Review Article

Resistance training for children and adolescents

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Abstract: As more children and adolescents are becoming involved in exercise and school or community based athletics, attention is turned towards proper training and conditioning to optimize performance, stimulate athletic development and ensure safety while tolerating long-term competition. Resistance training (RT) refers to the methodology of ensuring such optimal performance and safety. This is a common component of sports and physical fitness in schools and organized athletic programs around the country. RT is a physical conditioning program that involves various training techniques (e.g., machine based, free weight, plyometric, complex and functional training) and progressively increasing resistive loads to achieve desired muscle endurance, strength, power or a combination of the above. Proper RT programs have a plethora of associated benefits including increased strength, lower rates of sports-related injury, increased bone strength index (BSI), decreased risk of fracture and improved self-esteem and interest in fitness. There are risks involved with improper or poor training programs. Proper training programs involve knowledgeable trainers, effective supervision and tailored weight training.

Keywords: Resistance training (RT); eccentric contraction; concentric contraction; plyometrics; weight training; adolescent strength training

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Introduction

The goals of resistance training (RT) should focus on the specific goals of the participant in the exercise program. *Table 1* provides a close look at terms associated with RT techniques. RT design can focus on improving muscle strength, increasing power or muscle bulk, enhancing endurance or a combination of any of the above (1-4). In addition, studies have found that positive associations were noted between muscular fitness and bone health and self-esteem (1). These programs should be specifically designed by taking into account the various demands of the sport considered. For example, an athlete who runs track and an athlete who plays baseball may have similar goals in improving muscle strength but should have specific programs tailored towards the aerobic demands of each respective sport. As such, designing such programs for conditioning and sport-specific training should be done by appropriately trained professionals, taking the athlete's goals into consideration (2). Doing so will allow for fitness promotion to support motor skill acquisition, to enhance performance, to improve markers of well-being and to reduce the risk of sustaining sports-related injuries (1). Granacher *et al.* looked at three major benefits from implementing muscular fitness enhancing exercise. First, regular training stimulates athletic development and career. Second, RT enhances tolerance of the demands of long-term training, while, finally, inducing long-term health promoting effects that track into adulthood (1).

In addition to RT, one needs to take health-related fitness goals into account. These goals may revolve around aerobic and flexibility exercises, as well as stretching—

Table 1 Definition of terms

Term	Definition
Strength training	The use of resistance methods to increase one's ability to exert or resist force. May include free weights, body weight, machines or other resistance devices to attain this goal
Core strengthening	Focusing a program to the muscles that stabilize the trunk. Emphasizes on abdominal, lower back, gluteal muscles
Set	Group of repetitions separated by scheduled periods of rest
Reps	Abbreviation for repetitions
Strength	Maximal force a muscle generates at a specific velocity of movement
Power	Rate at which a muscle or group of muscles perform a given task
Hypertrophy	Increase in cross-sectional area or size of a muscle, primarily resulting from muscle fibers
Concentric contraction	Muscle shortening during contraction
Eccentric contraction	Muscle lengthening during contraction
Isometric contraction	Muscle length is unchanged during contraction (e.g., wall sits)
Isokinetic contraction	Speed of muscle contraction is fixed through motion
Isotonic contraction	Involves both concentric and eccentric components; Muscle tension remains constant during the movement
Progressive resistive exercises	Exercise regimen in which the athlete progressively increases amount of weight lifted and/or repetition number
Plyometric exercise	Repeated eccentric and concentric muscle contractions

another key component of RT. RT is considered safe if the training is designed appropriately for the emotional and developmental stage of the participant, rather than simply considering chronological age (1,2). This will help minimize any associated injuries to growth plates, cartilage and overall skeletal structure. The term RT may be used interchangeably with strength training, weight training and weight lifting, but this interchangeable use is often inappropriate. Competitive weight lifting is not recommended for children or adolescents (4). As such, the American Academy of Pediatrics has recommended that preadolescents and adolescents should avoid power lifting, body building and maximal lifts until they reach physical and skeletal maturity. The many positive effects of RT have been examined and will be discussed here. This article discusses the benefits, safety and risks associated with RT in children and adolescents, as well as analyzing current proper recommendations and techniques for proper resistance fitness. There is, however, a noted difference between specific characteristics of youth athlete physiology and level of expertise versus proficiency in motor performance in non-athletic youth. This review will focus on general principles applying to children and adolescents, primarily focusing on observed benefits, risks and general basic understanding of RT.

Benefits of RT

RT in youth is believed to capitalize on the synergistic effects of physiological adaptations demanded by RT along with the natural proliferation and adaptations due to maturation in the young athlete. During pre-pubescence, youth experience is heightened by neural proliferation and central nervous system (CNS) maturation (5). Increased load and stress on the body provides an added stimulus to the already natural proliferation taking place, resulting in a synergistic increase in neural proliferation compared to youth who do not partake in RT. Studies also show youth and adolescents that undertake initial RT of different forms show increased gains in strength compared to adults undergoing initial RT (5,6). This disparity between youth and adults also supports the suggestion that increased neural adaptation during normal physiological maturation is synergistic with the physical demands of RT.

There are many ways to measure the effects of RT. The largest benefit of RT to many athletes is an observed increase in power generated by the stretch shortening cycle (SSC). SSC activity is a naturally incorporated movement used to increase power output during particular movements. SSC is described as a muscle undergoing an eccentric contraction immediately prior to undergoing a concentric contraction. The SSC is seen commonly in an individual attempting a jump from a standing position. Instead of remaining static prior to the jump, the individual will appear to uncoil before recoiling and then jumping. RT designed to enhance the SSC is the main target for plyometric training to increase the contractile force of muscles, stiffness of the tendons and efficacy of neurons to function synergistically to produce greater force and speed during competition (6,7). The increased force provided by stronger SSC activity allows for increased speed during initial acceleration or directional change, arm speed during throwing or swinging or force during vertical leap (5,7).

It has been widely demonstrated that the increased strength experienced in adolescent athletes gained from RT is attributed to the nervous system as opposed to hypertrophy (5,7,8). This is evidenced by increased strength without a statistically significant increase in muscle cross sectional area demonstrating hypertrophy (8).

The main mechanism of increased neuronal function due to RT is increased motor unit activation leading to greater muscle output, increasing demonstrated strength. This was measured using the interpolated twitch technique that measures maximum voluntary contraction compared to complete activation by electrostimulation. The interpolated twitch technique demonstrated increased motor activation in children who underwent a 20-week RT regimen focusing on the elbow and knee extensors (8). Studies that demonstrated an increase in agonist motor activation also measured a decrease in antagonistic muscle activation during exertion. The decrease in antagonistic muscle activation allows for greater overall muscle output (8). This has been specifically measured in adults but has not yet been proven in adolescents but is theorized to yield similar findings.

Two other neural adaptations related to increased strength are rate of force development (RFD) and electromechanical delay (EMD). RFD is the rate at which a particular amount of force can be developed and exerted by a particular muscle group. An 8-week study of involving high velocity RT resulted in significant increases in RFD for participants. Similar findings were not supported in a study conducted with lower intensity RT suggesting that only high velocity RT can develop an increased RFD. Decreased EMD, the time it takes from neuronal signaling to contraction, has been shown to decrease with RT largely due to increased tendon stiffness, allowing a faster transfer of force from muscle contraction to bone movement via the tendon. An increase in tendon stiffness causing a decrease in EMD has been demonstrated; however, the expected association to increased RFD was not supported in the study. A decreased EMD does lessen the reaction time in competition for athletes adding to the benefits of RT (8).

In the past, it was thought RT was detrimental to youth athletes and was specifically avoided out of concern for damage caused by the high forces exerted upon the adolescent skeleton resulting in concern for increased physeal injuries and the potential for stunted growth (6,9). Multiple studies have since discredited this theory by demonstrating there is no adverse effects of RT in youth athletes, when designed properly, and is often completed injury free (5-7,10). Instead, athletes who incorporate RT into their training regimen have demonstrated decreased rates of fracture, musculotendinous and muscle injuries associated with sport specific practice and competition (8). RT has been shown to decrease injury rates by increasing bone strength index (BSI) and mineral content, strengthening tendons and improving the strength of accessory muscles to prevent injury during practice and competition.

RT is beneficial to the immature skeleton in several ways. The increased loading on the skeleton causes changes in the bone mineral content. Increased bone content is positively correlated with an increase in bone strength. Increases in bone content are also correlated with increased time of RT. Soccer players who had 4 or more hours of RT per week showed significantly greater gains in bone content compared to soccer players who had only 2 h of RT per week. Those soccer players who had 2 h of RT per week showed increases in bone content greater than the control group of soccer players who had no RT (8). RT is also correlated with increased BSI calculated from the cross sectional moment of inertia multiplied by cortical bone mineral density. Increased BSI has been observed in sport specific bones critical to athletic performance. Gymnasts have been found to have increased BSI in the radius. Track and field athletes have been found to have increased BSI in the distal and proximal tibia; and water polo players have been found to have increased BSI in the distal radius. Studies show an increased BSI is correlated with a decreased risk of fracture (8).

Athletes' tendons undergo changes in composition and thickness due to RT. During athletic development the muscle undergoes adaptation faster than the tendon does leading to an imbalance in maximum stress that puts the athlete at increased risk for tendinous injury. This change in tendon composition allows for a higher amount of stress that can be tolerated without injury. Tendon composition changes at a faster rate due to RT compared to increases in tendon cross sectional area (8). Nine-year-old in a 10-week RT regimen demonstrated increased tendon stiffness with no significant change in cross sectional area. Tendons of adolescents are capable of increases in cross sectional area over longer periods of time as evidenced by gymnasts, cyclists and ball sport athletes having larger cross sectional areas of Achilles tendons compared to non-sport controls of similar age. The exact mechanism of how RT leads to changes in cross sectional area and tendon composition requires further studying at this time (1,8).

Musculature in children is enhanced by RT in several ways. Physiological cross sectional area does increase with longer term RT; but because most of the studies completed on RT in youth are limited, this specific finding is not widely demonstrated. RT does reliably increase fascicle length and pennation angles that are associated with increased strength independent of the maturation process (8). The most beneficial way RT reduces the risk of injury is through the use of free weights and the utilization of balance aids during RT. Free weights allow for multi planar movements that mimic more the demands of competitive play and exertion more so than static machines do. The multi planar movements combined with balance training actively strengthen stabilizer muscles needed to prevent injuries during high levels of exertion (1).

RT causes many physiological and metabolic changes in the adolescent. Studies regarding the metabolic changes associated with RT in adolescents are not well established, but a general trend of mildly decreased adiposity and increased muscle strength as well as increased muscle mass in longer studies has been observed. Studies have shown that while RT does not demonstrate a significant change in body composition for overweight and obese adolescents, large increases in physical strength and self-esteem after a 6-month training regimen have been documented (11). This suggests a positive correlation between exercise efficacy and self-esteem that is supported by multiple studies. However, it was noted that these values returned to baseline 6 months after the end of the training regimen suggesting the need to continue physical activity to maintain gains in both fitness and self-esteem. It is also hypothesized that introducing overweight, obese and sedentary adolescents to RT can also be used to help acclimate youth to physical exercise in a less strenuous and intimidating way that eventually builds to more vigorous and regular cardiovascular exercise (12).

Risks of RT

A major risk that is mentioned any time childhood RT is discussed is the risk of epiphyseal plate injury. This is a unique risk in this population as adult populations lack open physeal plates. In particular, separation of the epiphyseal plate is the biggest fracture mentioned in the literature. This would be classified as a Salter-Harris type 1 fracture, often viewed as a less traumatic epiphyseal plate injury usually without long-term risk of growth abnormalities. However any fracture of this region has the potential for deformity. Injuries of this region of the bone can lead to early physeal closure and limb length anomalies as the non-injured arm continues to grow, and therefore are of significant concern for medical practitioners. Literature review demonstrates that this concern grew from studies and case reports published in the 1970s and 1980s (13). These were based on data from the National Electronic Injury Surveillance System (NEISS) that showed increasing trends of epiphyseal injuries in youth lifters. Several retrospective studies from this time demonstrate damage to the growth cartilage in youth (14-17). However, as this data was further evaluated, it was found most of these injuries were related to improper form and lifting program design leading to injury (18). One particularly clear example is a young lifter who was lifting in a makeshift gym at home. While pressing a 30 kg load overhead, he lost control of the weight resulting in bilateral separations of the radial epiphysis (19). Current expert opinion in the field supports the belief that RT prior to epiphyseal closure is not inherently harmful (13). The prospective studies that have provided effective supervision and guidance have demonstrated no increased incidence of physeal injury in children weightlifting (20-24).

Soft tissue injuries are some of the most frequently reported injuries in the literature with regards to pediatric RT. In particular, trunk injuries are one of the more commonly reported weightlifting injuries in children and adolescents (25). This is thought to be due to an individual emphasis on building superficial "mirror muscles" and therefore neglecting core and trunk strength training. Due to this imbalance in lifting, this could be viewed as an injury due to an improper RT program. There are certainly many case reports of injuries from RT, but only a few reported studies of lifting that demonstrated significant injuries. One study had a participant who required a week of rest due to shoulder pain (21). Another had a shoulder strain that required them to miss a single training session (26). It is important to highlight that the most commonly injured sites from RT are the back and trunk. One study reports trunk injuries being approximately 36% of the injuries reported for men and 27% for women (25). Other studies of young athletes note high rates lumbar spine pain. One study noted that 29 of 43 adolescents with weight lifting injuries had injury of their lower back. Most of these were minor, but 4 were severe enough to require surgery (27). That being said, these are rare injuries requiring time away from training, and studies have demonstrated quite low injury rates when lifting programs are well designed. Two separate prospective studies demonstrated injury rates of 0.053 and 0.055 per 100 participant hours (26,28). There are even studies showing that high stress lifting, such as 1 rep max training, do not demonstrate significant injury risk. One study looked at 96 children doing one rep max training with weight machines and found there was no increased risk of injury (29). Another study evaluated similar training using free weights and found similar results (30).

In discussion of injuries from RT itself, it is critical to put this into the context of the sports these young individuals are participating in. With effective supervision and training, as well as a properly designed lifting program, the rates of injury are quite low. In fact, one study found the rate to be around 0.035 injuries per 100 participant hours in RT (31). A separate study of adolescent power-lifters showed an injury rate of 0.29 per 100 participant hours, and these are individuals who would be lifting larger loads and more complicated lifts such as bench press, deadlift, and back squats (32). This is in comparison to heavier contact sports such as rugby, which have been shown to have injury rates near 0.800 per 100 participant hours, much higher than those demonstrated in RT (31).

In fully examining the risks of RT it is quite apparent that, though some risk of injury does exist, this is comparable to that of sports these children are already participating in. Children do have unique injury risks, such as physeal plate injury. However, this risk is not dramatically elevated by lifting. Furthermore, all injury risk can be minimized with effective training program development, supervision, and effective lifting form education.

Plyometric training

Plyometric exercise is unique in its combination of power and strength. It involves both eccentric loading of a muscle or muscle group followed immediately by concentric contraction. This combination utilizes the SSC or reflex in which the concentric action releases stored energy for subsequent muscular actions. The stored energy is preloaded during the eccentric phase and is used to produce more force than can be provided by concentric muscle action alone (9). Plyometric training has been demonstrated to improve endurance in vertical jumping, leg strength and acceleration (9). Most activities include hopping, skipping, jumping, focused on lower extremities. Plyometrics may also involve throwing to condition upper extremities. As with any exercise or training program, a plyometric training program must follow careful design and recommended intensities to avoid injury. It is also recommended to incorporate plyometrics at a maximum of 2–3 times per week to prevent muscular injury.

Requirements for good training

In evaluating RT in pediatric populations, it can be concluded that there is significant benefit in numerous areas to effective RT. The benefit does not come at a significant injury cost; and, given the possible reduction in injury in athletics due to increased overall strength, there is support for the efficacy of RT in these populations. However, all of these are dependent upon proper execution of RT programs. In the proper design of training programs there are three critical aspects—education regarding proper lifting form, adequate supervision, and effectively scaled lifting.

One of the most important aspects of good training is education on proper techniques of lifting. There are numerous lifts that can be incorporated into a training program, and as previously discussed, these are not programs that are more likely to cause injury. It is important that instructors of weight training are comfortable teaching proper lifts in various training programs. When introducing new athletes to lifting, it is important to initially introduce simple lifts (33). This allows these individuals to gain comfort on simple motions prior to progressing to more difficult lifts. When to progress to more difficult lifts is dependent upon the individual supervising the lifting.

Effective supervision is the second important aspect of a training program. The individual supervising is responsible for reinforcing proper form and addressing any mistakes being made in training by the athletes. With that in mind, trainers should be confident overseeing the lifts being performed and identifying areas for improvement in the lifters they are supervising. The supervising individual will also determine when trainees are able to progress to more difficult or heavier loads. Especially in newer lifters, it is important for the supervising adult to determine when the athlete appears comfortable enough to progress in the lifting program both in complexity of activities and weight used for lifting.

Lastly, designing a program that is effective without overly taxing the youth lifter is critical to gaining the benefits of RT without increasing injury risk. It is important to exercise all large muscle groups as part of the lifting program. In addition, starting a lifting session with complex motions requiring multiple muscle groups is favorable as these lifts can be performed before muscles are fatiguing, causing imbalance in the activity. Progression to more isolated lifts may then occur. Beyond these core aspects, there is no specifically favored lifting program in this age group. Lifts involving weight machines, free weights, barbell lifts, and bodyweight lifts have all shown efficacy in this population (33). It is upon the judgement and expertise of the individual designing the program to ensure identification of goals for both the lifting program and its participants. This information will then encourage and allow for proper research to identify and design the most effective training program to ensure safety.

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Footnote

Conflict of Interest: The authors have no conflicts of interest to declare.

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