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Youth Resistance Training: Past Practices, New Perspectives, and Future Directions

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Since the publication of the seminal review on youth resistance training by Kraemer and colleagues in 1989, a compelling body of evidence has found that resistance training can be a safe, effective, and worthwhile method of conditioning for children and adolescents. New perspectives for promoting resistance exercise as part of a long-term approach to youth physical development highlight the importance of integrating resistance training into youth fitness programs. Youth who do not enhance their muscular strength and motor skill proficiency early in life may not develop the prerequisite skills and abilities that would allow them to participate in a variety of activities and sports with confidence and vigor later in life. The identification of asymptomatic children with muscular weaknesses or imbalances may facilitate the development of a management plan which should rectify movement limitations and educate children and their families about the importance of daily physical activity.

While much of what we understand about the stimulus of resistance exercise has been gained from research on adults, over the past 25 years a compelling body of evidence has found that resistance training can be a safe, effective, and worthwhile method of conditioning for children and adolescents. In 1989, Kraemer and colleagues authored a seminal review on resistance training for youth and presented an interactive model for the integration of developmental factors related to the potential for training-induced strength gains in children and adolescents (28). Although some observers questioned the safety and efficacy of youth resistance training in the 1980s and 1990s, Kraemer and associates provided insightful program design considerations based on the available evidence and highlighted practical applications for integrating resistance exercise into youth fitness programs (28).

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Since the publication of the review article by Kraemer and his author team (28), researchers and practitioners have expanded our understanding of the effects of resistance exercise on school-age youth, and the qualified acceptance of youth resistance training by medical and fitness organizations has increased (1,2,4,16,31,41). Nowadays, global health recommendations aim to increase the number of youth who participate in muscle-strengthening activities and a growing number of schools and sport centers offer youth programs that are purposely designed to increase muscular strength, enhance motor skill performance, improve physical fitness, and reduce the risk of sports-related injuries (43,59). The purpose of this commentary is to provide an update on the role of resistance training in modern-day youth and offer new perspectives for promoting resistance exercise as part of a long-term approach to youth physical development. In this article, the term resistance training refers to a method of conditioning that involves the progressive use of a wide range of resistive loads, different movement velocities and a variety of training modalities. The terms *youth* and *young athletes* are broadly defined to include both children and adolescents.

Resistance Training and Physical Development

Public health recommendations indicate that children and adolescents should accumulate at least 60 min of moderate to vigorous physical activity (MVPA) each day (59), yet recent epidemiological data indicate that contemporary youth are not as active as they should be and reductions in physical activity start in early preadolescence (46,57). Consequently, structured interventions and public health policies that prepare youth for a lifetime of physical activity are needed to promote healthy lifestyle choices. Since a certain level of muscular strength is necessary to jump, hop, skip, and kick proficiently (39), the importance of resistance training during the growing years should not be overlooked when designing fitness programs for children and adolescents. Just like the skills of reading and writing, physical activity is a learned behavior that is influenced by family, friends, and the environment. Consequently, youth who are not exposed to an environment with opportunities to enhance their muscular strength and motor skill proficiency early in life may not develop the prerequisite skills and abilities that would allow them to participate in a variety of activities and sports with confidence and vigor later in life (3,27,34).

Concerted efforts by practitioners and researchers are needed to raise awareness about the importance of enhancing muscular strength and motor skill proficiency in the early years because sedentary behaviors appear to track at moderate levels from childhood and adolescence (7) . Many chronic diseases that become clinically manifest during adulthood begin in childhood when lifestyle habits such as physical activity are established and reinforced (13). Children who do not develop sufficient levels of muscular strength and movement skill competency may be less efficient "movers" on the playground and the sport field (26,27,58). Without opportunities to gain confidence and competence in their abilities to be physically active, youth will be less likely to engage in the recommended amount of MVPA (e.g., free play and sports) and more likely to experience negative health outcomes.

Data from several reports indicate that motor skill performance is inversely associated with being overweight or obese during childhood (11,27,35). Furthermore, recent findings from a population-based study found that nearly half of all

obese young adults were either diagnosed with Type 2 diabetes, hypertension, myocardial infarction, stroke or venous thromboembolism or died before reaching 55 years of age (52). Collectively, these findings highlight the need to refocus our efforts on the prevention of adverse health outcomes early in life before youth become resistant to our interventions. As illustrated in Figure 1, children with inadequate muscle strength and poor motor skill performance are less likely to gain competence and confidence in their physical abilities and more likely to have disease risk factors and experience adverse health outcomes (18).

Along with declines in aerobic fitness among children and adolescents over the past 20 years, a contemporary corollary of the sedentariness among youth is a lower level of muscular fitness (9,10,40,51). Researchers examined 10-year secular trends in muscular fitness in English children and found declines in bent arm hang, sit-up performance, and handgrip strength over the study period (9). Similar secular trends in selected measures of muscular fitness were also observed in Dutch primary school children and Spanish adolescents (40,51). Without interventions that target deficits in muscular fitness and motor skill performance early in life, these contemporary trends will likely continue and the gap between youth with low and high levels of muscular fitness and motor skill competence will widen across developmental time (11,26).

Although enhancing the physical abilities of young athletes to maximize athletic success is not a novel concept, a youth physical development model that

Figure 1 — The cascade of adverse health outcomes that may result from low muscle strength and poor motor skill development during childhood. Adapted from Faigenbaum and Myer (18).

emphasizes muscular strength and motor skill prowess early in life is needed to provide a logical and evidence-based approach to the long-term physical development of children and adolescents (32). Age-related youth physical development models should explain when specific training components should be emphasized and why physical qualities such as muscular strength and motor skill development need to be targeted early in life. While the need for individualization should not be overlooked when designing programs for school-age youth of different sex, maturity status, and training experience, the formation of a long-term plan to maximize physical development and promote well-being is critical for the promotion of physical activity as an ongoing lifestyle choice (32,47). Of note, school-based physical education taught by trained specialists is an ideal setting to enhance muscular strength in children (33).

Resistance Training Prescription

Nearly 25 years ago, Kraemer and colleagues eloquently illustrated the theoretical interplay between factors that likely contribute to the expression of muscular strength during childhood and adolescence (28). Namely, lean body mass, hormonal responses, neural development, and fiber type differentiation (i.e., Type I and Type II fiber composition) were identified as factors that influence strength gains observed throughout the growing years. These researchers noted that the ability of youth to adapt to a resistance-training program is influenced by the physiological plasticity at each stage of development in addition to the design of the training program (28). More recently, Dotan et al. refined this contention by suggesting that child-adult differences in muscle activation are due to children's inability to recruit or fully use Type II motor units to the extent typical of adults (12). Figure 2 illustrates developmental factors related to the potential for muscle strength during the growing years and the mature performance potential if training begins during preadolescence.

The available data indicate that training-induced strength gains in children are primarily related to neural adaptations (e.g., a trend toward increased intra- and intermuscular coordination) and possibly intrinsic muscle adaptations rather than hypertrophic factors (24,43,50). Improvements in the coordination of the involved muscle groups to perform multijoint exercises (e.g., plyometrics and weightlifting movements) may also play a significant role. Although there is a possibility that training-induced anabolism may contribute to observed strength gains during preadolescence, it appears that children experience more difficulty increasing their muscle mass in response to resistance training. However, muscle hypertrophy appears to be more common following resistance training in adolescents, especially for males, because testosterone and other hormonal influences on muscle hypertrophy would be operant (16).

Owing to the high degree of neuromuscular plasticity during preadolescence, it has been suggested that strength development should be targeted during childhood to set the stage for enhanced physical development during adolescence (32,43). Indeed, data from recent meta-analyses indicate that resistance training can enhance the muscular strength and motor performance of school-age youth, and the effects of resistance training on motor performance skills appear to be more pronounced in children than in adolescents (5, 6). Different combinations of sets and repeti-

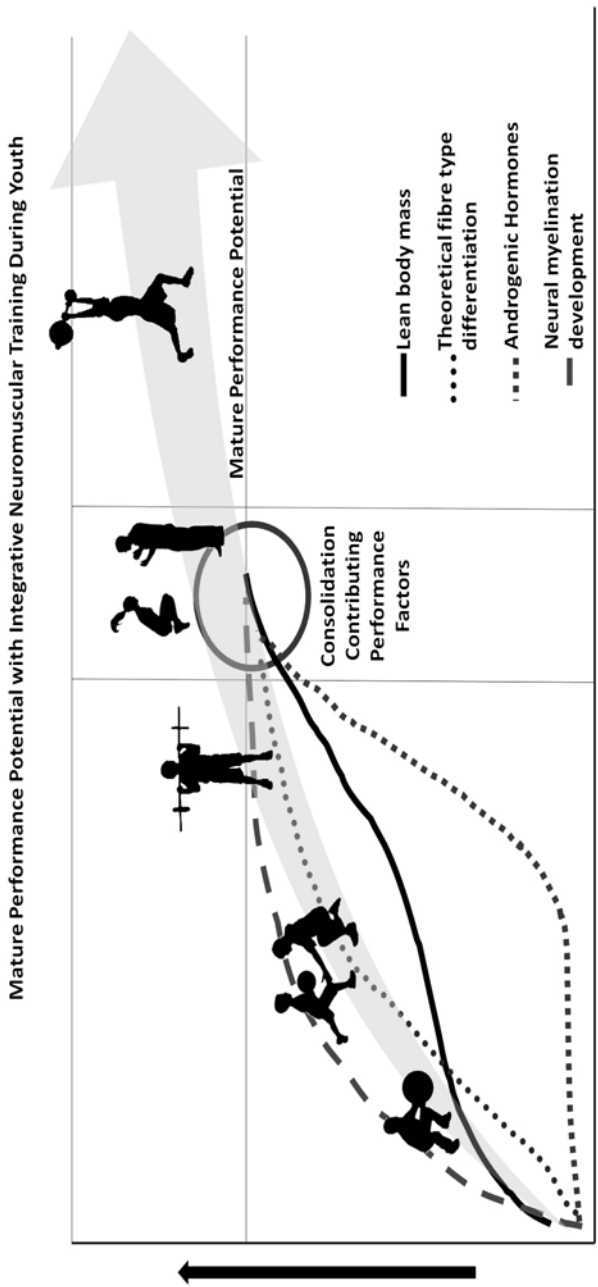

Figure 2 — Interactive model for the integration of factors related to the potential for muscle strength adaptations and training-induced performance gains during preadolescence, adolescence, and early adulthood. Adapted from Kraemer et al. (28) and Myer et al. (43).

tions may be effective, although the average program in a meta-analysis on youth resistance training consisted of 2–3 sets of 8–15 repetitions with loads between 60% and 80% of the 1 repetition maximum (RM) on 6–8 exercises (6).

Of interest, Kraemer and colleagues commented that some observers feared that maximal or near-maximal lifting could increase the probability of structural injury in children. Although this concern still lingers today, no injuries have been reported in research studies that used 1 repetition maximum testing or heavy resistance training loads (17,31). Moreover, there is no evidence to suggest that resistance training will negatively impact linear growth during childhood and adolescence (22). Paradoxically, the mechanical stress from heavy resistance training or high strain eliciting sports such as gymnastics or weightlifting may actually be beneficial for bone formation and growth during childhood (4,25). However, regardless of the resistance exercise intensity, improper training (e.g., poor lifting technique) or inappropriate pedagogical approaches (e.g., erroneous progression of training loads) should not be performed under any circumstances due to the risk of injury (44)

The minimal *dose* of resistance exercise required to elicit the desired effect is likely to be different in untrained and trained youth, and therefore it is critical to consider the dose-response relationship for intensity when designing youth resistance training programs. For example, a significant positive correlation has been found between gains in motor performance skills (e.g., running, jumping, and throwing) and the mean intensity (% 1 RM) of the resistance-training program (5). Therefore, after beginners develop proper form and technique with light and moderate loads, the amount of resistance should be gradually increased depending on individual needs and goals. Moreover, by periodically varying the training stimulus with periods of low-, moderate-, and high-intensity training, it is likely that long-term performance gains will be optimized, boredom will be reduced, and the risk of overuse injuries will decrease. In 1989, Kraemer and associates noted the importance of periodically varying program variables when designing youth resistance training programs (28). To date, however, surprisingly few long-term studies have investigated the effects of resistance training periodization on neuromuscular adaptations and performance outcomes in children and adolescents.

Few studies have examined the temporary or permanent reduction or complete withdrawal of the training stimulus (referred to as detraining) on measures of muscular fitness in youth. Unlike adults, the evaluation of performance changes in youth following a period of detraining is complicated by the concomitant growth-related increases during the same time period. At present, it appears that training-induced gains in muscular strength and power are impermanent and tend to regress toward untrained control group values during the detraining period (15,21). However, it is possible that the design of the training program could influence the adaptations as well as the retrogressions that take place during the detraining period. New insights into the effects of detraining on children suggest that the degree of strength, power, or neuromuscular skill required to perform a selected movement may influence the detraining response in children (15). The importance of youth regularly engaging in resistance training, or some type of maintenance training, to enhance or preserve training-induced gains in muscular fitness should be recognized by physical education teachers, youth coaches and health care providers.

Resistance Exercise is Medicine

The impact of a sedentary lifestyle during childhood and adolescence on lifelong pathological processes and associated health care costs has created an immediate need to manage, if not prevent, unhealthy behaviors such as physical inactivity during this vulnerable period of life. While guidelines for health promotion and risk reduction in children and adolescents typically include activities such as jogging or swimming, youth who are deficient in muscle strength and motor skill competence require a more individualized and specialized approach. Clearly, if the pleiotropic benefits of exercise during the growing years are to be realized later in life, specific details of the intervention need to be properly prescribed by qualified professionals and the "dose" of exercise must be developmentally appropriate, meaningful, and enjoyable.

Early research found that muscular strength and physical development measures could account for up to 70% of the variability in a range of motor skills that involved throwing, jumping and sprinting in children (56). More recently, new insights into the design of youth physical development programs have highlighted the importance of enhancing muscle strength and initiating interventions early in life to alter physical activity trajectories and reduce associated injury risks (32,43). It is likely that improvements in muscle strength and motor skill performance with age-related interventions during the growing years will facilitate the establishment of desired behaviors and provide an optimal mechanism for promoting physical activity as an ongoing lifestyle choice. This view is supported by longitudinal data that found 6-year-old children with low and average levels of motor coordination had lower levels of physical activity at age 10 compared with children with higher levels of motor coordination (34). Others reported that low levels of motor skill competency among school-age youth were associated with reduced levels of physical activity, low levels of cardiorespiratory fitness and increased risk of being overweight or obese (27).

Suboptimal levels of physical activity during childhood and adolescence may also increase the risk of injury. Researchers found that low levels of physical activity in children aged 9–12 years significantly increased the injury risk during physical education class, recreation, and sports (8). The steepest increase in injury risk in the aforementioned report was found for the quartile with the lowest habitual physical activity and the cut-off for this level was 5 hr per week of physical activity (8). These observations are consistent with others who noted that young athletes are at greater risk of a sports-related injury if they do not possess adequate muscular strength and physical conditioning (41,43). Although most activity-related injuries that occur in youth are minor, these findings highlight the importance of identifying and treating vulnerable children because any injury that occurs during physical education class, recreation, and sports can result in pain, school absence and health care costs.

Over two decades ago, Kraemer and coauthors noted that the greatest value of resistance training might be in its ability to prepare a young child's body for sport (28). Yet contemporary findings indicate that all school-age youth, especially those who are the least active, can benefit from regular participation in a structured resistance training program (16,32). Recent findings from a systematic review highlight the potential benefits of resistance training on the strength and body composition

of children and adolescents who are overweight and obese (53). Of note, resistance training allows youth who are overweight or obese to experience success and feel good about their performance which, in turn, may lead to an increase in regular physical activity and exposure to an exercise modality that can be carried over into adulthood (20).

Sedentary youth are unwilling and at times unable to perform prolonged periods of aerobic training, and participation in organized sport does not ensure adequate exposure to recommended levels of MVPA (30). While youth eventually learn how to jump, skip, catch and throw, many 6–9 year old boys and girls do not develop a level of motor control proficiency which is sufficient to accomplish mature patterns of fundamental movements (38). Hence, physical activity promotion efforts should not begin with endurance-type training or competitive sport participation, but rather training centered on resistance exercise owing to its performance-enhancing and injury-reducing benefits (32,43). Of potential relevance, the American College of Sports Medicine suggests that in the early stages of an exercise program muscle-strengthening exercises may need to precede aerobic-training activities in frail seniors (2). In the same light, resistance training may be particularly beneficial for sedentary youth who are often unwilling and unable to perform prolonged periods of aerobic exercise. Without developmentally appropriate interventions that include qualified instruction, strength-building exercises and directed movement practice, inactive youth will be ill-prepared to become motorically competent adults.

Shifting the Focus

In a prospective study of over one million male adolescents age 16–19 years who were followed over a period of 24 years, low muscular strength was recognized as an emerging risk factor for major causes of death including cardiovascular disease (48). Others reported that muscular strength, endurance, and power in youth aged 9–15 years were inversely associated with clustered cardiovascular disease risk, and that muscular power may protect against clustered cardiovascular disease risk independently of cardiorespiratory fitness (37). These findings emphasize the importance of early recognition of low muscle strength in youth and the necessity of age-related interventions to enhance muscular fitness.

Kraemer and colleagues noted that adult programs should not be imposed on children and recognized the importance of integrating resistance training into a total fitness program (28). More recently, new insights into the design of youth programs have highlighted the potential value of integrating strength-building exercises with other fitness activities (42). While structured resistance training programs and advanced training methods (e.g., weightlifting progressions) have proven to be safe and effective (17,31), integrative neuromuscular training (INT) is an effective type of conditioning that includes general and specific exercises purposely designed to enhance both health- and skill-related components of physical fitness (42). INT addresses common barriers to implementing school-based programs (e.g., lack of resources and insufficient time) and provides an opportunity for children to engage in physically effortful and mentally engaging exercises that increase muscle strength and enhance a range of physical qualities including fundamental movement skills (14).

The incorporation of INT into physical education classes and youth recreation programs may be an important first step in building the foundation for future participation in context-specific games, fitness activities, and sports. Childhood is an opportune time to develop motor skills and enhance muscle strength (5,36), and unlike adolescents, children are not as self-conscious about making a mistake in front of their peers. The dynamic relationship between muscular strength, motor skill proficiency, MVPA, and sports training will likely be reinforced over time which is consistent with the proposed existence of a positive feedback loop. That is, youth who enhance their muscle strength and motor skill proficiency will be better prepared to engage in fitness activities and transitional sports with energy and vigor. In turn, these youth will be more likely to continue participating in physical activities that enhance both health- and skill-related components of physical fitness while further improving their physical prowess. Naturally, as muscle strength and motor skill proficiency improve, the load and complexity of the prescribed training program should reflect the training experience, age, and technical abilities of the child.

Back to the Future

Current physical activity recommendations for youth may be suboptimal for children and adolescents who need to improve their muscle strength and movement skills. When designing youth physical activity interventions, it is important to remember that the goal of the program should not be limited to time spent in MVPA. In addition to considering the dose-response of exercise and related health benefits, the quality of the movement experience needs to be considered when implementing and evaluating youth fitness programs (49). Exercise programs and resistance training paradigms designed for adults are suboptimal for younger populations who are active in different ways and for different reasons.

It is important to complement research on the quantitative parameters of exercise and its physiological consequences with research investigating the role of its qualitative characteristics (49). This is where the art and science of developing youth resistance training programs come into play because the principles of pediatric exercise science need to be balanced with effective teaching to enhance a child's physical, emotional, social, and cognitive well-being. In our view, high-tech electronic games and gadgets (i.e., exergaming) may not be ideal for enhancing muscle strength, learning movement skills, or preparing youth for a lifetime of physical activity. Exercising on these devices may elevate energy expenditure and increase time spent in MVPA, but the long-term impact of exergaming on children's health seems suspect. Moreover, at a time when the median physical education budget in the United States is only $764 per school year, and 61% of physical education teachers report an annual budget of under $1,000 (45), factors related to the expense of these devices, and costs associated with maintenance should also be considered when developing school-based programs.

Low-tech strength-building exercises and inexpensive skill-enhancing activities that were somewhat characteristic of 20th century physical education may need to be integrated back into youth programs. Today, concerted efforts are needed to identify and treat deficits in muscle strength and motor skill ability early in life before youth feel worthless and become disengaged during physical education class

or sports practice. Since there are no pharmacotherapies to treat deficits in movement skill proficiency and muscular strength, a preventive strategy that includes resistance training and motor skill development is needed to prevent the eventual decline in physical activity and upsurge of high-risk behaviors during this critical period of life. Of course, trained specialists who are skilled at teaching school-age youth is an essential requirement for long-term success.

In 1961, Kraus and Raab coined the term *hypokinetic disease* to refer to the "whole spectrum of inactivity-induced somatic and mental derangements" (29). These physicians noted the importance of daily physical activity for healthful living and stated that a lack of exercise, particularly in a growing individual, was a deficiency state comparable to avitaminosis (29). At the time, they said pediatricians need to recognize the potential dangers of *under-exercise* to prevent their wards from "motion deficiency" as much as from lack of vitamins or contagious disease (29). These concerns were reinforced by Kraemer and colleagues who stated that regular resistance training during the growing years can play a vital role in the promotion of lifetime health (28).

At present, a population-wide approach for prevention is required, and novel strategies for identifying inactive children, prescribing age-related interventions that target strength and motor skill deficits, and raising public awareness are desperately needed. The impact of a sedentary lifestyle during childhood and adolescence on lifelong pathological processes is so compelling the term *exercise deficit disorder* or EDD was recently introduced to convey a fresh view of this conventional health care concern (18,19). The construct of EDD is unique because there are not any blood tests that can identify a child with poor muscle strength or below average motor skills. Consequently, pediatric health care providers may need to screen youth with an exercise history or fitness test to identify boys and girls who are deficient in exercise and, subsequently, initiate preventive strategies (55). Since primary prevention is designed to prevent disease rather than treat it, the identification of asymptomatic children with muscular weaknesses or imbalances may facilitate the development of a management plan which should rectify movement limitations and educate children and their families about the importance of daily physical activity.

Trained specialists who are well-versed in kinesiology, physical development and pediatric exercise science, and who are skilled in teaching and communicating with youth who have different needs, goals, and abilities should design, supervise and instruct fitness programs for children and adolescents. These professionals should have practical experience working with youth and a philosophy that is consistent with long-term health and well-being. Without such knowledge, they may not have an adequate understanding of how ontogenic factors and phylogenetic differences can influence strength development, fitness performance, and motivation in children and adolescents. However, few postsecondary programs in North America currently offer a course in pediatric exercise science, and the content covered in the lecture portion of most undergraduate exercise physiology courses focuses on adult fitness and athletic performance rather than developmental physiology and youth fitness (23). Moreover, only 7% of pediatric physical therapy programs in the United States require a clinical pediatric education placement; thus, a majority of physical therapy students matriculate to licensure without any experience treating youth (54).

Clearly, there is a need to create academic and practical learning opportunities for students and professionals who want to enhance their instructional content and delivery of youth fitness programs. While Kraemer and associates recognized the importance for teachers and coaches to understand the physical and psychosocial uniqueness of children and adolescents (28), there is an emerging need for a new pediatric certification due to the growing number of professionals who work with youth in schools, sports clubs, fitness centers, YMCAs, and sports medicine clinics. Without such initiatives that focus on professional education, evidence-based practice, and age-related interventions, new health care concerns with far-reaching biomedical, social and economic consequences will continue to emerge.

Years ago, Kraus and Raab also commented that it was "incongruous" for under-exercised youth to spend countless hours performing therapeutic exercise to restore muscular fitness that never should have been lost in the first place (29). Today, scientific evidence supports their contention as well as the modern-day concept that the foci for promoting physical activity during the growing years should be on enhancing muscular strength and improving the competence and confidence in the ability of children and adolescents to engage in a variety of games, sports, and fitness activities. While future research investigating the potential long-term benefits of youth resistance training is needed, due consideration must be given to the identification of youth with inadequate muscle strength and the promotion of sustainable programs that can prevent the cascade of adverse health outcomes later in life.

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