Sports Conditioning for Children

- 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 years and 13 years respectively) who have not developed secondary sex characteristics
- 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, 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
- 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
- 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
- Training age refers to the number of years an athlete has been involved in a formalised training programme

Introduction

Despite outdated misperceptions that resistance training was unsafe or inappropriate for youth, there is now a compelling body of scientific evidence that supports its use by children and adolescents for a wide range of performance, health, and injury reducing benefits.

Research has indicated that various forms of resistance training can elicit significant performance improvements in muscular strength, power production, running velocity, change-of direction, speed and general motor performance, in youth.

From a health perspective, evidence suggests that resistance training can make positive alterations in overall body composition, reduce abdominal and trunk fat, improve insulin-sensitivity in overweight adolescents and enhance cardiac function in obese children. Importantly, it has also been suggested that regular participation in an appropriately designed exercise programme, which includes resistance training, can enhance bone mineral density and reduce sports-related injury risk in young athletes.

This would appear to be an important consideration given that the European Network for Sports Injury Prevention previously estimated nearly 1.3 million cases of sports injuries requiring hospitalisation in Europe were for children under the age of 15 years.

Additionally, muscular fitness and resistance training have been associated with positive psychological health and wellbeing in children and adolescents.

Despite the apparent health, fitness and performance benefits for school-age youth, there is little reference to resistance training in the physical education national curriculums within the UK. Of note, no information regarding age-appropriate resistance training is included for primary aged children (11 years and under), and resistance training guidelines for secondary school age children (11 years and upwards) are limited and inconsistent. Compounding this issue, recent evidence indicates that muscular strength levels of children within the United Kingdom are decreasing. Such a tendency of declines in muscular strength levels is commensurate with other European countries. Progressive resistance training under the supervision of qualified health and fitness professionals can offer a method for reversing this undesirable trend while encouraging participation in resistance training as an ongoing lifestyle choice. The importance of effective education by qualified personnel is essential, as positive early experiences in physical education have been associated with lifelong physical activity.

Therefore, the current manuscript will dispel the myths surrounding youth resistance training, and provide guidance and support for those individuals responsible for the long-term development and general wellbeing of school-age youth.

The Effects Of Growth And Maturation On The Development Of Muscular Strength During Childhood And Adolescence

It has previously been established that muscular strength development is a multi-dimensional fitness component that is influenced by a combination of muscular, neural and biomechanical factors. 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.

Similarly, a non-linear pattern emerges when examining the development of physical performance qualities in younger populations. Assessments of muscular strength in children and adolescents have traditionally been attained from isometric testing, and this data suggest that strength increases in a relatively linear fashion throughout childhood for both boys and girls.

As children reach the onset of puberty, they experience rapid growth and increases in muscular strength. During this period, sex-differences in muscular strength levels start 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.

Factors inherently responsible for increases in strength during childhood appear to be related to the development of the central nervous system. Specifically, improvements in motor unit recruitment, firing frequency, synchronisation, and neural myelination are all deemed to enhance neuromuscular performance. Conversely, natural strength gains during adolescence are driven by further neural development, but also structural and architectural changes resulting largely from increased sex androgen concentrations, including testosterone, growth hormone and insulin-like growth factor (IGFI). Further increases in muscle cross-sectional area, muscle pennation angle (direction of muscle fibres), and continued muscle fibre type differentiation will all enable adolescents to express greater levels of force, and partly explains the differences in strength between children, adolescents and adults.

Sex-related differences in muscular strength are more evident as children enter adulthood, with males consistently outperforming females. Research has indicated that muscle growth will largely explain the disparity between genders, especially for absolute measures of muscular strength and power.

It is essential that physical education teachers, paediatric fitness specialists, health care providers, and strength and conditioning coaches who train children and adolescents, are aware of these basic paediatric scientific principles in order to ensure that exercise prescription is always planned according to the unique demands of the individual, irrespective of chronological age. Owing to the highly individualised nature of growth and maturation, children and adolescents of the same chronological age will vary markedly in biological status (possibly up to 4-5 years difference), and consequently, chronological age is deemed a weak indicator of maturational status.

Awareness of the potential variation in biological age amongst children of the same chronological age group is a central tenet of most long-term athlete development programmes in a bid to ensure that children are trained according to their biological status, as opposed to age-group classifications. 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. From a developmental perspective, this becomes critically important when training an adolescent who is approaching adulthood, but has no experience of participating in structured resistance training programmes. Conversely, a 10 year old child with a two-year training age, who can demonstrate

proficient technical competency on basic exercises, should not be restricted to introductory training methods typically commensurate with their chronological age.

Health Benefits Of Resistance Training For Youth

The World Health Organisation 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. Since contemporary youth are not as active as they should be, 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 fundamental movement skill performance early in life appear to build the foundation for an active lifestyle later in life. Since muscular strength is an essential component of motor skill performance, developing competence and confidence to perform resistance exercise during the growing years may have important long-term implications for health, fitness and sports performance.

Resistance training can offer unique health benefits to children and adolescents when appropriately prescribed and supervised. Regular participation in a youth resistance training programme can have a favourable influence on musculoskeletal health, body composition, and cardiovascular risk factors. Moreover, since physical inactivity is a risk factor for activity related injuries in children, youth who participate regularly in age-appropriate fitness programmes, which include resistance exercise, may be less likely to suffer an injury.

These observations are particularly important for sedentary youth whose musculoskeletal system may be ill prepared for the demands of recreational games and sports practice. The International Olympic Committee recognises the importance of physical activity and sport for youth, and promotes the early identification of fitness deficits in aspiring young athletes, and the proper prescription of training programmes to address individual limitations.

From a public health perspective, it is noteworthy that traditional fears and misinformed concerns that resistance training would damage 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. Fears that resistance training would injure the growth-plates of youths are not supported by scientific reports, which indicate that the mechanical stress placed on the developing growth plates from resistance exercise, or high strain eliciting sports such as weightlifting, are actually beneficial for bone formation and growth.

While numerous factors, including genetics and nutritional status, influence skeletal health, regular participation in impact-loading sports and physical activity programmes, which include multi-joint, moderate to high intensity resistance exercise, can help to optimise bone mineral accrual during childhood and adolescence. Furthermore, no scientific evidence indicates that resistance training will have an adverse effect on linear growth during childhood or adolescence, or reduce eventual height in adulthood.

Given the growing prevalence of overweight and obesity among children and adolescents and the associated health-related concerns, the influence of resistance training on the metabolic health, body composition and injury risk profile of overweight and obese youth has received increased attention. Although aerobic exercise is typically prescribed for overweight or obese youth, excess body weight hinders the performance of physical activities such as jogging, and overweight and obese adolescents are more than twice as likely to be injured in sports and other physical activities compared with non-overweight and non-obese adolescents. Furthermore, overweight and obese youth seem to demonstrate significantly lower motor coordination than normal weight youth.

While the treatment of overweight and obese youth is complex, participation in a multi-faceted treatment programme, including resistance training, may provide a gateway for this population to improve muscle strength, enhance motor coordination and gain confidence in their perceived abilities to be physically active. The available evidence indicates that resistance training has the potential to offer observable health value to sedentary youth and young athletes, and this type of training can be prescribed to meet the needs of all children and adolescents, regardless of body size or physical ability.

Injury Prevention Benefits Of Resistance Training For Youth

The total elimination of sport- and physical activity related injuries is an unrealistic goal; however, preparatory resistance training programmes that are appropriately designed and sensibly progressed for youth may help to reduce the likelihood of injuries in these populations. Lehnhard and colleagues were able to significantly reduce injury rates with the addition of a resistance training regimen to a male soccer team. Cahill and Griffith incorporated resistance training into their preseason conditioning for adolescent football teams and reported a reduction in non-serious knee injuries, as well as knee injuries that required surgery, over four competitive seasons. Hejna et al. reported that young athletes who incorporated resistance training in their exercise regimen suffered fewer injuries and recovered from injuries with less time spent in rehabilitation as compared to teammates who did not resistance train. Similarly, Soligard et al. successfully reduced the risk of severe and overuse injuries in female youth football players, following the implementation of a comprehensive warm-up programme that incorporated resistance based exercises. Likewise, Emery and Meeuwisse reported a reduction in overall injuries and acute injury incidence in youth football players with the use of an integrative neuromuscular training (INT) programme focused on resistance training. It should be noted that INT refers to a training programme that incorporates general and specific strength and conditioning activities that improve health- and skill-related physical fitness components.

Resistance training that is focused to address the risk factors associated with youth sport injuries (e.g. low fitness level, muscle imbalances and errors in training) has the potential to reduce overuse injuries by up to 50%. For example, several investigations indicate that reduced relative hamstring strength is related to both hamstring strains and ACL injury. Integrative resistance training protocols incorporated into pre-season and in-season conditioning programmes reduced these injury risks, and decreased anterior cruciate ligament injuries in young athletes. Even stronger associations of injury reduction are reported for decreased hamstring strains in young adult athletes who utilised hamstring resistance training exercises in preseason conditioning for their respective sports, such as football, rugby, and Australian rules football. While there is not one combination of resistance training exercises that has proven to optimise training adaptations, it appears that multi-faceted programmes that increase muscle strength, enhance movement mechanics, and improve functional abilities appear to be the most effective strategy for reducing sports related injuries in young athletes.

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. Owing to the apparent decline in free time physical activity among children and adolescents, it seems that the musculoskeletal system of some aspiring young athletes may not be prepared for the demands of sports practice and competition. Of concern, research has suggested that physical activity levels in youth peak at approximately 6 years of age, and consistently decline throughout childhood and into youth. Consequently, the supporting structures of some young athletes may be ill prepared to handle the demands of weekly sports practice sessions and weekend competitions. Cumulatively, these findings indicate that young athletes should participate regularly in multi-faceted resistance training programmes prior to sports seasons to reduce their risk of sports related injury.

Special 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 girls. These intrinsic risk factors, if not addressed at the proper time, may continue through adolescence and into maturity, thus predisposing female athletes to increased risk of injuries.

In a recent longitudinal study, Ford et al. noted that young females who did not participate in resistance training programmes as they matured developed injury risk factors. Conversely, those who did report participation in resistance training activities during maturation were found to have safer movement mechanics and associated increased posterior chain strength.

Well supervised, multifaceted resistance training programmes reduce these abnormal biomechanics and appear to decrease injury rates in female athletes. The findings of a recent meta-analysis revealed that an age-related association between integrative resistance training implementation and reduction of ACL incidence only occurred in the youngest female athletes. Integrative 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 these measures.

In addition to reduced knee injuries in adolescent and mature female athletes, regular participation in a multifaceted resistance training programme may also induce measures of the “neuromuscular spurt” which are not typically seen in females. 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.

Observed relative gains in females may be greater than in males because baseline neuromuscular performance levels are lower on average in females. Although there are many mechanisms to potentially reduce sports related injuries, enhancing muscular fitness and strength using resistance training as a preventative health measure should be considered a cornerstone of year-round, multifaceted training programmes for school age youth.

Effectiveness Of Youth Resistance Training

As previously documented, children and adolescents will naturally increase muscular strength levels as a result of growth and maturation. The appropriate development of strength as a result of training can have important implications for sport and daily life. In order to induce adaptations in muscular strength levels above and beyond those of growth and maturation alone, the magnitude and intensity of training stimulus must be sufficient. However, research clearly indicates that appropriately designed, and well supervised resistance training programmes can benefit youth of all ages, with children as young as 5 years of age making noticeable improvements in muscular fitness.

Interestingly, whilst the magnitude of absolute strength gains have been reported as being greater in adolescents (ES = 1.91) in comparison to children (ES = 0.81), relative increases in strength appear to be similar across childhood and adolescence. The term ‘trainability’ describes the sensitivity of developing athletes to a given training stimulus at varying stages of growth and maturation. Growth and maturation complicate the concept of trainability, as combined they can quite often imitate potential training effects.

Recently, Keiner et al. examined the trainability of 141 youth football players (11 to 19 years old). Participants were divided into either a football training only group, or a combined football training and resistance training group. The data indicated a high level of trainability for all age groups (under 19’s, under 17’s, under 15’s and under 13’s). Using absolute and relative back squat measures, two years of resistance training resulted in differences between control and resistance trained groups ranging from 125% in the younger group to 54% in the older group. Interestingly, the strength profiles of the football players was compared against data of 105 youth weightlifters, and it emerged that the

young weightlifters were stronger than the soccer players at each age group. Considering the effect of increased strength on reducing injuries and increasing sport related performance variables such as sprinting, jumping, and general sport performance, the investigators suggested that with 4-5 years of training, relative strength levels (1RM kg/kg body mass) in the back squat should be a minimum of 2.0 for late adolescents (16-19 yrs); 1.5 for adolescents (13-15 yrs); and 0.7 for children (11-12 yrs).

These findings, in addition to several reviews of the literature including three metaanalyses, highlight the effectiveness of resistance training for sports performance for all youth, and underline that resistance training programmes should not be limited to adult populations. Despite the growing body of evidence demonstrating that resistance training can lead to established improvements in performance through increases in strength, speed, power and other related characteristics (e.g. rate of force development), an aspect that has caused debate amongst researchers, deals with the degree of hypertrophy that is possible as a result of strength training among children prior to puberty.

Existing research suggests that increases in muscular strength are a result of both architectural (muscle size, movement arm length) and neural (voluntary activation level) adaptations. However, the mechanisms appear to differ according to the stage of development. The primary mechanisms underlying training-induced gains in muscular strength and related characteristics before puberty appear to depend upon neural adaptations. However, among early and particularly late adolescence, the effects of resistance training appear to be a result of additional gains in lean body mass and muscle cross-sectional area, with further alterations in neural mechanisms appearing to be the same as those adaptations experienced by adults. Thus, it is among children that very special care should be taken in their development, and coaches should avoid using training methods aimed at increasing overall muscle mass, instead focusing on strength development and movement skill competency. Indeed, among children, from a conceptual standpoint, the adoption of a longterm approach to athletic development should be implemented. Combined, the existing literature highlights a number of important concepts:

- Firstly, at all ages, appropriate resistance training can clearly result in an increased level of strength and related characteristics. Within the literature, gains in maximum strength have ranged from approximately 10% to 70% depending upon several factors including the type of training programme, duration of the training programme, and the type of exercise used to measure strength (e.g. isometric versus isoinertial, large muscle mass versus small muscle mass, and partial versus complete range of motion). However, in general, expected strength gains of 30-40% are typically observed in untrained youth following participation in an introductory resistance training programme.
- Secondly, strength 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.
- Thirdly, evidence indicates that more effective programmes lasted more than 8 weeks, involved multiple sets and that generally, gains increased with the frequency of training sessions per week. However, it should be noted that youth with extensive resistance training experience need to follow periodised training programmes with systematic variation in intensity, volume, frequency and repetition velocity to facilitate continued adaptation. This is supported with evidence from adult based data that suggests a reduction in training frequency accompanied by an increase in training intensity produces superior results.

Weightlifting (Olympic): an Effective Training Tool for Young Athletes

Previous literature highlights that weightlifting is considerably safer for children and adolescents than many have generally believed, providing qualified supervision and instruction are available and progression is based on the technical performance of each lift.

Therefore, despite previous misconceptions surrounding its safety, Feedback

Weightlifting injury rate is reportedly lower than other forms of resistance training and sports in general. For example, Pierce et al. observed 70 female and male children participating in weightlifting ranging in age from 7 to 16 years, who regularly completed maximal and near-maximal lifts in competition and training. Over a 12 month period, no days of training were lost as a result of injury from weightlifting, and both boys and girls increased physical strength as measured by weightlifting performance. A more detailed follow-up study of 3 females (13.7 ± 1.2 y) and 8 males (12.5 ± 1.6 y) across a year's competition (534 competition lifts) showed similar results. Both boys and girls showed marked enhancement of weightlifting performance, and no injuries requiring medical attention or loss of training time occurred.

Furthermore, these two observational studies indicated that if training and competition are appropriate for the age group, and are properly supervised and sensibly progressed, then weightlifting exercises may provide a unique stimulus for enhancing strength, explosiveness and power performance in school-age youth.

Due to the high skill level required to perform weightlifting movements, it is important that individuals responsible for teaching these complex movements to youths, hold the requisite coaching qualifications, and have suitable experience of teaching youths. Weightlifting training uses a variety of large multimuscle, multi-joint exercises, such as squats, snatches, and clean and jerks (plus variations of these movements).

Weightlifting has been used to examine potential effects of strength-power training on a number of performance and physiological variables among children and adolescents. A series of studies carried out in the Soviet Union examined the effects of weightlifting training on the physical development, physiology and performance of children and adolescents. The data gleaned from these studies indicate that from 12 years to 22 years of age, weightlifting training can produce positive alterations in body composition, cardiorespiratory variables, various motor fitness parameters (e.g. jumping and sprinting), and overall weightlifting performance.

Considering the observational, correlation and longitudinal data as a whole, it is accepted that resistance training (inclusive of weightlifting training) can improve strength and strength related variables among children and adolescents. These studies also offer evidence as to the efficacy of strength gain alone in producing positive alterations in skill related variables among children and adolescents.

Resistance Training Guidelines For Children And Adolescents

Whilst recent evidence has indicated that both children and adolescents can make significant gains in muscular strength and other health- and skill-related fitness components, it is imperative that suitably qualified personnel are responsible for coaching and instruction of youth-based resistance training programmes. Such qualifications would include a relevant strength and conditioning qualification (for example, the Accredited Strength and Conditioning Coach (ASCC) status), a strong understanding of paediatric exercise science, and crucially, relevant pedagogic experience and a communication skill-set to enable effective engagement with youth of varying abilities and personalities.

Training Variable Considerations

Exercise selection

Whilst a range of exercises, performed on 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. Researchers have previously highlighted the importance of equipment modifications and habituation when testing youth for any fitness component, and promote the use of 'child-sized' or 'child friendly' machinery wherever possible.

The principles of equipment suitability and familiarity for paediatric testing, should also apply for youths participating in resistance training. Some of the resistance modes available to those prescribing youth resistance training programmes include: bodyweight, machine weights, free weights, resistance bands, medicine balls, and manual resistance, all of which have been successfully implemented within the training programmes of both children and adolescents.

Selection of resistance modality will largely depend upon the technical ability and baseline fitness levels of the individual. For example, it may be necessary to gradually introduce sedentary youth to simple resistance training exercises via the use of machine-based resistance, in order to enhance their self-perception of competency, before progressing to more complex, free weight based activities. It should be recognised however, that when competency is sufficiently developed, free weight resistance should be used wherever possible, as machine-based resistance has been reported to stimulate lower muscle activation in lower, upper, and whole-body exercises compared to free-weight resistance.

Recent evidence demonstrated that whilst a 10-week weight-machine based training programme was successful in increasing isokinetic peak torque of the knee extensors and knee flexors in prepubertal children, it was unsuccessful in improving more dynamic athletic qualities, including vertical jump height and postural sway. Such dynamic qualities can be enhanced in youth with multi-joint, velocity-specific training in the form of free weight resistance training, weightlifting, and dynamic exercise using body weight, such as plyometrics.

For youths with a low training age, coaches should employ a range of exercises which are designed to promote the development of muscular strength and enhance overall fundamental movement competency. Childhood is deemed to be a crucial time in which to develop movement competency, as it is during these formative years that neuromuscular coordination is most susceptible to change. During this stage of development, children will experience rapid brain maturation and exposing children to key athletic movement patterns at a time where natural strengthening of existing synaptic pathways and synaptic pruning takes place, is considered crucial for long-term athletic development and life-long physical activity.

Once the child can demonstrate appropriate technical competency, they should be introduced to more advanced exercises that challenge the child in terms of coordination and require greater levels of force generation. In the case of weightlifting exercises, which by their nature are complex, multi-joint exercises, authors have previously suggested that early exposure should focus on technical development using body weight, modified equipment and light external loads.

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, and is comprised of the number of sets, and number of repetitions within each set. Volume can also relate to the overall loading within short- and long-term training blocks, but for the purposes of the current manuscript the former definition will be used.

Intensity most commonly refers to the magnitude of resistance that is required to be overcome during a repetition. 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. Both variables must be considered synergistically when prescribing resistance training for youth, however, training intensity is arguably more important owing to the injury risk associated with exposing a child or adolescent to excessive external loading at the expense of correct technique.

In order to prescribe appropriate training intensity, coaches typically stipulate a percentage of an athlete's one repetition-maximum (1RM). Research indicates that maximal strength and power testing of children and adolescents is safe and reliable when standardised protocols are implemented

and monitored by qualified instructors. Whilst 1RM measurements are routinely used within a research environment or elite level sport, owing to time and equipment constraints, physical education teachers will typically benefit more from the use of predictive equations that estimate 1RM values from sub-maximal loads in youth populations. However, it should be acknowledged that methods of predicting 1RM values from higher repetition ranges possess less accuracy, in particular when repetition ranges exceed more than 10.63. Additionally, it should be noted that a child or adolescent must be able to demonstrate sound technical competency irrespective of the RM range selected.

Progression of Volume and Intensity

When biologically immature children, or youth with a low training age, first begin to participate in formalised resistance training in schools and recreation programmes, the use of 1RM measurements (actual or predicted) to determine training intensities will typically be unnecessary. Consequently, teachers and coaches should prescribe an appropriate repetition range to develop technical competency and acquire a base level of adaptation, and over time increase external load until technique is deemed to have sufficiently improved. Therefore, a beginner may be prescribed 1-2 sets of 8-12 repetitions with a light or moderate load (50-70% 1RM or equivalent), however, with increased exposure to formalised resistance training, they may increase prescription to 2-4 sets of 6-10 repetitions with a heavier load (70-85% 1RM). Once technical expertise is sufficiently high, adolescents may be introduced to lower volumes (2-5 sets of 3-5 repetitions) and higher external loads (>85% 1RM).

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, a relatively experienced adolescent may begin a resistance training session performing 3 sets of 5 repetitions of a power-oriented exercise (e.g. power clean); then complete 3 sets of 6-8 repetitions of a large compound, multi-joint movement (e.g. back squat); and then finish with 2 sets of 6-10 repetitions of a unilateral exercise (e.g. barbell step-up).

Depending on the learning environment, coaches will need to provide feedback to ensure technical competency does not decrease towards the end of a prescribed set. The frequency and mode of feedback will depend to a large degree on the number of individuals training, mode of exercise being performed, and the stage of learning and personality traits of the young athletes involved. For example, when coaching a novice weightlifter, feedback may be provided after individual repetitions; however, for a primary school physical education class of 25 pupils, where the focus of the lesson is aimed at fundamental movement skill development, feedback may be provided less frequently.

Rest Intervals During Training Sessions

While limited evidence exists examining the optimal rest periods for youth-based resistance training, available research indicates that children can recover more quickly from fatigue-inducing resistance exercise. It is suggested that children are less likely to suffer muscle damage following such exercise, owing to the increased pliability of their muscle tissue. Rest periods of approximately 1 minute should suffice for inexperienced children, however, this should be increased as children enter adolescence and become more experienced (2-5 minutes), especially if the exercises require high levels of skill, force or power production.

Whilst children can recover more quickly from short, intermittent, high intensity training than adults, as a caveat, teachers and coaches should monitor within-session resistance training performance to ensure correct technique is maintained.

Training Frequency

Training frequency refers to the number of sessions performed within a week. Previous research has indicated that 2-3 sessions per week on nonconsecutive days is most appropriate in order to develop

muscular strength levels in children and adolescents. Behringer and colleagues recently substantiated these previous recommendations, indicating that across 42 studies (where mean training frequency was 2.7 ± 0.8 sessions per week), training frequency was significantly correlated with increased resistance training effect.

Training frequency may increase as children go through adolescence and approach adulthood, especially for youths in competitive sport. While promoting sampling and exposure to a variety of physical activity experiences to help promote physical development, in the interests of athlete welfare and well-being, coaches, parents and educators should be cognisant of the potential difficulties when children are asked to participate in numerous activities and thus accumulating high exercise volumes.

For youth participating in competitive sports, in-season resistance training should be viewed as mandatory to maintain muscular strength levels and reduce injury-risk. Physical education classes may offer a suitable time for youths involved in sport to receive such training (providing suitably qualified personnel are responsible for the delivery), as research demonstrates that exposure to resistance training during exercise lessons or physical education classes does not have an adverse effect on after-school performance in adolescent athletes.

Repetition Velocity

Whilst existing guidelines promote the use of controlled, moderate movement velocities for youths, there is arguably a need to promote the intention to move quickly to develop motor unit recruitment patterns and firing frequencies. Variations in repetition velocity may also be indicative of the training age of the child; for example, a child with limited training history may need to perform all exercises with slow to moderate speed to maximise control and ensure correct technical development, whereas an early adolescent with three years training history could be exposed to much greater movement velocities.

Repetition velocities may also fluctuate within a session; for example, the movement preparation phase may consist of slow and controlled movements, the main dynamic and explosive exercises (plyometrics or weightlifting derivatives) will involve rapid movement speeds, whilst the main strength development exercises (squatting, deadlifting, pressing and pulling) will typically include slow to moderate movement velocities. However, even when external loads are sufficient to produce slow movement speed, there should arguably be an intention to move explosively wherever possible to promote appropriate neuromuscular adaptations and to maximise the transfer of training effect.

Arguably, the development of high velocity movement is especially important for children and adolescents at a time when neural efficiency and motor coordination is most sensitive to change. Table 1 provides a summary of suggested guidelines for youth-based resistance training prescription aimed at improving muscular strength levels for a range of abilities and experiences. These are only guidelines, and flexibility will be required in order to ensure prescription of resistance training protocols for youths is at all times individualised. It should be noted that resistance training prescription for youths should always be age-related and not age-determined. Sensible progression should be made from beginner status through to advanced, and those responsible for determining an athlete's level of competency should consider a range of compounding variables, inclusive of maturational stage, training age, fundamental movement skill competency, technical proficiency, existing strength levels and psychosocial factors (such as confidence and self-perception of motor competency). Regardless of training status the level of instruction, education and feedback provided to the child or adolescent will be fundamental to the success of the training programme.

Training experience	Beginner	Intermediate	Experienced	Advanced
Volume (sets x reps)	1-2 x 8-12	2-4 x 6-10	2-4 x 5-8	2-5 x 2-5
Total number of exercises per session	6-10	3-6	3-6	2-5
Intensity (% 1RM)	BW or 50-70% 1RM	60-80%	70-85%	85-100%
Repetition velocity (speed of movement)	Moderate-Fast	Moderate - Fast	Fast-maximal	Maximal
Rest intervals (minutes)	1	1-2	2-3	2-5
Frequency (sessions per week)	2-3	2-3	2-4	2-5
Recovery (hours in between sessions)	72-48	72-48	48	48-24

Table 1

Summary

A compelling body of scientific evidence supports participation in well-designed youth resistance training programmes that are supervised and instructed by qualified professionals. The current manuscript has added to previous position statements from medical and fitness organisations, and has clearly outlined the performance, health, and injury reducing benefits associated with this training mode for school age youth.

In summarising this manuscript:

1. The use of resistance training by children and adolescents is supported on the proviso that qualified professionals supervise training programmes that are consistent with the needs, goals, and abilities of younger populations.

2. Specifically, the use of weightlifting as a resistance training mode by children and adolescents is supported, providing appropriate equipment and logical progressions are prescribed and implemented by suitably qualified personnel.

3. Parents, teachers and coaches, should recognise the potential health-related benefits of resistance exercise, because youths who do not participate in activities that enhance muscle strength and movement skills, may be at increased risk for negative health outcomes later in life.

4. Well designed resistance training programmes are not only safe for young athletes but may also reduce sports-related injuries.

5. An appropriately designed resistance training programme can elicit noticeable improvements in motor skills, and consequently may positively enhance sports performance.

6. A properly designed resistance training programme can improve and maintain psychological health and wellbeing.

7. Resistance training prescription for children and adolescents should be age-related and not age-determined. Consequently, prescription should be based according to biological status, training age, motor skill competency, technical proficiency, existing strength levels, and psychosocial maturity.

8. Regardless of resistance training mode, training volume and intensity should never be increased at the expense of technical competency.