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Review

Resistance Training in Youth – Benefits and Characteristics

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Abstract

Insufficient physical activity (PA) is one of the major health risks in the 21st century. Along with secular trends of lower PA in youth there have been significant declines in muscular fitness over the last decades. PA recommendations, nevertheless, focus predominantly on aerobic exercise. Despite research showing no harm or increased injury risk with resistance exercise there remain concerns about the implementation of resistance training in youth. Properly administered resistance training, however, has been associated with lower injury risk compared to various other physical activity youth generally engage in. Resistance training has also been shown to provide important complementary health benefits to aerobic exercise. In addition to beneficial effects on muscular strength and power, resistance training has been associated with increased bone mineral density, reduced risk for chronic disease markers and improved psychological well-being. Resistance training further appears to facilitate a sustainable participation in various physical activities. Even though hypertrophic effects may be limited in children, relative strength gains have been similar between children, adolescents and adults. The utilization of adult resistance training programs, however, is not applicable in youth. Ensuring postural balance along with proper exercise technique are crucial components of resistance training in youth. In addition, individual needs and maturational readiness need to be considered in developing age appropriate resistance training programs that will promote a sustainable participation in PA throughout youth and into adulthood.

Key words: children, adolescence, strength training, resistance exercise, active lifestyle, chronic disease risk

Introduction

Physical activity (PA) is an important contributor to the physical and psychological development and to the future health status in children and adolescents [1-3]. Nevertheless, a majority of youth reports insufficient PA levels [4, 5], which is accompanied by declining levels of physical fitness worldwide [6-11]. Deficiencies in muscular fitness have been suggested to contribute to low PA levels [12]. Current PA recommendations, however, focus predominantly on aerobic activities (i.e. minimum of 60 min/day of moderate-to-vigorous PA (MVPA) in youth) [13, 14]. The incorporation of muscle strengthening activities, subsequently referred to as resistance training (RT), is only addressed briefly even though poor muscle strength has been associated with increased cardiovascular disease risk in adolescents [15] as well as lower participation in sports and recreational activities [16-18].

RT consists of a variety of resistive loads that are introduced in a progressive manner to improve muscular strength and athletic performance [19]. It has been shown to provide important complementary benefits to MVPA [3, 20] (Table 1). In addition to increased muscle strength, power and motor skill performance [21], participation in RT has been associated with reduced central adiposity and unhealthy weight gain [22], cardiovascular and metabolic diseases [23-25], increased skeletal health [26, 27], as well as reduced risk for fractures and sports-related injuries [20, 28], independent of aerobic fitness [19]. There are also beneficial effects of RT on academic performance [26, 29] and psychological well-being [20, 30-32]. Specifically, RT has been associated with improved physical self-perception [33-35], perceived competence [33, 34], overall self-worth [36] and global self-esteem [37]. As self-perception and self-concept are associated with an individual's motivation towards and engagement in PA, this may have important implications for sustainable participation in various forms of PA [38, 39]. Furthermore, muscular fitness has been shown to track into adulthood [40], and, therefore, can provide a strong foundation for a sustainable active lifestyle. Due to the non-linear relationship between muscular fitness and various health indicators, greatest benefits with RT have been observed in participants with lowest muscular fitness levels [23, 41]. Further, overweight youth experienced the most distinct benefits with RT [23].

Table 1: Health benefits associated with resistance training in children and adolescents

	Component	Children	Adolescents
Physical Fitness	Increased Strength & Power	++	++
	Increased Local Muscular Endurance	++	++
	Enhanced motor skills	++	++
	Injury Prevention	++	++
Body Structure	Increased Bone Mineral Density	++	++
	Improved Body Composition	++	++
Chronic Disease Risk	Improved Lipid Profile	++	++
	Reduced Blood Pressure	+	++
	Improved insulin Sensitivity	++	++
Psychological Aspects	Improved perceived competence	++	++
	Improved Self-Efficacy, Self-Esteem and Self-Concept	?	++
	Improved academic performance	+	+

++ proven beneficial effect; + potential beneficial effect; ? insufficient data
Based on Faigenbaum et al. [21] and Mühlbauer et al. [42]

Various statements from professional organizations have clarified that participation in appropriate RT improves overall health in youth rather than adversely affect the development of children and adolescents [19, 43-45]. There is also no scientific evidence that properly administered RT adversely affects linear growth during youth or results in reduced height attained in adulthood [19, 46-48]. Nevertheless, there remain concerns regarding the implementation of RT in pediatric populations as it is commonly considered inappropriate or unsafe for children and adolescents [49]. Even though, there is some inherent risk for musculoskeletal injuries with RT, as with any other form of PA, this risk is no greater than that of many other recreational activities or sports youth generally participate in [19]. In fact, properly administered RT programs may actually reduce injury risk during various physical activities in children [20, 50] while providing a variety of health benefits [20, 21, 50-52]. Childhood and adolescence have been suggested as the opportune time to induce beneficial adaptations in bone development due to synergistic effects of mechanical stress induced by RT and growth-related increase in bone mass [27, 43, 46, 47, 53-55]. Furthermore, RT, including plyometric exercises, has been shown to enhance movement biomechanics and functional abilities, which reduces the risk for sports-related injuries in young athletes [56-58]. Accordingly, a prospective study examining 1576 injuries in youth showed lower injury rates with RT compared to football, basketball or soccer [59]. In adolescents, RT has been shown to be markedly safer than many other common sports and physical activities [60]. Most injuries associated with RT in youth are due to lack of or improper instruction and supervision [21] and, therefore, could be avoided with age-appropriate training programs. Nevertheless, almost one third of a representative sample of Dutch parents stated that they would not allow their 12- to 15 year-old offspring to participate in RT due to concerns about the impact on linear growth, while only 4% would prohibit participation in aerobic exercise [49]. Physical education programs also focus predominantly on team sports, and provide only limited exposure to RT [61]. Accordingly, only a small number of young people report regular participation in RT [62] and only a few adolescents appear to be competent in RT skills [63].

Engagement in RT at younger ages may also positively affect behavioral choices in adulthood [64-66] as PA habits are established early in life and muscular strength and RT have been shown to positively affect overall PA in adults [67, 68]. In addition, the intermittent nature of RT has a greater resemblance with youth's habitual PA compared to prolonged continuous exercise. Continuous activities, traditionally used for aerobic conditioning are often considered boring or discomforting [69]. It should further be considered that children with excess body weight can often not compete with their normal weight peers in aerobic exercises [19] and are only able to engage in low intensity continuous exercises due to their low aerobic fitness level [70]. This potentially negatively affects self-efficacy resulting in a vicious cycle of disengagement from PA and increased body weight [71], contributing to further declines in physical fitness. Weight bearing activities such as jogging may also increase the risk of musculoskeletal overuse injuries, particularly in youth with excess body weight [19]. RT, on the other hand, may be better tolerated and appears to be more enjoyable compared to continuous aerobic exercise [72, 73]. As overweight/obese youth are more likely to achieve similar or even better performance during RT compared to their normal weight peers [74] it increases their perceived competence and subsequently the autonomous motivation for PA. A regular participation in RT may further result in beneficial changes in body composition due to increased muscle mass [72], which facilitates participation in various physical activities supporting an overall active lifestyle [21, 75]. Accordingly, pretreatment participation with regular RT has been associated with higher attrition to weight management programs in children [76] while endurance-based exercise interventions are commonly associated with poor compliance due to insufficient motivation for prolonged continuous exercise in children [77]. It should also be mentioned that participation in RT resulted in similar socialization and mental discipline as participation in team sports [78]. Further, it has been argued that PA promotion programs should put a stronger emphasis on what children like to do, rather than what they should do [71]. Accordingly, RT may provide a viable option for a sustainable improvement in PA in youth.

Adaptations to Resistance Training in Youth

When basic principles of design and safety are followed, RT is associated with various beneficial adaptations contributing to increased muscular strength and improved health [50, 79-82]. Increased muscular strength is the result of alterations in architectural (muscle cross-sectional area and size, moment arm length) and neural adaptations [83]. During childhood and adolescence strength gains are also due to growth and maturation [84-86] and these changes potentially mask training effects in case of suboptimal straining stimuli [87, 88]. As indicated by the specific adaptation to imposed demands (SAID) principle, adaptations to RT are specific to the demands of the task, including movement pattern, velocity of movement, contraction type and contraction force [89]. Strength gains in children appear to be predominantly related to neural mechanisms rather than hypertrophic factors due to the lower levels of circulating testosterone that stimulate increases in muscle size [46, 84, 90, 91]. Specifically, a trend toward increased motor unit activation and changes in motor unit coordination, recruitment and firing rate along with increased twitch torque have been suggested to contribute primarily to increased muscular strength. In addition, a transition of type II fibers towards a more glycolytic profile has been suggested [92]. Improvement in inter-muscular coordination also appears to play a significant role as improvement in strength in response to RT is more pronounced than changes in neuromuscular activation [90, 91]. These adaptations along with a higher neural plasticity at younger ages may explain the greater training-induced gains in various strength-related motor skills (e.g. jumping, throwing) of children compared to adolescents [93].

Earlier studies also indicated increased muscle mass with RT even in prepubescent youth [94], which could be attributed to increased testosterone levels and free androgen index values due to alterations in hypothalamic-pituitary-gonadal axis [82]. These alterations may also contribute to beneficial changes in bone mass given the strong association between bone mass and lean body mass [26]. Changes in muscle mass, however, will become more apparent after puberty [94, 95]. Particularly males experience pronounced gains in lean body mass and cross-sectional area in response to RT during late adolescence [93]. Females experience less hypertrophy due to lower testosterone levels [86]. Alterations in growth-hormone and insulin-like growth factors, however, still contribute to muscle growth in females [96]. More pronounced hypertrophic effects of RT result in greater absolute strength gains in adolescents compared to children [97]. Relative strength gains, however, appear to be similar between children, adolescents and adulths [81, 86, 98]. RT lasting between 8 and 20 weeks has been associated with average strength gains between 30% and 40% [19] with maximum strength gains of up to 90% [97]. The variability in response to RT can at least partially be explained by differences in training volume, intensity, frequency, duration, type of training along with quality of supervision [99].

The previously described qualitative and quantitative changes in muscle tissue have also been associated with a risk reduction for various chronic diseases due to beneficial alterations in insulin sensitivity, lipid profile, blood pressure and abdominal fat in adults [100-103]. Even though clinical symptoms of cardiovascular disease may not become apparent until adulthood, some of these risk factors already occur in early childhood [104]. Further, a clustering of chronic disease risk factors observed during childhood has been shown to persist into adulthood [105]. Particularly overweight and obese children have shown favorable changes in body composition and insulin sensitivity with RT, which was attributed to qualitative changes in skeletal muscle [24, 52, 74, 106, 107]. Further, the previously addressed beneficial adaptations in bone development could reduce the risk for osteoporosis and associated fractures later in life [108]. One of the greatest benefits of RT in youth, however, may be the improvement in selected motor skills [93], which is associated with increased perceived competence that increases motivation towards PA [3]. Greater enjoyment with participation in various sports and physical activities would also facilitate a more active lifestyle during adulthood [20].

Characteristics of Resistance Training in Youth

Despite the fact that youth experience comparable benefits in response to RT as adults, it would be a mistake to submit children and adolescents to an adult training program [19]. RT in youth requires careful and evidence-based exercise prescription that considers the specific needs, goals and interests of the participants along with their physical and psychological uniqueness (e.g. training age, technical competency, maturation). Table 2 displays seven fundamental principles, summarized by the acronym *PROCESS*, that should be considered in order to provide safe and effective RT programs. There are no minimum age requirements for participation in RT and noticeable improvements in muscular fitness following RT have been shown in children as young as 5 to 6 years [109-111]. In order to successfully and safely implement RT, children, however, need to be emotionally mature enough to accept and follow directions and display competency in balance and postural control [19, 112]. Participants need to be familiar with basic exercise etiquette including handling and storage of exercise equipm-ent. Further, individual and realistic goal setting should be part of any RT program [19]. Given these requirements, 7- to 8-year-old children should gener-ally be able to safely participate in RT [113]. Further, a year-round participation in RT should be encouraged. Short training programs followed by longer periods of detraining provide only limited health benefits due rapid decline of the initial gains in neuromuscular activation and motor coordination [114-117].

Table 2: PROCESS - Fundamental principles of resistance training in youth.

P	**Progression**	Gradual increase in the demands placed on human body
R	**Regularity**	Continuous participation in exercise (2-3 days per week)
O	**Overload**	Stress the body beyond what it is accustomed to
C	**Creativity**	Introduction of novel exercises and training equipment to maintain motivation (possible participation of youth in development of training routines in safe environment)
E	**Enjoyment**	Facilitation of prolonged exercise engagement by balancing skill and challenge
S	**Socialization**	Facilitation of gain in competence and confidence along with optimization of training progress due to interaction with others
S	**Supervision**	Safe exercise environment along with meaningful feedback

Based on Faigenbaum and McFarland [12]

There appears to be no single optimal combination of exercises, sets and repetitions to induce beneficial adaptations in youth [21]. A variety of RT programs including free weights, weight machines, medicine balls, elastic bands and body weight exercises have been shown to provide beneficial outcomes [19]. Accordingly, a systematic and sensible variation in exercise selection and alterations in intensity, volume and frequency of repetitions should be employed in order to facilitate a sustainable participation in RT and reduce the risk of overuse injuries [118]. Body size, training age and fitness levels need to be considered as well when selecting exercises. Less experienced participants should start with relatively simple movements and gradually progress towards more advanced multi-joint exercises [21]. Given the differences in adaptations, RT in children should predominantly focus on strength gains due to function and motor control rather than increased muscle size, which becomes more pronounced during adolescence. Such an approach requires an emphasis on movement technique at the appropriate movement speed rather than pushing for high exhaustion. Any exercise program should include warm-up and cool-down along with information on selection and order of exercises, training intensity and volume, movement velocity and rest intervals (Table 3).

RT prescriptions are commonly based on the maximum load that can be moved one time (one-repetition maximum, 1RM). With qualified supervision to ensure proper technique along with participation in a habituation period before testing, healthy children and adolescents have been shown to be able to safely engage in 1RM testing [19]. Several common field tests (e.g. long jump, handgrip strength), however, also provide viable information on force capacity in youth and correlate with 1RM

[119]. When starting an RT program, light loads (≤ 60% 1RM) and simpler movements to learn the proper exercise technique should be used. Subsequently intensity, complexity of exercises and movement speed can gradually be increased [118]. Each exercise session should address all major muscle groups and exercise selection should promote muscle balance across joints to ensure equal development of opposing muscles. More challenging exercises such as multi-joint exercises should be performed early in the training session when there is less fatigue in the neuromuscular system. While up to 15 repetitions per set can be performed for strength exercises, fewer than 6 to 8 repetitions are generally recommended when performing more intense power exercises (e.g. plyometrics) [19, 21]. Rest intervals between sets can be shorter in children as they have been shown to recover more quickly from RT than adolescents and adults (about 1 minute compared to 2-3 minutes in adults) [120-122]. Due to increased pliability of muscle tissue youth are also less likely to experience muscle damage and delayed onset of muscle soreness [123]. Nevertheless, strength training sessions are not supposed to be performed on consecutive days. In addition to the actual training protocol, the importance of proper nutrition along with sufficient hydration and adequate sleep should be addressed as well [20].

Table 3: Guidelines for resistance training in youth.

General Considerations
Qualified instruction, close supervision and safe exercise environment
Systematic variation of exercise selection and training intensity to keep program fresh and challenging
Consideration of individual needs and concerns (e.g. training age, body size, maturation, fitness)
Focus on proper exercise technique
2-3 training sessions per week on non-consecutive days
Exercise Session
Start with 5-10 minute dynamic warm-up
Inclusion of exercises addressing all major muscle groups and emphasis on symmetrical muscular development around joints
Performance of multi-joint exercises prior to single-joint exercises
Training of large muscle groups prior to small muscle groups
Inclusion of exercises for balance and coordination
End exercise session with cool down, including stretching
Intensity and Volume
Start with 1-2 sets at ≤ 60% 1RM
Following familiarization 1-3 sets of 6-15 repetitions for strength exercises around 80% 1RM
Following familiarization 1-3 sets of 6-8 repetitions for power exercise

Based on Faigenbaum et al. [19, 21]

Summary and Conclusion

Insufficient PA in youth is becoming a major threat to public health. It not only affects immediate health and well-being but also has important implications in later life [124]. Given the consistent and measureable decrements in muscular fitness in youth over the last decade [7, 10] RT should be recognized as important component in the promotion of an active lifestyle [89]. While there remain reservations about the implementation of RT in youth, research has not shown any detrimental effects of RT on growth and development in youth; rather RT appears to be a safe, effective and worthwhile form of exercise for children and adolescents. Lack of participation in RT in early life may actually increase the risk for negative health outcomes later in life [20]. In addition to improved muscular fitness and motor skills, RT has been associated with increased bone mineral density, improved body composition, reduced risk for cardiovascular and metabolic diseases, as well as increased perceived competence and general psychological well-being [3, 20, 21, 40]. These benefits, however, only occur with sustainable participation in RT.

Prescription of RT requires an individual approach that considers training age, current strength level, motor skill competency as well as psychological and maturational readiness. Emphasizing proper technique not only ensures safety; it also promotes motor competence in foundational skills that facilitate participation in a variety of sports and physical activities. At this time there is no single best RT program for youth and various exercises, including own body-weight, free weights, weight machines and elastic bands, among others should be implemented. Accordingly, more research is needed to clarify exercise selection in RT (frequency, volume, intensity) regarding specific adaptations in children and adolescents. The utilization of a broad range of exercises in RT programs may actually be a crucial component in itself as it increases the likelihood for sustained motivation towards engagement in RT along with the reduction of injury risk. RT has also been associated with positive attitudes towards PE and lifelong exercise [125] which could facilitate a sustainable increase in PA throughout childhood, adolescence and adulthood [126]. As insufficient PA has been identified as one of the leading threats to future public health [14], RT should be considered a viable intervention strategy in the promotion of an active lifestyle.

Competing Interests

The authors have declared that no competing interest exists.

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