Training the Developing Brain, Part I: Cognitive Developmental Considerations for Training Youth

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Abstract
Based on the fundamental principles of pediatric exercise science and developmental physiology, childhood provides a critical window to develop the physical readiness of youth through age-related training programs that are designed purposely to teach and reinforce fundamental movement skills to enhance preparedness for physical activity and sport. Successful implementation of developmental programs requires age-related instruction by qualified professionals who understand the physical and psychosocial uniqueness of children and adolescents. An understanding of the interaction of physical and cognitive development is needed to design and implement training strategies that optimize training outcomes. Regular training with structured and integrative modalities throughout the developmental years as part of physical education, recreation, and sports practice can improve athletic performance while reducing common sports-related injuries and can facilitate the adoption of healthy lifestyles throughout adulthood. In this commentary, we outline cognitive developmental considerations in youth that may influence the design and implementation of training programs aimed at optimizing motor skill development in youth.

Introduction
Participation in organized youth sports has seen a dramatic growth over the past decade (53). There has been a 21% increase in the number of young athletes participating in sports in the United States that has now risen to an estimated 30 to 40 million youth (2,29,45). Furthermore young athletes are initiating training for organized sports competition at earlier ages. This trend may stem from increased competition to make teams or from misinformed parents who encourage their child to specialize early; assuming specialization in sports is the key to their child’s future athletic success. The escalation of early competition and sports specialization combined with the rise in total participants is associated likely with the disturbing increase of sports-related injuries in young athletes (1,32,47).

The interest from parents, coaches, and health care providers to help youth enhance sports performance has fostered a concomitant growth in youth strength and conditioning, performance enhancement, and injury prevention programs in fitness centers, private training facilities, and health care organizations (50). It is warranted that young athletes who wish to participate in competitive sport are prepared adequately for the physical and cognitive demands of competition and physical activity. Participation throughout the growing years in structured activities that are designed purposefully to enhance both general physical fitness (i.e., endurance, strength, power, and flexibility) and specific skill sets associated with physical fitness (i.e., agility, balance, coordination, and reaction time) has been proposed as an ideal mechanism to reduce the risk of activity-related injuries and to promote continued involvement in sports and recreational fitness activities (4,48). Based on the fundamental principles of pediatric exercise science and developmental physiology, childhood may provide a critical window to develop the physical readiness of aspiring young athletes through age-related training programs that are designed purposely to

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1537-890X/1205/004-310
Current Sports Medicine Reports
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teach and reinforce fundamental movement skills to enhance preparedness for sport (27,28,63).

However, considering the widespread age range of youth that are involved in sports training programs and athletic competitions, it is important for coaches and trainers to be cognizant of their training instruction and feedback methods. The effectiveness of these methods is influenced by the individual participant’s developmental maturation and prior learning experiences. Particularly the role of cognitive development and its interaction with physical and motor development must be considered to design appropriately and maximize strategically the benefits of training program outcomes for youth. The purpose of this review is to outline cognitive developmental considerations for youth that can influence the design and implementation of training programs aimed at optimizing motor skill development, promoting continued involvement in physical activity, and ultimately reducing the risk of physical activity-related injuries.

Integrated Neuromuscular Training

Integrated neuromuscular training is a conceptual training model that utilizes a developmentally appropriate conditioning program that incorporates general (e.g., fundamental movement skills) and specific (e.g., exercises targeted to motor control deficits) strength and conditioning activities to enhance muscular fitness and motor skill performance that ultimately influences sport performance and reduces injury risk in youth (50,51,57). Integrated neuromuscular training activities integrate resistance training, dynamic stability training, core-focused strength development, and plyometric and agility exercises. These activities are focused to promote development of neurocognitive processing and visual-motor abilities, which are improved further by a qualified instructor’s appropriate delivery of corrective feedback for identified deficits. Potential benefits of youth strength and conditioning include increased muscle strength, power and endurance, improved body composition, increased bone mineral density, increased cardiorespiratory fitness, improved blood lipid profile, improved insulin sensitivity in overweight youth, improved motor performance skills, enhanced sports performance, increased resistance to injury, enhanced mental health and well-being, and simulation of a more positive attitude toward lifetime physical activity (21,50). The cornerstone of integrated neuromuscular training is an age-related exercise prescription based on the fundamental principles of pediatric exercise science and instruction and supervision by qualified professionals who genuinely appreciate the physical and psychosocial uniqueness of youth (Fig. 1) (22,50,57).

What Is Age-Related Training?

Due to the rapid rate of growth and maturation of the nervous system and the sensory and perceptual abilities of children, it is imperative to recognize and strategize training interventions based on age-related guidelines. Similar to the instruction of arithmetic and language arts in academic settings, instruction of physical activity and exercise technique must utilize age-related strategies and tools to optimize coherence and outcomes. “Age appropriate” in most contexts typically refers to chronological age. However, chronological age only denotes the number of years a person has lived and does not take behavior, biological maturation, or intellectual capabilities into account (70). Biological age, on the other hand, is determined by physiology as opposed to chronology and accounts for changes in physical structure such as height, body mass, and secondary sex characteristics (70). Training age represents an individual’s prior experiences and learning of task-related activities; this development plays a significant role in one’s ability to learn new related tasks to execute proper exercise mechanics and technique (57). Training age can provide a theoretical construct that should guide the practitioner in selecting appropriate exercise criteria. While a child’s training age is particularly important, considerations of cognitive development can be the key determinant to a child’s ability to perform simple and complex movement patterns with energy, vigor, and confidence. It may be that a child’s cognitive-perceptive-motor interactions that are necessary to perform complex movements should be the primary determinant of how to initiate the individualized programming of integrative neuromuscular training. Cognitive age comprises one’s cumulative ability to execute mental tasks of differing complexity, which requires a combination of attention, alertness, memory, comprehension, application, judgment, and problem-solving skills (13,31,62). All of these “age-related” factors that are linked to childhood development affect the design and implementation of training programs, which influence the potential to improve fundamental movement patterns and ameliorate functional deficits indicative of injury risk in children.

In this article, we propose that exercise training protocols for children are limited often by their consideration of solely chronological factors without sufficient attention to cognitive development or training age. The ultimate limiting factor is not one’s chronological or biological age but rather one’s cognitive ability to focus, take direction, and execute a task to gain competence and confidence in one’s abilities (57). These factors are interdependent and must be considered together when strategizing instruction and feedback for neuromuscular training at various ages. However, the importance of matching a child’s cognitive age and training age cannot be underestimated because it sets the foundation for physical development programming and ultimately determines the success of programs aimed to promote healthy behavior, enhance physical fitness abilities, and reduce injury risk of youth (48).

It is important to understand that development is sequential in nature, and this sequence of maturation and development should be the basis for developing a training strategy. The sequence of maturation can be identified through the achievement of neurodevelopmental milestones. While it is unlikely that a single gene encodes for motor performance ability in children, there may be genetically linked nervous system thresholds that differentiate between a child’s ability to exploit critical maturation thresholds for the development of dynamic interceptive actions (i.e., physical acts of the body or an implement must be moved into the right place at the right time in order to accomplish a task) (52). Children and adolescents likely have a genetically predetermined range of physical ability potential. Hence integrative neuromuscular exercise

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progressions should be designed purposefully in relation to a child’s physical and cognitive development, while care should be taken to ensure that the progressions do not push beyond one’s physical limits (53).

Genetic factors are key determinants of cognitive development; however environmental factors also play a significant role. Environmental factors are especially important in cognitive development and learning of perception/action relations within a specific environmental task. Specifically, with regard to psychosocial behavior, this constitutes the development and refinement of communication and language abilities (30). It is required that an individual passes this basal level threshold (e.g., acquisition of language and communication skills that influence the child’s ability to train at increasingly higher levels of challenge) in order to benefit from training. Acquisitions of necessary neuromotor skills are required in order for an individual child to attain thresholds relative to the ability to comprehend instructions and then physically execute a task. For example, appropriate neuromotor thresholds must be achieved before a toddler can learn to walk. Then an additional threshold must be passed before this young child can learn more advanced movements such as running and jumping (16,39). These developments may not always occur at the same chronological age in individuals. However normal children progress through a similar sequential development process.

It is important to recognize that an individual’s ability to reach one developmental threshold at an earlier than average age does not guarantee that an individual will reach all developmental thresholds early (16,39,62). The initiation of integrative training programs that are matched with cognitive abilities early in youth can help increase training age that is vital for children and adolescents whose motor capabilities are highly “plastic” and responsive to training. Research demonstrates that significant, amenable benefits can be gained from training age-appropriate interventions (57). Quality physical education or sport programs that are designed purposely to consider both cognitive and developmental abilities are taught often by master teachers and experienced coaches. Outlined below are key strategies that may help to enhance the delivery and implementation of integrative neuromuscular training programs by other

Figure 1: Qualified education and instruction support the complex programming components for effective implementation of integrative neuromuscular training. (Reprinted from Myer GD, Faigenbaum AD, Clark JF, Ford KR, Best TM. Train the developing brain: integrative neuromuscular training to optimize motor skill development in youth. Med. Sci. Sports Exerc. 2013; Submitted for Publication. Used with permission.)
qualified professionals who work with youth in sports facilities and medical centers.

It is important to note that physical growth and neuromuscular development are gradient in nature and are influenced by both genetic factors and environmental stimuli (53). Differences in training strategy for various ages should not be taken as clear-cut rules but rather as general guidelines that should be utilized as a base plan to adapt to the demands of individuals. It has been proposed that there is a high degree of plasticity in neuromuscular development during preadolescence (53). This concept combined with an appropriately timed implementation and progression of integrative neuromuscular training may allow for strengthened physical, mental, and social development, which may contribute favorably to their physical fitness and athleticism later in life (52). Specifically the behavior of a child emerges via an interconnected dynamical system that is composed of a network of critical subsystems (e.g., cognitive, sensory, emotional, perceptual, and motor control) that optimally evolve throughout the time course of childhood development (33,51). Over time, the child learns to organize efficiently these subsystems, and as described in classic motor development theory, the skill acquisition process links the relationships among neural codes and movement patterns (71). A similar process of this phenomenon is seen in the developing brain via synaptic pruning (43,75). Brain development during childhood likely corresponds to the time when these subsystems are developing optimally, and/or rapidly changing, for the formulation and fine tuning of specific skills during skill acquisition (51,72). Therefore specific considerations to cognitive development and maturation of neuromuscular development in youth can support the formation of specific strategies used to design and instruct integrative neuromuscular training programs. When these skills are learned at an early age, similar skills may be learned more efficiently because they can use complimentary pathways that exist from that earlier training.

**Integrative Neuromuscular Training across the Developmental Spectrum**

One common outlet for children and adolescents to increase physical activity is through sports and recreational fitness programs. Compared with inactive youth, children and adolescents who are physically active demonstrate increased musculoskeletal strength, enhanced cardiorespiratory function, and improved metabolic health (41,67,73). As previously described, integrative neuromuscular training is a conceptual training model that utilizes a developmentally appropriate conditioning program instructed by qualified professionals who understand the physical and psychosocial uniqueness of children and adolescents. Accordingly integrative neuromuscular training incorporates general (e.g., fundamental movement skills) and specific (e.g., exercises targeted to motor control deficits) strength and conditioning activities to enhance muscular fitness and motor skill performance that ultimately influences performance and reduces injury risk in youth (50,51,57). Therefore integrative neuromuscular training programs provide a mechanism to train youth across all stages of skill and development and reduce their risk factors for injury during sport and recreation.

Well-designed sports practice sessions can be associated with increased energy expenditure and enhanced aerobic and muscular fitness in participating athletes compared with non-sports participants. This makes sport participation a viable option to improve physical fitness and contribute to the daily activity levels of children and adolescents. While sport participation provides a mechanism to increase physical activity levels in youth, sports participation without adequate preparatory conditioning may increase risk of injury (9,49,59). A drastic and sudden deficit in physical activity from chronic pain or acute injury can initiate a “negative spiral of disengagement,” whereby reduced physical activity leads to diminished cardiorespiratory fitness, increased adiposity, and poor health outcomes (66). Preliminary data from our laboratory indicates that young girls who reported a new knee injury demonstrated significantly greater increases in body mass index z-score and body fat percentage relative to their uninjured peers during the year of the reported injury (49). In addition, youth who cease sport participation during adolescence may be at the highest risk of metabolic disease due to an inactive adult lifestyle (24). Ultimately sports-related injury to children may initiate a vortex of detrimental health outcomes, making them less active during adolescence, which may manifest into sedentary lifestyle habits and an increased risk of obesity and diabetes during adulthood (5,6,19,20,25,26,50,52,65).

Based on Bernstein’s phases of motor learning, skill acquisition in sport requires both learning and adaptation that encompasses three levels: coordination, control, and proficiency (8,42). In this context, coordination arises as a child learns to exploit the many available relations between the neuroanatomical and neuromuscular properties of their body and the physics of the environment within they move. During this stage of exploration, the child explores and discovers their systems’ degrees of freedom (e.g., ranges of their physical movement and neuromuscular control) (33). Control arises through the management, or optimization, of constraints via contributions from the vestibular, visual, and proprioceptive systems that serve to link the systems’ degrees of freedom to form softly assembled functionally specific units of control (i.e., coordinative structures). The acquisition of skilled movement is a transition into exploitation of the motor control systems and controlling those systems. Once the coordination of the various body segments is established, they are honed over time through progressive training. During early learning, movements are constrained overly due to the tendency of the child to freeze or limit the various degrees of freedom, and the result is movement inefficiency. As the child’s skill level increases, the degrees of freedom are released gradually during the intermediate stage of learning. It is here that feedback systems (whether augmented with visual/tactile or real time via verbal biofeedback) that associate movement kinematics and kinetics will benefit likely the child and allow further advanced development of the desired skill (58,68). Task proficiency is achieved once the coordinative structures have reached a level of efficiency in which the child is able to exploit the coordination of the myriad subsystems in pursuit of performance goals in the late stages of learning (8,42).

This progression of motor learning in youth often coincides with the transition of internal focus attention
(induced when a performer’s attention is directed toward their actual movements) to a more external focused attention that is directed toward an outcome, or the effects, of the movement being produced (e.g., a goal, target, and intended effect) (7,51). This stage of motor acquisition is associated with youths’ ability to achieve cognitive and motor system learning that can be retained for life, such as riding a bicycle and learning to ski. Long-term retention of adaptable motor performance is important for overall success of integrative neuromuscular training. Therefore both verbal and visual feedback given to youth during integrative training exercises should be refined systematically to enhance overall motor skill learning and ultimate improvement in movement patterns (51,77).

Limiting Distractions and Optimization of Peripheral Reaction Time with Integrative Neuromuscular Training in Youth

Another cognitive developmental consideration to optimize integrative neuromuscular training for youth is to acknowledge the varying attentive abilities of young athletes. Hicks law describes that the more choices an individual has, the longer it takes them to make a decision (64). In sports with neuromuscular and neurocognitive processing, an athlete may hesitate as he or she considers their options. This hesitation may result in slower reaction times. Neurocognitive processing training in youth, which helps youth learn to focus on task performance during distressing sports-related scenarios, or active perturbations to attention, may have the potential to decrease injury risk reference. Pilot evidence in our laboratory suggests that younger or new learners are often not prepared to adapt to complex processing (e.g., movement and cognitive) and likewise susceptible to distraction during complex sports-related tasks. Conversely our more experienced athletes who have acquired a strong motor skill base may remain consistently focused on task performance and are less susceptible to distractions. The improved focus on the motor task actually can enhance overall motor skill learning and ultimate improvement in movement patterns.

Integration of neurocognitive processing training (e.g., multitasking or dual tasking such as vision and reaction training combined with vestibular/balance task) can improve reactive and adaptive movement skills to adverse conditions and unanticipated events. These skills may not only improve an athlete’s general fitness and performance but also enhance their ability to reduce their risk from sports-related injuries. Gary Wilkerson (76) has suggested an association between slower reaction times and increased incidence of injury. For example, a leading theory related to the underlying causes of concussion in youth sports is an unanticipated blow to the head. With the unexpected blow, the young athlete is unprepared to stabilize adequately the head and trunk against oncoming forces. The proposed theory states that if visual and cognitive awareness provide an athlete time and ability to prepare for a hit, there may be less adverse effects from potential concussive events.

Prevention of Knee Injury with Integrative Neuromuscular Training in Youth

Interestingly there are known linkages between knee injury and neurocognitive function (69). For instance, traumatic knee injuries can occur as the result of an unexpected perturbation during dynamic sport scenarios (3,37,61). Furthermore anterior cruciate ligament (ACL)-injured athletes demonstrated slower reaction time and processing speeds compared with uninjured athletes. In addition, those athletes who went on to have an ACL injury also performed worse on visual and verbal memory composite scores (69). Therefore integrative neuromuscular training that combines visual-motor and reactive perturbation training can expand a young athlete’s peripheral attention to more information that is readily available within their field of view. These expanded abilities for risk identification and awareness may improve a young athlete’s perceptual accuracy and assist them to avoid the negative consequences (such as an injury) of unexpected perturbations, ultimately improving sport performance (12).

Contemporary young athletes tend to specialize earlier in a favored sport and partake in associated specialized training with the assumption that this specialization is key to their future athletic success (13). The escalation of competition and specialization at younger ages without widespread acceptance of associated integrated preseason training may be related to the concerning increase in the number of sports-related injuries in young athletes (1,32,47). Youth participation in sport should not be initiated with competition but instead should evolve out of a well-rounded preparatory conditioning program that is progressed sensibly over time. The addition of integrative neuromuscular training into existing preseason activities better equips coaches to ensure that youth will achieve gains in skill-related fitness and health, with likely reductions in risk of sports-related knee injury as a result.

While the total elimination of sports-related knee injuries in youth is an unrealistic goal, appropriately designed and sensibly progressed integrative neuromuscular training programs may help to reduce the likelihood of sports-related injuries in young athletes (23,34,36,60). By addressing the specific risk factors (e.g., low fitness level, muscle imbalances, and errors in training) associated with certain youth sport injuries, integrative neuromuscular training programs reduce acute and overuse injuries by 15% to 50% (46,60,74). A traditionally effective adolescent training program (35,44,56) was modified into a 9-wk “integrated injury prevention program” for use as an additive training regimen during the warm-up period in young soccer players (10 to 12 years). The addition of such an integrative injury prevention training program into standard soccer training influenced improvements in balance ability and vertical jump height in the young soccer players (14). The addition of similar resistance training into preseason conditioning for adolescent football teams influenced a reduction in overall knee injuries as well, including the incidence of knee injuries that required surgery over four competitive seasons (11). In both cases, integrative neuromuscular training was protective of all injuries, but most notably, injuries to the lower extremity and knee in young soccer players (18).
Notably protocols that incorporate resistance training into preseason and in-season conditioning programs reduce ACL injury risk factors and incidence in female athletes (34,36). In addition, young female athletes took part in a preseason integrative neuromuscular training program and found a reduced prevalence of knee pain at postseason follow-up (40). This is not surprising given that female athletes who demonstrate risk factors associated with increased lower extremity injury (38,54) are more responsive to specially designed integrative neuromuscular training (55). Although only a small minority of young athletes participate in integrative neuromuscular conditioning programs prior to sports participation (10), current data indicate that such multifaceted integrative conditioning programs reduce sports-related injuries, and they may be most effective in early youth (e.g., primary school years) (17,60).

Strong evidence indicates that integrative neuromuscular training is most effective at reducing injury when implemented in younger populations (59). The accumulation of the current evidence indicates that integrative neuromuscular training interventions implemented in childhood, which take advantage of enhanced neuroplasticity, can support the development of muscular fitness and fundamental movement skills that support safe, enjoyable, and worthwhile participation in sports and recreational physical activities. Integrative neuromuscular training programs that are considerate of the cognitive development abilities of children and adolescents will be best prepared to capitalize on the neuroplasticity and motor learning potential in youth.

Conclusion

Integrative neuromuscular training programs that consider the cognitive and physical development of youth are needed to support motor skill development, promote continued involvement in physical activity, and ultimately reduce the risk of common sports physical activity-related injuries such as knee injuries in adolescent females. Preparatory training with developmentally appropriate programs also appears crucial to circumvent the current rise in the risk of injuries in competitive youth athletics. Integrative neuromuscular training requires age-related instruction by qualified professionals who understand the physical and psychosocial uniqueness of childhood and adolescence. Furthermore these professionals must understand the components of physical and cognitive development in order to implement training strategies that optimize performance outcomes and reduce the risk of training-related injuries. Regular training throughout the developmental years as part of physical education, recreation, and sports practice can support regular physical activity, improve sport performance, reduce injury risk, and further influence healthy lifestyles habits throughout adulthood.

Acknowledgments

The authors would like to acknowledge the funding support from the National Institutes of Health/NIAMS Grant R01-AR05563.

The authors report no conflicts of interest.

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