May the Force Be with Youth: Foundational Strength for Lifelong Development

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Abstract

Today's youth are weaker than previous generations, and measurable reductions in physical fitness are beginning to emerge. Without targeted initiatives that recognize the foundational importance of resistance training, weaker children and adolescents may be more likely to experience the inevitable consequences of neuromuscular dysfunction and less likely to experience the pleiotropic benefits of exercise and sport. Early exposure to strength-building activities is needed to prepare today's youth for ongoing participation in varied physical activities throughout this developmental phase of life. The novel iceberg of physical development is a metaphoric image that illustrates the sequential and cumulative influence of muscular strength on motor skills and physical abilities. Efforts to enhance the physical capacity of youth should include resistive skills that improve basic movement patterns and enhance motoric competence. A shift in our conceptual thinking about youth resistance training is needed to alter the current trajectory toward physical inactivity and related comorbidities.

Introduction

Today's children and adolescents ("youth") are physically weaker than previous generations, and a vast majority are not accumulating at least 60 min of moderate to vigorous physical activity (MVPA) daily (1–3). Despite public health guidelines that recognize the potential physical, psychosocial, and cognitive benefits of MVPA, only one out of five adolescents meet international physical activity recommendations, which include aerobic and muscle-strengthening activities (4,5). Along with declining measures of cardiorespiratory fitness in children and adolescents (6), temporal trends indicate a steady decline in selected field measures of muscular fitness (*i.e.*, muscular strength, muscular endurance, and muscular power) in youth across the globe (7–9). Because a certain amount of force production (*e.g.*, propulsion during a jump) and force reduction (*e.g.*, landing from a jump) is needed to move and play skillfully, weaker youth may be less likely to accumulate at least 60 min of MVPA daily and more likely to experience functional limitations, activity-related injuries, and related comorbidities (10–12).

Measurable reductions in physical fitness are emerging, sport participation rates during adolescence are declining, and the medical and financial burden of activity-related injuries in young athletes are substantial (2,13,14). Developmentally appropriate interventions that recognize the foundational importance of muscular fitness are needed to prepare today's youth for the demands of rough and tumble play, vigorous exercise, and sports competition (11,15,16). Low levels of muscular strength during childhood tend to track into adulthood (17,18), and therefore weaker children may not simply "outgrow" strength deficits. An integrative approach that develops biomotor abilities including muscular strength, speed, and coordination is needed before youth become disinterested, disengaged, and disconnected from active play, recreational exercise, and sport activities.

The aim of this article is to discuss the interaction of neuromuscular factors that drive physical (in)activity in youth, illustrate the novel iceberg of youth physical development, and describe basic resistive skills that can be used to enhance health, improve fitness, and reduce injury risk. In this article, the term resistance training refers to an inclusive method of conditioning that involves the use of a wide range of resistance loads, different movement velocities, and varying training modalities, including body weight, free weights (barbells and dumbbells), elastic bands, weight machines, and medicine balls. As such, resistance training includes calisthenics, isometrics, circuit training, and advanced multijoint lifts.

Understanding Pediatric Dynapenia

The term dynapenia has traditionally been used to describe the loss of muscle strength that may increase the risk of physical dysfunction in older adults (19). Age-related declines in

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muscle strength and physical capacity have been linked to falls, disability, morbidity, and mortality (20). Yet the life-changing consequences of dynapenia are not limited to older adults or elderly patients with clinical conditions. Muscular weakness early in life predisposes youth to the inevitable consequences of muscle disuse, neuromuscular dysfunction, and physical inactivity (10,21,22). Even young athletes with strength deficits may be more likely to suffer a sport-related injury and less likely to reach elite level performance (23–25). Of interest, population handgrip muscle strength has been found to be an important predictor of summer Olympic games medal success in low-, middle-, and high-income countries (26).

Pediatric dynapenia can limit a child's ability to perform fundamental movement skills (FMS) proficiently and engage in exercise and sport activities with confidence, competence, and motivation (27–29). FMS include locomotor (*e.g.*, jumping), object control (*e.g.*, kicking), and stability (*e.g.*, balancing) skills that are recognized as building blocks for more advanced, complex movements (30). "Fragile" youth with strength deficits and poor movement skills may avoid nonessential physical activity to guard against failure, humiliation, and negative health outcomes, which can reduce participation in MVPA even further (16,31,32). Data from a cross-sectional study found almost 90% of children whose actual motor competence was below average did not accumulate at least 60 min of MVPA daily (33). These findings are consistent with others who reported that children with lower baseline motor performance scores maintained a stable trajectory of little to no sport participation over a 5-year study period (34).

Weaker youth increasingly engage in sedentary activities such as watching television, playing video games, or using smart phones, which are related to poor health outcomes and increased health care costs (35–37). Fraser et al. (38) compared the contributions of muscular strength measured in youth, young- and mid-adulthood with prediabetes or type 2 diabetes in midlife. They found that grip strength at each time point was equally associated with prediabetes or type 2 diabetes in mid-adulthood, with weaker participants at increased odds of poor cardiometabolic health across the life course (38). Data from a prospective cohort study of 1.2 million men found a strong association between muscular weakness during adolescence and disability 30 years later, with the strongest associations found for nervous system and psychiatric conditions (39). Others found that muscular weakness in adolescent males was inversely associated with cardiovascular disease events in middle age, independent of cardiorespiratory fitness (40).

These findings underscore the need to develop healthy, capable, and resilient youth who are able to adapt to difficult situations, withstand the demands of MVPA, and cope with life challenges (24). Because being physically strong is integral for developing and maintaining a state of resilience across the lifespan (41,42), it seems prudent to identify individuals with strength deficits early in life to reduce the burden of poor health outcomes later in life. Cut-points of muscle strength have been proposed to identify impairments in physical performance in older adults (43), and it seems similar strategies could be used to identify "at risk" youth (44). The estimated long-term economic impact of children's physical inactivity in the United States is $1.1 trillion in direct medical costs and $1.7 trillion in lost productivity (37). Without life course interventions that restore the loss of muscle potential, health care costs for adults living with muscular weakness are projected to increase (45,46). Contemporary analyses of physical inactivity should recognize the critical importance of managing dynapenia in children and adults to reduce adverse health effects and the economic burden of muscle disuse (Fig. 1).

Divergence in Physical Capacity

Without early exposure to inherently enjoyable strength-building activities, current trends in MVPA will likely continue unabated as weaker youth fail to gain confidence and competence in their physical abilities (16–18). Because the decline in MVPA begins to emerge during the primary school years (about the age of 7 years) (47), interventions that prepare youth for a lifetime of physical activity should start before adolescence. Youth who do not have ongoing opportunities to improve their muscular strength may not develop the requisite physical capacities that are needed to tolerate high loads associated with exercise training and sport competition (27,48,49). This view is supported by meta-analytic data that show youth should build a foundation of strength before participating in power training activities (27).

Most children and adolescents will develop a minimal level of muscular fitness with periodic bouts of physical activity. However, regular participation in structured interventions that include resistance training (*e.g.*, physical education classes, youth fitness programs, preparatory sports conditioning) may be needed to develop robust physical capacities that optimize performance and protect against injury (50–52). Without such interventions, youth with strength deficits may be limited in their ability to generate force and explore context-specific solutions to exercise- and sport-related challenges (12,27,51). Both underweight and overweight children have been found to have impairments in muscle function, which may impact their ability to perform motor skills proficiently and engage in sport activities (53,54). An analysis of resistance-training-based sports injury prevention programs found a dose–response relationship between resistance training volume and intensity and sports injury risk reduction in participants aged 12 to 40 years (25). Of note, a relative 1 repetition maximum squat of 105% of body mass was established as the best cut-off value to distinguish high versus low risk of traumatic knee injury in adolescent female athletes (23).

Children and adolescents who enhance their muscular fitness with interventions that improve their ability to produce force may be better prepared for ongoing participation in exercise and sport activities (27,55,56). Findings from a systematic umbrella review of 14 meta-analyses found that resistance training has the potential to enhance proxies of muscular fitness in children and adolescents beyond a level achievable with growth and maturation (57). As youth enhance their muscular strength, they can build their strength reserves, which may be used (or not) to meet the workload demands of vigorous exercise and overcome unpredictable stressors on the sports field. Young athletes who continue to participate in more advanced resistance exercise programs and gradually develop their physical capacities can dramatically improve their ability to produce force, reduce force, and tolerate the workload demands of sports practice and competition (27,51,58). Conversely, those who do not participate in strength-building activities may regress along the physical capacity continuum as their muscular strength and load

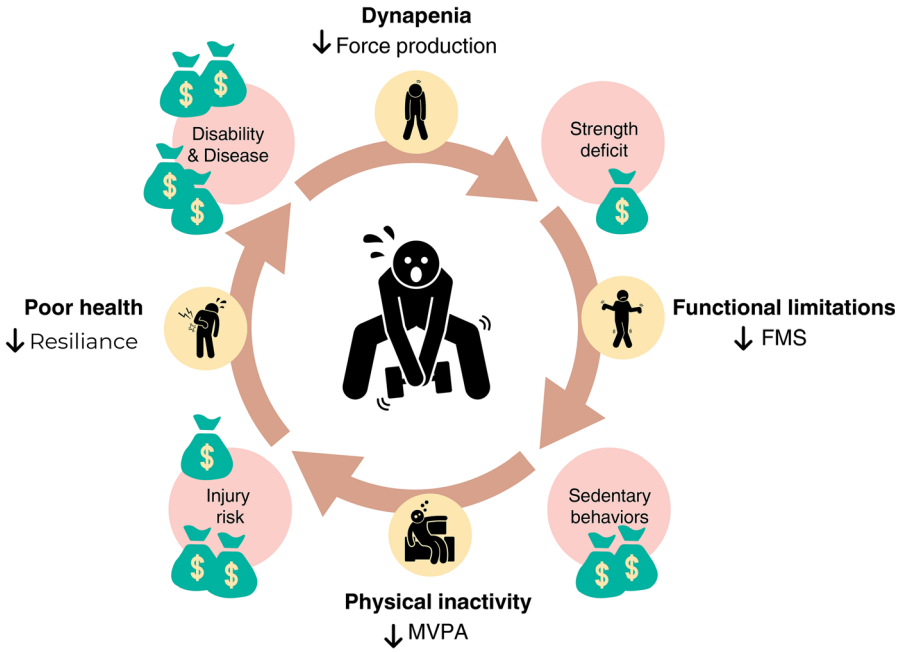

Figure 1: Hypothetical representation of the costs and consequences of dynapenia throughout the life course.

tolerance begin to wane (Fig. 2). The gap between stronger and weaker youth will likely widen across developmental time without school- and community-based interventions that target strength deficits and build strength reserves (17,18). Lifestyle factors including sleep and nutrition can moderate the trajectory toward physical development or physical dysfunction (24).

Underrated Benefits of Youth Resistance Exercise

In addition to measurable improvements of muscular fitness (57,59), regular participation in youth resistance training can lead to favorable changes in musculoskeletal health, cardiometabolic health, and mental health (60,61). Evidence supports muscular strength as a useful marker of skeletal health during development and maturation (62). High-effort resistance training (along with adequate calcium intake) can be a powerful osteogenic stimulus in youth with enduring skeletal benefits years after program completion (63,64). Higher levels of muscular fitness are associated with lower obesity and reduced cardiometabolic risk in youth (65), with evidence suggesting that low muscular fitness is causally related to the development of unfavorable levels of insulin resistance (61). Stronger youth also may be less vulnerable to mental health

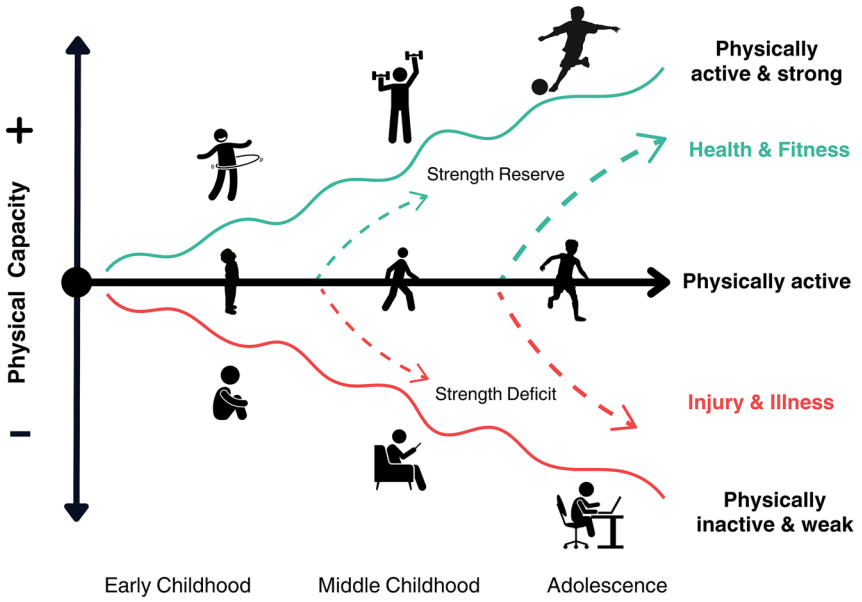

Figure 2: Divergence in physical capacity among youth with varying levels of muscular strength.

disorders (42,66). Meta-analytic data indicate that resistance training can have a positive effect on some aspects of psychological well-being in youth (60).

With qualified instruction and technique-driven progression, resistance training has the potential to improve skill-related components of physical fitness, including sprinting, jumping, throwing, and agility (change of direction) (55,57,67). Because resistance-training-induced neural adaptations (*i.e.*, improvements in motor unit recruitment, firing, and coordination) can influence movement patterns in youth, regular participation in well-designed resistance training programs is likely to have a positive effect on FMS performance (57,68). These findings underscore a potential synergistic adaptation whereby training-induced gains in muscular fitness can reinforce improvements in FMS and increase participation in MVPA throughout this developmental phase of life (68–70). Emerging evidence supports a link between muscular fitness and physical activity, particularly vigorous physical activity and organized sport in children and adolescents (56).

Ongoing participation in resistance training that includes periodic bouts of higher-intensity and higher-volume lifting can enhance the load capacity of young athletes and consequently facilitate desired adaptations in musculoskeletal supporting structures (51,71,72). Stronger adult athletes are better prepared to tolerate higher workloads and larger week-to-week changes in workload than weaker athletes (73). Likewise, well-developed younger athletes with higher levels of muscular fitness may have the physical capacity to tolerate a wide range of workload demands effectively (25,71,74). Meta-analytic data from anterior cruciate ligament (ACL) injury reduction programs (which included resistance training) found an overall 50% reduction in the risk of all ACL injuries in all athletes and a 67% reduction for noncontact ACL injuries in females (75).

In light of ongoing challenges associated with adherence to injury reduction programs in youth athletes (76), early exposure to resistance training may facilitate the establishment of desired behaviors and set the stage for even greater gains in physical fitness and sport performance later in life (12,74,77). As youth learn how to perform muscle-strengthening exercises skillfully and gain confidence in their physical abilities (*i.e.*, self-efficacy), they may enhance their resistance training skill literacy as they explore different types of resistance training, learn from instructors and peers in a supporting setting, and feel good about their accomplishments (78,79). As such, resistance training skill literacy is not just about lifting weights for a prescribed number of sets and repetitions. Rather, resistance training skill literacy is an inclusive concept of knowledge, understanding, and skill performance that evolve over time to maintain interest in strength-building activities among participants with different needs, goals, and abilities (78).

All youth, especially those who are the least active, can benefit from regular participation in integrative fitness programs that include resistance training (12,80). Inactive youth are often unwilling and unable to perform prolonged periods of aerobic exercise, and participation in physical activity should not begin with competitive sport. Therefore, physical activity promotion efforts should include strength-building activities owing to its potent skill-building, performance-enhancing, and injury-reducing effects (3,57,74). An acute bout of resistance training that included body weight, medicine ball, and battling rope exercises resulted in an exercise intensity of 61% to 92% of maximum heart rate in healthy children (81). These findings suggest that well-designed resistance training programs can enhance neuromuscular fitness and contribute to the recommended 60 min or more of MVPA daily. The underrated benefits of resistance training are becoming increasingly evident, including managing cardiometabolic risk, promoting MVPA, reducing sports-related injuries, and improving mental well-being (22,25,42,56) (Fig. 3).

Iceberg of Youth Physical Development

Years ago, Seefeldt (82) proposed that youth with poor movement skills would not be able to break through a so-called "proficiency barrier" and, therefore, would be limited in their ability to develop more mature movement patterns. Although empirical evidence supports Seefeldt's proficiency barrier hypothesis (33,83), it appears that weaker youth with poor resistive skills may be unable to overcome a strength barrier that would allow them to perform movement skills proficiently. Because a prerequisite level of muscular strength is needed to perform a movement task skillfully (84), weaker youth may be limited in their ability (both real and perceived) to engage in MVPA with confidence, competence, and motivation (3,16). At present, global levels of FMS in children are "below average" despite the expectation that competency in these basic skills should be achieved by the age of 7 years to participate successfully in context-specific physical activities (85).

Childhood is an important period to experience the joy of moving, learn FMS, and maintain healthy developmental trajectories for future MVPA (18,34,86). The novel iceberg of physical development is a metaphoric image that graphically illustrates the sequential and cumulative influence of muscular strength on FMS and physical abilities (Fig. 4). Involuntary reflexes such as rooting and sucking and rudimentary skills that involve locomotion and manipulation provide the basis for establishing requisite levels of resistive skills as youth acquire basic movement patterns and achieve independent function. As one develops physically, more advanced movement skills that are considered foundational for ongoing participation in active play, exercise, and sport activities begin to emerge (87). The strength barrier is placed at the surface of the iceberg (the "water line") because what is seen on the playing field is influenced by less obvious physical abilities and resistive skills developed earlier in life. As such, muscular strength can be considered a limiting factor of physical development as infants lift their body mass (*e.g.*, tummy time), toddlers grasp an external object (*e.g.*, rattle toy), preschoolers engage in outdoor activities (*e.g.*, climb a jungle gym), and children participate in active play, exercise, and sport. Importantly, ongoing participation in resistance training is needed throughout the life course to stay above the "water line" and avoid sliding down the iceberg toward a lower level of physical function.

Without adequate levels of muscular strength and neuromuscular dexterity, children may be predisposed to dynapenia and associated changes in musculoskeletal structure and function (10,21,88). Conversely, youth with adequate levels of muscular strength may be more likely to engage in vigorous physical activities, tolerate feelings and sensations associated with sport competition, and optimize gains in other important components of physical fitness (3,16,56). In support of these observations, higher levels of muscular fitness have been found to be one of the best predictors of MVPA in 5- to

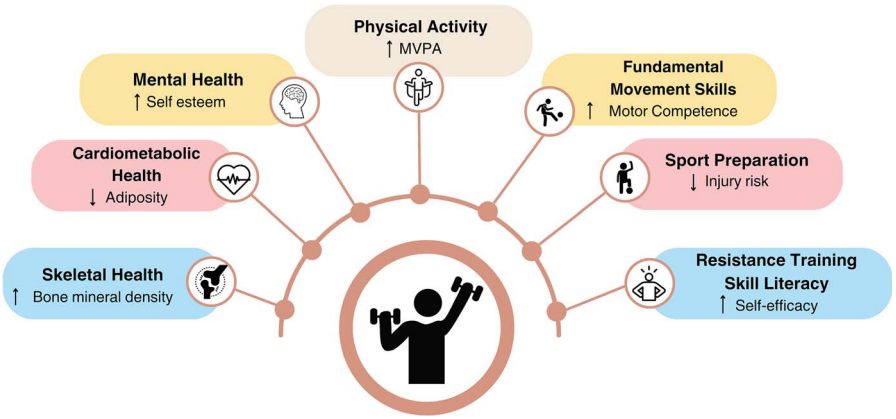

Figure 3: The underrated benefits of youth resistance training.

10-year-old children (31). From a developmental perspective, stronger youth who move with confidence, competence, and motivation appear better prepared to sustain participation in MVPA across the life course (12,89). Contemporary insights into long-term physical development underscore the importance of resistance training for health improvements, performance enhancement, and injury-risk reduction (24,48,77).

Basic Resistive Skills

The importance of enhancing muscular strength to improve physical fitness was recognized by prominent leaders in early "gymnastics-oriented" physical education (90). However, current youth guidelines that focus on the quantity of MVPA accumulated throughout the day overshadow the importance of strength-building activities (3). Efforts to enhance the physical capacity of youth should include basic resistive skills (*e.g.*, pushing, pulling, and rotation/anti-rotation exercises) that prepare youth for more advanced forms of exercise and sport training (Fig. 5). In light of further reductions in selected measures of muscular fitness during the COVID-19 pandemic (91–93), a nuanced approach for integrating resistance training into fitness and sport programs is needed. Notably,

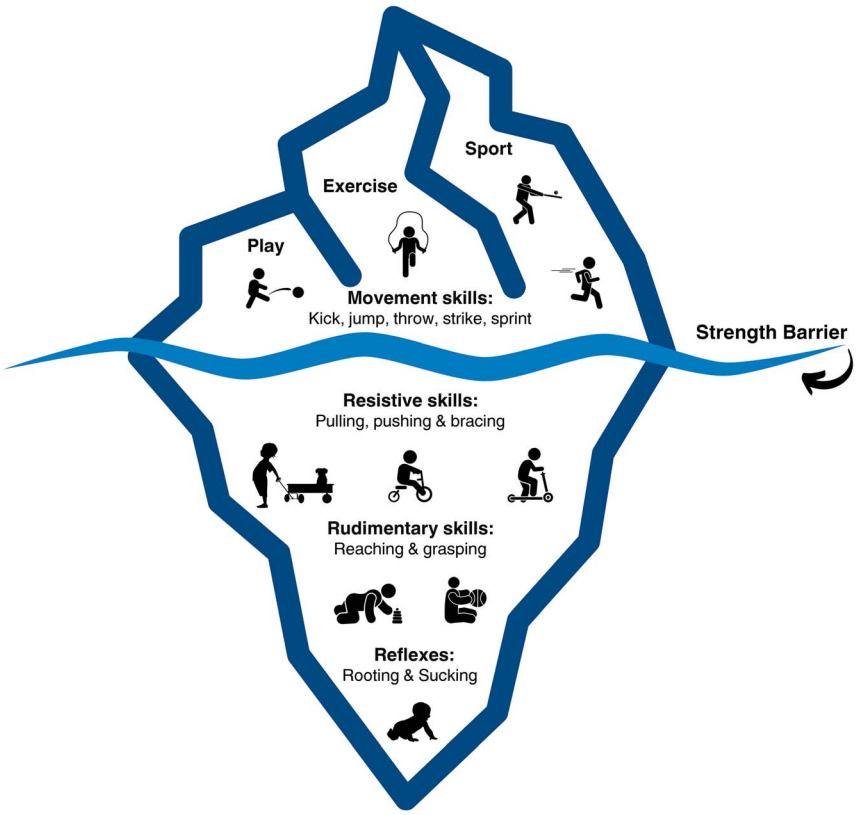

Figure 4: The iceberg of physical development.

misperceptions associated with youth resistance training still persist (94), and participation in muscle-strengthening activities among adolescents is falling short of expectations (95,96).

Resistance training should be integrated into school- and community-based programs to provide an important opportunity for all youth to engage in physically effortful and mentally engaging activities that enhance both health- and skill-related components of physical fitness (52,97). For example, young children could perform animal-like movements that challenge their body to function as a unit as they "frog squat," "crocodile plank," and "gecko lunge" (80). Child-friendly animal movements allow one to creatively paint a picture of the desired strength-building movement pattern while placing an emphasis on having fun. Resistance training with medicine balls, elastic bands, and battling ropes can be incorporated into a youth fitness circuit and individually progressed so each participant can start at a safe level and gradually progress as warranted (98). Young athletes can perform a warm-up during training sessions that includes strength-building exercises to improve neuromuscular dexterity and reduce injury risk (99). Many 5- to 7-year-olds are already involved in sport activities, and it is reasonable they also could benefit from developmentally appropriate strength-building activities (97).

The timing of brain development and its associated neuroplasticity make the early years of life an ideal time to practice basic resistive skills, learn to control posture, facilitate coordination, maintain tempo, and navigate movements efficiently (12,78). Targeting basic resistive skills that allow for movement exploration can help to develop the requisite abilities that are needed to progress to more advanced, complex movements over time. The periodic manipulation of resistive skills as well as other program design variables (*e.g.*, sets, repetitions, rest intervals) can optimize strength gains, maintain adherence, and reduce injury risk (100). Qualified instruction, technique-driven progression, and peer support can help youth progress along the resistance training skill literacy continuum as they model desired behaviors and perform foundational movements skillfully. Detailed program design considerations are beyond the scope of this article but are available elsewhere (101).

Conclusions

Today's youth are physically weaker than previous generations and more susceptible to dynapenia and its consequences (21). Sustained reductions in muscular fitness can have significant public health consequences in terms of premature morbidity and mortality (102,103). These observations underscore the importance of enhancing muscular fitness early in life before youth possibly develop functional limitations, suffer activity-related injuries, and experience costly health conditions. If youth are not exposed regularly to interventions that include strength-building activities, they will be less likely to develop the requisite confidence and competence in their force-generating physical capabilities that are needed for ongoing participation in active play, recreational exercise, and competitive sport. A shift in our conceptual thinking about

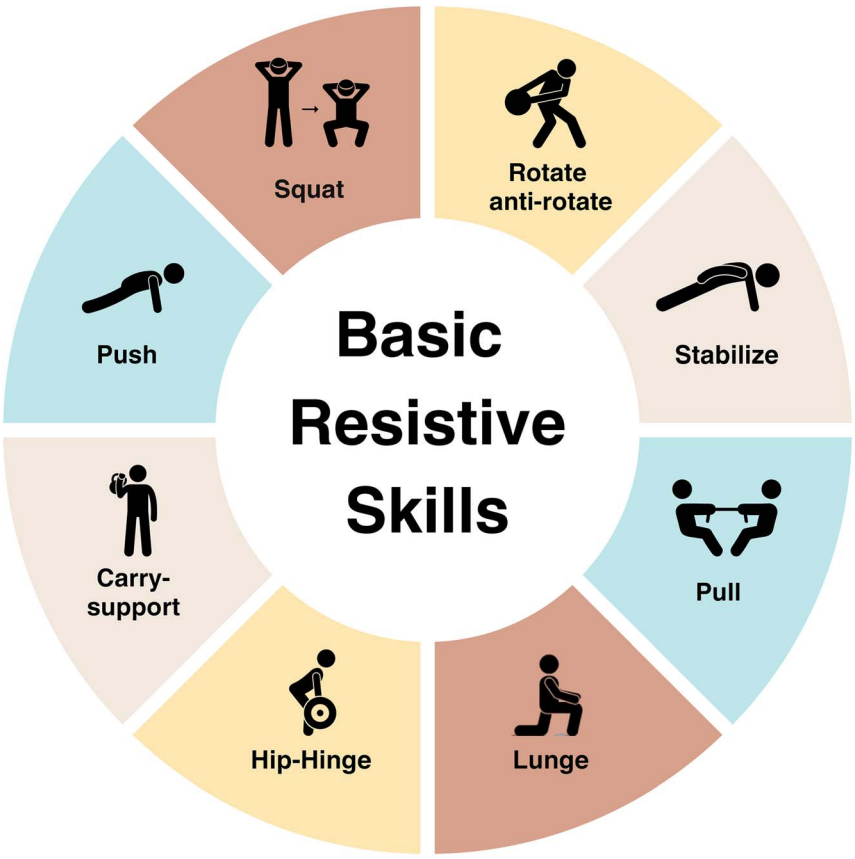

Figure 5: Basic resistive skills.

muscular fitness is needed because established levels of physical inactivity will become more difficult to change without interventions that recognize the foundational importance of resistive skills right from the start.

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