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Resistance Training in Youth: Laying the Foundation for Injury Prevention and Physical Literacy

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Context: The rising incidence of physical activity– and sports-related injuries has prompted the present-day investigation of resistance training as a potential means of injury prevention and physical literacy development among youth.

Evidence Acquisition: Relevant studies on the topics of athlete development, physical literacy, resistance training, and injury prevention in children and adolescents were reviewed (PubMed and Sports Discus, 1982-2016). Recommendations from consensus guidelines and position statements applicable to resistance training and injury prevention in youth, in addition to young athlete development, were reviewed. Additionally, hand searches, expert requests, article reference lists, and gray literature were utilized and reviewed for pertinent content.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: Youth throughout the physical activity spectrum are at risk for physical activity– and sports-related injury. Of highest priority are early specializers, physically inactive youth, and young girls, owing to increased injury rates. Resistance training among these at-risk populations has been shown to reduce injury risk by up to 68% and improve sports performance and health measures, in addition to accelerating the development of physical literacy. Recent recommendations, position statements, and national initiatives advocate for the incorporation of resistance training with qualified instruction among these groups.

Conclusion: Resistance training in addition to free play and other structured physical activity training can serve as a protective means against injury and a positive catalyst for the development of physical literacy to offset the impact of diminishing physical activity and early sport specialization in today's youth.

Keywords: strength development; fundamental movement skills; youth sports injuries; early specialization; exercise deficit disorder

Childhood and early adolescence have been hailed as critical windows for the development of optimal physical literacy.[9,73] Defined as the "ability, confidence, and desire to be physically active for life,"[4,5] physical literacy is thought to be a cornerstone to lifelong health and fitness.[131,132] There is growing recognition that a foundational set of movement skills should be mastered during childhood to facilitate the potential for long-term engagement and confidence in physical activity.[14,99] Insufficient mastery of these skills can lead to an inability to physically and socially keep up with active peers, which in turn can lead to cascading effects for motivation, desire, and ability to be physically active and avoiding injury in later adolescence and adulthood.[14,31,32,52,128] Of particular concern is insufficient muscular fitness among children,[19,114,119] which is marked as a vital component to the health, wellness, and success of any youth looking to participate in sports and recreational activity. A compelling body of evidence, including position statements from the International

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Figure 1. Core musculature stability training.

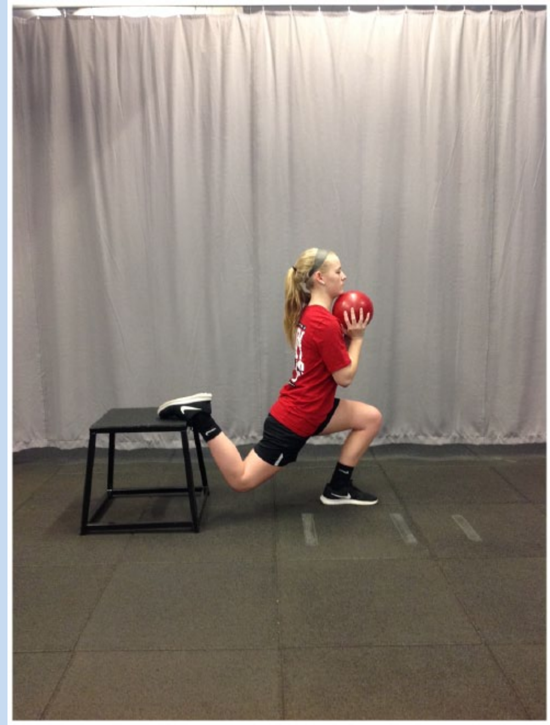

Figure 2. Lower body resistance training.

Olympic Committee (IOC)[14] and the National Strength and Conditioning Association (NSCA),[73] strongly support regular participation in resistance training as a means of reducing sports-related injury risk and improving physical literacy among youth.[14,73,75,127] The evidence has dispelled myths and addressed previous concerns regarding prepubescent resistance training, calling to action the qualified professionals who are well-suited to facilitate the improved health, performance, and well-being of children through resistance training.[75]

Over the past several years, there has been considerable world-wide interest in the emerging concept and field of study of physical literacy. However, recent recommendations and position statements promoting physical activity in youth from the World Health Organization (WHO),[134] the NSCA,[73] and the IOC[14] have all highlighted that the population of youth today is alarmingly less physically active compared with the generations that have preceded them. From a different perspective, there are rising concerns about emerging trends of pushing our youth to higher intensities and more frequent training schedules at younger and younger levels in youth sport programs.[63,68,86] Thus, we see a dichotomy of physical activity in our youth. On one end of the physical activity spectrum sit the kids who lead increasingly sedentary lifestyles, with little to no access to recess or physical education and increasing rates of disease, such as diabetes and obesity.[48,78] At the other end of the physical activity spectrum live the kids who participate in intense amounts of physical activity, specializing early in their respective sports and at high risk for overuse injuries and burnout.[48,65] Both of these extremes paint a bleak picture for the physical literacy and overall health and well-being of the next generations.

The purpose of this article was to synthesize and review the most recent literature related to young athlete development as it pertains to resistance training and physical literacy. The role of resistance training as a means of injury prevention for children and adolescents will be considered. Subsequently, resistance training during childhood and adolescence as a facilitator for the development of physical literacy will be discussed.

For the purposes of this article, and in accordance with existing literature, *childhood* refers to the developmental period of life from the end of infancy to the beginning of adolescence, and the term *children* represents girls and boys (generally up to the age of 11 and 13 years, respectively) who have not developed secondary sex characteristics.[74,75] Because of maturational differences, girls 12 to 18 years and boys 14 to 18 years are generally considered *adolescents*.[75] The terms *youth* and *young athletes* are broadly defined to include both children and adolescents.[74] As such, articles that studied individuals older than 18 years were not included. In accordance with previous definitions,[10,41,75] this article will define *resistance training* as a specialized method of conditioning that involves the progressive use of a wide range of resistive loads, including body mass, and a variety of training modalities (eg, machine-based training, free weight training, plyometric training, complex training, functional training) designed to enhance muscular fitness and athletic performance (Figures 1 and 2).

METHODS

Studies from 1982 through 2016 indexed in PubMed and Sports Discus on the topics of young athlete development, physical literacy, resistance training, and injury prevention in children and adolescents were reviewed. Search terms included the following: *strength training* OR *resistance training* AND *children, strength training* OR *resistance training* AND *adolescents, strength training* OR *resistance training* AND *injury prevention, physical literacy*, and *young athlete development*. Also reviewed were recommendations from consensus guidelines and position statements applicable to resistance training and injury prevention in youth, in addition to young athlete development. Furthermore, information through hand searching, expert requests, article reference lists, and gray literature, such as noncommercially published reports, was reviewed for pertinent content.

PHYSICAL ACTIVITY INJURY RISK

Young athletes and nonathletes alike require a basal level of strength and power to build a strong foundation for a sustainable active lifestyle.[42] As a result of declining physical literacy levels, youth across the activity level spectrum are at an increased risk for what are considered to be preventable injuries.[16,18,58,99]

The number of youth reporting overuse-type injuries has become a growing concern for sports health professionals, a consequence of overexposure to high volume and intensity of sport-specific training without adequate rest.[65] The overall estimate of the proportion of injuries that are overuse in nature among children and adolescents ranges from 45.9% to 54.0%.[26] Youth aged 7 to 18 years participating in more hours of sports per week than his or her number of age in years and/or whose ratio of organized sports to free play time is more than 2:1 hours per week have increased odds of having a serious overuse injury.[65] The detrimental impact of overuse injuries among this population involves the potential for nonfunctional overreaching, burnout, and eventual dropout from sport.[26,91]

While intense participation in a single sport has been linked to an increase in overuse injuries,[65] an insufficient amount of physical activity, or exercise deficit disorder (EDD),[47] and inadequate preparation for sports participation results in "underuse" sports-related injuries in children and adolescents.[16,78] Many youth with EDD lack the foundational muscular strength and endurance to safely execute motor skills within the demands of sport or recreational activity, a potential underlying cause of musculoskeletal injury, described as "underuse" in nature.[73,120] Young people lacking adequate physical activity levels also tend to have lower fitness levels,[99] which is linked to an increased risk of sports-related injury.[22,118] Data regarding the incidence of underuse injuries are severely lacking, as most estimates of sports-related injury rates among youth do not account for what may be an increasing number of unreported sports-related injuries suffered by children and adolescents with EDD.[26]

Irrespective of activity level, young girls are especially prone to unique injury patterns and medical conditions that differ from their male counterparts due to biomechanical, anatomic, and hormonal factors.[59] Numerous reports have shown that puberty has a more significant impact on the neuromuscular development of girls, resulting in the development of risky joint mechanics and other injury risk factors.[49,57] Girls presenting to a pediatric medical center suffered overuse injuries at a greater rate than boys (63% vs 40%, respectively).[121] In addition to patellofemoral disorders[28,62] and lower extremity stress fractures,[59] which are both overuse in nature, greater rates of traumatic injuries such as anterior cruciate ligament (ACL) tears occur among adolescent girls.[112,123,129] Increases in body mass and the height of center of mass in pubertal girls are not accompanied by the same adaptations in strength and power seen in boys, placing young girls at increased risk of lower extremity injury.[103] Similarly, deficits in lower extremity strength increase from prepubertal to pubertal stages in young girls,[113] which may predispose them to develop poor neuromuscular control strategies during sports-related movements.[24,66,75,93,111] Specific sex differences in strength are both muscle-group and muscle-action specific; however, by late puberty, a sex difference in the expression of strength of approximately 50% occurs in girls.[14,75,113] Coupled with a physical activity sex gap that arises by age 9 among girls of all ethnicities and races,[107] training programs designed to facilitate improved strength and safer movement mechanics specifically geared toward young girls of racial and ethnic minority statuses could be particularly impactful.[75]

PROTECTIVE EFFECTS OF RESISTANCE TRAINING FOR YOUTH

Successful performance of fundamental movement skills is associated with positive, long-term engagement in movement-related activities,[82] and consequently, greater activity levels moving into adulthood.[124] Stronger youth become more efficient "movers" and will likely move with more confidence and competence in their physical abilities, resulting in enhanced physical literacy.[37,53,54] Stronger children and adolescents are also likely to be better prepared for the rigors of sport and moderate to vigorous physical activity participation and less likely to suffer a preventable physical activity–related injury.[76,100] Collectively, these factors suggest that youth across the activity spectrum could potentially benefit immensely from resistance training.[44,100,102]

Over the past decade or so, there has been a shift in attitudes and level of support for resistance training among children and adolescents. A compelling body of evidence has emerged in recent years that has resulted in a progression beyond the argument for or against resistance training among youth to improve performance[42,73] and instead led to an emergence of numerous international position statements supporting youth resistance training as a vital piece of physical development.[14,75,94,127]

Resistance training among youth aged 6 to 18 years elicits improvements in muscular strength,[13,116] power,[55,71] running speed,[96] kicking velocity,[133] endurance,[51,130] dynamic balance,[27] flexibility,[97] and general motor performance.[12] These gains make young athletes more resistant to sports-related injuries.[42,44,106,119] A recent meta-analysis of children and adolescent athletes indicates that resistance training reduces sports-related injuries, both overuse and acute, by up to 66%.[69] In addition to strength, power, and endurance gains, youth who engage in resistance training programs can also improve their general fitness levels,[75] increase confidence in their physical abilities,[14] and experience enhanced mental health and well-being.[33] These findings emphasize that resistance training is also a beneficial activity for nonathletes.

For those who limit participation to intense training in a single sport during childhood, a multifaceted resistance training program with qualified instruction can ensure that the diversification of motor skill development occurs prior to the onset of puberty.[78] Additionally, the enhancement of strength can address ensuing muscular imbalances that may heighten risk of overuse or overexposure injury in the future.[78] A consensus statement on youth athlete development issued by the IOC suggested there is a critical need for preparatory muscular fitness training to achieve optimal young athlete wellness and maintain long-term performance into adolescence and adulthood.[14] Participation in a multifaceted resistance training program by athletes who specialize in a sport at a young age may assist the development of physical literacy skills typically acquired through free play and involvement in other sports.[79]

On the opposite end of the physical activity spectrum, young children with insufficient exposure to sports and physical activity can benefit from early onset of structured resistance training as an intervention for muscular strength deficiencies and overall lack of physical activity. With similar or even less amounts of free play than early sport specializers, children in this segment of the population may be ill-prepared to tolerate recommended levels of moderate to vigorous physical activity.[40,47] Interestingly, less active youth may actually find themselves at an advantage with regard to trainability compared with their athletic peers because great initial enhancements of motor performance skills are found in young, untrained subjects after a resistance training intervention.[12,71,116]

By the same token, a recent meta-analysis reported that female athletes have significantly larger training-induced improvements in sport-specific performance than male athletes, suggesting the trainability of girls may be higher compared with boys.[71] With baseline neuromuscular performance levels lower on average for female athletes,[50,56,104] observed gains secondary to resistance training, such as improved vertical jump height and lower extremity biomechanics,[104] have also been found to be higher among female athletes compared with males.[75] Furthermore, another meta-analysis on the effects of preventative neuromuscular training intervention on ACL injury risk in young female athletes named “strengthening,” in addition to proximal control exercises and multiexercise genres, as one of the most efficacious injury prevention interventions for this at-risk population.[122] In addition to reducing injury risk among young girls by up to 68%,[122] resistance training programs improve skeletal growth,[11,15] induce a protective “neuromuscular spurt,”[38,104] and improve physical self-perception,[83] all of which may increase the likelihood of trained girls remaining physically active in the long term.

PHYSICAL ACTIVITY RATES AND PHYSICAL LITERACY

More than 60 million US youth participate in organized sport activities,[109] with 27 million kids between the ages of 6 and 18 years active in team sports.[6] However, there is growing recognition that the number of children and adolescents classified as having EDD by not engaging in the minimum recommended amount of physical activity is increasing, beginning as early as age 6 years.[37,60,126] A recent survey of sport participation rates by age, sex, and income level revealed the percentage of youth participating in “high-calorie burning activities” a minimum of 151 times per year has fallen since 2008 from 30.2% to 26.6% for children aged 6 to 12 years and from 42.7% to 39.3% among adolescents.[6] Thirty percent of youth discontinue participation in at least 1 sport club annually,[25] and up to 70% will quit sports all together by age 14 years.[30]

Participation in organized sports alone does not guarantee the recommended amount of moderate-to-vigorous physical activity.[42,70,125] Only 24% of youth sports participants were able to meet the moderate-to-vigorous recommendation during team practice, as more than 55% of time can be spent standing in line and receiving verbal instruction.[70] Comparable to the “active couch potato” classification in adults, which identifies an individual who sits long hours despite meeting physical activity recommendations, a rising number of young athletes who remain sedentary outside of all sports practices can also be diagnosed with EDD.[110] Interestingly, a large percentage of children and adolescents with EDD actually are participants in registered youth sports.[45]

At the other end of the activity spectrum, young, elite-level athletes often train year-round, intensely, in 1 sport at the exclusion of all other sports. These athletes are *specializers*.[63,64,86] They are *early specializers* if they meet these conditions prior to 13 years of age.[48] Clear data regarding the number of children specializing early in 1 sport are not available at this time,[48] though there is evidence of increased early sport specialization in the rising number of year-round select leagues for preadolescents.[63,95]

This dichotomy of physical activity among youth has resulted in declining free play physical activity.[8,43] Children and adolescents benefit immensely from unstructured physical experiences, such as child-driven deliberate play, which is any intrinsically motivating sporting activity,[23] and free play.[5] Deliberate play and free play allow early sport specializers to perform movements different than their sport-specific skill set and also foster creative thinking.[42] For those who are not early specializers, physically oriented free play provides an opportunity for motor skill acquisition during the stage of development that is crucial for children to “invest” in the exploration and learning of a broad range of fundamental movement skills. These skills will serve as strong foundations for

Figure 3. Integrative neuromuscular training.

more advanced movement skills later in life and protect them from physical activity–associated injuries throughout development.[65,77,101] Free play can also increase levels of autonomy, motivation, and enjoyment of physical activities by allowing children to explore movement patterns and receive immediate gratification not associated with winning or losing.[23]

A particularly susceptible population that is of special interest to sports health professionals is female adolescents. Despite an explosion of sports participation rates after the passage of Title IX,[108] girls are less active than boys, regardless of race and ethnicity.[29] Girls tend to enter sports at a later age than boys, and by 14 years of age, girls are dropping out of sports at 2 times the rate of boys, demonstrating a narrower window of opportunity for girls in organized sports.[115] Within a culture of diminishing free and deliberate play, young girls are particularly at risk for poor physical literacy.

CURRENT RESISTANCE TRAINING RECOMMENDATIONS FOR YOUTH

For sports health professionals, injury prevention remains an evolving science. Yet, an ample amount of research exists supporting resistance training as a beneficial activity to optimize long-term health and wellness of youth. Therefore, resistance training has been classified as an essential component to youth physical development and a fundamental element of sports medicine.[42] Accordingly, the development of guidelines for resistance training for children and adolescents is a recent priority.[17,35,42,72] The initiation of resistance training serves as a valuable supplement to the recommended exploratory free play and deliberate play during early childhood[73] and accelerates the development of a functional foundation of strength,[42] optimizing performance[14] and reducing injury risk during sport sampling in childhood[118] and possible specialization after adolescence.[1,41]

Timing of Strength and Resistance Training Initiation

Youth not exposed to resistance training at a young age will inevitably need to address neuromuscular deficiencies to enhance athletic development or potentially in rehabilitation after an injury.[14,31,32,51,128] With concerns regarding the safety of resistance training in children as young as age 6 dispelled,[73,87,90] attention has turned to the age or maturation stage at which it becomes necessary and/or advantageous to intervene with resistance training programs. In concurrence with the IOC[14] and other advocates of long-term athlete and youth development models,[73,75] many experts agree that earlier participation is better.[42,43,45,105] A child may begin participating in a structured resistance training program when he or she is emotionally mature enough to receive and follow directions and demonstrates proficient levels of balance and postural control, which typically occurs around ages 6 to 7 years.[67,75,105] Children demonstrate greater training-induced gains in strength[51,71,116] and motor skill performance[12] than adolescents. Prior to puberty, children demonstrate higher levels of neural plasticity[73,76] that render them more “pliable” to the acquisition of protective fundamental motor skills,[76] foundational strength,[14] and the desire to be physically active.[73] Children as young as 5 years have benefited from school-based resistance training programs.[3,15,80,81,84,85,88]

Training Prescription for Youth

Meta-analytical studies examining the effects of resistance training on performance in children and adolescents have addressed inquiries on dose-response relationships of training, including frequency, intensity, volume, and rest.[13,71] Significant positive correlation has been found between gains in motor performance skills and the mean intensity (%1 RM [repetition maximum]) of the training program,[12] suggesting that children and adolescents demonstrate greater improvements in running, jumping, and throwing performance secondary to greater exercise intensity (ie, 60%-80% of 1 RM). As such, the average resistance training program most effective in eliciting gains among youth consisted of 2 to 3 sets of 8 to 15 repetitions, with loads between 60% and 80% of 1 RM on 6 to 8 exercises.[13]

Of equal importance in the training prescription is an emphasis on physical literacy instruction. Physically literate youth perform exercises with enhanced technical ability, competence, and confidence.[42] Integrative neuromuscular training (INT) is a concept that emphasizes general and specific strength and conditioning activities to enhance both health- and skill-related components of physical fitness (Figure 3).[100] A cornerstone of INT is age-appropriate, qualified, and enthusiastic instruction tailored to meet a child’s needs, goals, and abilities.[75,100] This qualified instruction is necessary to facilitate the mastery of fundamental movements, and ultimately, maintain open pathways for all types of physical activity and promote the confidence and desire to stay physically active for life.[42]

Integration With Other Physical Activities

A combination of supervised, structured training and deliberate and free play can maximize a child’s ability, confidence, and desire to pursue athletic goals and physical activity in the long term.[7,23] Sports health professionals should adjust to the needs of today’s youth by advocating for and facilitating the improvement of programs such as school-based physical education and organized sports programs to incorporate resistance training, opportunities for free and deliberate physical play, and INT to foster the development of physical literacy.[42,45]

The National Athletic Trainers' Association position statement on the prevention of pediatric overuse injuries includes a recommendation for preseason and in-season training programs with a focus on strengthening of the lower extremities.[127] It also suggests that young athletes could benefit greatly from a general fitness program with a specific emphasis on strengthening 2 months prior to the onset of a sport season to avoid a rapid transition to higher levels of physical activity demands in training and competition.[127] This may be particularly important for athletes who adopt the "active couch potato" lifestyle.

When wisely scheduled into preseason and in-season sports training of the early specializer, the incorporation of an appropriately-designed resistance training program has the potential to reduce muscle imbalances due to repetitive motor patterns[73] and effectively keep the athlete healthy and involved in intense competition long term.[42] Of particular concern in early sport specialization is the week-to-week accumulation of high volume and frequency of training. In addition to sport sampling and free play, resistance training should be viewed not as an additional training session but as an alternative commitment in place of sport-specific training or competition.[75]

A convincing body of evidence has found that resistance training programs implemented in primary schools are effective in improving aerobic capacity,[36,89,92] strength,[2,12,34,36] and the acquisition of fundamental movement skills.[98] The continuity of quality school-based programs also shows potential to promote staying physically active for life, guarding against the potential regressions in training-induced strength and power gains seen during periods of detraining among youth.[39,42,61,117] School-based programs in the Netherlands have reduced sports-related injuries among children.[20,21] Primary school represents a potential sex-specific window for optimal implementation of training, as prepubertal girls are particularly sensitive to resistance training in standard physical education classes.[46,101] Sex aside, the advancement of resistance training activities in physical education, and particularly INT, within schools may be the best means of exposing children and adolescents to the protective effects of resistance training through qualified instructors.[100]

CONCLUSION

Resistance training integrated with free play and other structured physical activity training can provide protective mechanisms against injury and positive catalysts for the development of physical literacy to offset the impact of diminishing physical activity and early sport specialization among today's youth. Of highest priority are those children and adolescents at increased risk for insufficient physical and motor skill development including early sport specializers,[65] the growing population of children and adolescents who are not satisfying current health-related physical activity recommendations,[99] and young adolescent girls.[59,121]

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