoing lifestyle choice later in life.
5. Resistance training prescription should be based according to training age, motor skill competency, technical proficiency and existing strength levels. Qualified professionals should also consider the biological age and psychosocial maturity level of the child or adolescent.
6. The focus of youth resistance training should be on developing the technical skill and competency to perform a variety of resistance training exercises at the appropriate intensity and volume, while providing youth with an opportunity to participate in programmes that are safe, effective and enjoyable.

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